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Magnet Power System for the Microwave Tokamak Experiment (MTX)

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MAGNET POWER SYSTEM FOR THE MICROWAVE TOKAMAK EXPERIMENT (MTX)*

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Abstract

The system configuration, layout, and general philosophy for the MTX magnet power system is described. The vast majority of the magnet power equipment was quite successfully used on the ALCATOR-C experiment at the Massachusetts Institute of Technology. The AC power for the magnet system at MIT was obtained from a 225MVA alternator. The power for the system at LLNL is obtained directly from the local utility's 230 kV line. This installation, therefore, necessitates the addition of a great deal of equipment in the AC distribution network. The added equipment ranges from new switchgear in the substation to using existing switchgear obtained from MIT as contactors for intershot electrical isolation as well as safety isolation for personnel entry into the experimental area. Additionally, some discussion is made of the unique layout of this facility and the tradeoffs made to accommodate them.

The MTX experiment will comprise a tokamak (formerly ALCATOR-C) which has been relocated to Livermore from MIT [1] and a new source of microwave heating that will be generated by free electron laser (FEL) technology [2]. The project is designed to make maximum use of existing systems and equipment.

The magnet power one-line of Figure 1 shows the system from the 230 kV utility feed down to the MTX magnet coils. Seven power supplies (four toroidal field, two ohmic heating, and one equilibrium field) are among the equipment relocated to Livermore, and each of these requires a new 13.8 kV power feeder. The horizontal field coil will be powered by four existing power supplies that have existing feeders. The power supply ratings are shown in Figure 1.

The main thrust of this paper will be a description of the systems employed to feed the 13.8 kV power to the magnet supplies obtained from MIT and to describe some of the changes necessitated by the differences in these two feeder sources.

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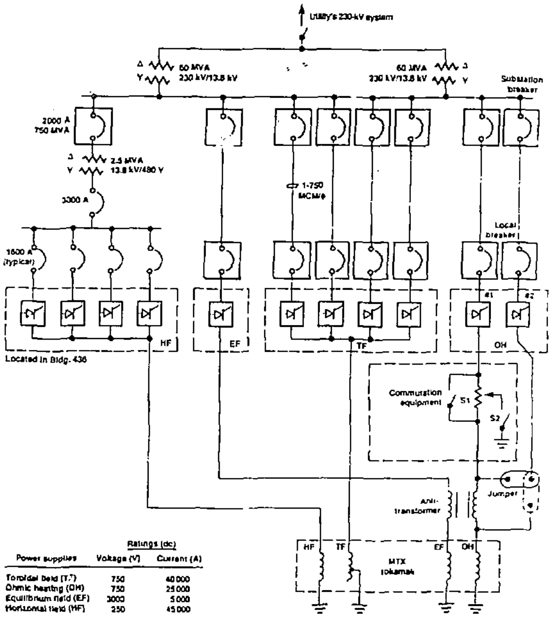

Power supplies	Ratings (dc) Voltage (V)	Current (A)
Toroidal field (TF)	750	40 000
Ohmic heating (OH)	750	25 000
Equilibrium field (EF)	3000	5 000
Horizontal field (HF)	250	45 000

Figure 1. MTX Power System One-Line

Design work for the 13.8 kV system is complete and installation is well underway by three subcontractors. The design for the DC feeders is partially complete and some installation has begun The entire magnet power system is scheduled to be operable in April 1988.

MTX New 13.8 kV Power Feeders

The two 60 MVA transformers feeding the magnet supplies were originally installed for supplying power to the twenty-four neutral beams for the Magnetic Fusion Test Facility (MFTF). The system was designed to pulse to 250 MVA or a little more than twice the ratings of the transformers. Since MFTF is not presently running, MTX is free to use the pulse power substation. Therefore, four breakers that were used to feed the neutral beams were disconnected with their feeders neatly stowed for future reactivation. This does not present a problem since only one experiment can operate at a time for power and personnel reasons. These four existing breakers and three new breakers can be seen in Figure 2.

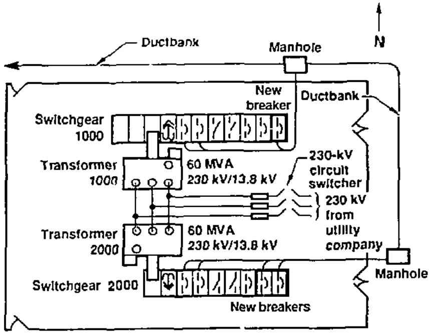

Figure 2. MTX Pulse Power Substation

The power is carried from the substation via an underground ductbank system to building 433 shown in Figure 3. At building 433 advantage was taken of an existing pipe rack structure to reach the experiment located in building 431. This was done to avoid extensive underground utilities around building 431, which is one of the oldest buildings on the site. These utilities made it very difficult to cross this area with a major ductbank. In addition, we included throughout the design provision for an eighth feeder, OH3, if it should ever be required to produce increased ohmic heating. Further, extra ducts were included in the underground, and provisions were made in the overhead so that we can add up to four more similar sized circuits in the future.

