STUDY OF LOADING
OF EBR-II ELECTRIC POWER SYSTEM

by

H. Kacinskas*

EBR-II Project
Argonne National Laboratory
Argonne, Illinois - Idaho Falls, Idaho

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ABSTRACT

This report describes the results of a study conducted to determine the loading of the electric power supply systems of the Experimental Breeder Reactor (EBR-II). The study includes 138-kV, 13.8-kV, 2.4-kV, 480-V and emergency power supply systems.

The general arrangement of the systems, the loads, and the procedures of the study are described.

The results of the study indicate that some of the electric power supply systems are overloaded and that their capacity must be increased and the system arrangement modified if a high degree in reliability of power supply to EBR-II electric loads is to be maintained. Several methods of modifying the electric system are proposed.

I. INTRODUCTION

From April 15 through April 18, 1969 the EBR-II electric power system was studied to determine the adequacy of the 138-kV, 13.8-kV, 2.4-kV, 480-V, and emergency power systems to serve the existing loads at the EBR-II site reliably and to ascertain their reserve capacity for future expansion.

The following procedures were followed in this study:

- 1.) observation of all permanently installed meters;
- 2.) measurements made with the portable clamp-on ammeter where no permanently installed meters exist;
- 3.) review of the data of previously performed metering, where available;
- 4.) discussions with Idaho EBR-II Project, Idaho Facilities, and Idaho Branch Administration (IBA) personnel;
- 5.) review of EBR-II drawings, operating manuals, and technical

reports related to the electric system arrangement and loading;

- 6.) review of the emergency diesel-generator test reports; and
- 7.) review of the future load requirements with IBA Plant Engineering.

II. GENERAL ARRANGEMENT OF EBR-II ELECTRIC POWER SYSTEMS

Most important in the EBR-II electrical design was achieving the highest degree of reliability and power supply continuity, commensurate with maintaining the least number of reactor scrams and thermal shocks to the fuel subassemblies and other reactor components.

A. 138-kV System

The EBR-II main outdoor substation is connected to a 138-kV power system. This system consists of a 65-mile-long, single-circuit power loop to serve all the facilities at the National Reactor Testing Station. The loop is served by a transmission line from a substation of the Utah Power and Light Company. In addition, the EBR-II 20,000-kW turbine-generator supplies power to the NRTS system on an "as available" basis.

Two 12,000/16,000 kVA, 132--13.8 kV power transformers at the EBR-II main outdoor substation provide duplicate main power interconnections while permitting essentially full-capacity operation of the EBR-II facility if one transformer is out of service.

B. 13.8-kV System

The 13.8-kV power is generated by the EBR-II generator when the reactor is operating; in case the power is not generated by EBR-II, it is supplied from the NRTS 138-kV system.

C. 2,400-V System

The 2,400-V system is used principally for large individual motors (200-800hp) and for large single-phase loads. This system--including power supply transformers, loads, and switching arrangement--is shown in Fig. 1.

Fig. 1. EBR-II 2,400-V System and ZPPR Emergency Power System

The 2,400-V switchgear is fed by two 13.8-2.4 kV transformers, rated 2,500 kVA each; in case one of the transformers fails or loses its primary power supply, the transformer is automatically disconnected from the 2,400-V bus, while the remaining transformer continues to supply power.

Such an arrangement maintains a highly reliable and uninterrupted power supply, provided:

- (1) one of the two 2,400-V transformers is operational,
- (2) 13.8-kV primary power is available to this transformer, and
- (3) the transformer is not overloaded by more than 10% of its full-load rating for longer than 8 hr in one day when the outside ambient temperature is around 90°F.

D. 480-V Normal Power System

The 480-V system is a wye-connected system with the neutrals of its two main 2,000-kVA power transformers solidly grounded. Figure 2 shows a simplified diagram of this system. The switching and protective relaying of the 480-V normal power system is similar to that of the 2,400-V system; the degree in power supply reliability is equivalent also.

E. Emergency Power System

Figure 2 shows the general arrangement of the emergency power system and includes the emergency diesel generators, switchgear, main feeders, and motor control centers.

The ZPPR emergency power system arrangement is shown in Fig. 1. Under normal operating conditions all the emergency loads are fed from the normal power supply systems. In case of a failure in the normal power supply, the power to the emergency loads is supplied by a diesel generator. Table I lists these auxiliary generators and their locations.

