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Transformer Requirements for the Year 2000

Final Report December 1979

Published June 1980

MASTER

Prepared for:

U.S. Department of Energy
Assistant Secretary for Resource Applications
Office of Electric Energy Systems
Under Contract No. ET-78-C-01-3291

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TABLE OF CONTENTS

<u>Tab. No.</u>	<u>Title</u>	<u>Page No.</u>
1.	I. EXECUTIVE SUMMARY	1-1
2.	II. PROGRAM OBJECTIVES AND IMPLEMENTATIONS.....	2-1
3.	III. PROGRAM METHODOLOGY	3-1
4.	IV. SYSTEM TECHNICAL CONSIDERATIONS AND THEIR QUALITATIVE IMPACTS ON TRANSFORMERS...	4-1
	A. Development of Technical Considerations...	4-1
	B. Determination of Qualitative Impact of Technical Considerations	4-3
5.	V. EXTERNAL INFLUENCES AND THEIR QUALITATIVE IMPACT ON SYSTEM TECHNICAL CONSIDERATIONS.	5-1
	A. Descriptions of External Influences	5-1
	B. Qualitative Impact on System Technical Considerations	5-8
6.	VI. TRANSFORMER REQUIREMENTS FOR THE YEAR 2000 ..	6-1
	A. Discussion of Transformer Design Parameters	6-1
	B. Qualitative Impact of Technical Considera- tions and External Influences on Trans- former Design Parameters	6-8A
	C. Status of Technical Considerations in the Year 2000	6-9
	D. Status of Transformer Design Parameters in the Year 2000	6-30
	E. Conclusions Based on the Status of Trans- former Design Parameters for the Year 2000	6-49
7.	APPENDIX I	7-1
8.	APPENDIX II	8-1
9.	APPENDIX III	9-1
10.	APPENDIX IV	10-1

TRANSFORMER REQUIREMENTS FOR THE YEAR 2000

I. EXECUTIVE SUMMARY

The principal objective of this program was to determine the design parameters required for transformers of the Year 2000. The approach to meeting this objective was to determine the changes which may occur in transmission and distribution systems over the next twenty years, and how these changes might affect design parameters of distribution and power transformers. Emphasis was placed on domestic requirements, although the impact of international practices was factored into the overall requirements for transformers. Possible investigations that could help transformer designers meet the long term technical requirements of future transformers were also identified.

The program dealt with transformers applied in utility systems under normal or typical applications and operating environments. Where applicable, distinctions were drawn between distribution and power transformers, and between changes that apply to transmission and distribution systems. In many cases, however, conclusions applied to both classes of transformers.

The investigation was scheduled on the basis of one day per week per man, for the principal investigators, for a period of one year. The conclusions drawn in this program represent the views of the principal investigators, based on analysis of system/transformer interactions; on estimation of the timing of commercial availability of various system technologies; on use of selective resource materials available to the investigators; and on the investigator's own experience and knowledge of power systems.

Considerable effort went into structuring the methodology used in the investigation to take into account the many forces which could affect transformer design parameters. These design parameters were defined as functional specifications or limitations that had to be met by the transformer designer. The transformer was considered to be a "black box" that must be in compliance with the designated functional requirements. How this compliance would be achieved was viewed as a designer's prerogative and would depend on skills, ingenuity, construction constraints, economic trade-offs, etc. The basis for determining the changes which would be required in transformer design parameters in the next 20 years is dependent on a large number of technical considerations affecting the planning and implementation of the T&D systems. Technical considerations are defined as the constraints within which the utility engineer must design the system. In turn, these technical considerations are acted upon by many diverse external influences, such as economics, political considerations, environmental and safety restrictions, new material technology, etc. Figure 1 on page 3-2 depicts the interrelationship of all these forces. Although the focus in this investigation was on transformers, the information contained under both external influences and technical considerations could be used for any future investigations of other apparatus applied in T&D systems, with only minor modifications.

A summary of the results of this investigation are presented in Exhibits I through V in this section. Exhibit I summarizes the status of the technical considerations in the Year 2000. Exhibit II summarizes the status of transformer design parameters in the Year 2000. Exhibit III is a summary of the investigations which might be useful in substantiating conclusions reached in this program.

Part VI-D, the status of transformer design parameters, was used to arrive at conclusions on the most important transformer requirements (from the transformer designer's viewpoint) to meet system needs in the Year 2000. Using three degrees of importance, each transformer requirement was judged on probability of occurrence, difficulty of achievement, and market demand. Judgment was based on several factors. For example, "Difficulty of Achievement" included not only achieving the development or change within the next 20 years, but also doing so at a competitive cost. "Market Demand" included the expected demand for the transformer requirement in the next 20 years, factoring in a cost justification. Exhibit IV gives the relative importance of the various transformer requirements for each of the three classifications given above. Exhibit V was developed from Exhibit IV to show the overall relative importance of the transformer requirements from a designer's viewpoint, based on the combined effects of the three classifications.

The most important transformer requirements in the next 20 years, considered from a designer's viewpoint, were excerpted from Exhibit V and are listed below, but not necessarily in order of importance.

- UHV (1200 kV) rating

1200 kV has been selected as the next standard maximum voltage level. With anticipated economic justification (primarily due to loss reduction and fewer rights-of-way) and current R&D efforts to overcome the technical problems, 1200 kV transmission could be in service by the late eighties. In conjunction with this, therefore, there will be a need for 1200 kV transformers. Although the demand may be small in number, these will represent a significant amount of MVA, and the demand for them will continue to grow beyond the Year 2000. Developing 1200 kV large power transformers presents many technical problems, beyond the prototypes that have already been built; therefore, it is essential

that transformer manufacturers now consider how to have a product that can meet the needs of utilities 10 to 20 years from today.

- Higher MVA Ratings (upper limits)

Higher power capacity transmission circuits will be built in the next 20 years due to both normal growth and emerging technologies, such as HVDC, GIT, and superconducting transmission. Also, there will be a need to pack more power into available rights-of-way. This will mean that higher transformer ratings will be required. Economy of scale will provide further incentive. The transformer manufacturer must be prepared to supply higher MVA ratings at all voltage levels, and accomplish this with limited increases in size and weight, particularly at higher transmission voltages, because of shipping limitations. New materials and techniques are needed to meet the conflicting requirements mentioned above. The manufacturers should intensify effort on this transformer requirement to meet the expected market demand in the next 20 years.

- Reduced Losses

By the Year 2000, transformer loss levels are expected to be much lower than the minimum levels of today. With energy supplies diminishing over the next 20 years, the evaluated cost of supplying these losses will continue to rapidly increase. Thus, there will be a strong demand for low loss transformers, whose total evaluated cost is minimized.

With present design techniques and existing materials, the transformer designer would find it very difficult to reduce

losses significantly lower than that of today without reaching practical limitation in size, weight, and cost. Therefore, transformer manufacturers will be faced with finding new lower loss materials and/or new transformer design concepts for loss reduction.

- Environmental/Safety Consideration

Environmental and Safety related issues have been increasing in importance over the past decade, and are expected to continue over the next 20 years. Some of these issues, pertinent to transformers, are audible noise level, flammability, and explosiveness. By the Year 2000, government regulations are expected for controlling at least some of these environmental/safety factors. Transformer manufacturers will have to expend much effort to meet these environmental/safety requirements without unreasonable increase in transformer cost. Therefore, this effort should be a continuous one between now and the Year 2000.

- Size and Weight Reductions

As the trend to upgrade circuit voltages continue, there will be a need to replace existing transformers with those having higher MVA and voltage ratings. There will be pressure to limit the size of these transformers so as to fit in the confines of the space available for them. Shipping limitation on size and weight will also result in pressure for smaller, lighter weight transformers.

Expected pressure for other requirements (such as reduced losses, higher voltage ratings, kVA ratings, increased thermal capacity, reduced impedance (transmission), more mechanical

integrity, and improved reliability), all would tend to increase the transformer size and weight. Therefore, the transformer manufacturer should begin efforts to develop new materials or concepts to meet these requirements. For example, one such concept would be design modularity, where larger, heavier transformers can be assembled in the field.

- Improved Reliability

Although the emphasis on overall system reliability has diminished somewhat over the last several years (due primarily to inflation and the subsequent higher cost to improve system reliability), component reliability is expected to be more important over the next 20 years. The reason for this is a rapidly increasing trend in the number of utilities developing large data bases which often include detailed information on each component failure. This may result in increased pressure by utilities to improve transformer reliability. Minimum acceptable transformer failure rates may also be specified by users. In either case, the manufacturer will be faced with making improvements in transformers to meet these reliability requirements over the next 20 years. Standards may be developed to make transformer test procedures (e.g. short circuit) more stringent. With expected reductions in BIL and increases in short circuit magnitude on T&D systems, this task will be a difficult one for manufacturers. Development work should be started now to meet these expected future reliability requirements.

The conclusions reached indicate there are no radical changes expected in transformer design parameters by 2000. It is expected that the majority of changes that do occur by the Year 2000 will come about through normal evolution. However, this does not imply that some major breakthrough in materials or a new technology will not alter the conclusions discussed above.

The emphasis during the next 20 years will be on more efficient and reliable transformer designs, with attention given to environmental and safety requirements. There may be special requirements which have to be met for special applications such as OTEC, but because these are not expected to be in general use by 2000, they were considered beyond the scope of this investigation. An in-depth study for such special applications is suggested to determine the transformer requirements.

The conclusions reached in this report are the opinions of the principle investigators as to the commercial viability of the various technologies by the Year 2000. No judgment was made or intended on the perceived value of any particular technology or its availability at some time beyond the Year 2000.

Exhibit I.

STATUS OF TECHNICAL CONSIDERATIONS IN YEAR 2000

1. Reliability Criteria	-	System criteria about the same as today; component criteria probably more defined, stringent, documented.
2. Trend from Overhead to Underground	-	Will continue to increase for distribution; only in special cases for transmission.
3. Higher voltage Levels	-	Economic incentives to raise voltage; general use of transmission at 1200 kV; some distribution up to 69 kV as an expedient.
4. Fewer Voltage Levels	-	Logical extension of trend to higher voltages; distribution below 15 kV sharply decreased; transmission voltage upgrading; reduction in, or virtual elimination of, subtransmission.
5. Voltage Regulation Criteria	-	Unlikely to change for transmission; at distribution level, voltage reduction for conservation could be possible reason for change; voltage unbalance could be an issue in this category.
6. Load Management	-	Probably Widespread
7. Regional Energy Transfer	-	Some may exist, but very limited; national grid unlikely to be a reality in 2000.
8. HVDC Circuits	-	Limited to very long lines and special cases requiring asynchronous ties.
9. Multi-Terminal Lines	-	Usage will increase on transmission.
10. Higher Phase Order Transmission	-	Some trials in 2000; very limited
11. System & Component Losses	-	Losses will be lower in relative terms, maybe in absolute as well; strong economic incentives to reduce.
12. Short Circuit Magnitudes	-	Other trends would tend to cause increase, but fault limitation will be practiced to keep levels down.

13. System Harmonics	-	Less harmonics from transformers, more harmonic sources of other types, but better control will be exercised to keep overall levels down.
14. Audible Noise	-	Criteria will tighten in populous areas; other design trends may make compliance easier.
15. Use of Gas Insulated Substations	-	Very popular by 2000, at least in urban areas.
16. Use of Gas Insulated Transmission	-	Used in special applications only; e.g., large blocks of power over short distances in congested areas.
17. Superconducting Transmission	-	Unlikely to be a factor in 2000; only for very specialized applications.
18. Phase Angle Regulators	-	Increased usage by 2000, but probably not significant.
19. Mobile Substations	-	No significant changes in relative usage.
20. Indoor Substations	-	Very popular in urban areas.
21. Low Voltage Networks	-	Today's decline in usage to continue; largely a replacement situation in 2000.
22. Power Electronics	-	Widespread usage by 2000 as cost and performance improvements continue; probable new application areas.
23. Substation Automation	-	General usage by 2000; dependent on reliable sensors and interfaces to micro-computers.
24. Distribution Automation	-	Probable increased usage, but little impact on transformers.
25. Transmission Single-Pole Switching	-	Greatly increased usage at EHV/UHV levels; limited impact on transformers.
26. Ultra-High-Speed Fault Clearing (Transmission)	-	Considerable usage by 2000; limited impact on transformers.
27. Fault Current Limiting	-	Increased usage of conventional means (e.g., reactors) for distribution; New FCL devices in general use for transmission.

- 28. Transient Overvoltage Control - Metal oxide and other advances lead to considerable improvement by 2000.
- 29. Dynamic Voltage Control - Improved control by 2000; even though more causes of overvoltage may exist.
- 30. System VAR Compensation - Generally increased usage, more complex schemes and finer control; strong economic incentive.
- 31. Stability Criteria - Likely to be the same or slightly relaxed in general; could be more stringent for areas of high generation concentration and earthquake-prone areas.

Exhibit II.

STATUS OF TRANSFORMER DESIGN PARAMETERS IN YEAR 2000

1. Voltage Rating	-	Transmission up to 1200 kV, possible 1500 kV prototype, some distribution up to 69 kV; reduction or possible elimination of lower voltage levels in both T&D.
2. Voltage Taps	-	Probably reduced usage in general, with possible elimination of no-load taps. Greater tap range of LTC may be required.
3. Insulation Levels	-	Continued pressure to reduce ratio of BIL to system voltage.
4. kVA Rating	-	No general need for MVA ratings greatly in excess of today's upper limits; however, prototypes will exist.
5. Thermal Considerations	-	Potential need for increased thermal capacity; may be solved by other requirements, such as lower loss designs.
6. Impedance Considerations	-	Pressure to reduce impedance on transmission; limited use of distribution transformer impedance to control short circuit current magnitude.
7. Transient Inrush Current Constraints	-	No new constraints likely.
8. Loss Levels	-	Trend toward continued reduction; constant re-evaluating of no-load vs. load losses for optimizing.
9. External Thru-Fault Withstand Requirements	-	Not likely to be any more stringent than today; may be less stringent with improvements in fault limitation and duration.
10. Internal Fault Withstand Requirements	-	Requirements unlikely to be more severe than today; continued efforts to prevent disruptive failures.

- 11. Induction Considerations - Induction levels reduced, unless research produces core material that can exhibit lower losses and less tendency for noise and harmonic generation at the same as, or higher than, induction levels used today.
- 12. Mechanical Requirements Due to External Factors - Increased pressure for improvements; such as lessened shipping and installation damage, better corrosion resistance, etc.
- 13. Environmental/Safety Considerations - Increasing importance; flammability/explosiveness, public safety, noise still major concerns.
- 14. Size and Weight Considerations- Strong pressure to reduce unit size and weight for any given MVA and voltage rating; one of the major concerns by year 2000; may result in requirement for modularity.
- 15. Reliability Considerations - Increasing pressure to improve; greater attempts to measure reliability, identify sources of unreliability, and take corrective measures.

Exhibit III

AREAS OF NEEDED FUTURE INVESTIGATION

A. SYSTEM-RELATED

1. Feasibility and economics of regional energy transfer
2. Economics of phase angle regulation for power flow control
3. New applications for power electronics
4. Studies of future equipment transport problems
5. Development of transmission fault current limitation techniques

B. TRANSFORMER-RELATED

1. New concepts in load tap changing
2. Intensified research on superconducting transformers
3. Development of low loss materials
4. Development of high strength-low weight materials
5. Methods of containing internal faults
6. Research on core materials that could be worked harder but with reduced noise and harmonic generation
7. Advanced insulation systems
8. Advanced cooling systems
9. Design modularity to meet space or weight limitations
10. Requirements for application with exotic generation sources (e.g., OTEC)
11. Transformer requirements for higher-phase-order transmission
12. Direction and extent impedance varies as losses are drastically reduced.
13. Cost versus reliability of insulation reductions as a function of overvoltage control

EXHIBIT IV.

CLASSIFICATION AND IMPORTANCE RATING OF TRANSFORMER REQUIREMENTS

TRANSFORMER REQUIREMENT	PROBABILITY OF OCCURRENCE			DIFFICULTY OF ACHIEVEMENT			MARKET DEMAND		
	High	Moderate	Low	Great	Moderate	Little	High	Moderate	Low
UHV (1200 kV) Rating	X			X				X	
46-69 kV Dist. Transfmr. Ratings		X			X				X
Greater LTC Tap Range		X			X			X	
Reduced Induction Levels	X				X			X	
Lower BIL/60 HZ ratios		X			X		X		
Higher kVA Ratings (upper limits)	X				X		X		
Extremely Higher kVA Ratings (transm.)		X		X					X
Increased Short Time Thermal Capacity		X		X				X	
Reduced Impedance (transm.)		X			X			X	
Higher Impedance Dist. Transf.		X			X			X	
Reduced Transient Inrush			X		X				X
Reduced Losses	X			X			X		
Increased Through-Fault Withstand			X	X					X
Better Means of Preventing Disruptive Failures		X		X				X	
Improved Mechanical Integrity		X			X			X	
Environmental/Safety Changes	X			X			X		
Size/Weight Reductions	X			X			X		
Improved Reliability	X				X		X		

EXHIBIT V.

Overall Importance Rating of Transformer Requirements (From a Designer's/Manufacturer's Viewpoint)

Most Important*

- UHV (1200 kV) rating
- Higher kVA ratings (upper limits)
- Reduced losses
- Environmental/Safety changes
- Size/Weight reductions
- Improved reliability

Moderately Important*

- 46-69 kV distribution transformer ratings
- Greater LTC tap range
- Reduced induction levels
- Lower BIL/60 Hz ratios
- Extremely higher kVA ratings (Transmission)
- Increased short time thermal capacity
- Reduced impedance (transmission)
- Higher impedance distribution transformer
- Better means of preventing disruptive failures
- Improved mechanical integrity

Least Important*

- Reduced transient inrush
- Increased through-fault withstand

* Requirements are not intended to be listed in order of importance within each group.

II. PROGRAM OBJECTIVES AND IMPLEMENTATION

The principal objective of this program was to determine the design parameters required for transformers of the Year 2000. This objective was to be accomplished by determining changes which may occur in transmission and distribution systems over the next twenty years, and how these changes might affect design parameters of distribution and power transformers. This program also identified possible investigations that could help transformer designers to meet the long term technical requirements of future transformers.

For the most part, this program dealt with transformers applied in utility systems under normal or typical applications and operating environments. Where applicable, distinctions were drawn between distribution and power transformers, and between changes that would apply to transmission and distribution systems. In many cases, however, conclusions applied to both classes of transformers.

The term of the project was one calendar year. Work was performed on the basis of one day per week per man, for the principal investigators. The principal investigators are from the Transmission and Distribution Systems Engineering department of the Westinghouse Electric Corporation, East Pittsburgh, PA. Consulting assistance was provided by transformer designers in the Westinghouse divisions which manufacture transformers.

The conclusions drawn in this program represent the views of the principal investigators, based on analysis of system/transformer interactions; on estimation of the timing of commercial availability of various system technologies; on use of selective resource materials available to the investigators, and on the investigators' own experience and knowledge of power systems.

It is assumed that most of the technologies discussed in this report will likely be commercially viable at some point in time. However, to focus this program to a particular point in time, the investigators have exercised their personal judgment as to the commercial viability of various technologies in the specific year, 2000. No judgment was made, or intended, relative to the perceived value of any particular technology, nor to the possible future availability of any technology, at any time beyond 2000.

The program was originally divided into six general tasks:

- 1) Identify Majority of System Changes
- 2) Qualitative Substantiation of Impact on Transformer Requirements
- 3) Quantitative Substantiation of Impact on Transformer Requirements
- 4) Identify Future Transformer Requirements
- 5) Identify Future Needed Transformer Developments
- 6) Identify Future Needed Investigations

Tasks 1 and 2 involved a considerable amount of organizational effort to develop an overall approach to the investigation. Because of severe time constraints, the amount of effort spent in research for Task 3 was restricted. Tasks 4 and 5 have been largely combined within this report, because of their extremely close relationship. Task 6 is a logical offshoot of areas where questions were created under Tasks 1, 2, 4, and 5, and is included under those discussions. A summary of the suggested investigations appears as part of sections VI-C and VI-D, and a summary is given in Exhibit III, in section VI-D.

III. PROGRAM METHODOLOGY

In order to achieve the primary objective of determining the functional requirements for the various design parameters for transformers of the Year 2000, it was necessary to identify the nature of transmission and distribution systems in that future time. To do so would not only require the assessment of the present state of T&D systems, but also the identification of the processes by which changes develop in the systems over a period of time. Accomplishing this latter task requires an organized approach to analyzing change.

It was recognized early in the project that proper definition of this approach was difficult to achieve, but crucial to later efforts, since a highly inefficient method of examining and evaluating large amounts of interrelated information would make later work all the more difficult. After considerable collective effort, a methodology was evolved with which all investigators agreed.

A methodology for analysis of change, and ultimately for arriving at the future effects on transformers, is illustrated schematically in Figure 1. The process of change can be viewed as a technical problem acted upon by a combination of external influences to produce effects on the T&D systems, and ultimately upon each component of those systems. The focus of the program would eventually fall on just one such component, the transformer; however, to be able to arrive at that point it was necessary to determine the entire picture of system change.

The starting point was to determine the technical aspects of system evolution. This would be accomplished by developing a list of technical considerations and identifying the various impacts each would have on the T&D systems as a whole. These impacts could then be separately related to a corresponding impact, or lack of impact, on the transformer design parameters. This "FIRST EFFORT" is indicated in Figure 1.

FIGURE 1 - ANALYSIS METHODOLOGY FOR PROGRAM

The next step, or "SECOND EFFORT" as indicated in Figure 1, would consist of developing a list of clearly defined external influences that bear upon the direction of the technical evolution. The impacts of all external factors on each technical consideration could then be determined. The overall result would be an organized pattern that relates external influences to technical evolution, then to system evolution, and finally to transformer (or other component) evolution.

Once this organized pattern would be laid out, the most significant path elements could be identified. The most significant external influences could be identified and ranked in terms of their overall effect on the transformer, via the links with technical considerations and system effects.

The original "THIRD EFFORT" shown in Figure 1 denotes a process of sifting through the work of the first two efforts, to determine priorities of investigation and the directions to be taken in the T&D systems and in transformers.

Because the diagram of Figure 1 is strongly oriented to a left-to-right approach, it seemed logical that the "THIRD EFFORT" would take the same orientation. That is, the "paths" to be analyzed would logically start with external influences and lead through the technical considerations into the system. At that point, a system scenario for the Year 2000 would result and conclusions would be made regarding the effects on transformers. These various paths would then somehow be ranked as to their "criticality," and decisions regarding the most important areas of investigation would be made.

After completion of the FIRST and SECOND EFFORTS shown in Figure 1, it became necessary to face the problem of how this path analysis would be handled. This proved to be even more difficult an effort

than the development of the original, overall methodology. Several approaches were tried and discarded. Basically, these all took the form of numerical weighting that involved assigning indices to various effects, based on their perceived importance, likelihood of occurrence, or both. Some indices would relate external influences, either individually or collectively, to each technical consideration. Other indices would relate the technical consideration to "the transformer," via the numerous identified system effects. All of the various indices would then be combined to point out a direction of effort. Various plans were developed, differing mainly in their complexity and their degrees of objectivity or subjectivity.

It soon became apparent that the numerical weighting approach was becoming too cumbersome a task and did not adequately represent the overall impact of the various influences. At that point, some more basic questions were asked about where the information was supposed to lead. The obvious answer was "the transformer," and more specifically, the identifiable design parameters.

Thus, a new plan of attack emerged, wherein the transformer design parameter served as a starting point, and all information relevant to that parameter would be gathered in one place, where it could be weighed and judged collectively in a single specific context. Schematically, this methodology for the revised THIRD EFFORT or "path analysis," is shown in Figure 2.

In essence, the method would involve extracting significant points from the work in the First and Second Efforts that relate to a specific transformer design parameter. For each parameter a listing would be developed to show (1) which technical considerations have an impact, (2) which specific system effects result in that impact, and (3) which external influences have the most impact. Having this information in one place should allow an easier determination of which influences are most predominant, as indicated by their

FIGURE 2 - PATH ANALYSIS METHODOLOGY (REVISED THIRD EFFORT)

repetitiveness, and which influences reinforce or contradict each other, in terms of their effects on the design parameter. This would also help to identify what questions must be asked and answered to be able to make a better judgment on the direction the design parameter may take in the future.

As the Figure 2 schematic indicates, using the listing for a specific design parameter would ultimately lead to a discussion of the forces acting upon, and the likely directions to be taken by, that parameter. Also shown is a "horizontal" approach, where pertinent information and questions related to each technical consideration could be analyzed to arrive at a "conclusion" regarding that technical consideration. Collectively, these would logically lead to the "system scenario" of the Year 2000, but only as the system relates to the transformer.

IV. SYSTEM TECHNICAL CONSIDERATIONS AND THEIR QUALITATIVE IMPACTS ON TRANSFORMERS

The first step taken by the investigators in predicting how the transmission and distribution system may change in the next 20 years was to determine what technical considerations would influence planning, design and implementation of future systems. What is meant by technical considerations is the constraints within which the utility engineer must plan and design the system. These are internal influences, in that they are under the utility's control. External factors influence the degree to which these technical considerations affect T&D system design. These have been taken into account in the overall analysis, and are discussed in Section V.

A. Development of Technical Considerations

A list of technical considerations pertaining to T&D systems was developed. The list is tabulated in Table I. Although additional topics could be added, the list contains essentially all the major technical considerations that impact on the T&D systems. It covers technical innovations which may be applicable in the near future, trends in design philosophy or practices, operating trends, and technical criteria pertaining to reliability, stability, regulation and environmental constraints. The purpose of the list was to be able to proceed in an orderly manner to determine how the system design and ultimately the transformer design parameters may be affected by each technical consideration, so that a scenario can be developed for the T&D systems in the Year 2000, based on the composite effects.

