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Proposed TFTR Electrical System

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G. Bronner
J. Murray

Abstract

The development of controlled thermonuclear fusion has progressed to the stage where the present facilities and energy available for future devices are not sufficient and must be increased by about a factor of ten.

This report describes the proposed TFTR AC utility power distribution system, an energy storage motor generator flywheel facility, and the rectifier conversion equipment for the Toroidal Field Confining System (TF), Ohmic Heating System (OH), Equilibrium Field System (EF) and the Neutral Beam Heating System (NB).

The general requirements are described and the special design considerations identified.

AC Power Distribution System

The pulse rate and energy require approximately 20 MVA average input to the experimental device for the 4 major loads. Thus, a transformer with a rating of 30/40/50 MVA was selected for connection to the PPPL existing 138 KV power system. A major consideration was to connect up to the existing system so that PPPL has only one billing meter. This connection also takes advantage of the deversity in load and hence, lower demand charges. The transformer will have two secondary windings with mutual impedances arranged so that the loading and unloading on the 13.8 KV pulsed lines will not produce voltage fluctuations on the 4.16 KV or 13.8 KV general building loads. (Fig 1)

Motor Generator Flywheel Sets

Providing the 4500 megajoules of pulsed energy to the loads once every 300 seconds requires approximately 32,000 HP motors and 950 KVA generators. To provide for the contingency of allowing operation (at low pulses) when there is a repair or shut down of an MG set and to keep the cost to a minimum, it was determined that two identical

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The large number of pulses which will occur in the 25 years' life (approximately 2 million pulses) will require that the fatigue failure be carefully considered.

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The drive-motors will each be approximately 16,000 horse-power wound-rotor motors with normal variable rotor resistors for starting. To control the pulsing every 300 seconds, cycloconvertors will be employed. These will provide control over the loading on the AC distribution system, keeping the pulse magnitute to a value equal to or less than the steady state rating of the motors. The cycloconvertor will also have the advantage over the variable resistor in that it will not result in high rotor circuit power loses and will provide for higher pulsed power capability on the AC power system when the TFTR Tokamak facility is not pulsing.

The generator must provide the pulse loads, as shown on Fig 2, with a peak of 475 MVA per generator. The steady state rating will be left to the recommendation of the machine designers. It is expected that the steady state rating will be lower than the peak pulse rating by a factor of about 3.

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Toroidal Field Rectifiers

The rectifiers for supplying the 6000 volts 73,200 amperes DC current to the Toroidal Field are shown on Fig. 4. They will be

12-pulse phase-controlled units. Because of the high inductive load and its experimental nature, the rectifiers will be subjected to a high probability of faults. The units must, therefore, be designed to not only handle normal fault conditions, but also the energy stored in the load coils. The prime protection for load faults will be provided by fault suppression techniques, where the thyristors shall be designed to withstand fault currents and turn off the rectifiers under load faults. The AC breaker between the generator and the rectifier will provide protection for a fault in the transformer or rectifier itself and be only a back up on a DC circuit fault.

The generators suppling the rectifiers will have relatively high inductance. Thus, there will be large variations of voltage at the AC input terminals of the rectifier. The rectifiers will not only be subject to the no-load to full-load regulation, but the pulsed generators will have overexcited fields. (So, in the cases where the generator voltages will be abnormally high.) The 13.8 KV voltage will go to the saturation voltage of the generator without resulting in a voltage breaking down the thyristors.

The high source impedance has the advantage that the fault currents will be low and thus, the coil and lead support mechanical requirements will be low. In addition, the volume and costs of thyristors needed to provide fault protection will be low.

The TF coils will need a forcing voltage to reach full current in the prescribed rise time, yet only need the IR drop during the flat top experimental time. The rectifiers will be phased back to provide the lower voltage, but this is accomplished only by producing a lower power factor. When the voltage required drops below the module voltage 4 series modules of 25%, one module will be allowed to free-wheel and only pass current but not provide input power or voltage. In this way the generator will operate at a higher power factor and it will be able to supply the 25% extra to other loads, such as the neutral beam system.