In case of a failure of the normal power supply system, the appropriate generator starts automatically. During tests of the emergency power and supply system the diesel generators start, accelerate to full speed, and reach full voltage in 12 to 15 sec. Some of the emergency loads are applied automatically without any intentional time delay as

Fig. 2. Simplified Diagram of EBR-II 480-V System

TABLE I. Auxiliary Diesel Generators

<u>Rating</u>	<u>Location</u>	<u>Loads</u>
500 kVA (400 kW) Continuous	Power plant	Reactor plant, power plant sodium boiler plant, lab & service bldg., yard & misc. service bldgs.
125 kVA (100 kW) Continuous	Power plant	Reactor shield and thimble cooling systems
*250 kVA (200 kW)	Fuel Cycle Facility	Fuel Cycle Facility
125 kVA (100 kW) Continuous	ZPPR	Zero Power Plutonium Reactor

*The available data do not confirm whether the 250-kVA unit, located in FCF, is rated for "steady" or "continuous" operation.

soon as the unit has reached full speed and voltage. Other, less critical loads, are applied automatically in 10-sec time delay steps.

Some of the loads, connected to the emergency bus during normal operation, are automatically disconnected during an emergency operation.

Certain loads may be connected manually to the emergency bus after an assurance that such a load application would not overload the unit.

Voltage-and frequency-regulated, 120-V, single phase, 60-Hz power for nuclear and process instrumentation and control is provided by a continuous power-supply system. This system includes a magnetic-amplifier type silicon power rectifier, a floating 240-V storage battery, and two motor-generator units. The system is fed from the power plant emergency power bus and, for the purpose of this study, it is treated as a single emergency power system load.

The EBR-II emergency system is described in a greater detail in report ANL-7202, dated June, 1966.*

III. LOADING OF EBR-II SITE ELECTRIC POWER SYSTEM

A. Load-Metering Devices

Metering, providing a continuous and permanent record of EBR-II electric power generation and consumption, is available in the 13.8-kV system only.

The 2,400-V and 480-V systems do not have any recording meters; however, all the 2,400-V main and branch feeders are equipped with indicating-type ammeters. In the 480-V normal power system the indicating-type ammeters are available only on the 13.8-kV-480-V transformer main feeders; the branch feeders, feeding motor-control centers and other load centers in various buildings, do not have any load meters.

The emergency power system has indicating ammeters on the emergency diesel generator output leads only; neither main nor branch circuits feeding the emergency bus sections from the normal power system have ammeters.

*F. Verber and H. L. Schmidt, The Electrical Design of EBR-II

B. Test Method for Determining Loading

1. 13.8-kV System

The total monthly EBR-II energy consumption and maximum power demand was determined from the Idaho Nuclear Corp. monthly electricity bills. These data, beginning with January, 1968, are shown in Table II.

2. 2,400-V System

Main and branch feeder loading data were obtained from indicating-type ammeters. Wherever one 2,400-V branch feeder feeds more than one load, the sub-branch ammeter readings were taken from any available, permanently installed, indicating-type ammeters, or a clamp-on, prong-type ammeter was used where such permanently installed meters were not available.

3. 480-V Normal Power System

Main incoming feeder loading was obtained from the permanently installed, indicating-type ammeters; the branch feeder loading measurements were performed with a portable, clamp-on, prong-type ammeter.

4. Emergency Power System

The measurements of the 480-V emergency power feeder and those of some of the individual loads were read with a portable clamp-on type ammeter.

C. Actual Loading of the Systems

1. Total EBR-II Site Electric Load

With the EBR-II generator in operation the following loads in kVA were observed on the 13.8-kV system indicating meters:

TABLE II. Power Consumption--EBR-II

(From Idaho Nuclear Corporation Electricity Bills)

<u>Month</u>	<u>kWH</u>	<u>Maximum Demand kW Max.</u>	<u>Estimated kVA at 0.85 PF</u>	<u>**Monthly Load Factor</u>
Jan. 1968	1,840,000	3800	4500	0.651
Feb. 1968	1,420,000	4000	4700	0.510
Mar. 1968	1,600,000	4000	4700	0.538
Apr. 1968	1,140,000	4000	4700	0.396
May 1968	1,120,000	4400	5200	0.342
June 1968	1,080,000	4200	4900	0.357
July 1968	1,220,000	4400	5200	0.373
Aug. 1968	740,000	4800	5700	0.207
Sept. 1968	2,260,000	4600	5400	0.682
Oct. 1968	1,040,000	4200	4900	0.333
Nov. 1968	920,000	4200	4900	0.304
Dec. 1968	460,000	4000	4700	0.155
Jan. 1969	1,380,000	4600	5400	0.403
*Feb. 1969	1,760,000	4200	4900	0.624