TABLE I

Technical Considerations That Influence T&D System Design

1. More stringent reliability criteria
2. Trend from overhead to underground construction
3. Use of higher voltage levels
4. Use of fewer voltage levels
5. More stringent voltage regulation criteria
6. Use of load management (voluntary/involuntary)
7. Use of regional energy transfer
8. Use of HVDC circuits
9. Use of multi-terminal lines
10. Use of higher phase-order transmission.
11. Higher system and component resistive losses
12. Higher short circuit magnitudes
13. Higher harmonic levels
14. More stringent audible noise level criteria
15. Use of gas insulated substation
16. Use of gas insulated transmission lines
17. Use of superconducting transmission
18. Phase angle regulation constraints
19. Use of mobile substations
20. Use of indoor substations
21. Use of LV networks
22. Use of power electronic equipment (switching, control, conversion)
23. Use of substation automation
24. Use of distribution automation
25. Use of transmission line single-pole switching
26. Use of ultra-high-speed fault clearing
27. Use of fault current limiting devices
28. Improved transient overvoltage control
29. Improved dynamic voltage control
30. System VAR compensation
31. Stability criteria

B. Determination of Qualitative Impact of Technical Considerations

The list was first used to determine how each technical consideration could impact on system design, and then whether or not the system change indicated would affect any transformer parameters. Each technical consideration was tested by the question, "How does this affect system design?" For each reply to this question, a judgment was made as to whether the statement relating to the system could affect transformer design parameters directly, indirectly, or not at all. Finally, for each affirmative reply, the statement was tested by the question, "How does this affect transformer design parameters?" This was the qualitative impact of the system technical considerations on transformer requirements. The information developed is included in Appendix I.

V. EXTERNAL INFLUENCES AND THEIR QUALITATIVE IMPACT
ON SYSTEM TECHNICAL CONSIDERATIONS

External influences can have considerable impact on the T&D technical considerations and the extent to which they will develop by the Year 2000. Fourteen external influences which were considered to have a significant impact on transmission and distribution systems were identified and a definition of each is given in the sections which follow.

A. Descriptions of External Influences

1. Load Characteristics

This area includes a wide range of load parameters, considered for all three classes of utility customer; that is, residential, commercial and industrial.. The concern for the next twenty years is related to long term changes in these parameters that may result in significant impact upon the T&D systems in the Year 2000. Some of the basic characteristics of interest would include:

- a. Power factor - this impacts the system from the standpoint of losses and degree of required VAR compensation.
- b. Load diversity - impacts the number of customers that can be served by a transformer, and may affect the system load factor substantially.
- c. Load factor - reflects upon the efficiency of utilization of available system capacity.
- d. Load density - significantly affects the type of system design selected to serve the load.
- e. Load patterns - basically a geographical consideration. The relative mix of high spot loads compared to uniform load densities significantly affects the system design considerations.

- f. Load growth rate - utilities usually plan for specific load growth rates; if actual rates are much different from planned rates, system evolution may be significantly altered.

Examples of a few possible causes of long term shifts in basic load characteristics might include such things as vast changes in housing mix and in actual housing starts, widespread acceptance and development of electric cars, increased use of electric heat for buildings or industrial processes, large shifts to use of heat pumps, and widespread railroad electrification.

2. Economics

This external influence includes two basic considerations:

- a. The State of the Economy, which will determine how much the utility can spend. It includes:
 - 1) The rate of inflation for materials, land, and labor.
 - 2) The national interest rates which reflect the money supply and the amount a utility must pay for capital.
 - 3) Whether the economy is in a time of recession or that of growth and expansion.
- b. Factors Used in the Evaluations of Economic Alternatives, which will determine how the utility will spend whatever is available to spend. The economic evaluations include: 1) the cost of capital investment (plant, equipment, and land) which depends on the fixed charge rate, the minimum acceptable rate of return on investment, state, local, and federal taxes and 2) operating costs including labor expenses and the cost of losses. An inflation rate may also be included in the evaluation.

3. Environmental Restrictions

This category covers a wide, diverse group of external influences which, in the final analysis, are all related to public acceptance. They are brought to the forefront by public interest groups, regulatory agencies or commissions and political bodies. Included are restrictions imposed by or due to:

- a. Release of by-product of power generation in excessive amounts, such as particulate pollution of water, air and land.
- b. Significant changes in normal (ambient) environmental levels affecting the senses, such as temperature rise of air and water, increased and objectionable noise, and objectionable odors.
- c. Unfavorable public perception relating to the aesthetics of the transmission system, requiring cosmetic effects such as low profile, compact substations, landscaping, substation facades, improved appearance of transmission towers, and blending transmission lines into the terrain.
- d. Toxicity and biogradability of insulating or cooling mediums inadvertently released to the environment.
- e. Biological effects of electric fields.
- f. Public non-acceptance of new technologies, such as nuclear fission as an energy source.
- g. Conservation acts, and public objections to ROW and transmission corridors in their localities.
- h. Plant siting, whether on land or off shore, or the development of generation parks.

4. Environmental Effects

Included in this category are the following:

- a. Earthquake (the seismic considerations)
- b. Sunspots (primarily relating to communications)
- c. EMP or Electromagnetic Pulse
(A high intensity, wide bandwidth radiation produced by a high altitude nuclear blast which could cause communication, control, and protection disruption)
- d. Floods (relating to submersible equipment)
- e. Weather conditions (including corrosive effects, salt contamination, hurricane and tornado damage, temperature extremes, etc.)

5. Reliability Constraints

This topic considers real or imaginary constraints that affect the overall design of the T&D systems, from the standpoint of reliability. Widespread availability of new reliability evaluation techniques and computational capacity make it possible to extend analysis and evaluation of reliability to other levels of the system, beyond system generation availability analysis. Consumer groups and individual customers may exert pressure in this area, based on their perceptions of the present levels of reliability in comparison to the direct costs of power or to various socio-economic needs. Regulatory bodies, in response to the public, may begin to focus more attention on this area, in light of increased demands for rate relief on the part of utilities. Utilities may begin to more routinely develop specific design guidelines for different

areas of their system. The pressures may go in either direction; that is, some areas may be seen as too reliable and others not reliable enough. Either course directly impacts the design level of reliability of components applied within the T&D systems, and the systems themselves.

6. Availability of National Resources & Basic Materials

The T&D Systems consist of plant and equipment utilizing processed and refined materials such as steel, insulating oil, copper, etc. The availability of these basic materials would be affected by such raw materials as crude oil, coal, gas, wood, metallic ores, and other materials. The availability of land for T&D construction, water as an energy source, and manpower as the human resource, may affect the T&D system by the Year 2000.

7. Generation Sources and Energy Storage

Included in this external influence are:

- a. Unconventional energy sources, including solar, geothermal, fuel cells, MHD, wind, and fusion.
- b. Energy storage, including hydro pumped storage, batteries, fly-wheel and thermal storage techniques.
- c. Generating plant concepts, including floating nuclear plants, superconducting generator (conventional and at transmission voltage), deep sea thermal plants, etc.

8. Safety Restrictions

This area concerns the various restrictions placed upon the system and its components, from the standpoint of safety to workers and

the general public. Safety guidelines and statutes, such as those promulgated by the NRC, OSHA, EPA, NEC, NESC and UL, certainly must be considered in system component and design. In recent years, specific attention has fallen on areas of particular timely interest, such as the flammability and toxicity of transformer insulating and cooling media, including by-products of these media produced under unusual circumstances; considerations related to accessibility of equipment to the public, in terms of enclosure integrity, heat levels, and so on; and considerations related to equipment failure modes, such as use of pressure relief to lessen the likelihood and severity of disruptive failure. Attention may be focused on additional areas in the future, and significantly impact upon the system design, equipment design, or both.

9. Political Considerations

Included in this external influence are the political responses to public and lobbyist pressure, and covers such areas as the impact of government regulations, pressure for a national grid, a national energy policy, policies on nuclear power, political implications of blackouts and impact of condemnation proceedings for sites and rights-of-way.

10. Energy Conservation

This external influence consists of:

- a. Voluntary conservation by utilities and/or the customer. This includes lowering the thermostat setting in winter, raising it in summer; using more insulating materials; voluntarily curtailing consumption during peak load periods; converting from electric heat to heat pumps; utilities reducing system losses. These may be brought about faster by either tax or rate incentives.

- b. Involuntary conservation by utilities and/or customer. This could include the factors under voluntary conservation, except they would be required by government regulators, or in the case of involuntary load management, the utility would interrupt customer loads without their consent. Energy rationing may also force customers to conserve.

11. New Materials Technology

The T&D system for the Year 2000 could be significantly different if new and improved materials technologies are developed. This includes such things as new insulating materials for T&D equipment, new alloys, and low loss conductors.

12. Shipping Considerations

This category includes the shipping limitations in the Year 2000 which may affect the size and weight of T&D equipment. New methods of equipment assembly or transportation may permit the shipping of larger equipment.

13. Effect of R&D Projects & Funding

T&D systems in the Year 2000 may be affected by the financial support provided by DOE, EPRI and utilities through their funded programs.

14. International Practices

This external influence would include international research and development efforts, new foreign technologies, and foreign transmission and distribution standards and practices which may ultimate-

ly be an influence in the development of international transmission and distribution standards and the U.S. T&D systems of the Year 2000.

B. Qualitative Impact on System Technical Considerations

The qualitative impact of external influences on a particular technical consideration required determining how it would be affected by each of the 14 external influences listed. This was done for each of the 31 technical considerations, and appears as Appendix II in this report. Since any particular external influence could affect the technical consideration being examined either favorably or adversely, it was necessary to assign a weighting factor to each one. Therefore, below each external influence appearing in Appendix II is a number which has been agreed upon by the investigators. It represents judgment as to the value of the impact and its likelihood of occurrence. The sign of the number implies either favorable (plus) or unfavorable (minus) impact on the stated technical consideration. The investigators felt that a single number applied to a specific item would have merit, since it would allow identifying the most important items and would indicate the degree and direction of their impact on the technical consideration. Introductory comments given in Appendix II explain the values of the numbers.

VI. TRANSFORMER REQUIREMENTS FOR THE YEAR 2000

This section describes the results of the "Third Effort" of this project. After developing a clearly defined list of design parameters, this effort consisted of gathering, in a specific format, the most important effects of both external influences and technical considerations on transformer design parameters. Based on the most significant of these technical considerations and external influences as related to transformer design parameters, a system scenario and the functional requirements for transformer designs for the Year 2000 emerged. Discussions of these topics revealed areas for future investigation. These are summarized in Exhibit III.

A. Discussion of Transformer Design Parameters

In order to perform the revised "Third Effort" of this program as displayed in Figure 2, in Section III, it was first necessary to compile and clearly define a list of transformer design parameters. The design parameters were viewed only as functional specifications or limitations that must be met. The transformer was considered to be a "black box" that must be in compliance with the designated functional requirements. How this compliance would be achieved is viewed as a designer prerogative and would depend on skills, ingenuity, construction constraints, economic tradeoffs, etc. Based on this, a list of fifteen broad categories of transformer design parameters was developed. These parameters, listed below, are not in order of importance. The listing was compiled by grouping areas which were closely related yet distinct. For example, the first three are all basically related to voltages, although each has its own distinct design consideration. The discussions of each parameter identify the perspective from which each design area was analyzed. Where appropriate, definitions, examples, and exclusions

were included. This listing of parameters has been discussed with transformer design experts to obtain their insights on the suitability and completeness of the parameters as shown.

1. Voltage Rating

Voltage rating is the nominal 60 Hz voltage specified for each winding of a transformer and the corresponding voltage limits given in industry transformer standards for both no load and full load operating conditions. Of concern are the changes that may occur by the year 2000, such as the maximum voltage class that would likely be developed and in service at that time, and how the limits of permissible operating voltage ranges might differ from present day standards. Consideration was given to voltage rating requirements from the standpoint of a possible reduction in the number of voltage classes on a system due to increasing the step change in voltage between classes, from the approximate 2:1 ratio commonly used in the past to some larger ratio. Of considerable interest to designers is the maximum turns ratio likely to be encountered in future transformers.

Discussions concerning this parameter did not attempt to give expected percentage of the market for specific voltage classes, but did attempt to identify which voltage classes would survive.

2. Voltage Taps

Consideration was given to the probable need for increased tap range; whether or not both no-load and LTC will be required; and the percentage change between taps. The need for more advanced concepts in tap changers would also be considered. This might be extended to innovations to voltage control which might eliminate tap changers as presently applied. Discussion did not attempt to specify actual number of steps for tap changer mechanisms, or locations within the windings.

3. Insulation Level Requirements

This parameter covers a number of interrelated items which determine the overall insulation level requirements for a transformer. It includes consideration of short time 60 Hz withstand capability, BIL (including neutral), BSL, front-of-wave and contamination withstand requirements. A comparison was made between present day requirements and those expected for the systems of the year 2000. This included such things as the ratio between BIL (and BSL) and the maximum system voltage, and the relative BIL requirements for distribution systems. Discussion attempted to establish trends and directions, but not specific numerical data.

4. kVA Rating

Consideration was given to the maximum kVA ratings that may be required in both transmission and distribution systems. The effect of technical areas on the system and transformers which "force" kVA ratings either up or down was considered in establishing the trend and degree of change, particularly to determine any limits that may be imposed on ratings. Discussion did not attempt to identify the market, but rather the rating levels.

5. Thermal Considerations

This parameter includes a number of interrelated items which determine the transformer's loadability. It includes the steady-state loading capability based on temperature² limits and/or name-plate rating, the short time emergency loading capability with associated loss-of-life considerations, and forced cooling capability considerations. It also includes the effects of system harmonics.

6. Impedance Considerations

This parameter is the magnitude of transformer leakage impedance and its resistive and reactive components. For the purpose of this study, the main concern was any anticipated changes in impedance by the Year 2000, relative to that of today. These changes may be brought about by transformer regulation requirements, which may affect both components of impedance; transformer loss limitations, which could affect the resistive component of impedance; and transformer thru-fault current limitations, which could affect the magnitude of impedance.

7. Transient Inrush Current

Transient inrush current is the exciting or magnetizing current which results when the transformer is being energized. This current is normally larger than the steady state current and may exist long enough so that it causes coordination problems with fusing and relaying. For this study the concern was for any constraints on the transient inrush current magnitude, duration, or frequency of occurrence that could be required for transformers by the Year 2000. Although inrush levels are not generally specified by design, this parameter was included because of the possible undesirable side-effects.

8. Loss Levels

This transformer parameter consists of both no-load (core) losses and load (winding) losses. For this study, the concern was both the magnitude of total transformer losses and the ratio of no-load to load loss. These parameters will be greatly dependent on the evaluated cost of transformer losses by utilities by the Year 2000. Losses in transformer auxiliary equipment may also have to be considered as part of the evaluation.

9. Thru-Fault Withstand Requirements

This parameter is the mechanical capability of the transformer to withstand faults occurring external to the transformer. This study was concerned with the thru-fault current magnitude, duration and frequency of occurrence which the transformer design in the Year 2000 must be capable of withstanding without loss of life, relative to the standards of today. This may include both strength requirements for unattenuated thru-fault current, and requirements to withstand cyclical fault duty.

10. Internal Fault Withstand Requirements

This parameter is the ability of the transformer to prevent a disruptive failure as a result of an internal transformer fault. A disruptive failure is one which results in equipment fragments, oil or other fluids, flames, or toxic gases being expelled from the transformer tank to the surroundings so as to pose a potential environmental or safety problem. For this study the concern was for any requirements by the Year 2000 in which the transformer must withstand or relieve the build-up of gas pressure within a liquid-filled transformer tank after the occurrence of a winding-to-ground or a winding-to-winding internal fault. There may also be requirements to help prevent disruptive failure by eliminating the generation of large volumes of gas to create high pressures, such as can be achieved with dry-type transformers. Additionally, new and better means of resistance to fire and explosion may be necessary, to achieve the desired results.

11. Induction (Flux Density) Considerations

The level of operating induction in a transformer core is a quantity which can be optimized to produce the most desirable effects

on transformer characteristics and material usage. Economics generally dictates that materials be worked close to their limits of capability, and in the case of induction this can sometimes lead to undesirable side effects or device properties. Too high an induction level can sometimes give rise to generation of harmonics as nonlinearity begins to appear near the material limits. The dissemination of these harmonics into the power system may give rise to a so-called Telephone Influence Factor (TIF), which accounts for the magnitudes, frequencies and relative noise-production tendencies of these harmonics on communication circuits.

Working the iron close to its limits also gives rise to a saturability problem generally referred to as the transformer's "Volts Per Hertz" capability. For large power transformers, this can result in the transformer being a limiting element, in terms of allowable frequency changes and operating voltage ranges. Additionally, high induction results in greater mechanical stress to the core, due to magnetostriction, giving rise to higher vibration levels and sound levels.

Investigations into areas related to operating induction focused mainly on trends that concern themselves with the symptoms of high-induction problems that could result in designers having to reduce their operating levels. The induction levels, per se, were not discussed, since this is a designer prerogative based on material properties, tradeoffs, etc. Focus was directed to trends that could produce limitations on the side-effects of high induction.

12. Mechanical Requirements Due to External Factors

Beyond the purely duty-related forces acting upon transformers, such as heating, short-circuit forces and pressure considerations, there are external factors that act upon the transformer. During shipping, a transformer can be severely mishandled. Once in

place, earth tremors can shake the transformer and potentially dislodge components. Corrosion is a constant threat to the structural integrity of the transformer vessel and fittings. In some instances, transformers in close proximity to the public can be subjected to physical abuse or vandalism. All of these factors must be considered when designing the transformer containment and mounts for all components within that containment.

There are already some requirements expressed in transformer specifications that relate to performance relating to the above-mentioned factors. For example, seismic qualification of equipment is becoming more common. Also, paint or coating specifications have long been a reality. Within this program, attempts were made to identify any system trends or external influences that may lead to strengthening existing requirements, or creating new such requirements to respond to forces not now considered harmful. Exact levels of performance were not addressed; rather, general directions in this area were investigated and defined to the degree possible.

13. Environmental/Safety Considerations

Whereas "Mechanical Requirements Due to External Factors," concerns itself with the impact of the external environment upon a transformer, this area addressed those ways in which the transformer may impact unfavorably upon its environment. These impacts include the visual effects of "unsightly" equipment; the aural effect of "loud" equipment, etc. On a higher plane are the more tangible concerns for safety. These include the flammability and toxicity of the coolant, the heat generated by equipment in close proximity to the public, and public accessibility to the equipment.

Some system-related trends could have a bearing on transformer siting, which may give rise to certain specific concerns which fall into the above category. More likely, a number of external in-

fluences may combine to produce more stringent requirements in this general area. Attempts were made to highlight the system trends and external influences that will most likely impact upon design requirements in the environmental/safety realm. Where possible, the specific environmental or safety concerns of most interest were identified and directions of these concerns investigated. Since most of these concerns are already apparent in greater or lesser degrees, this analysis took the form of extrapolation of present requirements.

14. Size and Weight Considerations

Certain influences may act in a manner that favors so-called "economies of scale," implying the construction of transformers with higher power ratings. To some degree, the physical size and weight of present transformers are already being restricted by difficulties in handling during construction, by shortcomings of available transport facilities, and by area constraints at the transformer site. Construction constraints are probably the most adjustable of the three. The major constraint will likely be shipping considerations, since this lies outside the realm of control of both user and builder.

Specific system trends could lead to reduction in transformer physical size, while others may require larger units. Where strong system pressures favor the larger designs, possibilities such as modular-construction-with-field-assembly may be an alternative.

15. Reliability Considerations

Any discussion of product design parameters must, at some point, address the subject of product reliability. Reliability is a parameter that has always been handled more implicitly than explicitly. A nominal life expectancy became factored into material

selection, and consideration was given to the expected operating environment's effects on operation over that lifetime. Significant advances in reliability were made more in response to economics or competitive pressures, than by any written specifications or design criteria. Within the past several years, however, product quality/reliability has begun to enter the political and legislative areas, and it could be possible that actual attempts might be made to legislate and enforce "reliability standards." In certain critical areas, such as Class 1E nuclear equipment applications, this type of standard is already a reality.

Analysis in this area focused on identifying any system-related or externally-forced trends to intensify or formalize the process of ensuring product reliability.

B. Qualitative Impact of Technical Considerations and External Influences on Transformer Design Parameters

Appendix III represents the initial part of the "Third Effort;" that is, a tabulated listing of the most significant system effects on a design parameter and the corresponding major external influences which affect the system changes. The listings were made for each transformer design parameter, based on the information contained in Appendices I and II.

The information in Appendix III appears in the form of brief phases to facilitate easier perusal of the total body of basic information pertaining to the specific transformer design parameter in question. The desire was to create a separate number of sheets for each parameter which could be withdrawn from the Appendix as a relatively complete picture of essential forces acting on one specific design parameter. Appendix III proved to be useful in developing the system scenario and the discussion of the status of transformer design parameters for the Year 2000, as given in parts C and D, respectively, of this section.

C. Status of Technical Considerations in Year 2000

To establish the likely directions to be taken by the various transformer design parameters in the Year 2000, it is first appropriate to define the status of the transmission and distribution systems of the future. This can be done by specifying which technical considerations will change, in what manner, and which will remain approximately the same as they are today. The likely directions of the thirty-one technical considerations are given in the paragraphs which follow. Suggestions for possible future investigation are included.

Exhibit I summarizes the status of technical considerations in the Year 2000, as discussed in this section.

(1) Reliability Criteria

Reliability criteria for future T&D systems are not expected to be significantly different than they are today. In recent years, with rising costs, it is becoming more desirable to reduce reliability standards by having less redundancy in system designs, in the interest of reduced capital costs. However, as cost of service continues to rise, it is unlikely that consumers would accept a steady erosion of service quality. Hence, a long-term trend in the direction of reduced reliability is not expected. On the other hand, increased spending for improved overall reliability would likely meet with consumer resistance. Thus, the counteracting forces of unwillingness to pay for more, and resistance to accepting less, will likely keep reliability criteria about the same as today.

This is not to say that more will not have to be done to bring the less reliable system areas up to the accepted standards. One method for improving system reliability without increasing redun-

dancy is by improved component reliability. For this there will be utility pressure for improved product reliability. With increasing capability to assemble and utilize large quantities of data will come increasing evidence of particular component shortcomings, and subsequent pressures to correct and demonstrate improvement in these areas. Advances in low cost computational equipment will ultimately bring large data bank usage into the design practices of greater numbers of utilities. Component reliability of the Year 2000, therefore, is expected to be more carefully defined, more stringent in nature, and more fully documented.

(2) Trend from Overhead to Underground

The present trend from overhead to underground construction in distribution systems is likely to continue in the foreseeable future. This trend has not been as rapid as once predicted, because the relative cost of underground to overhead has not yet come as close to the one-to-one ratio as was first expected. Underground system and equipment design is now reasonably mature, and the operational aspects are fairly well developed. It is not likely that significant cost breakthroughs will be made to accelerate the trend. What is expected to be the more significant factor in the trend towards underground distribution is pressure by governmental and other bodies to mandate or very strongly urge increased use of underground construction. This is already a reality in some areas, where all newly developed residential areas must be underground, where overhead circuit extensions are prohibited, or where any planned conversion or reconfiguration work on existing overhead lines must result in underground installation. Such pressures are unlikely to disappear from areas where they are already in existence; rather, they are likely to increase. The trend will likely extend more into the commercial and light industrial areas as well.

In the transmission area, the use of underground has been much more restricted. For transmission systems, the necessary technologies

and operational techniques are all more advanced compared to distribution. While some strides are gradually being made to develop underground transmission along the same basic principles of underground distribution, these are slow in coming, and generally limited to the lower range of transmission voltages. Consequently, the cost differential between overhead and underground transmission will likely continue to be great over the remaining years between now and the Year 2000. This cost differential now is in the range of an order of magnitude. If underground transmission is to be attractive to utilities it must come closer to the ratios prevailing in the distribution environment. Continued R&D expenditures on underground transmission and breakthroughs in materials technology may gradually narrow the gap in relative costs, but it does not seem evident that this will occur by 2000. Thus, it seems reasonable to assume that underground transmission will continue to be used only in special circumstances where constraints other than economic are overriding, or where vehement opposition to particular overhead line construction is encountered.

(3) Higher Voltage Levels

The same basic considerations which have encouraged development and usage of higher voltage levels in the past will continue to exert pressure in the future because of concerns such as system losses and effective use of right-of-way.

At the distribution level, the present higher voltage levels of 25 kV and 35 kV are expected to continue to grow in years ahead. Because of the separate parallel voltage increment structures which generated these two levels, it is not likely that any attempts will be forthcoming to standardize on one or the other. The same kind of situation could occur when utilities consider the next step in voltage. Those utilities now using 25 kV may consider 46 kV, while those using 35 kV would not see much additional benefit from 46 kV and would likely consider 69 kV. A common next higher distribution

voltage level could be a possible area for future investigation. In any case, there will be some distribution at new higher voltage levels, probably utilizing existing 46 or 69 kV subtransmission facilities as an expedient.

For transmission systems, current R&D efforts and Standards indicate that 1200 kV will emerge by the Year 2000 as the next generally applied maximum voltage level. There is, however, a question about how much need there will be for 1200 kV by 2000. There probably will be some usage by as early as the late eighties, which should provide the necessary operating experience to gain general utility acceptance. Assuming technical and economic feasibility of 1200 kV transmission is achieved within a few years, general usage would still be dependent on load growth between now and the Year 2000. The present outlook for generation additions indicates a relatively slow rate of growth until at least the late 1980's. Thus, a retardation in the trend toward higher voltage transmission may likely carry through to the Year 2000. There are circumstances which could alter the transmission picture. For example, the aftermath of Three-Mile-Island could result in a trend to create large generation parks in areas remote from population centers. This would tend to make 1200 kV much more attractive in order to achieve a higher power density over available ROW corridors.