The final selection of the detailed routing of the overhead tray and the design and analysis required for the modification of existing structures to accommodate the added wind and earthquake loads turned out to be an extensive design problem and consumed a substantial part of the total design effort for the 13.8 kV feeders. Construction drawings for the 13.8 kV feeder system, including detailed design of the required switchgear modifications, the duct and tray system, and the final ampacity deratings and cable heating calculations were prepared for us by SAI Engineers Inc. of Santa Clara, California.

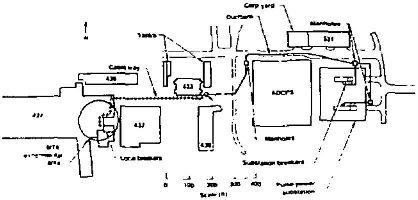

Figure 3. AC Feeder Layout

Our duct and tray configurations as finally designed, do not match those provided in IEEE and NEC publications. Consequently, final ampacities and temperature rises for these circuits were computed using a computer model. Special thermal allowances were added for overhead cable located in tray routed across a building roof and receiving reflected heat from the roof. The design basis load for this cable heating is a 3000 ampere AC pulse in each circuit for three seconds with a repetition rate of once every five minutes. From this analysis, the conductor temperature is expected to rise exponentially approximately 5°C during the actual shot and then decay slowly until the next shot. We have calculated the average temperature value reached to be 80°C with a peak of approximately 83°C during a shot. These temperatures are based upon the hottest days at Livermore and a continuation of shots, once per five minutes, until maximum temperature equilibrium is reached and the cable impedance losses exactly equal heat dissipation. The true load expected for each circuit is less than the design basis load, giving us a margin usable for future contingencies.

The cable installed in the underground ducts will be one 750 MCM, 15 kV cross-linked polyethylene cable per phase. In the overhead tray a three conductor triplexed, armor jacketed, 750 MCM, 15 kV, crossed-linked polyethylene cable is used for each circuit. This was used in the overhead tray for ease of installation, better weather and mechanical strength, and reduced interconductor forces.

The tray and underground duct systems will be completed in October 1987 and the cable installation will begin immediately thereafter.

Local Safety Disconnects

The nature of the SCR power supplies used with MTX and the LLNL safety policy require that the AC feed be positively killed between shots to assure safety during intershot inspections and adjustments by operational personnel. This was accomplished at ALCATOR-C by killing the generator field between physics shots. At MTX we are connected to a utility supply and the supply circuit must be opened by a breaker or switch. The substation switchgear breakers supplying each new 13.8 kV circuit are not suitable for use as safety disconnects for the power supplies. First, they are too remote, approximately 1500 feet away. Second, they are standard air-break breakers and are not designed for frequent operation - certainly not for the one shot per five minute duty cycle. Since these breakers provide the overload and short circuit protection for the feeders and the power supply transformers, breaker mechanical failure could be catastrophic. Therefore, we will not use our substation switchgear as our means of safety disconnect; these breakers will be intentionally opened only for longer shutdowns and/or on failure of the equipment used as the safety disconnect.

For safety disconnects, we are adapting switchgear received with the tokamak from MIT and mounting this switchgear local to MTX. We are disabling the 50/51 relays (overcurrent and short circuit) and will open and close these breakers on command from the control room. Because these are conventional 15 kV circuit breakers designed for limited operational cycles, we expect a severe maintenance problem due to the frequency of operation and the mechanical impacts during opening and closing. To accommodate the wear and tear, we will have spare breakers standing by and will implement a preventative maintenance schedule that is intended to eliminate failure during service. Realistically, we do expect some failures during service and we have included special breaker failure detection in our relays and controls. Upon failure, the appropriate substation breakers will be tripped automatically. This is more fully described in a later section.

Power Supply Arrangement

The power supply layout is based upon the size, configuration, weights, allowable distances from the tokamak, and existing available space. Because the floor space was limited near the tokamak, a two-level platform was built out over the twenty-two foot deep MFTF vault to hold auxiliary equipment. This platform and the power supply layout can be seen in Figure 4. To reduce costs, the platform was designed only to hold small pieces of equipment and not the 13 ton ohmic heating and equilibrium supplies. Therefore, the ohmic heating supplies shown in this area are positioned such that the rectifier transformer end of the supplies are supported by the existing concrete floor and the lighter rectifier end is cantilevered onto the platform. The equilibrium supply is located at the bottom of the vault on a solid concrete foundation.