Ohmic Heating Rectifier

The OH system, consisting of a 12-pulsed 1.5 KV, 40 KA rectifier, provides the power for the plasma current and is also fed from the generators (ref. Fig. 5). It is envisaged to have the same features as described above for TF rectifier, except that the "free wheeling" may not be employed, but it will

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To provide for the 150 to 300 volts around the major diameter of the TFTR Tokamak, required to start the build up of plasma current, the OH coil current is interrupted and the current commutated into a capacitor-resistor circuit which controls the maximum coil di/dt (maximum induced voltage) as well as the rise of plasma current.

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This interruption of current requires a 31 to 62 KV, 34 KA DC. This voltage is produced by interrupting the current in the primary of the OH coil by high voltage DC breakers which are not available as a production item.

The current in the coil is allowed to swing in the negative direction after it is interrupted by the breakers. Then the rectifier output leads must be reversed and the rectifier power again used to control the coil current. It is contemplated that ignitrons and/or mechanical switches will be utilized to reverse the rectifier leads.

After the reversal, the rectifier voltage may be varied, as desired, to provide the plasma control for the experimental time (one second maximum at full current and longer periods at lower currents).

Filters that may be connected in the circuit will be needed to provide the reduction of ripple, particularly when operated and disconnected when fast response is required of the system.

3

Both a positive and a negative conducting crowbar or shorting switch will be required across the load coil to be operated when plasma instabilities occur and prevent the dissipation of plasma energy into the vacuum tube wall. By shorting the OH coil, the energy can be dissipated in the OH coil circuit instead of the vacuum chamber. It is noted that this requirement will result in frequent short circuits applied to the OH rectifier.

If the plasma current fails to build up because the breakdown oscillator is not effective, then the OH coil energy will dump into the commutating capacitors and could result in an over voltage of the capacitors. To prevent damage to the capacitors an over voltage protective crowbar will be required.

The rectifier bridge shall be protected such that AC and load transients, as well as plasma transients, will not result in thyristor damage.

EF Rectifier Circuit

The EF rectifier will be a 12-pulse thyristor-controlled rectifier rated 3.KV and 80 KA (Fig.6). This unit will supply the necessary vertical field required to keep the plasma current loop, or ring, in the center of the vacuum tube. As the plasma current changes, the loop stress changes and

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The EF rectifier will have the same requirements as explained in the OH section above, except it will not have interrupting and reversing switches.

There will be bias, or correction fields, required to assure that the initial plasma current occurs at the desired location within the vacuum chamber. There may be separate supplies for both vertical and horizontal fields, but the SF system may be utilized to provide the vertical bias.

To provide plasma compression, where the major diameter of the plasmas loop is decreased, the EF field is increased by adding a pulsed current into the EF coils. This is supplied by switching in a 7.5 megajoule capacitor bank in series with the EF rectifier.

As previously noted, the rectifier must be designed for repeated crowbars or shorts with fault suppression protection and it must be self-protected against damage due to any transient voltage, including positive and negative plasma induced voltages.

Neutral Beam Supply

This system is the one which has the greatest number of unknowns. At the present time the design calls for 4 diode rectifier units feeding 12 sources, with a maximum voltage of 120 KV and supplying 90 amperes for each source. It is envisioned that each source will be supplied through 120 KV series modulators to provide the voltage regulation at ± 1%. Consideration is also being given to provide phase-controlled ignitron rectifiers with crowbars as the primary protective feature, and shunt regulators.

In addition to these 12 sources on the TFTR Tokamak, there will be a neutral beam test unit that must be independently supplied.

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The sources will all need conditioning, or rapid pulsing, before being used as injectors into TFTR and, hence, they shall be operable either from the MG sets or directly off the 60 Hz AC distribution system, independent of the other 3 major loads on the generator.

The regulation on fault protection for this equipment has not been clearly established. If the modulator tube is developed to provide primary protection for the load (neutral beam injectors), then crowbars will provide the back up protection for the load the major diameter of the plasmas loop is decreased, the EF field is increased by adding a pulsed current into the EF coils. This is supplied by switching in a 7.5 megajoule capacitor bank in series with the EF rectifier.