It is recognized there is R&D effort being done at 1500 kV today. It is possible 1500 kV may be used by the Year 2000, but not likely to the extent expected for 1200 kV.

(4) Fewer Voltage Levels

A logical offshoot of the trend to higher voltage levels is an elimination of lower voltage levels. This is already in evidence today. Many utilities are not expanding their 4 kV distribution

systems, and are, in fact, converting them gradually to a higher voltage level. By the Year 2000, the same effect is expected even for the predominantly used 15 kV systems of today. However, this trend would probably be limited due to the unavailability and high cost of capital expected between now and the Year 2000. For distribution, virtual elimination of voltage levels below the 15 kV class is expected. Elimination of these voltage levels could be offset in part by additions of new higher distribution voltage levels.

On transmission systems, there will be decreased use of voltage levels between 69 and 161 kV because many utility systems will eliminate the use of one or more of these levels in upgrading ROW's to higher voltages.

(5) Voltage Regulation Criteria

The voltage regulation criteria that presently exist will not likely change by 2000, at least at the transmission level. At the distribution level, there are conflicting opinions at present over the worth of reducing the top end of the accepted voltage range in order to conserve energy; consequently, it is difficult to determine whether this will be a common practice by the Year 2000. If it should prove beneficial, then an actual change would occur in the accepted regulation criteria, since the effective voltage bandwidth would then be tighter, and lowered from the top end.

(6) Use of Load Management

The use of load management was not found to be a significant factor in affecting transformer design parameters. Therefore, other than to note that the outlook for load management in the Year 2000 is promising, and that its usage is expected to be widespread, no

further consideration of this topic will be given.

(7) Regional Energy Transfer

Regional energy transfer has generated a great deal of interest since the energy crisis of 1974, primarily because it is a method of displacing energy produced by oil-fired plants in one region with energy from alternate sources in another region, by means of electric power transfer. However, because this topic is very controversial (regarding questions concerning efficiency, reliability and economics) among politicians, utilities and the public, especially regarding a national grid system, it is unlikely to be resolved in time to be implemented by the Year 2000, barring government mandated directives. Such mandates are not foreseen at the present time. Therefore, although some regional energy transfer will be used in the next 20 years, it will not be a significant factor in the majority of utility systems.

(8) Use of HVDC Circuits

Considerable research and development has gone into DC transmission in recent years, and several installations have been or are being built in the world today. HVDC has basically been shown to be cost-effective where very long lines are involved. It could become a competitor to UHV A.C. transmission, since this level of voltage implies long lines and large capacity power transfer requirements. It also solves some specific technical problems such as the need for asynchronous ties or transmission over long underground cables. Some drawbacks to HVDC exists in the complexity and costs of the terminals. Also, DC will not be truly flexible until suitable breakers are developed to allow DC to be networked in much the same fashion as the present AC systems. The terminal economics should gradually improve as greater experience is gained and R&D is performed to improve semiconductors and control schemes. However, at

present there is relatively little to indicate that HVDC will be applied in more than the special cases mentioned above by the Year 2000.

(9) Use of Multi-Terminal Lines

Although use of multi-terminal lines will likely increase for economic reasons by the Year 2000, it has little impact on transformer parameters. Therefore, for purposes of this report it will not be discussed further.

(10) Use of Higher Phase Order Transmission

Of considerable theoretical interest at present is the usage of 6-, 12-, or even 24-phase transmission to achieve larger power flows over narrower rights of way. There are no such systems in operation today and the operating philosophies, protection schemes, and problem areas are just now being studied. It is difficult to assess where the future of this technology may lie. By the Year 2000 it is likely that there will be some trial installations. However, these installations will not be significant in terms of their effects on typical power systems and associated equipment. The types of transformers that would be used for these higher-phase-order systems is of considerable, but specialized interest to transformer designers. Whether n-phase transformer designs will have to be developed, or whether one or more three-phase units will be used either by manner of connection or in conjunction with phase-shifting devices, is certainly an area that will receive close attention in future years. This is an area that should be studied further, both from the standpoint of technical and economic feasibility and transformer design considerations.

(11) System and Component Losses

The greatly increased cost of energy since 1974 has resulted in extensive efforts on the part of utilities and manufacturers to sub-

stantially reduce the level of losses in systems and components. The future will bring even greater incentives for reducing system and component losses and consequently, it is safe to assume that losses will be a smaller percentage of system output than they are today.

The subject of loss evaluation, and the relationships between no-load and load losses in transformers, is an extremely complicated one. For purposes of this study it is sufficient to know that the trend in both is to minimize the losses.

(12) Higher Short Circuit Magnitudes

Increased short circuit magnitudes result from other system trends, such as use of new higher voltage levels, voltage upgrading of existing systems, elimination of subtransmission, use of few but higher capacity substations, increased system inerties, and greater system redundancy. Because of these trends short circuit magnitudes will continue to grow if left unchecked. However, many utilities realize that increasing fault duties present both economic and technical problems. Replacement cost of breakers having inadequate interrupting and momentary ratings on large systems can become prohibitively expensive. Stresses to other equipment may pose potential hazards to workers and the public, particularly in the case of distribution systems. For this reason, many utilities consciously try to limit the available fault currents on their systems. Various methods have been used, particularly in distribution systems, such as high transformer impedances, bus-splitting, series reactors in lines or between bus sections, neutral reactors, and current limiting fuses. On distribution systems, which are closer to the public, fault current limitation will certainly be a reality in the future, as it is today. This is particularly true at the higher distribution voltage levels.

Various new fault current limiting devices have also been studied for use on transmission systems. These devices would present essentially zero impedance to the system during normal operation, but would increase to a high impedance when a fault occurs. The concepts which are considered technically feasible have not been economically attractive to date; however, continued R&D efforts will likely overcome economic limitations. As a result, fault current limiters are likely to be in general use by 2000.

There are several alternatives available to utilities to control transmission fault current levels. Some, like splitting the system, lessen reliability. Others, like the FCL devices being investigated, are costly. Whatever the alternative chosen, it is expected that utilities in the Year 2000 will maintain fault currents at levels about the same as the maximum levels existing today.

(13) System Harmonic Levels

Harmonics in power systems have always been of concern, for such reasons as interference with telephone service (TIF) and additional stressing of equipment, such as capacitors. Transformers, themselves, contribute to the problem due to saturation of their cores. Over the years the telephone problem was largely solved, but the advent of computers created a new interest in purity of waveform on power systems. By the Year 2000 it is expected that there will be an increase in harmonic sources on power systems. These will largely be in the form of power electronic devices. The transformer, however, will not be as great a harmonic generator due to expected reductions in operating induction or new core materials.

With the advent of even more harmonic sources, it would very soon become an intolerable situation. By the Year 2000 a great deal more will probably be done to recognize and control the increased number of sources of harmonic generation. Therefore, it is expected that the level of harmonics on systems will be no worse than today, and may even be reduced by better control methods. Harmonic control is an area which deserves increased investigation in the future, because of the potential severity of the problem, if not properly controlled.

(14) More Stringent Audible Noise Criteria

Environmental protection legislation brought about an awareness and concern over all forms of "pollution." Thus the term "noise pollution" has come into being, and the topic has received increased attention in the form of various regulations and guidelines. It is anticipated that there will be a gradual stiffening of noise criteria, probably with more precise definitions and conditions stated for a wider variety of general and specific applications.

Utilities, therefore, have become more concerned with audible noise. Such concerns are typically stronger in a crowded urban area. Equipment for use in these areas will probably have to meet tighter criteria than that used in less populated areas. Thus, transformers, and their auxiliaries for use in buildings, indoor substations, network vaults, etc., as well as pad-mounted distribution transformers, will likely bear the brunt of the noise-reduction efforts.

(15) Use of Gas Insulated Substations (GIS)

By the Year 2000, gas insulated substations should be widely used. As long as population continues to grow and inflation soars, real

estate price escalation will be very rapid. Since GIS requires less land area than conventional substations there will be substantial savings in real estate costs. This will occur in urban areas at first, but gradually in other areas as well. Gas insulated substations are expected to have an economic advantage over conventional substations, with the economic margin increasing at higher voltages. Increased operating experience, cost improvement, and development of more GIS-compatible equipment will serve as extra economic and technical incentives to use GIS.

(16) Use of Gas Insulated Transmission (GIT)

By the Year 2000, it is not likely that GIT will be used extensively, because the economics of GIT are generally unfavorable except for special cases. There is also an esthetics problem to some degree, and a public access consideration as well. Today it is used only for very special applications, such as line crossings, the transfer of large blocks of power through already congested areas, and situations where cables are desirable but inadequate for the task. This situation is unlikely to change drastically by the Year 2000. The number of circuit miles in use by 2000 will be very limited because it is unlikely GIT will be cost competitive with conventional transmission lines in the near future.

(17) Use of Superconducting Transmission

Many of the same arguments which apply to GIT also apply to superconducting transmission. The additional complications of the cryogenic aspects of the latter will likely limit any applications by the Year 2000 to very specialized areas.

(18) Phase Angle Regulation Constraints

Phase Angle Regulation is a method of controlling power flows through portions of the transmission system. To date, phase angle regulation has not been used to any great extent. Power flow can usually be maintained adequately by proper system design (i.e. using additional circuits) without the need for phase angle regulation; hence, system reliability would in general be better without phase angle regulation. Another disadvantage of phase angle regulation is that as a system grows, the phase angle regulator may no longer be needed at the point of installation; therefore, it must be moved to a new location at an additional expense.

Nevertheless, economic dispatching may dictate the need for phase angle regulation as the economic choice over additional lines. Also, possible imposition of a national grid could make it desirable, if not a necessity, to use phase angle regulation.

By the Year 2000 it is expected that phase angle regulation will be used to a greater extent than today but will still not be in general use. Its application could be enhanced through any R&D projects which lead to more compact and less expensive means of phase angle regulation tap changing.

(19) Use of Mobile Substations

Mobile substations are used as a backup to reduce outage-related difficulties caused by failure of key equipment. It appears likely that this particular usage pattern will not be significantly different by the Year 2000. Presumably there could be very specific instances where these devices could be used temporarily to defer the addition of a line as an economic alternative. Such applications are too specialized for general usage, and it is unlikely the mobile substation will be utilized in this way except for isolated cases.

(20) Use of Indoor Substations

The indoor substation utilizes relatively conventional equipment in a non-standard package application. In urban areas, where land costs might be excessive, this type of substation can be built on a relatively small space; can be constructed vertically, rather than horizontally; and can be more easily protected because it is inconspicuous to the general public. Consequently, it is expected that this concept will be widely used in many urban areas by the Year 2000. Advances made in the reduction of size and weight of various equipment types will likely give extra impetus to the trend towards indoor substations in these areas.

(21) Use of Low Voltage Networks

That the use of low voltage networks is already in a state of decline is readily evident in the industry today. The highly touted reliability of this method of service is probably justified in isolated special situations, but most utilities seem to be concluding that such reliability is probably not warranted for most applications, particularly considering the cost of network systems compared to the likely alternative system designs. It appears that many grid networks are remaining fairly static in size, or in some cases may be shrinking, due to pressures of urban renewal with reconstruction using less expensive service methods. By the Year 2000, probably only the largest cities with established L.V. grid networks in stable downtown areas will continue to use the grid network. Spot networks may still be popular for specialized service to what are considered critical load centers, but by and large most equipment for networks will be used for replacement, rather than expansion.

(22) Use of Power Electronics

The usage of semiconductors for direct switching and control of power within utility systems is still in a relative state of infancy

today. Even though power semiconductor equipment has been developed and used for many years, neither the number of possible applications, nor the range of possible semiconductor improvements has been exhausted. The history of the semiconductor industry indicates ever-increasing progress in reducing size, increasing current and voltage capability, reducing losses, providing better control schemes, increasing reliability, and lowering costs. Progress is expected to continue in the next twenty years. Continued investigations will unearth new applications, and improvements in semiconductors will enhance their use in applications where they previously were non-competitive, either in cost or performance.

Harmonics, one of the side effects of power electronic switching applications, could be a potential problem and deterrent in their application. However, harmonic suppression schemes will be part of the development of this technology and, therefore, harmonics will not be any more of a system problem than exists today. Widespread usage of power electronics by the Year 2000 is anticipated.

(23) Use of Substation Automation

The concept of substation automation includes the local monitoring, control and protection of the substation via small local computers, combined with appropriate sensors and interfaces. Some of the possibilities for this type of automation are being investigated today, along with development of the necessary information gathering sensors. Continued advances in microcomputers will most certainly take place. The key to the future of substation automation lies in the abovementioned sensor and interface realms. A high degree of reliability in these areas is a necessity, and will likely be achieved.

By the Year 2000, substation automation should be in general usage. It is conceivable that the ability to obtain and analyze greater quantities of various types of data could lead to modifications in equipment and/or system design and operation. There is a necessity for continuing investigative work, both in the area of reliable automating equipment and system design, and in the area of effective utilization of the potentially large amounts of data that could be obtained.

(24) Use of Distribution Automation

Greater use of automation to monitor and control certain functions on the distribution systems of the Year 2000 is almost assured. The workability of multi-function automation is in the process of being established at the present time, and it is likely that this type of automation will become mature over the next several years, permitting utilities to take advantage of the numerous benefits that can be obtained through automation. However, the use of distribution automation has little or no impact on the design parameters of transformers. Consequently, further consideration or discussion of this concept within this report will not be undertaken.

(25) Use of Transmission Line Single Pole Switching

By the Year 2000, the use of single pole switching to enhance stability will likely be greatly increased at EHV and UHV levels, 345 kV and above. However, since the use of single pole switching does not affect transformers directly, no further discussion of this technical consideration is given.

(26) Use of Transmission Ultra-High-Speed Fault Clearing

Development and usage of ultra-high-speed (UHS) fault clearing schemes is being contemplated in order to improve stability margin

and power transfer capability, while also reducing short circuit stresses in the system. It is expected that there will be substantial use of UHS fault clearing schemes in the Year 2000. Theoretically, this would allow reduction in the relative short circuit strength of transformers and other equipment. However, the maximum strength is predicated on the assumption that back-up relaying may be the ultimate clearing mechanism. Consequently, the use of UHS only results in less cumulative stress over the life of the transformer, but will not determine the required design strength of the unit.

(27) Use of Fault Current Limiting Devices

As discussed under the section on higher short circuit magnitudes, there will likely be fault current limiting devices on the T&D systems of the Year 2000, to limit faults to some desired maximum current. The conventional devices used today for limitation of fault currents include series reactors, neutral reactors and distribution current limiting fuses. Increased transformer impedance is another method for controlling fault levels. The latter method may be an effective technical solution for distribution systems, but generally is not economically feasible because of losses and regulation. By the Year 2000, some form of "true" fault current limiting devices (defined as having negligible impedance during normal operation, but high impedance during faults), will likely be technically and economically feasible, and therefore, in general use on utility systems.

(28) Improved Transient Overvoltage Control

Improved transient overvoltage control and protection will exist by the Year 2000. Advanced system and equipment design concepts will likely emerge to control switching transient overvoltages to levels

lower than obtained by the present practice of using resistors in circuit breakers. For example this may be in the form of power electronic equivalents of circuit breakers or controls for conventional circuit breakers which will optimize the point of closing and opening to eliminate any significant switching overvoltage. Better protective devices, such as the emerging metal oxide arresters, will also help to prevent equipment insulation failure due to the presence of high transient overvoltages.

(29) Improved Dynamic Voltage Control

It is expected that new sources of dynamic overvoltages may be identified in the years ahead. Overvoltages due to faults, system swings, or transformer ferroresonance have been known for many years; however, recent investigations have led to discovering of new sources of dynamic overvoltages, such as that caused by voltage transformer ferroresonance, or improper feedback control of generator excitation. It is expected that other sources of dynamic overvoltages may be discovered in the next 20 years. Some may be newly created by new devices applied to power systems. Having identified these new sources of overvoltage, new methods of control or system and/or component design will most likely emerge to limit the overvoltages to acceptable levels. An example would be an arrester capable of absorbing the power frequency energy for the duration of the overvoltage. Therefore, by the Year 2000, it is expected that better dynamic voltage control techniques will exist.

(30) System Var Compensation

Economic benefits and improved voltage regulation are gained by system var compensation at all voltage levels. Its usage will likely increase significantly in the next 20 years. At the distribution voltage levels, compensation will continue to be in the

form of shunt capacitor banks, and will likely utilize distribution automation schemes to achieve more optimum control. At higher transmission voltages, increased use of shunt and series capacitor banks and shunt reactors should occur in the next 20 years. In addition to these passive forms of compensation, recent developments in static var compensators, which provide dynamic control of both capacitive and reactive vars for improved voltage control and stability performance of a system, will likely become a significant factor by the Year 2000. EHV and UHV voltage levels will likely require all forms of compensation discussed. The trend to more sophisticated control and improved economics of system var compensation will lessen the need for transformers with load tap changers.

(31) Stability Criteria

As with reliability criteria for the system, stability criteria are not likely to be any more stringent in 2000 than they are today. The emphasis will be on improvements in methods to insure that the criteria can be effectively met. In some cases, the criteria may even be slightly relaxed to avoid large capital expenditures. For example, an added transmission line may not be economically justified if constructed only for the purpose of meeting some specific stability criterion. Exceptions might be in specific areas which require tightening of stability criteria such as areas of high concentration of generation (generation parks), and areas which may be more prone to earthquakes or other disruptive phenomena. In such cases, potential economic loss will justify the additional capital expenditures necessary for more stringent stability criteria.

Exhibit I.

STATUS OF TECHNICAL CONSIDERATIONS IN YEAR 2000

1. Reliability Criteria - System criteria about the same as today; component criteria probably more defined, stringent, documented.
2. Trend from Overhead to Underground - Will continue to increase for distribution; only in special cases for transmission.
3. Higher voltage Levels - Economic incentives to raise voltage; general use of transmission at 1200 kV; some distribution up to 69 kV as an expedient.
4. Fewer Voltage Levels - Logical extension of trend to higher voltages; distribution below 15 kV sharply decreased; transmission voltage upgrading; reduction in, or virtual elimination of, subtransmission.
5. Voltage Regulation Criteria - Unlikely to change for transmission; at distribution level, voltage reduction for conservation could be possible reason for change; voltage unbalance could be an issue in this category.
6. Load Management - Probably Widespread
7. Regional Energy Transfer - Some may exist, but very limited; national grid unlikely to be a reality in 2000.
8. HVDC Circuits - Limited to very long lines and special cases requiring asynchronous ties.
9. Multi-Terminal Lines - Usage will increase on transmission.
10. Higher Phase Order Transmission - Some trials in 2000; very limited
11. System & Component Losses - Losses will be lower in relative terms, maybe in absolute as well; strong economic incentives to reduce.
12. Short Circuit Magnitudes - Other trends would tend to cause increase, but fault limitation will be practiced to keep levels down.

13. System Harmonics	- Less harmonics from transformers, more harmonic sources of other types, but better control will be exercised to keep overall levels down.
14. Audible Noise	- Criteria will tighten in populous areas; other design trends may make compliance easier.
15. Use of Gas Insulated Substations	- Very popular by 2000, at least in urban areas.
16. Use of Gas Insulated Transmission	- Used in special applications only; e.g., large blocks of power over short distances in congested areas.
17. Superconducting Transmission	- Unlikely to be a factor in 2000; only for very specialized applications.
18. Phase Angle Regulators	- Increased usage by 2000, but probably not significant.
19. Mobile Substations	- No significant changes in relative usage.
20. Indoor Substations	- Very popular in urban areas.
21. Low Voltage Networks	- Today's decline in usage to continue; largely a replacement situation in 2000.
22. Power Electronics	- Widespread usage by 2000 as cost and performance improvements continue; probable new application areas.
23. Substation Automation	- General usage by 2000; dependent on reliable sensors and interfaces to micro-computers.
24. Distribution Automation	- Probable increased usage, but little impact on transformers.
25. Transmission Single-Pole Switching	- Greatly increased usage at EHV/UHV levels; limited impact on transformers.
26. Ultra-High-Speed Fault Clearing (Transmission)	- Considerable usage by 2000; limited impact on transformers.
27. Fault Current Limiting	- Increased usage of conventional means (e.g., reactors) for distribution; New FCL devices in general use for transmission.

- 28. Transient Overvoltage Control
 - Metal oxide and other advances lead to considerable improvement by 2000.
- 29. Dynamic Voltage Control
 - Improved control by 2000; even though more causes of overvoltage may exist.
- 30. System VAR Compensation
 - Generally increased usage, more complex schemes and finer control; strong economic incentive.
- 31. Stability Criteria
 - Likely to be the same or slightly relaxed in general; could be more stringent for areas of high generation concentration and earthquake-prone areas.

D. Status of Transformer Design Parameters in the Year 2000

The discussions in this section constitute the major conclusions of this project. These conclusions were derived by using the relationships between the technical considerations and the design parameters, as outlined in Appendix III, in combination with the conclusions regarding the future status of the technical considerations, discussed at length in Section IV-C above. These conclusions represent the most logical directions for the various transformer design parameters, in the view of the principal program investigators. Also included, as in Section C, are possible areas of future investigation.

The status of the transformer design parameters in the Year 2000, discussed in this section, is summarized in Exhibit II. A summary of the investigations suggested in this section is given in Exhibit III, under the heading "Transformer Related."

(1) Voltage Rating

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Higher Voltage Levels, Fewer Voltage Levels, Use of Power Electronics, Use of System VAR Compensation.

Discussion: The expected trend to using higher voltage levels (on an overall average basis), combined with elimination of some of the lower voltage levels, will lead to transformers having higher turns ratios, in addition to the obvious need for higher primary voltage ratings. The number of transformers having unusually large turns ratios (for example, distribution substation transformers stepping down from 230 or 345 kV to 15 kV), would not be expected to be very significant, but they would be a consideration in designing transformers. On the whole the trend to higher distribution voltages, as

well as to higher transmission voltages eases some of the concern over these larger ratios, since both the primary and secondary voltages would be increasing, in general.

The increased use of more sophisticated VAR compensation schemes (such as the static var compensator or other forms of power electronic equipment) would likely produce finer control over the voltage spread as seen by both the primary and secondary of the transformer. Consequently, it might be possible to take advantage of this fact by reducing the operating bandwidth requirements of the transformers of the Year 2000. This, however, would have to be investigated to see if any real gains could be obtained.

More imaginative usage of power electronics in the future could also require specialized transformers for interfacing exotic generation sources to the system. The voltage of the winding connected to the system might be the only established or "standard" voltage rating for a specific set point in such transformers. However, there is nothing that disallows unusual voltage ratings of the windings which are on the source side. It is likely that more non-standard source-side voltage ratings would appear in some specialized transformer designs in the future, since the cost and effectiveness of the entire source/interface package up to the point of connection to the system could be optimized on the basis of the most desirable voltage on the source end. Coupled with the non-standard voltage in these cases, there might also be a need for non-standard winding connections, again to take advantage of some particular cost or performance characteristics.

The discussion of "Use of Higher Voltage Levels" in Part C gives the likely maximum voltage levels expected in the Year 2000, as well as the voltage levels where little activity would be expected.

Future Investigations: As discussed above, the need to interface exotic sources of generation to the power system could produce a need for non-standard voltages and/or winding configurations, in order to optimize the cost and performance characteristics of the total generator-transformer packages. As these packages are developed in the future, such analysis should be an integral part of the process. Only then can the transformer voltage rating and winding configurations be determined.

Along much the same line of thought, special transformers for use with the gradually developing higher-phase-order transmission systems of the future could also utilize what are now non-standard voltages. As indicated in Section C, however, this technology will probably not be too significant by the Year 2000.

(2) Voltage Taps

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Use of Power Electronics, Use of Substation Automation, System VAR Compensation.

Discussion: To provide reasonable limits of voltage fluctuations over the daily load cycle requires that some form of voltage regulating devices be applied at strategic locations throughout the system. One method of voltage regulation which has been used extensively is voltage taps on transformer windings. Var compensation, such as use of shunt capacitor banks, is another method which can provide voltage control, and also additional system benefits, such as loss reduction. Taps can only change voltage and tend to reduce transformer reliability. As a result, var compensation will likely be the overall economic choice. This will lessen the need for transformer load tap changing equipment.

However, the need for taps will continue to exist. The complexities of system design and operation will likely still produce circumstances where taps are perceived to be necessary, or desirable for specific

reasons. In applications where both no load and load tap changers are used on an individual transformer, it is expected that a shift will be made to using only LTC on one winding, likely spanning the same tap voltage range as the combination. This would have an economic advantage to the utility in lower transformer cost and a reduction in labor costs associated with changing the no load taps when required.

With substation monitoring and control expected to be in general use by 2000, it may be possible to develop, from the history of voltage changes on the system and over a long time, a tap philosophy that would lead to taps with non-uniform percent steps. Present tap structures usually involve uniform percent steps in the regions above and below the center voltage. The non-uniform tap arrangement could provide finer steps in the normal operating range, with coarser steps to control major disturbances. Such a development would necessitate the analysis of a large number of voltage records from automated substations, in order to evaluate whether a discernible pattern exists, to provide an optimum tap arrangement for a particular substation.

Future Investigations: The two major areas of future investigation, both outlined above, are the development of new concepts in LTC, possible involving power electronics or other means, and the non-uniform tap structure.

(3) Insulation Level Requirements

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Higher Voltage Levels, Use of GIS, Use of Indoor Substations, Power Electronics, Use of Current Limiters, Transient Overvoltage Control, and Dynamic Voltage Control.