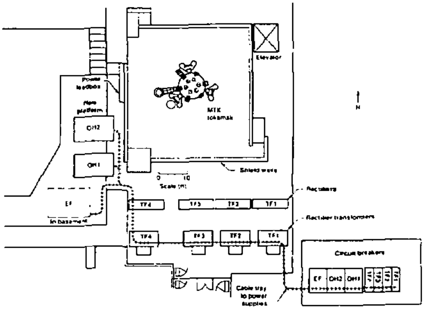

Figure 4. Power Supply Layout

The ratings of each of the supplies can be seen on Figure 1. Each toroidal field (TF) unit has its transformer and rectifier mounted separately as shown. These are connected by an aluminum bus and stainless steel resistor system, rated at 750 V and 40,000 amperes. The four TF outputs are paralleled in a water cooled copper bus system which in turn feeds an aluminum bus system that feeds through the south shield wall to the tokamak. We have arranged the equipment to make maximum use of the existing buswork. Each ohmic heating (OH) and equilibrium field (EF) supply contains a transformer and recitfier within a single cabinet. The OH DC outputs will be fed by aluminum buses through a power feedbox located on the west shield wall. These buses will be new to match the new commutation system we are designing as well as the physical arrangement dictated by the building. The outputs of the four horizontal field (HF) supplies will be connected in series and fed to the tokamak in cable conductors routed via the power feedbox.

At this writing, the power supply cabinets have been mounted at MTX, and a substantial amount of buswork is in place. Work is underway on the HF cable trays and the design of the new OH buses. The documentation of the relocated power supplies is essentially complete and the reconnection of power supply controls within and between cabinets has begun.

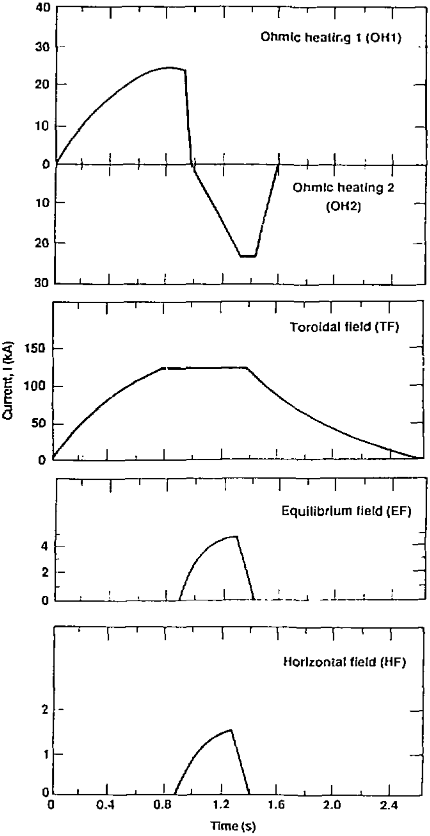

Figure 5. MTX Magnet Currents

Commutation and Anti-transformer Systems

As can be seen from the last section, the DC portions of our design are still underway. This section is included to complete the description of the operation from the utility all the way to the magnet coils and to show our thoughts to this point. The commutation system as described here is used to control the current, or more specifically the dI/dt, in the OH winding. This in turn controls the dV/dt on the tokamak for plasma breakdown and the subsequent plasma current. Figure 5 shows a typical curve for the OH current plus the current for the other magnets. In a simplified form using the notation of Figure 1, the OH coil is charged, using supply OH1, with S1 closed and S2 open. When the coil is charged to the specified current, S1 is opened generating the large dV/dt to create the plasma. Then the decay is controlled by switching out part of the resistance by closing S2. When zero current is achieved, supply OH2 is switched on to continue to drive the current in the negative direction as shown in Figure 5. The mechanics of the system are much more complicated than described here and will be described fully at a later date.

The platform was arranged so that the commutation equipment can be located on the second level. The output of power supply OH1 will go through the floor of the platform to the commutation equipment and then to the power feedbox where the connections to the anti-transformer and the tokamak are made.

The anti-transformer is used to decouple the OH and EF which are strongly coupled in the tokamak. This close coupling causes problems when the OH circuit is commutated. This rapid dI/dt causes a large voltage to appear on the EF coil. To avoid this, the research personnel at MIT devised a method of winding a transformer with the opposite coupling to cancel out this effect and they called it the anti-transformer.