* Typical month with no power generation by EBR-II

** Monthly Load Factor: $LF = \frac{\text{Average Power Demand}}{\text{Maximum Power Demand}} = \frac{\text{kWH}}{\text{Hours} \times \text{kW Max.}}$

EBR-II generator output	17,500 kVA
Power delivered from EBR-II to NRTS network	12,900 kVA
Power used at EBR-II site	4,600 kVA

If there were no power generation by EBR-II, the power to the EBR-II site is supplied by the NRTS 138-kV network by means of two 138-13.8 kV power transformers (rated 12,000/16,000 kVA each) at the EBR-II main substation.

Assuming that the NRTS network has an adequate capacity to supply power to EBR-II site when electric power is not generated by EBR-II, the 13.8-kV system load could be tripled without exceeding its capacity.

2. 2,400-V System Load

The general arrangement of the system, including the power supply transformer ratings, connected loads, and load measurement data are shown in Fig. 1.

Most of the 2,400-V loads are composed of larger EBR-II auxiliary drives, with the exception of feeder #12. Feeder #12 serves as a primary feeder for two 2,400--480-V substations -- each rated 500 kVA. One of these substations serves the Inspection and Test Facility (ITF) and machine shop buildings; the other serves the ZPPR Facility. The 2,400-V bus is fed by two transformers, rated 2,500 kVA each. The total connected 2,400-V load is 4,600 kVA.

On April 17, 1969, the measured total 2,400-V load was 1,860 kVA with the EBR-II reactor and electric power generator in operation. At the time of the measurement the following 2,400-V loads were not in operation:

Well pump No. 1	175 kVA
Well pump No. 2	175 kVA
Boiler feedwater pump	694 kVA

The well pumps never operate simultaneously; one of the pumps is selected to come on the line automatically when a demand for water is initiated. Records show that with the EBR-II facility in operation and the 2,400-V load at its maximum, the well pump operates an average of 4 times for about 1.25 hr every 24 hr. Such intermittent loading does not materially affect the transformer loading and can be tolerated even

when it is added to a fully loaded transformer. The boiler feedwater pump (BFW) is not operated under the normal conditions when the steam-turbine-driven pump is used; however, the electric pump operations would be required if the steam turbine-driven pump were not available. This would add about 620-kVA load (adjusted for an estimated load factor of 0.9); the total 2,400-V load, based on the measured present load, would be $1,860 + 620 = 2,480$ kVA. Thus, if the 2,400-V system were operated with only one 2,500-kVA transformer, at the May 1969 loading conditions it would be fully loaded if the electric BFW pump is used with an intermittent overload by the well pump. Such a loading would not have any significant effect on the reliability of the transformer or on its life expectancy.

When the EBR-II reactor is operated at its full design power rate of 62.5 MW, some of the auxillary drive loads could increase slightly; in such a case, the ZPPR load of approximately 300 kVA could be switched from the 2,400-V primary system to the 13.8-kV primary system by means of the existing ZPPR standby transformer, rated 750 kVA, 13.8 kV-480 V.

No new larger loads should be added to the 2,400-V system if the dual power supply capability is to be maintained under all operating conditions; this includes the operation of the electric motor-driven boiler feedwater pump. Only minor load additions in the ITF and materials handling warehouse area can be tolerated.

If new larger loads must be added to the 2,400-V system, forced-air cooling fans could be installed on the transformers to increase the capacity of the transformers by 25%, or 625 kVA each.

3. 480-V Normal Power System Load

The general arrangement of the system, including the power supply transformer ratings, main and branch feeder arrangement and load measurement data, is shown in Fig. 2. The 480-V bus is fed by two 13.8 kV-480 V transformers, rated 2,000 kVA each.

At the time of the measurement on April 16, 1969, the EBR-II reactor and electric power generator were in operation. The total 480-V normal and emergency load was 1960 kVA; 530 kVA of this load

were delivered to all the loads connected to the emergency bus at the EBR-II site. The ZPPR facility, however, has a separate emergency power system.

Loads as high as 2,300 to 2,500 kVA have been observed on the 480-V meters during the EBR-II reactor shutdowns.

To maintain a dual 480-V power supply feature without exceeding the transformer overload by more than 10% (in case one of the transformers is lost) and to provide a reserve of 300 kVA for future expansion, at least 500 kVA of additional 480-V power is needed now. Should the expansion of the plant create an overload condition again, additional increases in system capacity could be made.