Discussion: The trend towards higher voltages has generally resulted in a lower ratio of BIL to system voltage, for reasons of cost and size improvement. Consequently, the pressures to reduce BIL requirements will be even stronger in the future than it is today. Advances expected in the area of transient voltage control (including new arrester materials and power electronics for switching) should make it easier to achieve the desired reductions. Improvements in dynamic voltage control may also permit lower 60 Hz insulation requirements as well.

As the insulation requirements are reduced within the transformer, resulting in generally smaller tank sizes compared to today's designs, a need is created to improve upon present-day bushing designs as well. Therefore, it is important that the entire transformer package, including bushings, be reduced in size.

Future Investigations

Studies which show the cost versus reliability of reductions in BIL and 60 HZ insulation as a function of various levels of transient and dynamic overvoltage control should be made.

(4) KVA Ratings

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Higher Voltage Levels, and to a lesser extent Ultra-High-Speed Fault Clearing.

Discussion: The concern with kVA ratings is primarily the upper limit that will be reached by the Year 2000. Larger MVA ratings generally result when a higher system voltage is introduced in the industry, or new technology is developed which requires larger ratings by components to obtain maximum economic benefit. For example, HVDC, GIT, superconducting transmission and UHV all have

the capability to handle large power capacity, and could utilize transformers having increased MVA ratings over those used today. However by the Year 2000 these technologies are not expected to be in general use. In addition, as discussed later in the section "Size and Weight Considerations," shipping limitations will tend to hold down MVA ratings unless new materials and technology permit reductions in physical size. Therefore, it is unlikely that there will be a general need for transformer MVA ratings greatly in excess of those available today. Nevertheless, prototype transformers having higher MVA ratings will likely be manufactured for use with initial installations of the advanced technologies mentioned above.

Future Investigations: It would probably be worthwhile to intensify research on superconducting transformers, which could provide a logical interface between the superconducting generators and superconducting transmission lines which will eventually be developed and applied.

(5) Thermal Considerations

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were the Trend from Overhead to Underground, Component Loss Levels, Use of Indoor Substations, Power Electronics, and, to a lesser degree, Load Management.

Discussion: The trend to underground (at least for distribution transformers), the increased use of indoor substations, and possible harmonic load caused by greater usage of power electronic equipment, all tend to create a potential need for increased thermal capacity in transformers. However, it is believed that better

harmonic control will exist in future systems, due to the expected development of new harmonic generation sources. Continued intense pressures for lower loss transformer designs may result in improved thermal capability as a beneficial side-effect. Hence, the apparent need may be solved indirectly by solutions to other more pressing needs, such as lower losses.

The use of load management in the future may permit reduced transformer thermal capability. However, reduction most likely will never take place, due to the overriding need for lower loss designs, which might be inherently better from a thermal capability standpoint. This is dependent on the hot spot control and cooling design over which the designer has control.

Future Investigations: In the area of thermal considerations, much of the knowledge and guidelines that are in use today are based on a limited amount of data obtained over the years. With the availability of ever more advanced equipment and techniques, more thorough investigations should be undertaken in the area of loss-of-life, to better determine a transformers' actual thermal capability.

(6) Impedance Considerations

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were the Trend to Underground, Use of Higher Voltages, Lower Voltage Levels, Higher Short Circuit Magnitudes, and Use of Indoor Substations.

Discussion: From the standpoint of improved regulation, lower losses and smaller sizes, lower impedance provides economic advantages. The drawback to lower impedances is an increase in short circuit current magnitude.

On transmission systems, in most cases, this drawback will not be enough of a factor to cause utilities to request increased transformer impedance for the purpose of reducing short circuit magnitudes. This is because circuit breakers have (and will probably continue to have) the capability to interrupt the available fault currents. In the future, fault currents may not be a problem because of the expected development of fault current limiters. Therefore, it is expected that there will, in general, be pressure to reduce impedances of transformers used at transmission voltages.

On distribution systems, secondary fault current magnitudes of distribution transformers, primarily for residential and commercial applications, must be examined in a different context than that of power transformers on transmission systems because the primary concern is public safety. With the trend towards using higher distribution transformer kVA ratings, utilities are concerned that secondary fault currents can exceed the interrupting ratings of service entrance protective devices, normally supplied by the building contractor.

Several years ago an EEI-NEMA group addressed this problem and proposed a recommendation that distribution transformer impedances be increased to limit fault currents to 10,000 amperes. This concern for reducing secondary fault current levels is expected to continue in the years ahead, especially since these fault current levels will continue to increase, if left uncontrolled.

The most direct and economical method used by utilities up to this time to reduce the fault current level has been higher impedance distribution transformers. Until other better and/or more economical alternatives are developed, possibly such as inexpensive fault current limiters, it is likely utilities will continue to use distribution transformer impedance as a means of controlling secondary fault levels. However, the extent to which distribution trans-

former impedances can be increased for this purpose will be limited in practical applications by considerations of voltage drop, losses and tank size.

Future Investigations: Studies should be made to determine the direction and extent impedance varies as losses are drastically reduced.

(7) Transient Inrush Current Constraints

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were the Trend to Underground, Higher Short Circuit Magnitudes, and Use of Fault Current Limiting Devices.

Discussion: Any influences leading to greater short circuit magnitudes will, in general, lead to higher inrush currents if nothing is done to alleviate the problem. However, under present standards, transformers must be able to withstand the inrush from an infinite bus. Therefore, unless this situation changes (this does not appear likely), designers will have to contend with inrush currents limited only by the transformer's impedance.

(8) Loss Levels

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were higher System and Component Resistive Loss and Higher Harmonic Levels.

Discussion: The problem of losses is one that is receiving a great deal of attention in recent times, and is extensively documented. The trend is to ever lower loss levels, but the determination of exactly what levels, and of the optimum relationship of no-load and

load losses, is an extremely complicated issue that is closely tied to a broad range of system and utility cost parameters, many of which cannot be controlled. Thus, while the industry now has a better ability to analyze the problem, it still does not have a truly clear-cut direction to follow, other than the very general course of reduction. Hence, this particular transformer design parameter is one which will have to come under almost constant re-evaluation in the years ahead.

Future Investigations: Continued work should be done to find new methods of achieving low losses in transformers, and to study the effects and evaluations of various loss levels. This latter work should be directed at achieving a more unified view of the problem than is now prevalent in the industry.

(9) External Through-Fault Withstand Requirements

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Component Reliability Criteria, Trend to Underground, Higher Voltage Levels, Fewer Voltage Levels, Higher Short Circuit Magnitudes, Power Electronics, Ultra-High-Speed Fault Clearing, Use of Fault Current Limiters.

Discussion: Several of the key influences tend to result in higher system short circuit magnitudes. However, the expected trend toward use of fault current limiting devices may permit a reduction in transformer external through fault withstand. A desire for increased component reliability might counteract any reduction in transformer strength. Increased pressures for size and weight reductions, coupled with a need for lower loss designs (which normally require more core material) would also make it desirable to reduce transformer strength. Hence, through-fault withstand requirements very likely will not be any more stringent than they

are today. They may in fact, be less stringent, at least from the standpoint of fault duration. There are movements in the industry today to have fault duration requirements reduced. With further improvements in the future in both fault limitation and faster clearing, it would not seem likely that the industry would require more conservative designs.

Future Investigations: In keeping with the need for smaller, lighter designs, continued work should be done in the area of finding ways to achieve acceptable strength with reduced weight.

(10) Internal Fault Withstand Requirements

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were the same as for the parameter, "External Through-Fault Withstand Requirements."

Discussion: This design parameter is similar to through-fault withstand requirements, except that it basically relates to one-time performance of the transformer containment during a fault within that containment, rather than to cumulative exposure to outside shocks. The only system parameter of any real interest, therefore, is the amount of energy available to supply such an internal fault. As noted earlier, the trend will be toward limitation of fault current magnitudes, and probably toward faster fault clearing, as well. Hence, containment strength requirements will probably be no more severe than they are today. Because of possible hazards to humans during disruptive transformer failures, it is conceivable that added emphasis on strength could be placed on those transformers having greater proximity to the public, such as pad-mounted transformers for underground distribution. These types of transformers, however, have already been shown to have an inherently higher strength level, due in large part to the energy-absorbing characteristics of the shape of the tanks.

Future Investigations: All suggested investigations relate to the problem of reducing the probability of disruptive failure. Continued work should be performed to investigate ways to reduce shocks to the containment during internal faults. Coolants/insulating media that generate lower gas pressures is one example; another might be containment and accessories modifications that provide better inherent strength, possibly with reduced weight as well.

(11) Induction Considerations

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Harmonic Levels, Audible Noise Criteria, Use of Indoor Substations, and Power Electronics.

Discussion: Higher levels of operating induction in transformer cores contribute to increased harmonic generation and audible noise. Increased concern over the levels of noise and system harmonics, coupled with a need for lower loss transformers, already is resulting in moves to reduce the induction level of today's transformers, compared to those of a few years ago. It is likely that this trend would continue in the future, at least as long as transformers continue to use conventional core steels. Any breakthroughs that may take place in core materials, however, could alter this trend.

Future Investigations: Investigations into lower loss core materials which simultaneously exhibit lower noise and less tendency for harmonic generation at higher induction levels could help to reverse the present trend to putting more core material into transformers to solve these problems. Any such breakthroughs could also help with the weight problem.

(12) Mechanical Requirements Due to External Factors

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Component Reliability Criteria and the Trend to Underground.

Discussion: Increased pressure for component reliability will result in measures designed to reduce "infant mortality" failures and to prolong the expected service life of equipment. Such increased requirements might include such things as greater resistance to shipping damage, mechanically stronger accessories, more secure internal bracing, etc. Underground systems equipment may be less susceptible to some types of weather-exposure concerns, but corrosion and seismic considerations may pose other problems. It is difficult to clearly identify directions in this area, since there are essentially few benchmarks available today. That is, requirements tend to be measured rather subjectively today in most areas. By the Year 2000 there will likely be attempts made to create more clear guidelines, or possibly even standards, in this area. Extensive use of outage reporting and causes of component failures should reveal where most emphasis on design improvements should be directed.

Future Investigations: Future studies should be performed to arrive at better analytical tools for determining types of stresses, their magnitudes and effects, and where they are most likely to occur in the equipment.

(13) Environmental/Safety Considerations

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were the Trend to Underground, Audible Noise Criteria, and Use of Indoor Substations.

Discussion: Environmental and safety related issues have been increasing in importance over the past ten years, or so. By the Year 2000, some concerns, such as the toxicity of fluids in transformers, should be a thing of the past. No doubt others will emerge to take the place of those that are solved. Audible noise criteria will continue to be of more concern, though other modifications for lower losses, etc., should make these criteria easier to meet, possibly without any additional work being done specifically on the noise problem. Public and worker safety will remain strong concerns. Work on reduced flammability and explosiveness of various materials will continue. This may also help to alleviate any requirement for additional containment strength. With the advent of exotic generation sources, such as OTEC, very special environmental problems may appear. Better definition of the locations of these sources, and the precise nature of the problems and requirements unique to these applications, needs to be done. Actual overall trends in this design parameter are, again, difficult to predict, since this whole area is also one that invites a great deal of subjectivity.

Future Investigations: Studies on fluids and insulation systems, and on special concerns in exotic application areas should be performed, as noted above.

(14) Size and Weight Considerations

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter were Higher Voltage Levels, Fewer Voltage Levels, Use of GIS, Use of Indoor Substations, Ultra-High-Speed Fault Clearing, Transient Overvoltage Control and Dynamic Voltage Control.

Discussions: The use of higher voltages and fewer levels will tend to bring higher voltage units into physical locations where somewhat lower voltages have normally been used. Hence, there will be strong pressure to reduce unit size and weight for any given voltage class and kVA rating. As noted earlier, extremely large MVA ratings (relative to those today) will not be likely, so the thrust is only towards making the existing range of ratings physically smaller and lighter. Trends in lower insulation levels due to improved transient and dynamic voltage control will likely bring about considerable size reduction by the Year 2000. In general, size and weight will be very crucial design parameters to consider in the future.

Future Investigations: As mentioned previously, studies on BIL and 60 Hz insulation improvements, and on methods of achieving smaller low-loss designs should continue. Studies should also be performed on the future capabilities of transport systems, to ensure that the largest units will still be capable of being shipped. An alternative might be to investigate possible approaches to design modularity to allow movement to, and assembly at, locations having severe space constraints.

(15) Reliability Considerations

Key Influences: The major technical considerations found to have a bearing on the direction of this parameter are Component Reliability Criteria, the Trend to Underground, Higher Voltage Levels, Higher Short Circuit Magnitudes, Use of Substation Automation, Use of Fault Current Limiters, Transient Overvoltage Control and Dynamic Voltage Control.

Discussion: Increased pressure will continue to be on improving reliability of all system components, including transformers. Many system trends tend to produce effects which could be detrimental to reliability, such as reduced insulation, and higher short circuit magnitudes. However, countermeasures such as fault current limitation and better transient and dynamic voltage control can lessen the detrimental qualities or negate them. On large transformers, substation automation will likely produce more extensive monitoring of the units, enabling possible prediction of incipient failure, so that these might be either prevented or their impact lessened. Most likely there will be more extensive record keeping regarding failures. This should help to pinpoint trouble areas more easily, and allow proper corrective measures to be taken to improve overall reliability.

Future Investigations: No specific recommendations. Changes will take place in an evolutionary manner, based on growing industry consensus.

Exhibit II.

STATUS OF TRANSFORMER DESIGN PARAMETERS IN YEAR 2000

1. Voltage Rating
 - Transmission up to 1200 kV, possible 1500 kV prototype, some distribution up to 69 kV; reduction or possible elimination of lower voltage levels in both T&D.
2. Voltage Taps
 - Probably reduced usage in general, with possible elimination of no-load taps. Greater tap range of LTC may be required.
3. Insulation Levels
 - Continued pressure to reduce ratio of BIL to system voltage.
4. kVA Rating
 - No general need for MVA ratings greatly in excess of today's upper limits; however, prototypes will exist.
5. Thermal Considerations
 - Potential need for increased thermal capacity; may be solved by other requirements, such as lower loss designs.
6. Impedance Considerations
 - Pressure to reduce impedance on transmission; limited use of distribution transformer impedance to control short circuit current magnitude.
7. Transient Inrush Current Constraints
 - No new constraints likely.
8. Loss Levels
 - Trend toward continued reduction; constant re-evaluating of no-load vs. load losses for optimizing.
9. External Thru-Fault Withstand Requirements
 - Not likely to be any more stringent than today; may be less stringent with improvements in fault limitation and duration.
10. Internal Fault Withstand Requirements
 - Requirements unlikely to be more severe than today; continued efforts to prevent disruptive failures.

- 11. Induction Considerations - Induction levels reduced, unless research produces core material that can exhibit lower losses and less tendency for noise and harmonic generation at the same as, or higher than, induction levels used today.
- 12. Mechanical Requirements Due to External Factors - Increased pressure for improvements, such as lessened shipping and installation damage, better corrosion resistance, etc.
- 13. Environmental/Safety Considerations - Increasing importance; flammability/explosiveness, public safety, noise still major concerns.
- 14. Size and Weight Considerations- Strong pressure to reduce unit size and weight for any given MVA and voltage rating; one of the major concerns by year 2000; may result in requirement for modularity.
- 15. Reliability Considerations - Increasing pressure to improve; greater attempts to measure reliability, identify sources of unreliability, and take corrective measures.

Exhibit III

AREAS OF NEEDED FUTURE INVESTIGATION

A. SYSTEM-RELATED

1. Feasibility and economics of regional energy transfer
2. Economics of phase angle regulation for power flow control
3. New applications for power electronics
4. Studies of future equipment transport problems
5. Development of transmission fault current limitation techniques

B. TRANSFORMER-RELATED

1. New concepts in load tap changing
2. Intensified research on superconducting transformers
3. Development of low loss materials
4. Development of high strength-low weight materials
5. Methods of containing internal faults
6. Research on core materials that could be worked harder but with reduced noise and harmonic generation
7. Advanced insulation systems
8. Advanced cooling systems
9. Design modularity to meet space or weight limitations
10. Requirements for application with exotic generation sources (e.g., OTEC)
11. Transformer requirements for higher-phase-order transmission
12. Direction and extent impedance varies as losses are drastically reduced.
13. Cost versus reliability of insulation reductions as a function of overvoltage control

E. Conclusions Based on the Status of Transformer Design Parameters for the Year 2000

In order to determine what would be most important to the transformer manufacturers regarding the transformer design parameters for the Year 2000, the specific requirements associated with each parameter were first categorized according to the degree of importance for each of the following three classifications:

- (1) Probability of Occurrence
- (2) Difficulty of Achievement
- (3) Market Demand

Probability of occurrence concerns the likelihood that a transformer requirement would be commercially available or in general use by the Year 2000. This requirement should be beyond the prototype stage. For example, it is reasonable to assume, based on present research, that 1200 kV transformer ratings would be available to utilities by the Year 2000.

Difficulty of achievement not only includes the difficulty for the manufacturer to achieve the transformer requirement within the next 20 year period, but also his ability to achieve that requirement at a competitive cost. For example, a manufacturer might be able to significantly reduce losses rather easily if there was no concern for the additional cost (or size, or weight, or impedance, etc.) to do so. Producing a low loss, low cost transformer would be much more difficult to achieve, and this must be factored into the degree of importance for a given transformer requirement in this classification.

Market demand is the demand expected for the transformer requirement between now and the Year 2000. It would also factor in the cost justification for such a requirement. For example, if cost was not a factor, there would probably be a high demand for increased external

thru-fault withstand for transformers. However, because this requirement would probably cost much more to achieve, market demand during the next 20 years is expected to be low, especially since the existing standards on thru-fault withstand are generally accepted by utilities today.

Exhibit IV shows the manner in which the transformer design parameter requirements were categorized for each of the 3 different classifications. For each classification, three degrees of importance were considered. Exhibit V is a listing based on the combined effects of the three classifications to show the overall importance of the various transformer requirements from a designer's viewpoint. From Exhibit V, the most important transformer requirements in the next 20 years are listed below, but not necessarily in order of importance.

- UHV (1200 kV) rating

1200 kV has been selected as the next standard maximum voltage level. With anticipated economic justification (primarily due to loss reduction and fewer rights-of-way) and current R&D efforts to overcome the technical problems, 1200 kV transmission could be in service by the late eighties. In conjunction with this, therefore, will be a need for 1200 kV transformers.

Although the demand may be small in number, these transformers will represent a significant amount of MVA, and the demand for them will continue to grow beyond the Year 2000. Developing 1200 kV large power transformers presents many technical problems, beyond the prototypes that have already been built; therefore, it is essential that transformer manufacturers now consider how to have a product that can meet the needs of utilities 10 to 20 years from today.

- Higher MVA Ratings (upper limits)

Higher power capacity transmission circuits will be built in the next 20 years due to both normal growth and emerging technologies, such as HVDC, GIT, and superconducting transmission. Also, there will be a need to pack more power into available rights-of-way. This will mean that higher transformer ratings will be required. Economy of scale will provide further incentive. The transformer manufacturer must be prepared to supply higher MVA ratings at all voltage levels, and accomplish this with limited increases in size and weight, particularly at higher transmission voltages, because of shipping limitations. New materials and techniques are needed to meet the conflicting requirements mentioned above. The manufacturers should intensify effort on this transformer requirement to meet the expected market demand in the next 20 years.

- Reduced Losses

By the Year 2000, transformer loss levels are expected to be much lower than the minimum levels of today. With energy supplies diminishing over the next 20 years, the evaluated cost of supplying these losses will continue to rapidly increase. Thus, there will be a strong demand for low loss transformers, whose total evaluated cost is minimized.

With present design techniques and existing materials, the transformer designer would find it very difficult to reduce losses significantly lower than that of today without reaching practical limitation in size, weight, and cost. Therefore, transformer manufacturers will be faced with finding new lower loss materials and/or new transformer design concepts for loss reduction.

- Environmental/Safety Consideration

Environmental and Safety related issues have been increasing in importance over the past decade, and are expected to continue over the next 20 years. Some of these issues, pertinent to transformers, are audible noise level, flammability, and explosiveness. By the Year 2000, government regulations are expected for controlling at least some of these environmental/safety factors. Transformer manufacturers will have to expend much effort to meet these environmental/safety requirements without unreasonable increase in transformer cost. Therefore, this effort should be a continuous one between now and the Year 2000.

- Size and Weight Reductions

As the trend to upgrade circuit voltages continue, there will be a need to replace existing transformers with those having higher MVA and voltage ratings. There will be pressure to limit the size of these transformers so as to fit in the confines of the space available for them. Shipping limitation on size and weight will also result in pressure for smaller, lighter weight transformers.

Expected pressure for other requirements (such as reduced losses, higher voltage ratings, kVA ratings, increased thermal capacity, reduced impedance (transmission), more mechanical integrity, and improved reliability), all would tend to increase the transformer size and weight. Therefore, the transformer manufacturer should begin efforts to develop new materials or concepts to meet these requirements. For example, one such concept would be design modularity, where larger, heavier transformers can be assembled in the field.

- Improved Reliability

Although the emphasis on overall system reliability has diminished somewhat over the last several years (due primarily to inflation and the subsequent higher cost to improve system reliability), component reliability is expected to be more important over the next 20 years. The reason for this is a rapidly increasing trend in the number of utilities developing large data bases which often include detailed information on each component failure. This may result in increased pressure by utilities to improve transformer reliability. Minimum acceptable transformer failures may also be specified by users. In either case, the manufacturer will be faced with making improvements in transformers to meet these reliability requirements over the next 20 years. Standards may be developed to make transformer test procedures (e.g. short circuit) more stringent. With expected reductions in BIL and increases in short circuit magnitude on T&D systems, this task will be a difficult one for manufacturers. Development work should be started now to meet these expected future reliability requirements.

The conclusions reached indicate there are no radical changes expected in transformer design parameters by 2000. It is expected that the majority of changes that do occur by the Year 2000 will come about through normal evolution. However, this does not imply that some major breakthrough in materials or a new technology will not alter the conclusions discussed above.

The emphasis during the next 20 years will be on more efficient and reliable transformer designs, with attention given to environmental and safety requirements. There may be special requirements which have to be met for special applications such as OTEC, but because these are not expected to be in general use by 2000, they were

considered beyond the scope of this investigation. An in-depth study for such special applications is suggested to determine the transformer requirements.

The conclusions reached in this report are the opinions of the principle investigators as to the commercial viability of the various technologies by the Year 2000. No judgment was made or intended on the perceived value of any particular technology or its availability at some time beyond the Year 2000.

EXHIBIT IV.

CLASSIFICATION AND IMPORTANCE RATING OF TRANSFORMER REQUIREMENTS

TRANSFORMER REQUIREMENT	PROBABILITY OF OCCURRENCE			DIFFICULTY OF ACHIEVEMENT			MARKET DEMAND		
	High	Moderate	Low	Great	Moderate	Little	High	Moderate	Low
UHV (1200 kV) Rating	X			X				X	
46-69 kV Dist. Transfmr. Ratings		X			X				X
Greater LTC Tap Range		X			X			X	
Reduced Induction Levels	X				X			X	
Lower BIL/60 HZ ratios		X			X		X		
Higher kVA Ratings (upper limits)	X				X		X		
Extremely Higher kVA Ratings (transm.)		X		X					X
Increased Short Time Thermal Capacity		X		X				X	
Reduced Impedance (transm.)		X			X			X	
Higher Impedance Dist. Transf.		X			X			X	
Reduced Transient Inrush			X		X				X
Reduced Losses	X			X			X		
Increased Through-Fault Withstand			X	X					X
Better Means of Preventing Disruptive Failures		X		X				X	
Improved Mechanical Integrity		X			X			X	
Environmental/Safety Changes	X			X			X		
Size/Weight Reductions	X			X			X		
Improved Reliability	X				X		X		

EXHIBIT V.

Overall Importance Rating of Transformer Requirements (From a Designer's/Manufacturer's Viewpoint)

Most Important*

- UHV (1200 kV) rating
- Higher kVA ratings (upper limits)
- Reduced losses
- Environmental/Safety changes
- Size/Weight reductions
- Improved reliability

Moderately Important*

- 46-69 kV distribution transformer ratings
- Greater LTC tap range
- Reduced induction levels
- Lower BIL/60 Hz ratios
- Extremely higher kVA ratings (Transmission)
- Increased short time thermal capacity
- Reduced impedance (transmission)
- Higher impedance distribution transformer
- Better means of preventing disruptive failures
- Improved mechanical integrity

Least Important*

- Reduced transient inrush
- Increased through-fault withstand

* Requirements are not intended to be listed in order of importance within each group.