13.8 kV Relaying, Controls and Interlocks

The relaying, control, and interlocks used with the 13.8 kV system are designed to provide central shot control from the control room and to provide, in conjunction with the sequence controller and the personnel access control system, a system that is safe for all personnel. A simplified function diagram is shown in Figure 6.

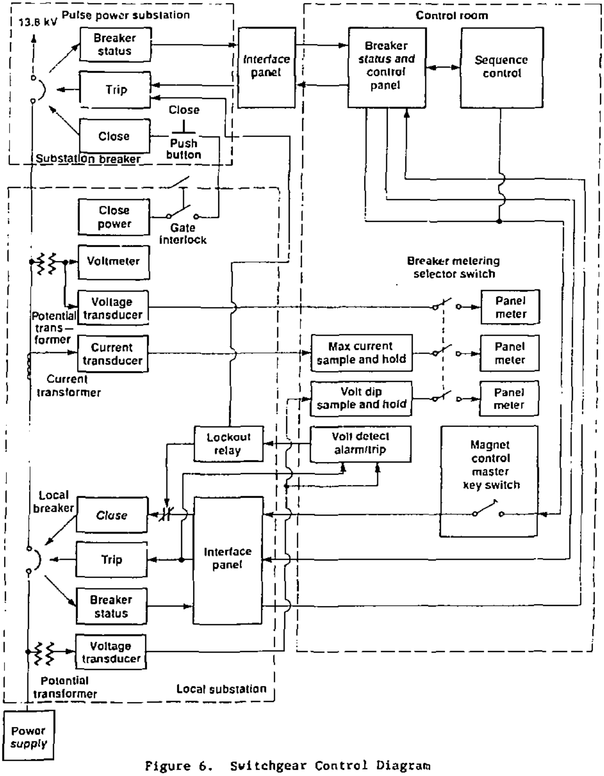

Figure 6. Switchgear Control Diagram

During normal operations, the substation breakers will remain closed and the local breakers (safety disconnects) will be closed by the shot sequence controller just prior to a shot and opened following shot completion. In addition, there is a provision for manual trip and close of the local breakers from the control room. Status of all breakers is provided in the control room. The functions of trip, close, and status are connected through an intermediate interface panel as shown in Figure 6. This panel is used to assure that only 24 VDC control signals enter the control room. The breakers themselves operate on a 125 VDC battery system and therefore the circuits must pass through interposing relays.

The immediate opening of each local breaker is essential for the safety of personnel and equipment. As described earlier, we determined the need for a breaker failure protection system. Voltage detection alarm/trip units that receive a signal from a voltage transducer in the local switchgear are used for this purpose. Following a trip signal to the local breaker, if the detector continues to read a voltage above a set value (0.5% of normal) the alarm contact is closed tripping a lockout relay which will lockout the close function of the local breaker and will trip the substation breaker. We believe, that no matter how well the local breakers are maintained, they still might fail to open due to a minor part that cannot take the repetitive mechanical operations. This detection scheme has the unique feature that it does not rely on a breaker auxiliary contact or other part that also might fail but uses the actual voltage as the controlling factor.

The voltage transducer used for breaker failure protection also is used to monitor the voltage dip of the circuit during a magnet shot. A sample and hold circuit holds this value for each of the seven power supplies fed from the 13.8 kV system. A seven position switch can then be turned to the supply under investigation and this value read out on a digital voltmeter. The maximum current in each circuit is also held by a sample and hold circuit and switched with the same switch. Lastly, the actual voltage on the line side of the local breaker is brought to the control room and switched through this switch to confirm the status of the substation breaker and the voltage available for the shot.

A key switch is used as a main power supply interlock. If the key is not in the control room panel in the "on" state all local breakers are tripped through the sequence controller and the close circuits are disabled so that no power supply can be run. The key also is the door access key to the power supply area and the local switchgear pad. This means that if a person opens a door to the power supply area or local switchgear pad and keeps the key with him then no one can energize the system.

There is an interlock on the gate to the local switchgear pad. This interlock disables the closing circuit on the pulse power substation breaker. This is not intended to replace grounding the load side of the substation breaker while performing maintenance at the local switchgear, but only as a check so that no one can close the breaker in the substation and surprise a person who is inspecting the area or removing a breaker. Otherwise, the remote controls for the substation breakers are similar to the local breakers with the exception that these breakers cannot be closed remotely. They must be closed locally so that if they trip the operator is required to make an inspection and determine the reason before reclosing the breaker.

Acknowledgments

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