Four methods of achieving these objectives were considered and are discussed below:

- (a) Forced Air Cooling. An addition of fans for the forced-air cooling would increase the capacity of the 2,000-kVA transformers by 15% and thereby increase the normal full-load capacity of the transformers to 2,300 kVA each.

Although such an increase in capacity would be adequate for the present loading, it would not provide reserve capacity for future loadings.

- (b) Power Factor Improvement. On systems with low power-factor loads (P.F. of 0.7 - 0.8) an application of power-factor improvement capacitors can increase the system loading capacity by 15-25%. EBR-II 480-V system maximum load occurs when the reactor is shut down and the resistance-type, primary sodium heaters are used. Under such conditions the power factor is high (over 0.9), and application of the capacitors would not provide the needed significant increase in system load capacity.
- (c) Replacement of Transformers. The existing 2,000-kVA transformers could be replaced with 2,500-kVA rated transformers; the main secondary circuit breakers and main 480-V switchgear bus have 3,000-amp capacity and are adequate to handle the full load of 2,500-kVA transformers.

The other circuit breakers in the 480-V system do not have an adequate short-circuit-interrupting capacity to handle the increased short-circuit current; the necessary modifications to the system that will reduce the short-circuit current to a tolerable level are not economically feasible.

- (d) Additional 480-V Unit Substation. A 13.8 kV-480-V substation could be installed to relieve the overload on the 480-V system and provide a reserve for future expansion. Such a substation would supply power to all the area loads except the reactor plant, power plant, sodium boiler plant, and the proposed HFEF. From a technical consideration, it is a good arrangement; however, cost disadvantage may be increased because the 480-V loads are dispersed over a large area, and long 480-V cable runs would be required from one centrally located unit substation.

Other, less costly, methods of increasing the 480-V system capacity include the following two:

- (1) Initial Transfer of Loads. To provide an adequate power supply, including 300-kVA reserve capacity for future expansion, at least 500 kVA for the 480-V loads would have to be transferred from the existing system to some other power supply source. Those loads, not directly related to EBR-II and its auxiliaries, should be considered first for such a transfer.

A review of the 480-V system loads, shown in Fig. 2, indicates that the laboratory service building load is 334 kVA, and that the FCF load is 510 kVA. Since the transfer of the laboratory and service building load would provide only temporary relief, the transfer of the FCF load should be considered first.

A technically feasible, more economical solution to this problem is to provide a common substation for the proposed HFEF and Fuel Cycle Facility. A double-ended, open tie-breaker type substation with two

transformers rated 1,500 kVA each, and equipped with forced-air cooling is estimated to provide an adequate power supply for the HFEF, FCF, proposed cold line facility, and some other minor loads in this area. The substation should be located somewhere between FCF and HFEF; it could be either an outdoor or indoor type. An indoor type substation would require a 40 x 12 x 10-ft-high building with minimal heating to prevent moisture condensation when the equipment is shut down in cold weather.

- (2) Additional Increase in 480-V Capacity. Should the operating experience indicate that the 480-V reserve capacity, provided by the initial transfer of loads is being depleted or that there is a need for further expansion, the following additional steps in increasing system capacity could be taken:
- (a) adding 300 kVA to the transformer capacity by application of forced-air colling fans, and
 - (b) transferring the laboratory and service building load of 350 kVA to some other source, such as to the existing 750-kVA ZPPR standby transformer.

In accordance with information obtained from Plant Engineering, IBA, the future additions to ZPPR would increase the electric load in this area by 190 kVA. In view of the present ZPPR load of 290 kVA, this future load would load the ZPPR 500-kVA transformer to its full rating; therefore, any additional loads could cause an overload.

An application of forced-air cooling is not considered effective on any transformer smaller than 750 kVA. If the 500-kVA transformer becomes overloaded, it may be feasible to use the existing 750-kVA, 13.8-0.48 ZPPR transformer as a normal ZPPR power source and add another 13.8-0.48-kV transformer to be used as a standby for ZPPR and as a normal power source for the laboratory and service building. Such an arrangement would be advantageous to the 2,400-V system by removing the ZPPR load from it.

4. Emergency Power System Loads

(a) Present Loads. Measured loads of the emergency power system are shown (in kVA) in Figs. 1 and 2.

Table III summarizes the diesel-generator-rated capacities and the measured emergency loads those generators would have to feed in case the normal power is lost.