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
1. More stringent reliability criteria	a. Greater Redundancy of Lines & Equipment b. More Sophisticated Bus Arrangements c. Greater Number of Contingencies d. Degree of System Automation e. Greater Number of System Interties f. Degree of Sectionalizing g. Requires Improved Mechanical, Thermal & Insulation Requirements for System Components	Y	These requirements applied to transformer
2. Trend from overhead to underground construction	a. Different Reliability Characteristics <ul style="list-style-type: none"> 1. Less Exposure to Weather 2. Corrosion of Subsurface Distribution Equipment 3. Longer Outage Durations b. Different ROW Requirements c. Lower RIV d. Different Voltage Regulation e. Increased Charging Current f. Higher Fault Currents g. More Transmission Circuits Per MVA transmitted h. Less Flexibility in Expansion of Distribution i. Totally Different Physical Plant j. Smaller Overload Capability of Transmission Ckts. k. Smaller Overload Capability of Distribution Transformers in Subsurface Installations	N Y N N Y I Y I Y N Y	Corrosion-resistant materials or external protection Depends on system assumed, and whether T or D May require greater impedance. Requires greater short circuit strength May require greater short circuit strength May require new design concepts May require overdesigning

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
3. Use of Higher Voltage Levels	a. Greater ROW Requirements b. Increased Clearances c. Higher BIL d. More stringent control of transient overvoltages e. Higher circuit loading f. Fewer Substations & Lines g. Lower Losses Per MVA Delivered h. Better Voltage Regulation Per MVA Delivered i. Higher Fault Currents j. More RIV Problems k. Decreased Reliability l. Greater Physical Size of Equipment Due to Rating m. Possible higher transformation ratios n. Higher device voltage ratings	N Y Y Y Y N N N Y I N I Y Y Y	Larger physical size Larger physical size; Different insulation system design; higher impedance (T) BIL level requirements Larger Rating; physical size Short circuit strength May require higher impedance More conservative design Using 3Ø rather than 1Ø units; New insulating mediums; New innovations in physical construction; New materials Higher turns ratio Higher primary voltage
4. Use of Fewer Voltage Levels	a. Reduces Need for New ROW by Upgrading Existing ROW b. Requires Fewer Substations & Associated Equipment c. Better Regulation & Lower Losses d. Increased Short Circuit Currents e. Larger Substations	N Y N Y Y	Different transformation ratios; shift in primary voltages Short circuit capability requirements; May require higher impedance Need for smaller more compact designs
5. More Stringent Voltage Regulation Criteria	a. Greater Use of VAR Compensation b. More LTC & Voltage Regulators c. Lower Impedance Components	N Y Y	May require changes in % steps & range of LTC Lower impedance transformers; Increased short circuit requirements

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TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
Use of Load Management (Voluntary/Involuntary)	a. Improves Load Factor b. Better Utilization of Equipment c. Deferral of Added Capacity	N N N	
Use of Regional Energy Transfer	a. Requires More & Higher Capacity Tie Circuits b. Encourage Higher Voltage Lines c. May Require Phase Angle Regulation d. May Require Increased Capacity of Transmission Lines	Y Y Y Y	May require new higher MVA ratings Push to new UHV technology, higher voltage rating. May require phase angle regulating transformer special designs May require new higher MVA ratings
Use of HVDC Circuits	a. May Improve Stability Margin b. Permits Longer Circuits c. No Charging Current d. Lower Short Circuit Currents e. Permits Power Flow Control (Asynch- ronous) f. Generates Harmonics	N N N Y N Y	May reduce transformer short circuit requirements. Requires special design considerations (See sections on higher harmonic levels & use of power electronics)
Use of Multi-terminal Lines	a. May reduce Stability Margin b. Reduction in Number of Terminals in Substation c. Added Complexity in Protection	N N N	

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
10. Use of Higher ϕ Order Transmission	a. Greater Complexity of Terminal Equip- ment and lines	Y	3 ϕ to n ϕ and n ϕ -to-n ϕ transformer designs
	b. Greater Complexity of Protective Schemes	Y	
	c. Different Substation Configuration	N	May affect BIL levels & insulation system design
	d. May Hamper Reliability	Y	
	e. May Affect Stability	N	Increased transformer complexity may lessen reliability
	f. Connection to 3 ϕ system requires Transformation at Both Ends	N	
	g. May Affect Fault Current Magnitudes	Y	Affects Transformer Short Circuit Requirements
	h. Replaces higher voltage transmission	N	
11. Higher System & Com- ponent Resistive Losses	a. May Require Compensation to Reduce Line Current	N	Lower Loss Transformers
	b. May require larger line conductors to reduce resistance	N	
	c. Use of Lower Loss Components	Y	
12. Higher Short Circuit Magnitudes	a. Affects Bus & Structure Strength Requirements	N	May reduce short circuit requirements May reduce short circuit requirements Increased Short Circuit Requirements Higher Impedance for all transformers; LTC fewer autotransformers
	b. Higher Interrupting Ratings of Breakers, Reclosers, Fuses	N	
	c. May Require CL Fuses	Y	
	d. May Require Fault Current Limiting Devices	Y	
	e. Requires Higher Short Circuit Strength of Equipment	Y	
	f. May Require Higher Impedance Trans- formers	Y	

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
Higher Harmonic Levels	<ul style="list-style-type: none"> a. Higher System Losses (Currents) b. Could Produce TIF Problems c. May require Filtering Equipment d. Produces Extra Loading on Shunt Capacitors e. Can Produce Transformer Saturation Problems f. May Require Different Transformer Connections g. May Produce Protection and Control Problems h. May Require Change in Grounding System 	<ul style="list-style-type: none"> I Y N N Y Y N I 	<ul style="list-style-type: none"> May require increased rating May require lower induction levels May require more core iron or non-iron core May require tertiary winding May affect BIL rating required, including neutral
More Stringent Audible Noise Level Criteria	<ul style="list-style-type: none"> a. May Require Sound Barriers External to Equipment b. Use of Lower Noise Level Equipment c. May Require Sound Cancelling Techniques in Substations d. May Require Larger Area Substations e. May Require Indoor or Subsurface Substations 	<ul style="list-style-type: none"> N Y N N Y 	<ul style="list-style-type: none"> Lower induction; Use of lower audible noise designs (e.g., Dry-Type, Vapor-Cooled, etc.); Lower noise design of fans & other Auxiliary equipment (See Section on use of indoor substations)

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
15. Use of Gas Insulated Substation	a. Reduction in Substation Size b. Interfacing Required with Conventional Equipment c. Possible Constraints on Surge Protection due to physical layout d. Some Modifications to Protection Schemes	Y Y Y Y	Pressure to reduce size of transformers Different termination designs May affect BIL level required CT & VT may not be required <u>in</u> unit
16. Use of Gas Insulated Transmission Lines	a. Higher Circuit Capacity b. Lower Circuit Impedance Per Unit Length c. Less ROW Requirements d. Different ROW Requirements e. No Direct Exposure to Lightning f. No RIV Problems	Y I N N Y N	Larger Ratings Required May require higher impedance units Location of Arresters; BIL Requirements
17. Use of Superconducting Transmission	Same as "Use of Gas Insulated Transmission Lines" PLUS: a. Lower Losses b. Need for Auxiliary Power c. Higher Continuous Current Rating for Equipment d. Could Act as Fault Current Limiting Device	N N Y Y	Significantly larger units may be required; units may have to be superconducting designs Reduces transformer short circuit requirements
18. Phase Angle Regulation Constraints	a. Need for Phase Angle Regulating Transformers b. Fixed Phase Angle Line Compensation (Potential Use of Series Capacitors)	Y N	Requires Special Transformer Design

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
19. Use of Mobile Sub- stations	a. May Enhance Reliability of System b. May Defer Additional Substation Capacity	N N	Comment: Special Designs Required for Mobile Substation
20. Use of Indoor Substations	a. May Require Non-Flammable Materials b. May Require Lower Noise Levels c. May Permit Location of Substation Closer to Load Center d. Not Exposed to Weather (May Reduce Creep Rqmts.) e. Constraints on Physical Size f. Requires Ventilation Equipment	Y Y N Y Y N	More use of Dry-Type; Need for Non-Flammable Coolant; Higher temperature insulation materials Lowering induction levels; Use of sound attenuating materials Corrosion no Problem; Minimized surge protection considerations (Lower Creep) Need for Smaller Size per KVA
21. Use of LV Networks	a. Enhances System Reliability b. Larger Substation Capacity c. Increased Secondary Fault Current Levels d. Improved Voltage Regulation e. Reduced Losses f. Requires Dedicated Feeders (GRID) g. Increased Redundancy	N Y I N N N N	Leads to larger MVA Substa. Transformers Transformer Duty is Different, due to operating philosophy

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
22. Use of Power Electronic Equipment (Switching, Control, Conversion)	a. May Introduce Harmonics (Refer to "Higher Harmonic Levels," Above) b. Solid State Breaker Could Provide Sequential Fault Clearing and Higher Speed Clearing c. More Precise Control of Switching Capacitors and Reactors d. Ability to Interface Exotic Sources to T&D System e. Faster System Voltage Control With Solid State LTC f. Solid State Voltage Transformation g. Solid State Frequency Conversion h. Integration of HVDC into AC System	Y Y Y Y Y Y I Y	Saturation may require more core iron; possible stray flux losses; may require tertiary Shorter duration faults may permit less mechanical strength; reduced transients may permit lower insulation levels Reduced transients permit lower insulation level Interface transformer may require special design May allow more taps; may not require separate tank for LTC; overall transformer size may be smaller May eliminate transformer (See "Higher Harmonic Levels") (See "Use of HVDC Circuits")
23. Use of Substation Automation	a. Enhances System Reliability b. Optimizes Control of Substations and T&D System c. Reduces Responsibility and Workload of System Operator d. Increased Monitoring Devices	N N N Y	May require more sophisticated transformer instrumentation (e.g. Hot Spot Detectors, Fault Current and Surge Detectors, Gas Detectors, Pressure Detectors) & Tap Operation
24. Use of Distribution Automation	a. Enhances System Reliability b. Permits Load Management c. Permits Remote Switching of Capacitors & Lines d. May Permit Remote Fault Indication e. May Permit Remote Secondary Switching	N N N N Y	(Comment) Widespread use of carrier could lead to transformers with less signal attenuation) Control of transformer secondary breaker requires sensor & actuator

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
5. Use of Transmission Line Single-Pole Switching	a. Enhances Stability b. May require neutral reactor for Successful Arc Extinction c. Complicates Protective Relaying	N Y N	May permit reduced short circuit strength
6. Use of Ultra-High-Speed Fault Clearing	a. Enhances Stability b. Reduces Short Circuit Stresses on Equipment c. Permits Greater Power Transfer	N Y Y	May permit reduced short circuit strength May lead to larger MVA ratings
7. Use of Fault Current Limiting Devices	a. Reduces Short Circuit Stresses on Equipment b. Permits Lower Current Interrupting Ratings c. May Require More Substation Area To Accommodate F.C. Limiters d. May Permit Use of Substation Structures with Reduced Short Cir- cuit Strength e. C.L. Fuses May Prevent Disruptive Failures f. C.L. Neutral Reactors Impact System Grounding (Surge Protection) g. Increased System Losses May Result	Y I N N Y Y N	May permit reduced short circuit strength May permit installation of some devices within transformer May permit reduced mechanical withstand May require increased insulation levels
Improved Transient Over- voltage Control	a. Reduced BIL Requirements for Equip- ment b. May Enhance Reliability c. May Reduce Phase & Ground Clearances d. Reduces Physical Size of System Com- ponents	Y N Y Y	Lower BIL; smaller size May require size reduction of transformer May require size reduction of transformer

APPENDIX I - Qualitative Impact of Technical Considerations

TECHNICAL CONSIDERATIONS THAT INFLUENCE T&D SYSTEM DESIGN	HOW DOES THIS AFFECT T&D SYSTEM DESIGN?	COULD THIS AFFECT TRANS- FORMER DESIGN PARAMETERS? Y=YES, DIRECTLY N=NO, I=INDIRECTLY	IF YES, HOW DOES THIS AFFECT TRANSFORMER DESIGN PARAMETERS?
29. Improved Dynamic Voltage Control	a. Enhances Reliability b. Can Prevent Equipment Damage Due to Volts/Hz c. May Prevent Ferroresonance	N Y N	May permit reduced insulation levels
30. Use of System VAR Com- pensation	a. Better Voltage Regulation b. Improves Stability c. Lower Losses d. Improved Power Factor e. Reduced T&D System Capacity Require- ments f. Requires Additional Equipment and Space Requirements g. Complicates Protection and Control h. May Lessen Reliability i. SVG May Interface to System Through Transformer j. SVG May Produce Harmonics	Y N N N N N N Y Y	Operating voltage range decrease possible; tap modification May require special design (See Items 13 and 22)
31. More Stringent System Stability Criteria	a. May Require Greater Number of Trans- mission Lines b. May Require Faster Fault Clearing c. Increased Use of Series Capacitors d. Use of Static VAR Generators e. May Require Lower System Reactance f. May Require Shunt Reactors g. May Require Shunt Capacitors	N Y N Y Y N N	May permit reduced short circuit strength (See Items 13 and 22) May require lower transformer impedance

APPENDIX I - Qualitative Impact of Technical Considerations

APPENDIX II

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC TECHNICAL CONSIDERATION

Numbers and Titles of Technical Considerations are from Appendix I. Numbers and titles of External Influences are from Section V, where descriptions of what is encompassed by each External Influence are contained. Numbers below each External Influence are ranking numbers for the described impact, based on the judgment of the authors as to the value of the actual impact and its likelihood of occurrence by the Year 2000. To this extent, they represent a somewhat subjective view of the impact. The significance of the magnitude of each number is listed below:

- 5: High Impact
- 4: Moderately High Impact
- 3: Moderate Impact
- 2: Moderately Low Impact
- 1: Low Impact
- 0: Insignificant impact or no evident impact

The signs mean the following:

- + (plus) : favoring or reinforcing the technical consideration
- (minus) : discouraging or detracting from technical consideration

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 1. More Stringent Reliability Criteria
1. Load Characteristics -1	High density loads and large spot loads generally require more reliability.
2. Economics -5	A down economy may lessen pressure for more reliability. Each incremental improvement in reliability results in a higher marginal (incremental) cost; therefore, practical limits may be lower than desired.
3. Environmental Restrictions -2	R-O-W restrictions may preclude more stringent reliability criteria (use of double circuit construction less reliable than (2) single circuits). Remote generation makes it more difficult to meet criteria. Pollution control makes plant less reliable; hence, T&D must be more reliable. Aesthetic pressures for underground construction may make system more reliable.
4. Environmental Effects -1	All environmental effects listed are detrimental and would make it more difficult to meet criteria.
5. Reliability Constraints (components & system) +5	Externally forced criteria may be more stringent than utility wishes to maintain and is realistic from an economic consideration. Utility must meet any mandated levels.
6. Availability of Natural Resources & Basic Materials -2	Forced substitution or lack of natural resources and basic materials may make it more difficult to meet more stringent criteria (e.g. oil, manpower, shutdowns due to fuel shortages).
7. Generation Sources & Energy Storage 0	Exotic sources are in general less reliable until maturity is reached. Energy storage may improve system reliability.

(continuation)

External Influence	Technical Consideration: 1. <u>More Stringent Reliability Criteria</u>
8. Safety Restrictions -1	Safety restrictions tend to reduce reliability (e.g. longer duration outages as with CSP fuse blowings). Inability, to use certain kinds of equipment or to place equipment where desired may result in lower system reliability. Restricting access to system components may improve reliability.
9. Political Considerations (policies) +5	Policies on reliability constraints (see No. 5 above).
10. Energy Conservation +1	Overconducting for lower losses and use of lower loss equipment result in a stiffer system, but damage due to higher fault currents would be more and coordination may be difficult. Energy management equipment can help system in crisis situation.
11. New Material Technology +1	Theoretically new material technology should maintain or improve reliability in the long run (unless done for economics only), but may be detrimental in the short run.
12. Shipping Considerations -1	Hidden shipping damage may degrade component reliability. Limitations on size and weight have uncertain effects (more compact designs would generally be less reliable, but using 2 small units as opposed to 1 large unit is usually more reliable).
13. Effect of R&D Projects & Funding +3	Should tend to improve component reliability and ease pressure to meet more stringent reliability criteria.
14. Impact of International Practices +2	If U.S. equipment and design standards are changed in a compromise with international standards, component reliability will probably be improved, since international standards are generally more conservative.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 2. Trend from OH to UG Construction
1. Load Characteristics +4	Use of UG is enhanced by high density loads (electrically heated homes, electric cars, townhouse/condominium complexes), or spot loads as in shopping centers.
2. Economics +5	UG construction is enhanced by a favorable state of the economy. The economic alternative today favors OH construction, but by 2000, could be equal or favor UG due to learning curve with extensive use of UG.
3. Environmental Restrictions +5	Aesthetics strongly favors UG. Governmental and public pressure may force trend to UG; developers encourage UG.
4. Environmental Effects +2	UG free of direct weather exposure, but corrosion and water favors OH. UG is generally preferred during an earthquake.
5. Reliability Constraints (components & system) +2	UG generally perceived as being more reliable (tradeoff is between frequency and duration of outages). In general, if reliability constraints are more stringent in the Year 2000, UG would probably be more favorable than OH, but will not be the deciding factor.
6. Availability of Natural Resources & Basic Materials +1	Scarcity of wood poles or petrochemicals for cable insulation might discourage use of UG. Land availability generally doesn't favor OH or UG.
7. Generation Sources & Energy Storage -1	In general, remote generation favors OH construction, however, floating nuclear plants and other ocean site generation would require UG construction.

(continuation)

External Influence	Technical Consideration: 2. Trend From OH to UG Construction
8. Safety Restrictions +1	Accessibility to public restrictions would favor sub-surface components.
9. Political Considerations (policies) +3	Existing and new regulation, ordinances, and laws will continue to increase trend to UG.
10. Energy Conservation +1	Utility reduction of system losses favor UG, because circuits are larger than OH due to thermal constraints and inability to make changeouts conveniently.
11. New Material Technology +5	Superconducting technology, corrosive resistant materials, and improved cable insulation would all favor UG.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding +4	Projected funding would favor UG as a 'new' technology.
14. Impact of International Practices +2	May affect the trend to UG in transmission, if self-contained oil filled cable is used as it is used internationally.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 3. Use of Higher Voltage Levels
1. Load Characteristics +4	Long distances require higher voltages for stability & regulation. Higher voltages are more efficient for high load density area. Remote loads require higher capacity lines which can be obtained by higher voltages. Higher voltages allow higher capacity per unit area of R-O-W.
2. Economics +5	A poor state of economy would hamper conversions to higher voltages since the first cost of conversion is great. However, over the long term, higher voltages would be more efficient to operate, resulting in fewer dollars per delivered kW.
3. Environmental Restrictions -1	RIV problems, biological effects, aesthetics, R-O-W objections would tend to be worse at higher voltages.
4. Environmental Effects -1	Contamination presents more problems at higher EHV/UHV levels. Other effects largely similar at all voltages.
5. Reliability Constraints (components & system) -2	Cost to maintain same reliability is greater at higher voltages and tasks may be difficult or impossible to meet. Any mandated reliability levels may be difficult to meet.
6. Availability of Natural Resources & Basic Materials -2 Transmission -4 Distribution	Transmission: Higher voltages generally require less material and resources for same delivered kVA. Distribution: Fewer substations required (less land).
7. Generation Sources & Energy Storage +3	Remote generation sources favor use of higher voltages.

(continuation)

External Influence	Technical Consideration: 3. Use of Higher Voltage Levels
8. Safety Restrictions 0	Safety practices become more elaborate and stringent at higher voltages, but not limiting.
9. Political Considerations (policies) +3	Pressure for national grid encourages higher voltages; as do any other pressures to strengthen ties between pools, companies, or within a company.
10. Energy Conservation +3	Utility desire to reduce system losses encourages higher voltages.
11. New Material Technology +3	An indirect cost, mainly cost-related, may overcome a particular obstacle at some voltage level, but will ultimately filter down to lower levels as well. Incremental effect may be greater for higher voltages.
12. Shipping Considerations -1	Distribution: No evident effect. Transmission: Can limit voltage levels in some cases, due to large size of higher voltage equipment.
13. Effect of R&D Projects & Funding +4	Generally promotes development and earlier use of higher voltage levels.
14. Impact of International Practices +1	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 4. Use of Fewer Voltage Levels
1. Load Characteristics +4	Higher load density may result in fewer voltage levels (e.g, making lower distribution voltages obsolete, eliminating subtransmission voltages). Rapid growth rate may discourage use of subtransmission.
2. Economics +5	Fewer components to purchase and store would favor fewer voltage levels. Also fewer substation and lines would be required.
3. Environmental Restrictions 0	No evident effect.
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) +3	Distribution: Obsolete levels upgraded can lower reliability and substation sources become more reliable with fewer voltage levels. Transmission: Increased reliability is likely with fewer components and lines due to fewer voltage levels.
6. Availability of Natural Resources & Basic Materials +2	May require less material and land with fewer voltage levels.
7. Generation Sources & Energy Storage 0	No evident effect.

(continuation)

External Influence	Technical Consideration: 4. Use of Fewer Voltage Levels
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 1	Generally fewer voltages result in lower losses.
11. New Material Technology 0	No evident effect.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding 0	No evident effect.
14. Impact of International Practices 0	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 5. More Stringent Voltage Regulation Criteria
1. Load Characteristics -1	Poor load factor, high growth rate, & non-uniform load patterns make it more difficult to achieve regulation criteria. This may result in less stringent criteria.
2. Economics -5	Economics favors less stringent criteria.
3. Environmental Restrictions 0	No evident effect.
4. Environmental Effects , 0	No evident effect.
5. Reliability Constraints (components & system) -2	Tighter reliability constraints may result in relaxation of criteria (e.g., elimination of capacitors, regulators, etc.)
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage -1	Degree of stability (voltage) compared to present sources may influence regulation criteria.

(continuation)

External Influence	Technical Consideration: 5. More Stringent Voltage Regulation Criteria
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) +4	PUC demands for voltage reduction may result in more stringent criteria to achieve it.
10. Energy Conservation +4	Voltage reduction may require more stringent regulation criteria. Load management tends to improve load factor and, therefore, permitting more stringent criteria.
11. New Material Technology 0	No evident effect.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding -1	Funding to determine the effects of voltage reduction may influence criteria in future. Projects may result in new regulating devices or concepts.
14. Impact of International Practices + 1	Possible influence if international standard on regulation criteria is established.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 6. Use of Load Management
1. Load Characteristics +5	Load factor improvement is prime reason for using Load Management. Low growth makes load management more attractive.
2. Economics +5	Economic evaluation favors load management by deferral of of generation and transmission additions.
3. Environmental Restrictions -2	Public may not accept equipment required in home.
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) +1	With load management, utilities may find it difficult to maintain reliability constraints, due to malfunctioning of load management equipment. Load management may be a method of load shedding which does improve overall reliability level for consumer.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage -2	Some sources may be alternatives to load management (e.g., residential solar heating, substation fuel cells, etc.)

(continuation)

External Influence	Technical Consideration: 6. Use of Load Management
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) +3	Uncertain but pronounced effects on use of load management (mandated for or against by PUC's and resistance from consumers).
10. Energy Conservation +4	Favors use of load management by replacing most inefficient generation.
11. New Material Technology +2	Could hasten application for load management by economic improvements.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding +4	R&D developments may help determine the true value of load management.
14. Impact of International Practices +2	International experience with ripple control may influence our methods of implementation and may hasten the acceptance of load management.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 7. Use of Regional Energy Transfer
1. Load Characteristics +5	Regional load diversity is the reason for the transfer.
2. Economics +2	Decision requires economic evaluation of losses, DC vs. AC transmission, control of power flows, differential fuel costs, and added transmission capacity versus other methods of transferring fuel.
3. Environmental Restrictions -3	Aesthetic objections to added tie lines, R-O-W restrictions, or biological effects of EHV lines may hamper implementation of regional energy transfer. Plant siting problems could make it more attractive.
4. Environmental Effects +1	Earthquake, flood, and weather problems associated with fuel transfer may be alleviated by regional energy transfer. Sunspots; EMP would affect entire system.
5. Reliability Constraints (components & system) +2	Concern for reliability by strong ties could encourage use of regional energy transfer.
6. Availability of Natural Resources & Basic Materials -2	Lack of available land for R-O-W's may prohibit use of energy transfer.
7. Generation Sources & Energy Storage +2	Exotic generation sources may require graphically widespread plant locations that enhance the concept of regional energy transfer.

(continuation)

External Influence	Technical Consideration
<u>7. Use of Regional Energy Transfer</u>	
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) +4	Governmental bodies may mandate energy transfer in the name of reliability and conservation, or it may be the result of a national grid policy.
10. Energy Conservation -2	Excessive transmission losses may offset any other energy savings due to energy transfer.
11. New Material Technology +1	Any breakthroughs in low loss transmission lines may justify energy transfer.
12. Shipping Considerations +4	Use of energy transfer may be enhanced by fuel shipping limitations (e.g., lack of railroad cars, sufficient roadbeds, lack of pipeline capacity, long sea routes, etc.).
13. Effect of R&D Projects & Funding +3	UHV research would enhance transfer concepts. Studies to better define the economics could determine the outcome for use of energy transfer.
14. Impact of International Practices 0	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 8. Use of HVDC Circuits
1. Load Characteristics 0	No evident effect.
2. Economics +4	Long line bulk power transfer favors HVDC. DC cable circuits become economically attractive at relatively short distances. R-O-W costs for HVDC are less.
3. Environmental Restrictions -1	HVDC may have some biological effects that are different from AC (needs further research). Other than above, DC & AC face same problems.
4. Environmental Effects 0	Same as AC.
5. Reliability Constraints (components & system) 0	No evident effects (compared to AC).
6. Availability of Natural Resources & Basic Materials +1	R-O-W requirements are less for DC lines, but more for DC substations.
7. Generation Sources & Energy Storage +2	Remote sources may enhance use of HVDC. Possibilities of direct ties between DC generation and DC transmission may be an economic incentive.

(continuation)

External Influence	Technical Consideration	8. Use of HVDC Circuits
8. Safety Restrictions 0	No evident effects (compared to AC)	
9. Political Considerations (policies) 0	No evident effects.	
10. Energy Conservation 0	No clearcut advantage in losses (this would be factored into economic evaluation).	
11. New Material Technology +3	Breakthrough in HV, higher current semi-conductors would favor use of HVDC.	
12. Shipping Considerations 0	No evident effect.	
13. Effect of R&D Projects & Funding +3	Continued R&D may provide the necessary breakthrough to enhance use of DC.	
14. Impact of International Practices 0	No evident effect (since international practices are comparable with that of U.S.).	