TABLE III Diesel-Generator-Rated Capacities
and Emergency Loads to be Carried

<u>Unit Rating</u>	<u>Location</u>	<u>Measured Load - kVA</u>
500 kVA (400 kW)	Power plant	332*
125 kVA (100 kW)	Power plant	73*
250 kVA (200 kW)	Fuel Cycle Facility	150
125 kVA (100 kW)	ZPPR	108

*In case the 125-kVA unit fails, its load is fed from the 500-kVA unit.

(b) Future Loads. It is estimated that the following loads to be installed soon will require an emergency power supply:

. HFEF	130 kVA
. Sodium Chemistry Laboratory	10 "
. Cold-Line Facility	15 "
. Industrial Waste Facility	<u>10 "</u>
Total	165 kVA

The three smaller loads could be connected to the existing emergency power systems without overloading them; however, the HFEF requires an additional diesel generator unit of at least 187.5 kVA (150-kW) capacity.

D. Factors to be Considered in Emergency Load Analysis

All the units, with the exception of the 250-kVA FCF unit, are rated for a continuous duty, with 110% diesel engine capacity (adjusted for 5,100-ft altitude) of the required brake hp. The FCF unit generator is rated for a continuous duty; however, the data on the diesel engine, whether it is rated for continuous or standby duty and whether the indicated rating has been adjusted for 5,100 ft altitude, were not available as of April, 1969.

Emergency loads, listed in ANL-7202, report at the full rating of the motors and transformers; however, in actual operation the loads in some cases may be substantially lower. For example, continuous power supply load is listed in Table X, p.77, as 115 hp (or approximately the same number in kVA); however, two measurements, taken with the EBR-II facility in operation and during a shutdown, indicated the highest load to be 43 kVA (during a reactor shutdown). This load would be higher if the 500-kVA diesel could not be started for a prolonged time and the continuous power system standby storage battery would become discharged; on restoration of the ac power input into continuous power rectifier, part of this input would be used to charge the battery and to supply the loads connected to the continuous power system.

The Rotary Bridge Crane, listed in Table XI, p.78 of ANL-7202, has a manually applied emergency load of 67 hp. The original intent of the EBR-II electric system design was to provide a means of lowering the load to floor level in case the normal power failed with the load suspended from the crane. Lowering of the load would not add electric load to the emergency power system. Some power may be required if the load must be positioned; however, even in such a case the load would be of a short duration and only a fraction of the listed full load of 67 hp and should not materially affect the loading of the

generator and diesel engine.

ANL-7202 report (Table XIII, p.79) indicates that approximately 92 kVA of connected emergency loads would be automatically disconnected from the emergency bus in case the normal power failed and the emergency loads were fed from the 500-kVA diesel generator.

IV. SUMMARY OF FINDINGS AND RECOMMENDATIONS

A. 13.8 kV System

The load on EBR-II 13.8-kV electric system could be increased to almost triple its present magnitude, provided the NRTS network can supply such a load.

B. 2,400-V System

The system may be considered fully loaded under some operating conditions; new larger loads could be added by adding forced-air cooling fans to the existing transformers and transferring the ZPPR load either temporarily, when needed, or permanently to the existing standby transformer.

C. 480-V Normal Power System

Based on a dual power supply principle, the 480-V power system is overloaded and the following measures are recommended to alleviate the overload conditions and to provide some reserve power for the future expansion.

- (1) As a first step, the FCF should be disconnected from the existing 480-V system and connected to a common substation provided for both HFEF and FCF.
- (2) If more 480-V capacity is needed after the FCF is disconnected from the EBR-II 480-V power system, the installation of transformer cooling fans and transfer of the laboratory and service building to

the ZPPR standby transformer should be considered.

D. Emergency Power System

The field measurements and the test reports indicate that the 500-kVA and 125-kVA units located in the power plant have some reserve capacity for the addition of some smaller future loads or a selective manual application of some of the existing EBR-II loads.

The FCF 250 kVA has about 100-kVA reserve capacity.

The present design data indicate that the proposed HFEF will require an emergency diesel generator capacity of at least 187.5 kVA (150 kW).

It is suggested that a thorough review of the emergency loads be performed; the operating experience and changes in operating conditions may permit a transfer of some of the emergency loads to the normal power supply or indicate a need to transfer some of the other loads to the emergency power supply.

E. Improvement in Metering

It has become apparent that the lack of reliable records on systems loading over a longer period of time has been a considerable handicap in determining of the existing conditions and providing information for future planning.

The more important feeders, such as 2,400-V and 480-V main feeders and principal emergency power feeders, should be provided either with the maximum demand meters, recording kW meters, or recording ammeters.