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 9. Use of Multi-Terminal Lines
1. Load Characteristics +2	Load patterns may require tapped line to feed a particular load.
2. Economics +4	Economics favors multi-terminal lines but reliability considerations may restrict use.
3. Environmental Restrictions 0	No evident effects.
4. Environmental Effects 0	No evident effects.
5. Reliability Constraints (components & system) -2	Constraints may limit use of multi-terminal lines.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +2	Multi-terminal lines may be desirable for small generation sources.

(continuation)

External Influence	Technical Consideration: 9. Use of Multi-Terminal Lines
8. Safety Restrictions 0	No evident effects.
9. Political Considerations (policies) 0	No evident effects.
10. Energy Conservation 0	No evident effects.
11. New Material Technology 0	No evident effects.
12. Shipping Considerations 0	No evident effects.
13. Effect of R&D Projects & Funding +1 -1	Studies of effects on stability could enhance or detract from use of multi-terminal lines.
14. Impact of International Practices 0	No evident effects.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 10. Use of Higher Phase Order Transmission
1. Load Characteristics +3	High load density may favor multi-phase transmission.
2. Economics +5	Presently uncertain due to lack of information. Economics will eventually determine feasibility of using multi-phase transmission.
3. Environmental Restrictions -3	May result in narrower R-O-W and lower tower height. Visual impact of bundled line could be adverse.
4. Environmental Effects + 1	There may be marginal differences in performance under adverse conditions of weather, but conceptual designs are not established enough to tell.
5. Reliability Constraints (components & system) -2	Overall complexity will likely make it more difficult to achieve reliability constraints.
6. Availability of Natural Resources & Basic Materials +1	Less land requirements for R-O-W may make multi-phase transmission attractive.
7. Generation Sources & Energy Storage 0	No evident effect.

(continuation)

External Influence	Technical Consideration: 10. Use of Higher Phase Order Transmission
8. Safety Restrictions -1	May be more difficult to meet safety regulations from a maintenance standpoint.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation + 1	Extent of losses compared to conventional 3 phase are unknown.
11. New Material Technology +2	May need breakthrough in insulating materials to construct lines and multi-phase apparatus required.
12. Shipping Considerations -1	May require modular construction of terminal equipment to reduce size for shipment.
13. Effect of R&D Projects & Funding +4	Strong relationship between R&D funding and continued research. Further studies may determine the feasibility of multi-phase transmission.
14. Impact of International Practices + 2	No practices exist, but most likely U.S. and international practices will develop together.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 11. Higher System & Component Resistive Losses
1. Load Characteristics -1	Light load density and uneven load patterns generally result in higher system losses per delivered kVA.
2. Economics -5	Higher evaluated cost of losses make it more desirable to design the system for lower losses.
3. Environmental Restrictions 0	No evident effect.
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) -2	May force stronger system ties which would lower system losses.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +3	Remote generation increases system losses. Energy storage sources and sources requiring AC/DC conversion increase losses.

(continuation)

External Influence	Technical Consideration	11. Higher System & Component Resistive Losses
8. Safety Restrictions 0	No evident effect.	
9. Political Considerations (policies) 0	No evident effect.	
10. Energy Conservation -2	Intense interest in energy conservation would stimulate actions which reduce system and component losses.	
11. New Material Technology -2	Breakthroughs in low loss conductors, low loss transformer cores, and superconducting components would tend to reduce losses.	
12. Shipping Considerations 0	No evident effect.	
13. Effect of R&D Projects & Funding -2	May help make breakthroughs in new material technology. Funding may also identify the distribution of losses on the system.	
14. Impact of International Practices 0	No evident effect.	

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 12. Higher Short Circuit Magnitudes
1. Load Characteristics +5	High load density areas and large spot loads require higher capacity sources-higher voltage and/or more circuits-resulting in higher short circuit currents. Critical nature of certain loads requires redundancy of sources, leading to higher short circuit currents.
2. Economics -1	Economics favor least redundant system configuration that still satisfies other technical requirements. This implies lower short circuit magnitude. Economic design for loss reduction using larger conductors does not appreciably affect short circuit magnitude.
3. Environmental Restrictions +1	Increased use of underground distribution generally results in higher short circuit current. Remote plant siting tends to reduce available short circuit current.
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) +3	More stringent constraints lead to more redundancy and, therefore, higher short circuit currents.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage -2	Remote siting of plants tends to reduce short circuit capacity of system. Generation sources which interface through power electronic conversion equipment tend to lower short circuit capacity of system.

(continuation)

External Influence	Technical Consideration: 12. Higher Short Circuit Magnitudes
8. Safety Restrictions -3	May lead to requirements for reduced short circuit capacity to limit damage and/or reduce personnel hazard.
9. Political Considerations (policies) +2	Mandated national grid could result in higher short circuit capacity in underlying systems.
10. Energy Conservation 0	No evident effect.
11. New Material Technology +3	New or improved insulating mediums could result in equipment designs having lower impedance; therefore, higher short circuit currents. Development of current limiting devices using new materials technology would lower short circuit capacity of system.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding -4	Successful development of fault current limiting devices would lead to lower short circuit magnitudes. Developments which change line or component impedances would affect short circuit magnitude.
14. Impact of International Practices -1	If international practices limit available short circuit capacity in systems at any point it may affect U.S. limits, particularly if international standards are developed.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 13. Higher Harmonic Levels
1. Load Characteristics +5	Loads such as arc furnaces and rectifiers may produce higher levels of harmonics, but these may be filtered to lessen the impact on the system. Low PF loads require more capacitive VAR compensation which can aggravate harmonic problems.
2. Economics +3	Economy considerations favor the highest harmonic levels that can be technically tolerated or allowed by operating criteria.
3. Environmental Restrictions -4	TIF limits and audible noise restrictions may require reduction in harmonic levels permitted in system.
4. Environmental Effects 0	No evident effects.
5. Reliability Constraints (components & system) -1	If waveform distortion is interpreted as a reliability constraint, it may require controlling and limiting harmonic levels.
6. Availability of Natural Resources & Basic Materials +1	Shortages of basic materials, such as steel, which might lead to substitute materials for cores, could affect harmonic levels; however, the change could be either higher or lower levels.
7. Generation Sources & Energy Storage +3	Sources utilizing power electronics conversion equipment produce higher harmonics. Filtering must be provided to reduce harmonics to acceptable level.

(continuation)

External Influence	Technical Consideration: 13. Higher Harmonic Levels
8. Safety Restrictions 0	No practical impact on harmonic levels in system.
9. Political Considerations (policies) -1	Government bodies (e.g., REA) may impose restrictions on system harmonic levels for TIF control or similar reasons.
10. Energy Conservation +1	Loss optimized transformers will result in different harmonic levels produced. Application of system load equipment may affect system harmonic levels.
11. New Material Technology -3	New core materials for transformers could reduce or eliminate generation of harmonics.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding -3	Harmonic-free conversion equipment or systems could be developed through R&D. Elimination of iron magnetic circuits could lead to lower system harmonic content.
14. Impact of International Practices -1	International standards relative to harmonic generation could affect limits imposed on U.S. system harmonic levels.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration; 14. More Stringent Audible Noise Level Criteria
1. Load Characteristics 0	No evident effect.
2. Economics -3	Economic considerations tend to result in less stringent audible noise criteria.
3. Environmental Restrictions +5	Public pressure and/or regulatory bodies tend to demand more stringent criteria for audible noise. This may dictate the physical location of equipment or may require different physical locations (i.e., hospitals, residential, etc.)
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) 0	No evident effect.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage 0	Generating sources located within T&D systems (i.e., installed in substations) would have to meet system noise criteria or have special limits applied to them. In general, the criteria set for the system would not be changed for generating sources.

(continuation)

External Influence	Technical Consideration: 14. More Stringent Audible Noise Level Criteria
8. Safety Restrictions +1	Safety restrictions relating to tolerable noise levels directly affect the setting of audible noise criteria. However, this does not generally apply to T&D equipment.
9. Political Considerations (policies) 0	No effect on criteria established.
10. Energy Conservation 0	No evident effect.
11. New Material Technology 0	No evident effect.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding 0	No evident effect.
14. Impact of International Practices +1	Any international standards or guidelines would likely be considered in formulating audible noise criteria in U.S.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 15. Use of Gas Insulated Substations
1. Load Characteristics +5	High load density areas and urban situations where land availability is limited and expensive favor the use of GIS.
2. Economics +5	Economics will favor GIS as land becomes less available and more expensive. As on site construction costs rise, economics will also favor GIS.
3. Environmental Restrictions +4	Unavailability of land, aesthetics and noise restrictions favor use of GIS.
4. Environmental Effects +2	All environmental effects favor GIS, with exception of probable greater susceptibility to earthquake damage.
5. Reliability Constraints (components & system) +2	More stringent reliability constraints favor use of GIS on the assumption that GIS installation is more reliable than a conventional substation. If assumption is not correct, then opposite applies.
6. Availability of Natural Resources & Basic Materials +4	Less land availability in urban areas makes GIS more necessary. Scarcity of SF-6 gas would lead to higher GIS costs, tending to discourage use unless suitable substitute gas is found. Likelihood of SF-6 shortages is minimal, however.
7. Generation Sources & Energy Storage 0	No obvious impact on use of GIS.

(continuation)

External Influence	Technical Consideration: 15. Use of Gas Insulated Substations
8. Safety Restrictions +1	From standpoint of accessibility to live parts to personnel, GIS is safer and favored from safety considerations. From maintenance standpoint, procedures are more rigid and complex, but safety restrictions are not necessarily greater.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	No evident effect.
11. New Material Technology +2	Improved insulating mediums could improve cost of GIS and could improve performance characteristics.
12. Shipping Considerations 0	No problems evident except mishandling, which applies to all equipment.
13. Effect of R&D Projects & Funding +2	Research to obtain improved insulating mediums could enhance use of GIS.
14. Impact of International Practices +2	U.S. designs may have to be compatible with international practices to compete for market since they have more mature GIS market. Foreign market may lead to reduced costs by increased volume, favoring GIS.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 16. Use of Gas Insulated Transmission Lines
1. Load Characteristics +4	High load density requiring large power transfer over single corridor would favor GIT.
2. Economics +5	High costs make GIT generally unfavorable, except for special situations, such as line crossings in crowded areas.
3. Environmental Restrictions +4	A number of special situations favor the use of GIT, such as aesthetics (river crossings, urban installations), airport clearance restrictions, biological aspects of electric fields and congested get-aways from large plants and substations.
4. Environmental Effects +2	Could be more susceptible to earthquakes and more susceptible to corrosion problems. Other effects would favor GIT.
5. Reliability Constraints (components & system) +2	More stringent reliability constraints would favor use of GIT, on assumption GIT is more reliable. If assumption is not correct, then opposite applies.
6. Availability of Natural Resources & Basic Materials +1	Unavailability of sufficient R-O-W width for OH circuits favors GIT. Scarcity of SF-6 gas would discourage use of GIT unless suitable substitute gas is found. However, scarcity of SF-6 is minimal.
7. Generation Sources & Energy Storage 0	No evident effect on use of GIT.

(continuation)

External Influence	Technical Consideration: 16. Use of Gas Insulated Transmission Lines
8. Safety Restrictions +1	Safer from standpoint of accessibility to live parts to personnel. Safety restrictions would not necessarily be greater for GIT than for OH lines.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	Assuming no significant difference in overall losses, GIT would have no impact.
11. New Material Technology +2	Improved insulating mediums could improve cost of GIT, and could improve performance characteristics.
12. Shipping Considerations -1	Limitations in lengths of sections which can be transported could influence evaluation.
13. Effect of R&D Projects & Funding +2	Research to obtain improved insulating mediums could enhance use of GIT.
14. Impact of International Practices 0	Technology too new to be influenced by any international practices now existing.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 17. Use of Superconducting Transmission
1. Load Characteristics +5	High load density requiring large power transfer over a given corridor would favor use of superconducting transmission (SCT).
2. Economics -4	Economics generally unfavorable for most applications due to very high capital costs and operating and maintenance costs anticipated. Would result in lower losses.
3. Environmental Restrictions -3	Any restrictions would likely discourage use of SCT more than any alternative. System would require auxiliary equipment (Pumping stations). Would be more restrictive due to possibility of leaks.
4. Environmental Effects -2	More susceptible to earthquakes and disruptions due to environmental-caused loss of auxiliary power.
5. Reliability Constraints (components & system) -3	Reliability constraints would tend to discourage use due to (1) complex system (2) larger blocks of power in one circuit and (3) longer outage duration likely due to equipment failure.
6. Availability of Natural Resources & Basic Materials -2	Very susceptible to shortages of required more exotic materials.
7. Generation Sources & Energy Storage +1	May be more compatible with superconducting generators, particularly if there is no interposing transformer, or if superconducting transformer is used.

(continuation)

External Influence	Technical Consideration: 17. Use of Superconducting Transmission
8. Safety Restrictions -2	Probable increase in safety restrictions and difficulty in meeting them would discourage use of SCT.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	Although SCT would be loss free except for auxiliary power, it would not be enough of a consideration to promote use.
11. New Material Technology +2	Significant improvements in materials and cost reductions would favor use of SCT.
12. Shipping Considerations -1	Limitations on lengths of sections which can be transported could influence evaluation.
13. Effect of R&D Projects & Funding +4	Large amount of funding would be required to determine feasibility of concept. Results may discourage use.
14. Impact of International Practices +3	Foreign development breakthroughs would have great influence in setting standards and applications. Failures would discourage efforts in U.S.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 18. Phase Angle Regulation Constraints
1. Load Characteristics 0	No evident effect.
2. Economics +3	Economic dispatching may dictate the need for phase angle regulation as an economic choice over additional lines (assuming present lines can carry that total load).
3. Environmental Restrictions +1	Phase angle regulation could be an alternative to another line if there are R-O-W problems.
4. Environmental Effects 0	Required equipment is no more susceptible than other equipment.
5. Reliability Constraints (components & system) -2	Reliability constraints may favor other alternatives, such as additional circuits.
6. Availability of Natural Resources & Basic Materials 0	Required equipment is no more affected than other equipment used on system.
7. Generation Sources & Energy Storage 0	No evident effect.

(continuation)

External Influence	Technical Consideration: 18. <u>Phase Angle Regulation Constraints</u>
8. Safety Restrictions 0	Requirements are no different than other equipment of same type construction.
9. Political Considerations (policies) +2	Imposition of national grid could make it necessary to use phase angle regulation.
10. Energy Conservation 0	No evident effect.
11. New Material Technology 0	No evident effect.
12. Shipping Considerations -3	For same MVA rating, phase angle regulating transformers are larger than typical transformer, placing limitations on ratings, which could be restrictive in applications.
13. Effect of R&D Projects & Funding +2	Development of more compact and less expensive tap changers could enhance application of phase angle regulators.
14. Impact of International Practices 0	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 19. Use of Mobile Substations
1. Load Characteristics 0	No evident effect.
2. Economics +2	Economics could be favorable in cases where existing mobile subs could be used to postpone capital investment in additional lines or equipment.
3. Environmental Restrictions 0	Mobile subs are applied on an emergency or temporary basis; therefore, environmental restrictions are not likely to be a factor.
4. Environmental Effects +1	Areas having more severe environmental effects would favor the use of mobile substations.
5. Reliability Constraints (components & system) +4	Reliability constraints would favor the use of mobile subs as a backup to reduce outage time due to equipment failures
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage 0	No evident effect.

(continuation)

External Influence	Technical Consideration: 19. Use of Mobile Substations
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) +2	National defense policies to provide emergency backup power could dictate the need for more mobile subs.
10. Energy Conservation 0	No evident effect.
11. New Material Technology +2	Improved materials could reduce size and weight of components which would enhance the use of mobile subs and permit larger ratings.
12. Shipping Considerations -2	Road load limitations limit the size and weight of mobile subs, and where they can be used.
13. Effect of R&D Projects & Funding +2	R&D could reduce the size and weight of mobile sub, which would enhance its use.
14. Impact of International Practices 0	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 20. Use of Indoor Substations
1. Load Characteristics +4	High density loads encourage the use of indoor substations which can be vertically integrated to save land, and can be less accessible to public.
2. Economics -3	Economics are generally not favorable except where land costs are very high.
3. Environmental Restrictions +4	Land unavailability, aesthetics, noise restrictions, etc., all favor the use of indoor substations. Non-flammability restrictions discourage joint use of building with commercial concerns.
4. Environmental Effects +2	Less susceptibility to environmental effects enhance use of indoor subs.
5. Reliability Constraints (components & system) +2	Design would tend to have fewer outages, but duration of outage tends to be longer. Less susceptible to environmental effects.
6. Availability of Natural Resources & Basic Materials 0	No different than other equipment in T&D systems.
7. Generation Sources & Energy Storage 0	No evident effect.

(continuation)

External Influence	Technical Consideration: 20. Use of Indoor Substations
8. Safety Restrictions +2	More restricted access and more non-flammable equipment generally favors indoor sub.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	No evident effect.
11. New Material Technology +4	Technology resulting in more compact, lighter and non-flammable equipment would favor use of indoor subs.
12. Shipping Considerations 0	Shipping is not a problem since size is limited by access to building.
13. Effect of R&D Projects & Funding +4	R&D resulting in more compact and lighter equipment would enhance use of indoor subs.
14. Impact of International Practices 0	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 21. Use of Low Voltage Networks
1. Load Characteristics +5	High load density urban areas and large spot loads may justify the use of low voltage networks. Critical loads (i.e., hospitals) may enhance usage.
2. Economics -4	Economics for L.V. networks are generally unfavorable.
3. Environmental Restrictions 0	No significant effect.
4. Environmental Effects 0	No significant effect.
5. Reliability Constraints (components & system) +5	Reliability is the main reason for applying L.V. networks.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +1	Source like fuel cell could be connected directly to L.V. network and could enhance use of it. Most sources have no direct effect.

(continuation)

External Influence	Technical Consideration: 21. Use of Low Voltage Networks
8. Safety Restrictions -2	L.V. networks require more stringent safety practices. High fault currents at service entrance tends to discourage use of LV networks.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	No significant effect.
11. New material Technology 0	No significant effect.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding 0	No evident effect.
14. Impact of International Practices 0	No evident effect.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 22. Use of Power Electronic Equipment
1. Load Characteristics +5	Rapidly fluctuating voltage and power factor may enhance usage of power electronic equipment for purpose of direct control.
2. Economics +4 -2	May make usage more favorable as cost reduction of solid state equipment continues. (Note: HVDC is discussed separately, as technical consideration 8.)
3. Environmental Restrictions 0	No evident effect.
4. Environmental Effects -2	Power electronic equipment may be more susceptible to earthquakes, EMP. It is generally protected from weather and may have to be protected from other environmental effects.
5. Reliability Constraints (components & system) +1	Effect is uncertain. Experience to date indicates there is not a problem.
6. Availability of Natural Resources & Basic Materials +1	Usage could be enhanced by unavailability of materials for alternates to power electronics.
7. Generation Sources & Energy Storage +2	Certain exotic sources requires power electronic conversion equipment.

(continuation)

External Influence	Technical Consideration: 22. Use of Power Electronic Equipment
8. Safety Restrictions +2	Could enhance usage as replacement for equipment in areas requiring non-flammable or explosion-proof equipment.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation +1	Voltage reduction and control for energy conservation could make power electronic LTC and regulation attractive.
11. New Material Technology +4	Higher power density, lower loss and lower cost semi-conductor equipment could greatly enhance usage of power electronics.
12. Shipping Considerations +1	Modular construction could make power electronic devices more attractive in some cases.
13. Effect of R&D Projects & Funding +4	New materials research (11. above) and studies of new applications would enhance usage.
14. Impact of International Practices +2	May bring about new applications or influence designs.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 23. Use of Substation Automation
1. Load Characteristics +3	Widely fluctuating load characteristics may encourage use of substation automation for real-time control.
2. Economics +3	First cost is high, but long term benefits may make it worthwhile, particularly with reduced processor costs.
3. Environmental Restrictions 0	No evident effects.
4. Environmental Effects +2	In locations where environmental effects may be more drastic, substation automation may be attractive for real-time monitoring and control.
5. Reliability Constraints (components & system) +3	With more stringent constraints, substation automation will more likely be employed.
6. Availability of Natural Resources & Basic Materials +1	Lack of manpower may result in greater substation automation.
7. Generation Sources & Energy Storage +2	Local substation sources are likely to require automated monitoring and control systems. (e.g., fuel cells combustion turbines, storage batteries).

(continuation)

External Influence	Technical Consideration: 23. Use of Substation Automation
8. Safety Restrictions 0	Very minor impact, if any. Substations do not generally present severe safety problems.
9. Political Considerations (policies) +2	Policies for national grid, system security, blackout prevention would favor increased usage of substation automation.
10. Energy Conservation +1	Voltage reduction and control for energy conservation could encourage use of substation automation, if such programs are shown to be worthwhile.
11. New Material Technology +1	Indirect effect, through economic improvements in processor technology.
12. Shipping Considerations 0	No evident effects.
13. Effect of R&D Projects & Funding +3	Funding to help define functions and establish economics of usage could encourage greater employment of substation automation.
14. Impact of International Practices +1	Widespread successful usage anywhere could encourage worldwide usage, though actual nature of systems may be very diverse, due to differing operating needs from country to country.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 24. Use of Distribution Automation
1. Load Characteristics +4	Widely fluctuating load characteristics may encourage usage for monitoring and control. Load management function could improve factor.
2. Economics +3	First cost high, but long term benefits may make usage worthwhile.
3. Environmental Restrictions 0	No direct effect, though slight esthetic impact.
4. Environmental Effects +2	Locations having more severe environmental effects may make usage more attractive for control and monitoring.
5. Reliability Constraints (components & system) +4	In general, stricter constraints will favor automation. Service can be enhanced by feeder automation functions. Critical loads can be more closely monitored and controlled.
6. Availability of Natural Resources & Basic Materials +1	Lack of manpower could favor usage. (This may be even more true than for substation automation, since meter reader and some maintenance crew reductions may be possible.
7. Generation Sources & Energy Storage 0	No evident effect.

(continuation)

External Influence	Technical Consideration: 24. Use of Distribution Automation
8. Safety Restrictions 0	No direct effect.
9. Political Considerations (policies) +4	Mandated load management could require usage of distribution automation.
10. Energy Conservation +1	Load management feature could result in some energy conservation, and enhance usage.
11. New Material Technology +3	Size and cost improvements in home equipment would enhance usage. Reduction in carrier attenuation in transformers would also help usage.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding +3	Studies to establish performance levels, functions and economics may enhance usage.
14. Impact of International Practices +2	Long-standing usage of European ripple systems may lead to greater usage of this and other methods in U.S. or worldwide.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 25. Use of Transmission Line Single-Pole Switching
1. Load Characteristics 0	No evident effect.
2. Economics +2	Economics generally slightly unfavorable, though choice may not be based on economics. In some cases, usage may allow deferral of a new line.
3. Environmental Restrictions +3	Widespread restrictions on right-of-way may encourage usage to lessen risk of instability in existing system, until a new line is added.
4. Environmental Effects +2	May be attractive in high-lightning areas.
5. Reliability Constraints (components & system) +2	Tighter constraints favor usage, from a stability standpoint.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +2	Remote sources would encourage usage, based on stability.

(continuation)

External Influence	Technical Consideration: 25. Use of Transmission Line Single-Pole Switching
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) +2	Policies on national grid or interties would encourage usage.
10. Energy Conservation 0	No evident effect.
11. New Material Technology 0	No evident effect.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding +2	Investigations will determine effects of usage in large systems (e.g., arc extinction, elimination of neutral reactors).
14. Impact of International Practices +2	Foreign experience could generally favor usage.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 26. Use of Ultra-High-Speed Fault Clearing
1. Load Characteristics 0	No evident effect.
2. Economics -4 +1	High first cost would discourage usage. If an additional line could be deferred, economics could be favorable.
3. Environmental Restrictions 0	No evident effect.
4. Environmental Effects +1	Where environmental effects are severe, usage may be attractive to help reduce stresses on equipment.
5. Reliability Constraints (components & system) +2	Tighter constraints would generally favor usage, from stability standpoint.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +2	Remote sources favor usage, from stability standpoint.

(continuation)

External Influence	Technical Consideration:	26. Use of Ultra-High-Speed Fault Clearing
8. Safety Restrictions 0	No evident effect.	
9. Political Considerations (policies) +2	Policies on national grid or interties would favor usage.	
10. Energy Conservation 0	No evident effect.	
11. New Material Technology +3	New materials could enhance ultra-high-speed breaker technology.	
12. Shipping Considerations 0	Problem is not different from that with conventional breaker.	
13. Effect of R&D Projects & Funding +3	Funding could hasten emergence of UH: breakers and general usage, based on system technical or economic studies.	
14. Impact of International Practices +1	Foreign experience may influence usage.	

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 27. Use of Fault Current Limiting Devices
1. Load Characteristics +3	High load density areas have most heavily loaded circuits and highest fault current levels.
2. Economics -3	Transmission-Economics generally very unfavorable. Distribution-Intermediate currents-may be attractive based on tradeoffs with other equipment. Distribution-High Currents-Economics determine best method, where FCL is needed.
3. Environmental Restrictions +2	Transmission-No known effect. Distribution-Concern over action of expulsion devices could favor usage of CL fuses or reactors.
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) +3	More stringent constraints would favor usage.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +3	Transmission-Highly concentrated generation parks would favor usage. Distribution-Local sources at distribution substations may enhance usage.

(continuation)

External Influence	Technical Consideration: 27. Use of Fault Current Limiting Devices
8. Safety Restrictions +3	Strict safety or liability restrictions strongly encourage usage. (See 3. above)
9. Political Considerations (policies) +2	Liability-related governmental policies could make usage desirable.
10. Energy Conservation 0	Could affect the particular choice, based on losses, but is not likely to determine actual usage.
11. New Material Technology +3	New, lower cost materials or smaller size could enhance usage.
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding +4	Investigations of materials (Fl.) plus new FCL concepts could spur usage.
14. Impact of International Practices +1	Any experience could influence usage one way or another.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 28. Improved Transient Overvoltage Control and Protection
1. Load Characteristics 0	No evident effect.
2. Economics +3	Transmission-Better arresters are more costly, but trade-off occurs with equipment BIL levels and breaker resistors. Distribution-Pure economics unfavorable; better arresters give improved margins with existing BIL's.
3. Environmental Restrictions +1	Esthetics, land, R-O-W and equipment size restrictions may demand improved transient control to achieve size (BIL) reductions.
4. Environmental Effects +1	EMP may require consideration of methods to control it. Higher lightning currents could lead to development of improved control. High contamination areas may require, especially with respect to UHV.
5. Reliability Constraints (components & system) +5	Tighter constraints would encourage improvement, to achieve greater protective margins. Power electronics equipment and electronic controls may require better overvoltage control, to improve reliability.
6. Availability of Natural Resources & Basic Materials -1	Need for exotic materials, subject to uncertain availability would work against improvements.
7. Generation Sources & Energy Storage +2	Remote sources may require improved control. Sources interfacing through power electronics probably require better control.

(continuation)

External Influence	Technical Consideration: 28. Improved Transient Overvoltage Control and Protection
8. Safety Restrictions 0	No direct effect.
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	No evident effect.
11. New Material Technology +4	Improved materials for arresters, breaker resistors, etc., could lead to dramatic improvements in size, cost or performance.
12. Shipping Considerations +1	Transformer shipping constraints may require lower BIL, hence better transient voltage control.
13. Effect of R&D Projects & Funding +4	Materials-related projects (11.) and studies of new concepts could lead to improved transient control.
14. Impact of International Practices 0	International practices tend to be more conservative, hence unlikely to affect U.S. practice.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical 29. Improved Dynamic Voltage Consideration: Control and Protection
1. Load Characteristics +2	Rapidly fluctuating loads may require better dynamic voltage control (e.g. are furnaces).
2. Economics -1	If dynamic overvoltages pose a severe risk of damage to equipment or personnel, economics is not a consideration, except to choose between alternate methods. If control is only desirable, evaluation of cost vs. benefits is warranted.
3. Environmental Restrictions 0	No evident effect.
4. Environmental Effects 0	No evident effect.
5. Reliability Constraints (components & system) +4	Stricter constraints may demand better control, to prevent equipment damage.
6. Availability of Natural Resources & Basic Materials 0	No evident effect.
7. Generation Sources & Energy Storage +3	Remote sources with long series-compensated ties may require DV control. In general, all sources require control on V/Hz. Present methods are often not as sophisticated as they should be, implying a need for improved control.

(continuation)

External Influence	Technical Consideration: 29. Improved Dynamic Voltage Control and Protection
8. Safety Restrictions +1	In cases where dynamic overvoltages pose a severe threat of damage or injury, safety restrictions could require improved control. (e.g., use of wye-wye, rather than delta-wye for UG transformers in proximity to public).
9. Political Considerations (policies) 0	No evident effect.
10. Energy Conservation 0	No evident effect.
11. New Material Technology +3	Could lead to improved control. (e.g., arrester capable of withstanding ferroresonance).
12. Shipping Considerations 0	No evident effect.
13. Effect of R&D Projects & Funding +3	Materials research (11.) plus system studies of new concepts of control could lead to improvements.
14. Impact of International Practices +1	Improved methods developed outside U.S. would likely impact on our practices.

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 30. Use of System VAR Compensation
1. Load Characteristics +5	Power factor, fluctuations, load factor, load patterns all impact on type of VAR compensation and degree of usage.
2. Economics +5	Economics are generally favorable. Benefits include loss reduction, improved regulation, released capacity, improved stability, greater power transfer.
3. Environmental Restrictions +1	Capacitor fluid toxicity, biodegradability and flammability are of concern. Esthetics may hinder usage of large capacitor or reactor banks. Land and noise restrictions may hinder usage. Inability to get R-O-W for new lines may enhance usage.
4. Environmental Effects 0	Effect is same as on other equipment.
5. Reliability Constraints (components & system) +1	Uncertain effect - may enhance (stability) or degrade (series capacitor) system reliability.
6. Availability of Natural Resources & Basic Materials 0	Basic shortages could limit amount of VAR compensation.
7. Generation Sources & Energy Storage +3	Remote sources enhance usage. Some unconventional sources require it (e.g., fuel cells, batteries, MHD, photo voltaic).

(continuation)

External Influence	Technical Consideration:	30. Use of System VAR Compensation
8. Safety Restrictions -1	Fluid flammability may restrict usage in some application.	
9. Political Considerations (policies) 0	No evident effect.	
10. Energy Conservation +4	Loss reduction makes VAR compensation very attractive as energy conservation method.	
11. New Material Technology +3	May lead to better dielectrics and fluids, smaller designs, etc., all of which would enhance usage.	
12. Shipping Considerations -1	Possible limitations on reactor size could hinder usage.	
13. Effect of R&D Projects & Funding +3	Materials research (11.) and studies of new concepts and economic benefits generally enhance usage.	
14. Impact of International Practices 0	Practices abroad tend to be similar.	

IMPACTS OF EXTERNAL INFLUENCES ON A SPECIFIC
TECHNICAL CONSIDERATION

External Influence	Technical Consideration: 31. More Stringent System Stability Criteria
1. Load Characteristics 0	Criteria not load-related, but a function of geometry, fault types, economics.
2. Economics -4	Economics tend to discourage setting of more stringent criteria.
3. Environmental Restrictions -4	Environmental restrictions would tend to discourage stricter criteria, since more lines, generation, etc., would result.
4. Environmental Effects +3	More severe environment would likely lead to more stringent criteria, due to increased likelihood of multiple contingencies.
5. Reliability Constraints (components & system) +3	Reliability constraints directly favor stricter stability criteria.
6. Availability of Natural Resources & Basic Materials +1	No effect on criteria; may affect ability to achieve specific criteria. Shortages of certain fuels could result in stricter criteria with respect to other generation types.
7. Generation Sources & Energy Storage +3	High concentration of generation favors stricter criteria.

(continuation)

External Influence	Technical Consideration: 51. More Stringent System Stability Criteria
8. Safety Restrictions 0	No evident effect.
9. Political Considerations (policies) +2	Policies on national grid would likely encourage or require stricter criteria.
10. Energy Conservation 0	No evident effect on criteria.
11. New Material Technology 0	No evident effect on criteria.
12. Shipping Considerations 0	Unlikely to affect criteria.
13. Effect of R&D Projects & Funding 0	Unlikely to affect criteria or methods.
14. Impact of International Practices 0	No significant effect.

Transformer Design Parameter No. 1 : Voltage Rating

Technical Consideration	System Effects on Design Parameter	Major External Influences
3. Use of Higher Voltage Levels	Higher device voltage ratings Higher transformation ratios	<u>Load Characteristics</u> - high density; remoteness. <u>Economics</u> - large initial capital expenditures vs. lower operating costs. <u>Generation Sources</u> - remoteness <u>Energy Conservation</u> - loss reduction major reason for higher voltages. <u>R&D Projects</u> - most effect on transmission, little on distribution.
4. Use of Fewer Voltage Levels	Fewer substations & Associated Equipment and Less subxmsn implies higher ratios and primary voltages.	<u>Load Characteristics</u> - high density; rapid growth. <u>Economics</u> - fewer substa/lines; lower inventories. <u>Reliability Constrants</u> - better T rely; uncertain with D.
7. Use of Regional Energy Transfer	Encourages higher voltages.	<u>Load Characteristics</u> - regional diversity <u>Environmental Restrictions</u> - esthetics, ROW, biological, plant siting. <u>Political Considerations</u> - reliability, conservation, nat'l grid. <u>Shipping Considerations</u> - lack of sufficient fuel shipment cap'y. <u>R&D Projects</u> - needed to clarify concept.
10. Use of Higher Phase Order Transmission	Lower primary voltage, and possibly unusual non-std. L-G voltages, will result due to greater complexity of equipment.	<u>Load Characteristics</u> - high density favors use. <u>Economics</u> - uncertain but very important. <u>Environmental Restrictions</u> - narrow ROW & low towers, but complex bundle. <u>R&D Projects</u> - strong effect, but uncertain outcome.

Transformer Design Parameter No. 1 : Voltage Rating

Technical Consideration	System Effects on Design Parameter	Major External Influences
22. Use of Power Electronic Equipment	Interfacing exotic sources to T&D systems could lead to non-std. winding connections and voltage ratings. Solid-state transformation may require special voltage ratings.	<u>Load Characteristics</u> - fluctuation in V, PF <u>Economics</u> - cost reduction in electronics. <u>New Material Technology</u> - semiconductors <u>E&D Projects</u> - materials and application studies.
30. Use of system VAR Compensation	Better voltage regulation (tighter operating bandwidth), Interface to SVG (non-std. voltage).	<u>Load Characteristics</u> - PF, fluctuation, LF, patterns. <u>Economics</u> - generally favorable. <u>Generation Sources</u> - remote; exotic <u>New Materials</u> - dielectrics, fluids, size. <u>E&D Projects</u> - materials and concepts, economics.

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 2 : Voltage Taps

Technical Consideration	System Effects on Design Parameter	Major External Influences
5. More Stringent Voltage Regulating Criteria	Increased usage of LTC and regulating equipment. (Possible effects on range, number of steps with LTC).	<u>Economics</u> - generally favors less stringency. <u>Political Considerations</u> - see energy conservation, below. <u>Energy Conservation</u> - voltage reduction & load management for conservation could require or permit more stringent regulation.
12. Higher Short Circuit Magnitudes	Higher impedance transformers to limit current could need more LTC to permit better regulation.	<u>Load Characteristics</u> - high density & large spot loads require stiff systems. <u>Reliability Constraints</u> - greater redundancy produces greater stiffness. <u>Safety Restrictions</u> - potential hazards favor less fault current. <u>New Materials Tech</u> - developments in both directions. <u>R&D Projects</u> - most efforts at reducing fault levels.
18. Phase Angle Regulation Constraints	Phase angle regulating transformers a special application of LTC.	<u>Economics</u> - economics often better than for additional lines. <u>Shipping Considerations</u> - rating restriction, due to larger size of these units.
19. Use of Mobile Substations	Mobile substation transformer a special use of NL & LTC taps.	<u>Reliability Constraints</u> - use as backup the major reason for mobile subs.

Transformer Design Parameter No. 2 : Voltage Taps

Technical Consideration	System Effects on Design Parameter	Major External Influences
22. Use of Power Electronic Equipment	Faster voltage control by solid-state LTC, and advanced concept that could lead to finer steps/different range.	<p><u>Load Characteristics</u> - mainly rapid fluctuation; favors use.</p> <p><u>Economics</u> - probably favorable, if solid state cost reductions are made.</p> <p><u>New Materials</u> - could greatly enhance use.</p> <p><u>R&D Projects</u> - materials & application studies under way.</p>
23. Use of Substation Automation	Increased monitoring & optimum control could lead to changes in tap philosophy, steps, range.	<p><u>Load Characteristics</u> - widely varying characteristics favor real-time control.</p> <p><u>Economics</u> - operating benefits offset first cost.</p> <p><u>Reliability Constraints</u> - would favor better control.</p> <p><u>R&D Projects</u> - function definition & usage economics should help to promote.</p>
30. Use of System Var Compensation.	Better voltage regulation by VAR comp. could modify or eliminate tap usage, at least LTC.	<p><u>Load Characteristics</u> - PF, fluctuation, LF, patterns.</p> <p><u>Economics</u> - generally favorable.</p> <p><u>Generation Sources</u> - remote and exotic sources promote use.</p> <p><u>Energy Conservation</u> - makes usage very attractive.</p> <p><u>New Materials</u> - dielectric, fluids, size.</p> <p><u>R&D Projects</u> - materials, concepts, benefits</p>

Transformer Design Parameter No. 3 : Insulation Level Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
1. More Stringent Reliability Criteria	Improved insulation requirements, in general.	<p><u>Economics</u> - only favorable to a degree; systems already more reliable than economics would dictate.</p> <p><u>Reliability Constraints</u> - externally forced criteria may be tougher than economics dictate.</p> <p><u>Political Considerations</u> - policies on reliability constraints, levels.</p> <p><u>R&D Projects</u> - should help device reliability & lessen pressure for stringency.</p>
3. Use of Higher Voltage Levels	Higher BIL's, closer control of transient overvoltages, larger equipment size all impact on insulation requirements. Ratio of insulation to system voltage decreases.	<p><u>Load Characteristics</u> - higher density, remoteness encourage use.</p> <p><u>Economics</u> - operating costs vs. higher initial cost.</p> <p><u>Generation Sources</u> - remote sources favor</p> <p><u>Energy Conservation</u> - loss reduction major positive factor.</p> <p><u>R&D Projects</u> - most effect on transmission; little on distribution.</p>
10. Use of Higher Phase Order Transmission	Greater complexity of system and protective schemes may affect BIL and insulation system.	<p><u>Load Characteristics</u> - high density favors use.</p> <p><u>Economics</u> - uncertain but very important.</p> <p><u>Environmental Restrictions</u> - narrow ROW & lower towers, but complex bundle.</p> <p><u>R&D Projects</u> - strong effect; uncertain outcome.</p>

Transformer Design Parameter No. 3 : Insulation Level Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
13. Higher Harmonic Levels	May require different grounding system, affecting BIL, including neutral.	<u>Load Characteristics</u> - harmonic-rich loads filterable; capacitors may aggravate. <u>Economics</u> - favor higher harmonic levels. <u>Environmental Restrictions</u> - TIF/Audible Noise discourage. <u>Generating Sources</u> - power electronic conversion produces. <u>New Materials</u> - core materials.
15. Use of Gas Insulated Substations	Possible constraints on surge protection due to physical layout may affect BIL.	<u>Load Characteristics</u> - high density urban areas with scarce, expensive land favor use. <u>Economics</u> - high land and construction costs favor use. <u>Environmental Restrictions</u> - generally favor use. <u>Avail. of National Resources</u> - land scarcity favors use.
16. Use of Gas Insulated Transmission Lines	Limited lightning exposure may lead to lower BIL's, if switching surge levels permit.	<u>Load Characteristics</u> - large transfer over single corridor favors use. <u>Economics</u> - unfavorable except for special cases. <u>Environmental Restrictions</u> - generally favor use.

Transformer Design Parameter No. 3 : Insulation Level Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
17. Use of Superconducting Transmission	Limited lightning exposure may lead to lower BIL's, if switching surge levels permit.	<u>Load Characteristics</u> - large transfer over single corridor favors use. <u>Economics</u> - generally unfavorable. <u>Environmental Restrictions</u> - generally unfavorable. <u>Reliability Constraints</u> - would discourage use. <u>R&D Projects</u> - feasibility studies needed. <u>International Practices</u> - strong, uncertain effect.
20. Use of Indoor Substations	Limited lightning exposure may lead to lower BIL.	<u>Load Characteristics</u> - high density and scarce land favor use. <u>Economics</u> - unfavorable except with high land costs. <u>Environmental Restrictions</u> - generally favor use. <u>New Materials</u> - size, weight, flammability improvements would favor use. <u>R&D Projects</u> - see "new materials"
22. Use of Power Electronic Equipment	Precision switching & fault clearing can reduce transients and influence insulation levels.	<u>Load Characteristics</u> - Rapid fluctuation in V, PF favor use. <u>Economics</u> - require cost reduction to become favorable. <u>New Materials</u> - semiconductor cost & performance. <u>R&D Projects</u> - materials & application studies.

Transformer Design Parameter No. 3 : Insulation Level Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
27. Use of Fault Current Limiting Devices	CL neutral reactors impact on system grounding, hence on surge protection and BIL's	<u>Load Characteristics</u> - high density areas yield stiffest systems. <u>Economics</u> - often unfavorable; differs for T&D. <u>Reliability Constraints</u> - greater stringency would favor use. <u>Generation Sources</u> - high concentration & localized sources favor. <u>Safety Restrictions</u> - clearly favor <u>New Material</u> - lower cost & size would enhance use. <u>R&D Projects</u> - materials & concepts.
28. Improved Transient Overvoltage Control	BIL reductions could result.	<u>Economics</u> - favorable for T, usually not for D. <u>Reliability Constraints</u> - tightening would favor. <u>New Material</u> - better arresters & breaker resistors. <u>R&D Projects</u> - materials and concepts needed.
29. Improved Dynamic Voltage Control and Protection.	Possible reduction in insulation requirements at dynamic voltage.	<u>Reliability Constraints</u> - stringency would favor better control. <u>Generation Sources</u> - better control than is now available. <u>New Materials</u> - could help. <u>R&D Projects</u> - materials and new concepts needed.

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Technical Consideration	System Effects on Design Parameter	Major External Influences
3. Use of Higher Voltage Levels	Higher circuit loading may lead to larger kVA sizes.	<p><u>Load Characteristics</u> - long distances, high density, remote loads, favor higher voltages. Higher capacity R-O-W's are obtained by higher voltages.</p> <p><u>Economics</u> - first cost unfavorable, favorable in long term.</p> <p><u>Availability of Natural Resources</u>-fewer subs. with higher dist. voltages means less land requirements.</p> <p><u>Generation Sources & Energy Storage</u> - remote generator favors higher voltages.</p> <p><u>Political Considerations</u> - pressure for national grid may lead to higher voltages.</p> <p><u>Energy Conservation</u> - reducing losses favors H.V.</p> <p><u>New Material Technology</u> - may enable utilities to go to new higher voltages.</p> <p><u>Effect of R&D Projects & Funding</u>- favorable.</p>
7. Use of Regional Energy Transfer	More and higher capacity to circuits, potentially higher voltage lines, and an increase in transmission line capacity all may lead to higher kVA ratings.	<p><u>Load Characteristics</u>-regional load diversity is reason for it.</p> <p><u>Environmental Restrictions</u>- aesthetics, R-O-W biological effects hamper RET. Plant siting problems would make it attractive.</p>
16. Use of Gas Insulated Transmission Lines	Higher circuit capacity may require larger transformer ratings.	<p><u>Load Characteristics</u> - high load density favors GIT.</p> <p><u>Economics</u> - unfavorable except special cases as line crossings in crowded areas.</p> <p><u>Environmental Restrictions</u>- aesthetics, airport clearance, biological effects favor GIT.</p>

Technical Consideration	System Effects on Design Parameter	Major External Influences
17. Use of Superconducting Transmission	Higher continuous current ratings of components may lead to larger transformers.	<u>Load Characteristics</u> - high load density favors SCT. <u>Economics</u> - generally unfavorable. <u>Environmental Restrictions</u> - unfavorable (e.g. leaks) <u>Reliability Constraints</u> - unfavorable due to complexity, larger blocks of power in one circuit, longer outages expected. <u>Effect of R&D Projects & Funding</u> - required to determine feasibility. Results will determine use. <u>Impact International Practices</u> - may determine outcome.
21. Use of IV Networks	Larger substation capacity generally leads to larger MVA substation transformers.	<u>Load Characteristics</u> - high load densities, spot loads; critical loads enhance use. <u>Economics</u> - unfavorable <u>Reliability Constraints</u> - if stiffer, favor LV networks.
26. Use of Ultra-High Speed Fault Clearing	Greater power transfer capability may lead to larger MVA ratings.	<u>Economics</u> - generally unfavorable <u>New Material Technology</u> - could hasten UHS breakers. <u>Effect of R&D Projects & Funding</u> - would hasten use of UHS breakers.

Transformer Design Parameter No. 5 : Thermal Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
1. More Stringent Reliability Criteria	May require improved thermal performance for transformers.	<p><u>Economics</u> - unfavorable</p> <p><u>Reliability Constraints</u> - may mandate more stringent reliability criteria.</p> <p><u>Political Considerations</u>- mandated reliability policies?</p> <p><u>New Material Technology</u> - component improvements may allow more stringent reliability criteria.</p> <p><u>Effect of R&D Projects & Funding</u> - component improvements may allow more stringent reliability criteria.</p>
2. Trend From OH to UG Construction	Smaller overload capability of distribution transformers in subsurface installations may require improved thermal capability.	<p><u>Load Characteristics</u> -high density loads and spot loads favor UG.</p> <p><u>Economy</u> - good state of economy favors UG, economic alternative may favor UG by 2000.</p> <p><u>Environmental Restrictions</u> - aesthetics, favorable toward UG.</p> <p><u>Political Considerations</u>- mandate UG?</p> <p><u>New Material Technology</u>- superconducting, corrosion resistance, improved cable insulation help trend to UG.</p> <p><u>Effect of R&D Projects & Funding</u>- favors UG as new technology.</p>
6. Use of Load Management	Improved load factor may lead to less overloading of transformers. Consequently designs with lower short time overload capabilities may result.	<p><u>Load Characteristics</u> - load factor primary reason for load management, low growth makes it attractive.</p> <p><u>Economics</u> - economics favorable.</p> <p><u>Energy Conservation</u> - favors use by replacing inefficient generation.</p> <p><u>Effects of R&D Funding</u>- R&D developments help determine true value of load management.</p>

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 5 : Thermal Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
8. Use of HVDC Circuits	Harmonics generated may require higher transformer thermal capabilities.	<u>Economics</u> - long line bulk power transfer favor HVDC. HVDC economic at relatively short distances. R-O-W costs less. <u>New Material Technology</u> - breakthrough in HV, higher current semi-conductors favor use of HVDC. <u>Effect of R&D Projects & Funding</u> - may provide necessary breakthrough.
11. Higher System and Component Resistive Losses	Use of lower loss transformers will improve thermal capability of transformers.	<u>Economics</u> - favor lower losses.
15. Higher Harmonic Levels	May require higher transformer thermal capability.	<u>Load Characteristics</u> - arc furnaces, rectifiers, etc. produce more harmonics. Low PF loads require capacitive var compensation - more harmonics. <u>Economics</u> - favor higher harmonics <u>Environmental Restrictions</u> - TIF limits and noise restrictions may reduce system harmonics. <u>Generation Sources & Energy Storage</u> - power electronic converter produces more harmonics. <u>New Material Technology</u> - new core materials for transformers may reduce harmonics. <u>Effect of R&D Projects & Funding</u> - harmonic-free converters and iron-free cores would lower harmonics.

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 5 : Thermal Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
20. Use of Indoor Sub-stations	May require higher thermal capabilities of transformers.	<p><u>Load Characteristics</u>- high density load favorable.</p> <p><u>Economics</u> - generally unfavorable except where land costs are high.</p> <p><u>Environmental Restrictions</u> - land unavailability, aesthetics, noise restrictions, etc., favorable; non-flammability restrictions unfavorable.</p> <p><u>New Material Technology</u>- more compact, lighter and non-flammable equipment favor indoor subs.</p> <p><u>Effect of R&D Projects & Funding</u>- favorable</p>
22. Use of Power Electronic Equipment	More harmonics may require higher thermal capability of transformers.	<p><u>Load Characteristics</u> - rapidly fluctuating voltage or power factor may require power electronic control.</p> <p><u>Economics</u> - makes electronics more favorable as cost of solid state equipment goes down.</p> <p><u>New Material Technology</u> - higher power density, lower loss/cost semi-conductors may increase use of power electronics.</p> <p><u>Effect of R&D Projects & Funding</u> - new materials and studies of new applications increase use.</p>

Transformer Design Parameter No. 6 : Impedance Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
1. More Stringent Reliability Criteria	Requires improved mechanical and dielectric (insulation) strength in transformers; tends to increase impedance.	<u>Economics</u> - unfavorable for more stringent criteria. <u>Reliability Constraints</u> - mandated stringent criteria may be forced on utility. <u>Political Considerations</u> - same as preceding
2. Trend from OH to UG Construction.	May result in higher than standard impedance, to limit the higher short circuit current. May require special physical arrangement, affecting impedance.	<u>Load Characteristics</u> - favorable for UG. <u>Economics</u> - learning curve favorable to UG. <u>Environmental Restrictions</u> - favorable to UG. <u>Political Considerations</u> - laws force UG trend. <u>New Material Technology</u> - advances UG trend. <u>Effect of R&D Funding</u> - developments favor UG.
3. Use of Higher Voltage Levels	Higher BIL level increases impedance. Higher fault current levels may require higher impedance to limit S.C.	<u>Load Characteristics</u> - favorable for high density and remote loads. <u>Economics</u> - favorable due to lower \$/kW delivered. <u>Unavailability of Natural Resources</u> - favors HV levels. <u>Political Considerations</u> - national grid, pool ties encouraged by political bodies, favors HV. <u>Energy Conservation</u> - loss savings favors HV. <u>New Materials Technology</u> - developments favor HV. <u>Effect of R&D Funding</u> - same as preceding.
4. Use of Fewer Voltage Levels	Leads to higher fault currents; higher impedance may be required to limit S.C.	<u>Load Characteristics</u> - favorable for high density load. <u>Economics</u> - Reduction in number of components. <u>Reliability Constraints</u> - fewer components required increases reliability.

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 6 : Impedance Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
5. More Stringent Voltage Regulation Criteria	Regulation improved by lower impedance components.	<u>Economics</u> - unfavorable <u>Political Considerations</u> - favorable due to volt. reduction. <u>Energy Conservation</u> - favorable to more stringent criteria.
12. Higher Short Circuit Magnitudes	Higher impedance in system components may be required to limit S.C. currents.	<u>Load Characteristics</u> - high density, spot loads with redundant sources. <u>Reliability Constraints</u> - redundancy of sources. <u>New Material Technology</u> - could lead to decreased or increased S.C. <u>Effect of R&D Funding</u> - efforts to reduce S.C.
20. Use of Indoor Substations	Constraints on physical size may require special design impedances (either higher or lower).	<u>Load Characteristics</u> - high density loads favor use. <u>Economics</u> - generally unfavorable. <u>Environmental Restrictions</u> - favor use. <u>New Material Technology</u> - favor use if result in compact, non-flammable equipment. <u>Effect of R&D Funding</u> - favor use if result in compact, non-flammable equipment.
31. More Stringent System Stability Criteria	May require lower reactance to meet criteria.	<u>Economics</u> - unfavorable. <u>Environmental Restrictions</u> - unfavorable, need more lines and equipment. <u>Reliability Constraints</u> - favorable <u>Generation Sources</u> - high concentration favors stringent criteria.

Technical Consideration	System Effects on Design Parameter	Major External Influences
2. Trend From OH To UG Construction	Reduced impedance, charging current combine to produce greater inrush currents.	<u>Load Characteristics</u> - favorable for UG <u>Economics</u> - learning curve favorable to UG <u>Environmental Restrictions</u> - favorable to UG <u>Political Considerations</u> - laws force UG trend. <u>New Material Technology</u> - advances UG trend. <u>Effect of R&D Funding</u> - developments favor
12. Higher short circuit Magnitudes	Higher source capacity can produce greater inrush currents.	<u>Load Characteristics</u> - high density, spot loads with redundant sources. <u>Reliability Constraints</u> - redundancy of sources. <u>New Material Technology</u> - could lead to decreased or increased S.C. <u>Effect of R&D Funding</u> - efforts to reduce S.C.
27. Use of Fault Current Limiting Devices	Would limit maximum inrush current that would be subjected to when energized.	<u>Load Characteristics</u> - high load density. <u>Economics</u> - unfavorable, generally. <u>Reliability Constraints</u> - favors use. <u>Generation Sources</u> - concentration of generations favors use. <u>New Materials Technology</u> - lower cost, size favor. <u>Effect of R&D Funding</u> - developments favor use.

Transformer Design Parameter No. 8 : Loss Levels

Technical Consideration	System Effects on Design Parameter	Major External Influences
11. Higher System And Component Resistive Losses	Requires lower loss transformers to improve condition.	<u>Economics</u> - unfavorable - need to design for lower losses for evaluation. <u>Generation Sources</u> - remote generation increases losses.
13. Higher Harmonic Levels	Harmonics produce additional losses in transformers.	<u>Load Characteristics</u> - harmonic sources, i.e. arc furnaces, rectifiers. <u>Economics</u> - favor tolerating harmonics. <u>Environmental Restrictions</u> - force reduction of harmonics. <u>Generation Sources</u> - power electronics harmonic sources. <u>New Materials Technology</u> - new core material elimination of iron reduces levels. <u>Effects of R&D Funding</u> - new core material elimination of iron reduces levels.

Technical Consideration	System Effects on Design Parameter	Major External Influences
1. More Stringent Reliability Criteria	Improved mechanical strength to achieve better reliability.	<u>Economics</u> - only favorable to a degree; systems probably already more reliable than economics would dictate. <u>Reliability Constraints</u> - externally forced criteria may exceed economic level. <u>Political Considerations</u> - policies on reliability constraints and/or levels. <u>R&D Projects</u> - should help device reliability, lessening pressure for greater stringency.
2. Trend from OH to UG Construction.	Higher-fault currents and more transmission circuits per delivered MVA may require higher withstand capability.	<u>Load Characteristics</u> - high density loads, large spot loads favor. <u>Economics</u> - not totally favorable, but premium accepted. <u>Environmental Restrictions</u> - esthetic enhances use. <u>Political Considerations</u> - tends to enhance trend. <u>New Materials</u> - superconductivity, corrosion, insulation. <u>R&D Projects</u> - trend to favor UG as "new".
3. Use of Higher Voltage Levels	Higher fault currents with UG circuits, generally.	<u>Load Characteristics</u> - higher density, remoteness favor use. <u>Economics</u> - operating costs vs. higher initial cost. <u>Generation Sources</u> - remote sources favor. <u>Energy Conservation</u> - loss reduction a major positive factor. <u>R&D Projects</u> - most effect on transmission; little on distribution.

Transformer Design Parameter No. 9 : External Thru-Fault Withstand Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
4. Use of Fewer Voltage Levels	Probable increase in short circuit currents by elimination of intermediate transformation.	<u>Load Characteristics</u> - high density; rapid growth favor. <u>Economics</u> - fewer subs and lines; lower inventories. <u>Reliability Constraints</u> - better T reliability; uncertain with D.
5. More Stringent Voltage Regulation Criteria.	Short circuit currents may rise due to use of lower impedance devices.	<u>Economics</u> - generally favors less stringency <u>Political Considerations</u> - see Energy Conservation, below. <u>Energy Conservation</u> - voltage reduction and load management for conservation would require or permit tighter regulation.
8. Use of HVDC Circuits	Rapid control permits reduced short circuit magnitudes, and permit reduction in withstand requirements.	<u>Economics</u> - favorable for long lines, UG cables. <u>New Material</u> - lower cost, more efficient semiconductors would enhance use. <u>R&D Projects</u> - likely positive effect on use.
10. Use of Higher Phase Order Transmission	Possible effect on fault current magnitudes; uncertain, which direction.	<u>Load Characteristics</u> - high density favors use <u>Economics</u> - still uncertain, but very important. <u>Environmental Restrictions</u> - narrow ROW and lower towers, but more complex bundle. <u>R&D Projects</u> - likely strong effect, but uncertain outcome.
12. Higher Short Circuit Magnitudes	CL fuses and other limiting devices may reduce requirements. Otherwise, more strength is needed.	<u>Load Characteristics</u> - high density & large spot loads require stiff system. <u>Reliability Constraints</u> - greater redundancy produces greater stiffness. <u>Safety Considerations</u> - potential hazards encourage lower fault currents. <u>New Materials</u> - Developments in both directions <u>R&D Projects</u> - most efforts at reduction in levels

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 9 : External Thru-Fault Withstand Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
17. Use of Superconducting Transmission	Could act as current limiter, reducing strength requirements.	<u>Load Characteristics</u> - large transfer over single corridor favors use. <u>Economics</u> - generally unfavorable. <u>Environmental Restrictions</u> - generally unfavorable. <u>Reliability Constraints</u> - would discourage use. <u>R&D Projects</u> - feasibility studies needed. <u>International Practices</u> - strong, uncertain effect.
22. Use of Power Electronic Equipment	More precise, higher speed clearing could reduce fault stresses.	<u>Load Characteristics</u> - Rapid fluctuation in V, PF favor use. <u>Economics</u> - require cost reductions to become favorable. <u>New Materials</u> - semiconductor cost & performance. <u>R&D Projects</u> - materials & application studies.
26. Use of Ultra High Speed Fault Clearing	Faster clearing reduces fault stresses.	<u>Economics</u> - generally unfavorable. <u>New Materials</u> - needed for UHS breaker technology. <u>R&D Projects</u> - funding could hasten use, based on system tech. & econ. studies.
27. Use of Fault Current Limiting Devices	Limiting fault current magnitudes reduces the strength requirements.	<u>Load Characteristics</u> - high density areas yield stiffest systems. <u>Economics</u> - often unfavorable; differs for T&D <u>Reliability Constraints</u> - greater stringency would favor use. <u>Generation Sources</u> - high concentration and localized sources favor. <u>Safety Restrictions</u> - clearly favor <u>New Material</u> - lower cost & size would enhance use. <u>R&D Projects</u> - materials & concepts.

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 9 : External Thru-Fault Withstand Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
31. More Stringent System Stability Criteria	Possible need for faster fault clearing, hence reduced fault current stresses.	<u>Economics</u> - tend to discourage greater stringency. <u>Environmental Restrictions</u> - tend to discourage. <u>Environmental Effects</u> - more severe environment would likely result in tougher criteria. <u>Reliability Constraints</u> - directly favor. <u>Generation Sources</u> - high concentration favors greater stringency.

Transformer Design Parameter No. 10 : Internal Fault Withstand Requirements

Technical Consideration	System Effects on Design Parameter	Major External Influences
<p>Same as for "External Thru-Fault Withstand Requirements (No. 9)</p>	<p>Same as No. 9, basically fault current magnitude related. However, design parameter No. 10 is less directly related to systems evaluation. It only concerns itself with what energy the system can supply at the moment a single internal fault occurs. Hence, it is a one-time circumstance, that stands apart from considerations of cumulative duty, except where these may relate to increased probability of internal faults. The major concern with this design parameter is prevention of disruptive failures.</p>	<p>Same as for No. 9.</p>

Transformer Design Parameter No. 11 : Induction (Flux Density) Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
13. Higher Harmonic Levels	Lower induction level in transformer to minimize its contribution to harmonic level.	<u>Load Characteristics</u> - Harmonic sources, i.e. arc furnaces, rectifiers. <u>Economics</u> - favor tolerating harmonics. <u>Environmental Restrictions</u> - force reduction of harmonics. <u>Generation Sources</u> - power electronics harmonic sources. <u>New Material Technology</u> - new core material, elimination of iron reduces levels. <u>Effect of R&D Funding</u> - new core material, elimination of iron reduces levels.
14. More Stringent Audible Noise Level Criteria	Requires lower induction transformer design.	<u>Economics</u> - unfavorable. Pressure for less stringent criteria. <u>Environmental Restrictions</u> -strong pressure for it, from both public and regulatory bodies.
20. Use of Indoor Substation	Low-noise level requirements for components means lower induction transformer design.	<u>Load Characteristics</u> - high density loads favors use. <u>Economics</u> - generally unfavorable. <u>Environmental Restrictions</u> - favors use. <u>New Material Technology</u> - favor use if result in compact, non-flammable equipment. <u>Effect of R&D Funding</u> - favor use if result in compact, non-flammable equipment.

Transformer Design Parameter No. 11: Induction (Flux Density) Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
22. Use of Power Electronic Equipment	As source of harmonics, may require lower induction level in transformers.	<u>Load Characteristics</u> - rapidly fluctuating loads. <u>Economics</u> - learning curve will reduce costs, making more favorable. <u>New Material Technology</u> - semiconductor improvements and new concepts would enhance use. <u>Effect of R&D Funding</u> - semiconductor improvements and new concepts would enhance use.

Transformer Design Parameter No. 12: Mechanical Requirements Due to External Factors

Technical Consideration	System Effects on Design Parameter	Major External Influences
1. Reliability Criteria	Requires improved transformer mechanical strength.	<u>Economics</u> - unfavorable toward improved reliability. <u>Reliability Constraints</u> - if stiffer, may lead to more stringent criteria (may be political).
2. Trend From OH to UG.	Less exposure to weather eases mechanical requirements, but more corrosion on UG stiffens requirements.	<u>Load Characteristics</u> - high density loads & spot loads favor UG. <u>Economy</u> - Good state of economy favors UG, economic alternative may favor UG by 2000. <u>Environmental Restrictions</u> - aesthetics favorable toward UG. <u>Political Considerations</u> - mandate UG. <u>New Material Technology</u> - superconducting, corrosion resistance, improved cable insulation help trend to UG. <u>Effect of R&D Projects & Funding</u> - favors UG as new technology.

Technical Consideration	System Effects on Design Parameter	Major External Influences
2. Trend From OH to UG Construction	Closer proximity to public creates greater concern over equipment safety.	<u>Load Characteristics</u> - high density loads and spot loads favor UG. <u>Economy</u> - good state of economy favors UG, economic alternative may favor UG by 2000. <u>Environmental Restrictions</u> - aesthetics favorable toward UG. <u>Political Considerations</u> - mandate UG? <u>New Material Technology</u> - superconducting, corrosion resistance, improved cable insulation help trend to UG. <u>Effect of R&D Projects & Funding</u> - favors UG as new technology.
14. More Stringent Audible Noise Level Criteria	Need for lower noise level equipment may lower transf. induction; lead to lower audible noise designs (e.g. Dry-type Vapor-Cooled); lead to lower noise design of fans/auxiliary equipment.	<u>Economics</u> - unfavorable <u>Environmental Restrictions</u> - public pressure and regulatory bodies may demand it.
20. Use of Indoor Substations	Non-flammable material requirements necessitate use of Dry-Type or Non-flammable coolant and need for higher temperature insulation materials. Lower noise levels required means lowering induction levels or use of sound attenuating materials. Lack of exposure to weather may reduce creep requirements, minimize surge protection requirements, lessen likelihood of corrosion.	<u>Load Characteristics</u> - high density load favorable. <u>Economics</u> - generally unfavorable except where land costs are high. <u>Environmental Restrictions</u> - land unavailability, aesthetics, noise restrictions, etc. favorable; non-flammability restrictions unfavorable. <u>New Material Technology</u> - more compact, lighter, and non-flammable equipment favor indoor subs. <u>Effect of R&D Projects & Funding</u> - favorable

Transformer Design Parameter No. 14 : Size and Weight Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
3. Use of Higher Voltage Levels	Increased clearance, higher BIL, higher circuit loading all lead to larger size transformers.	<p><u>Load Characteristics</u> - long distance, high load density, remote loads, favor higher voltages. Higher capacity R-O-W's are obtained by higher voltages.</p> <p><u>Economics</u> -first cost unfavorable; favorable in long term.</p> <p><u>Availability of Natural Resources</u> - fewer subs. with higher dist. voltage means less land requirements.</p> <p><u>Generation Sources & Energy Storage</u>-remote generation favors higher voltages.</p> <p><u>Political Considerations</u> - pressure for national grid may lead to higher voltages.</p> <p><u>Energy Conservation</u> -reducing losses favors HV.</p> <p><u>New Material Technology</u> - may enable utilities to go to new higher voltages.</p> <p><u>Effect of R&D Project & Funding</u> - favorable</p>
4. Use of Fewer Voltage Levels	Larger substations may require smaller compact transformer designs.	<p><u>Load Characteristics</u> - high load density, rapid growth rate may encourage fewer voltages.</p> <p><u>Economics</u> - favorable</p> <p><u>Reliability</u> - improved with fewer voltage levels.</p>
7. Use of Regional Energy Transfer	More and higher capacity tie circuits, potential higher voltage lines, and potential increase in transmission line capacity all may lead to higher MVA or kV ratings, which would be larger in size.	<p><u>Load Characteristics</u> - regional load diversity is reason for it.</p> <p><u>Environmental Restrictions</u> - aesthetics, R-O-W, biological effects hamper RET. Plant siting problems could make it attractive.</p>

Transformer Design Parameter No. 14: Size and Weight Considerations**

Technical Consideration	System Effects on Design Parameter	Major External Influences
15. Use of GIS	Reduction in substation size may lead to reduced transformer size.	<u>Load Characteristics</u> - high load density favors GIS. <u>Economics</u> - favors GIS as land becomes more expensive and on site construction costs rise. <u>Environmental Restrictions</u> - land unavailability, aesthetics & noise restrictions favor GIS. <u>Availability of Natural Resources</u> - land unavailability in urban areas favor GIS.
16. Use of Gas Insulated Transmission Lines	Higher circuit capacity may require larger transformer ratings.	<u>Load Characteristics</u> - high load density favors GIT. <u>Economics</u> - unfavorable except special cases as line crossings in crowded areas. <u>Environmental Restrictions</u> - aesthetics, airport clearance, biological effects favor GIT.

Transformer Design Parameter No. 14: Size and Weight Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
17. Use of Superconducting Transmission	Higher continuous current ratings of components may mean larger transformers would be required (may have to be superconducting)	<u>Load Characteristics</u> - high load density favors SCT. <u>Economics</u> - generally unfavorable. <u>Environmental Restrictions</u> - unfavorable (e.g. leaks) <u>Reliability Constraints</u> - unfavorable due to complexity, larger blocks of power in one circuit, longer outages expected. <u>Effects of R&D Projects & Funding</u> - required to determine feasibility. Results will determine use. <u>Impact International Practices</u> - may determine outcome.
19. Use of Mobile Substations	Using mobile subs. may require more compact, lighter weight transformer designs.	<u>Reliability Constraints</u> - favorable.
20. Use of Indoor Substations	Constraints on physical size may lead to smaller size transformers.	<u>Load Characteristics</u> - higher load density favorable. <u>Economics</u> - unfavorable except where land is expensive. <u>Environmental Restrictions</u> - land unavailable aesthetics, noise restrictions favor indoor subs. Non-flammability restrictions discourage use. <u>New Material Technology</u> - more compact, lighter, non-flammable equipment favor indoor subs. <u>Effect of R&D Projects & Funding</u> - may enhance use..

Transformer Design Parameter No. 14 : Size and Weight Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
21. Use of LV Networks	Larger substation capacity may lead to larger MVA substation transformers; hence, larger size and weight.	<u>Load Characteristics</u> - high load densities, spot loads, critical loads enhance use. <u>Economics</u> - unfavorable <u>Reliability Constraints</u> - if stiffer, favor LV networks.
26. Use of Ultra-high Speed Fault Clearing	Greater power transfer capability may lead to larger MVA ratings.	<u>Economics</u> - generally unfavorable. <u>New Material Technology</u> - could hasten use of UHS breakers. <u>Effect of R&D Projects & Funding</u> - would hasten use of UHS breakers.
28. Improved Transient Overvoltage Control	Allowing reduced BIL, phase-grd. clearances may mean smaller size transformers.	<u>Economics</u> - favorable on transmission-allows lower BIL; unfavorable on distribution. <u>Reliability Constraints</u> - if tighter, leads to tighter protective margins; power electronics may require improved OV control. <u>New Material Technology</u> - improvements in arresters, breaker resistors may lead to improved transient OV control. <u>Effect of R&D Projects & Funding</u> - favorable.
29. Improved Dynamic Voltage Control	Lower volts/Hz may permit reduced 60 Hz insulation requirements and, therefore, size of transformers.	<u>Reliability Constraints</u> - stiffer constraints may demand better control. <u>New Material Technology</u> - favorable <u>Effect of R&D Projects & Funding</u> - may lead to improvements.

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 15 : Reliability Considerations.

Technical Consideration	System Effects on Design Parameter	Major External Influences
1. More Stringent Reliability Criteria	Stringent criteria requires improved mechanical and dielectric strength in transformers.	<u>Economics</u> - unfavorable for more stringent criteria. <u>Reliability Constraints</u> - mandated stringent criteria may be forced on utility. <u>Political Considerations</u> - same as preceding
2. Trend From OH to UG Construction	Different reliability characteristics required for UG transformers, particularly materials.	<u>Load Characteristics</u> - favorable for UG <u>Economics</u> - learning curve favorable to UG. <u>Environmental Restrictions</u> -favorable to UG. <u>Political Considerations</u> - laws force UG trend. <u>New Material Technology</u> - advances UG trend. <u>Effect of R&D Funding</u> - developments favor UG.
3. Use of Higher Voltage Levels	Trends to decrease transformer reliability, particularly as steps of BIL are reduced.	<u>Load Characteristics</u> - favorable for high density and remote loads. <u>Economics</u> - favorable due to lower \$/kW delivered. <u>Unavailability of Natural Resources</u> - favors H.V. levels. <u>Political Considerations</u> - national grid, pool ties encouraged by political bodies, favors H.V. <u>Energy Conservation</u> - loss savings favors H.V. <u>New Materials Technology</u> - developments favor H.V. <u>Effect of R&D Funding</u> - same as preceding

Transformer Design Parameter No. 15.: Reliability Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
12. Higher Short Circuit Magnitudes	Increased stresses decrease transformer reliability for through faults. Requires consideration of number of through faults which may be expected over life of transformer.	<p><u>Load Characteristics</u>- high density, spot loads with redundant sources.</p> <p><u>Reliability Constraints</u> - redundancy of sources.</p> <p><u>New Material Technology</u> - could lead to decreased or increased S.C.</p> <p><u>Effect of R&D Funding</u> -efforts to reduce S.C.</p>
23. Use of Substation Automation	May require more sophisticated transf. monitoring devices to increase reliability.	<p><u>Load Characteristics</u> - widely fluctuating loads favor.</p> <p><u>Economics</u> - first costs high, but has long term benefit.</p> <p><u>Reliability Constraints</u>- more stringent favors use.</p> <p><u>Effects of R&D Funding</u>- defines functions, economics.</p>
27. Use of Fault Current Limiting Devices	Reduces stress due to faults, improving reliability of given design.	<p><u>Load Characteristics</u>- high load density</p> <p><u>Economics</u> - unfavorable, generally.</p> <p><u>Reliability Constraints</u> - favors use.</p> <p><u>Generation Sources</u> - concentration of generations favors use.</p> <p><u>New Material Technology</u>- lower cost, size favor.</p> <p><u>Effect of R&D Funding</u> - developments favors use.</p>

Appendix III - Impacts of Technical Considerations and External Influences on Transformer Design Parameters.

Transformer Design Parameter No. 15 : Reliability Considerations

Technical Consideration	System Effects on Design Parameter	Major External Influences
28. Improved Transient Overvoltage Control	Reduces dielectric stress, improving transf. reliability for a given design.	<u>Reliability Constraints</u> - greater protective margins. <u>New Material Technology</u> - performance, cost improvements. <u>Effect of R&D Funding</u> - new materials concept studies lead to improved control.
29. Improved Dynamic Voltage Control	Reduces dielectric stress, improving transf. reliability for a given design.	<u>Reliability Constraints</u> - greater protective margins. <u>New Material Technology</u> - performance, cost improvement. <u>Effect of R&D Funding</u> - new materials concept studies lead to improved control.

APPENDIX IV

BIBLIOGRAPHY

A. Reports, Technical Papers, Articles, Etc.

1. Application of Optimization Methods in Power System Engineering
IEEE Power Engineering Society
Paper No. 76CH1107-2-PWR
2. BPA 1100 kV Transmission System Development
IEEE Power Engineering Society
Paper No. 79TH0057-0-PWR
3. Choice of the Characteristics of Power Transformers for UHV Systems
1978 CIGRE Paper 12-11 by Messrs. Bossi, Giannuzzi, Manzoni, Coppa doro & Sigandi
4. Energy Development
IEEE Power Engineering Society
Paper No. 74CH0913-4-PWR
5. Energy Development II
IEEE Power Engineering Society
Paper No. 76CH1102-3 PWR
6. Energy Development III
IEEE Power Engineering Society
Paper No. 77CH1215-3-PWR
7. Energy Development IV
IEEE Power Engineering Society
Paper No. 78TH0050-5-PWR
8. Evaluation of the Economical and Technological Viability of Various Underground Transmission Systems for Long Feeds to Urban Load Areas
- DOE Report HCP/T-2055/1 December 1977
9. Final Report - Feasibility Studies of Higher Order Phase Electrical Transmission Systems (Phase I)
by West Virginia University for the Allegheny Power System - May 15, 1977

10. Gas Insulated Substation Equipment for UHV Problems and Needs
R. W. Flugum, T. F. Garrity, J. P. Vora
US. ERDA
11. The National Energy Plan and Energy Conservation in the Electric Power Industry
IEEE Power Engineering Society
Paper No. 78TH0054-4-PWR
12. The National Energy Policy - Its Impact on the Electric Power Industry
IEEE Power Engineering Society
Paper No. 78TH0051-3 PWR
13. "138-kV Six-Phase Transmission System Feasibility,"
W. C. Guyker, et. al, American Power Conference,
Chicago, IL, April 25, 1978
14. "High Phase Order Transmission - A Feasibility Analysis. Part I - Steady State Considerations,"
J. R. Stewart and D. D. Wilson.
IEEE Paper F78-160-4
15. "High Phase Order Transmission - A Feasibility Analysis Part II - Overvoltages and Insulation Requirements."
J. R. Stewart and D. D. Wilson
IEEE Paper F78 161-2
16. "Effect of 60 Hz High Intensity Electric Fields on Living Plants," G. W. McKee et. al
IEEE Paper F 77 698-4
17. "Reliability Criteria for System Dynamic Performance,"
IEEE Working Group Report.
IEEE Publication 77 CH 1221-1-PWR
18. "Symposium Proceedings - New Concepts in Fault Current Limiters and Power Circuit Breakers,"
Electric Power Research Institute Special Report
EPRI EL-276-SR, April, 1977
19. Power Systems '2000': Hierarchian Control Strategies -
IEEE Spectrum, July 1978
20. The Role of Electrical Energy in the Early 21st Century -
1978 CIGRE Paper 41-04 by Messrs. J. R. Kiely and D. E. Hart
21. Shared Transmission Corridors Aid Grid Growth
Electric Light and Power, March 1972

22. Symposium on Reliability Criteria for System Dynamic Performance - IEEE Power Engineering Society
Paper No. 77Ch1221-1-PWR
23. Time for a Change
by R. W. Flugum - US - DOE
24. Underground Transmission - Current Developments
by T. F. Garrity - DOE and R. W. Sann - EPRI
25. The U.S. Energy Equation and the Role of Electricity -
A Position Statement IEEE Power Engineering Society
Paper No. 76CH1153-PWR

B. Surveys - Forecasts

1. Analysis and Forecast of Electrical Distribution
System Materials - Vol. I, II, III
ERDA Report - CONS/2050-August 23, 1976
2. Electric Power Supply and Demand 1978-1987 for the
Contiguous United States - DOE/ERA-0018
June 15, 1978
3. EEI - 1978 Annual Electric Power Survey
4. National Electric Reliability Council 8th Annual
Review of Overall Reliability and Adequacy of the
North American Bulk Power Systems - August 1978
5. NEMA - Sixth Biennial Survey of Power Equipment Require-
ments of the U.S. Electric Utility Industry 1977-1986
March 1978