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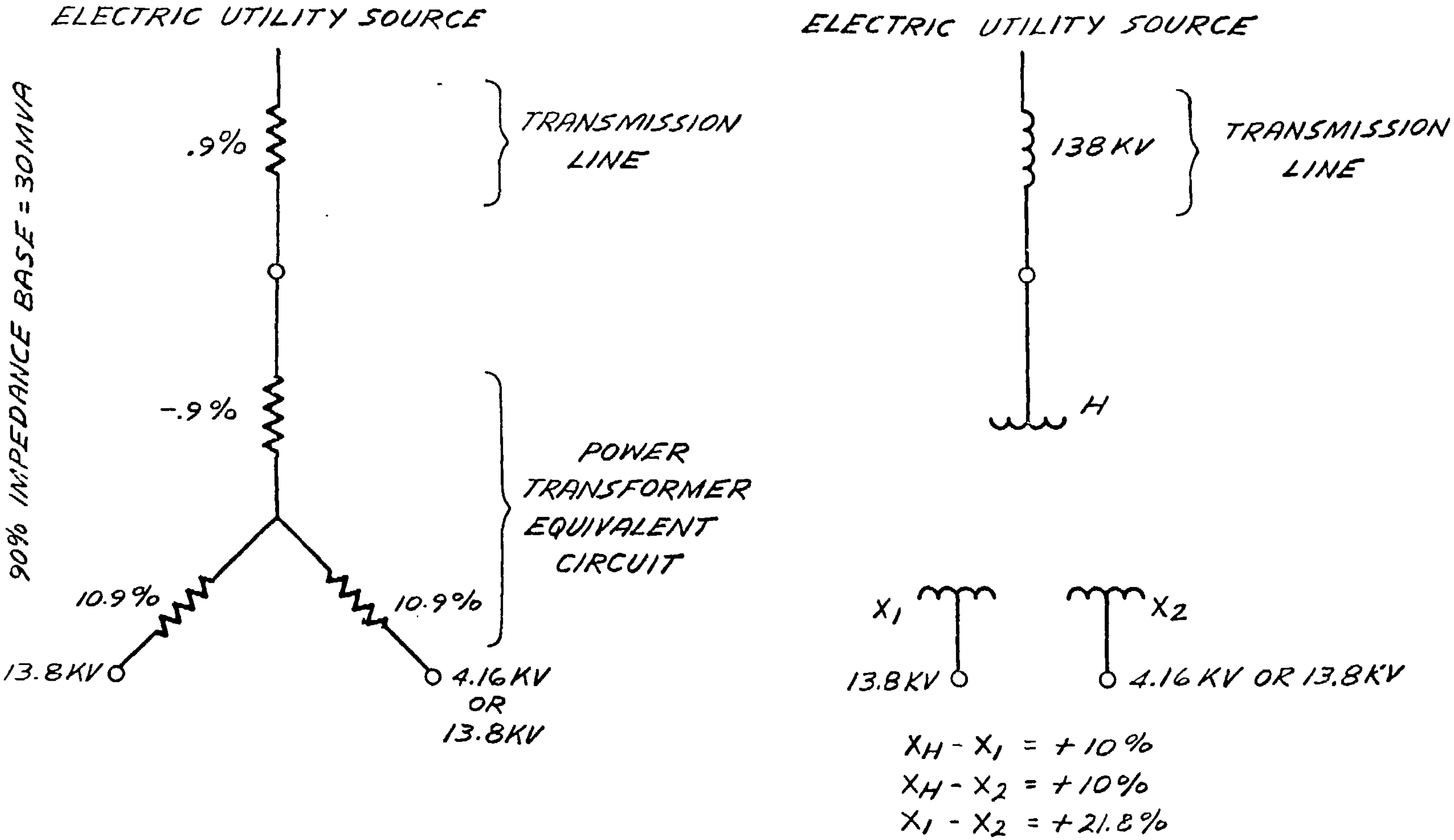
2

If phase-controlled rectifiers are not employed, then high speed interrupters (breakers) will be necessary.

CAPTIONS:

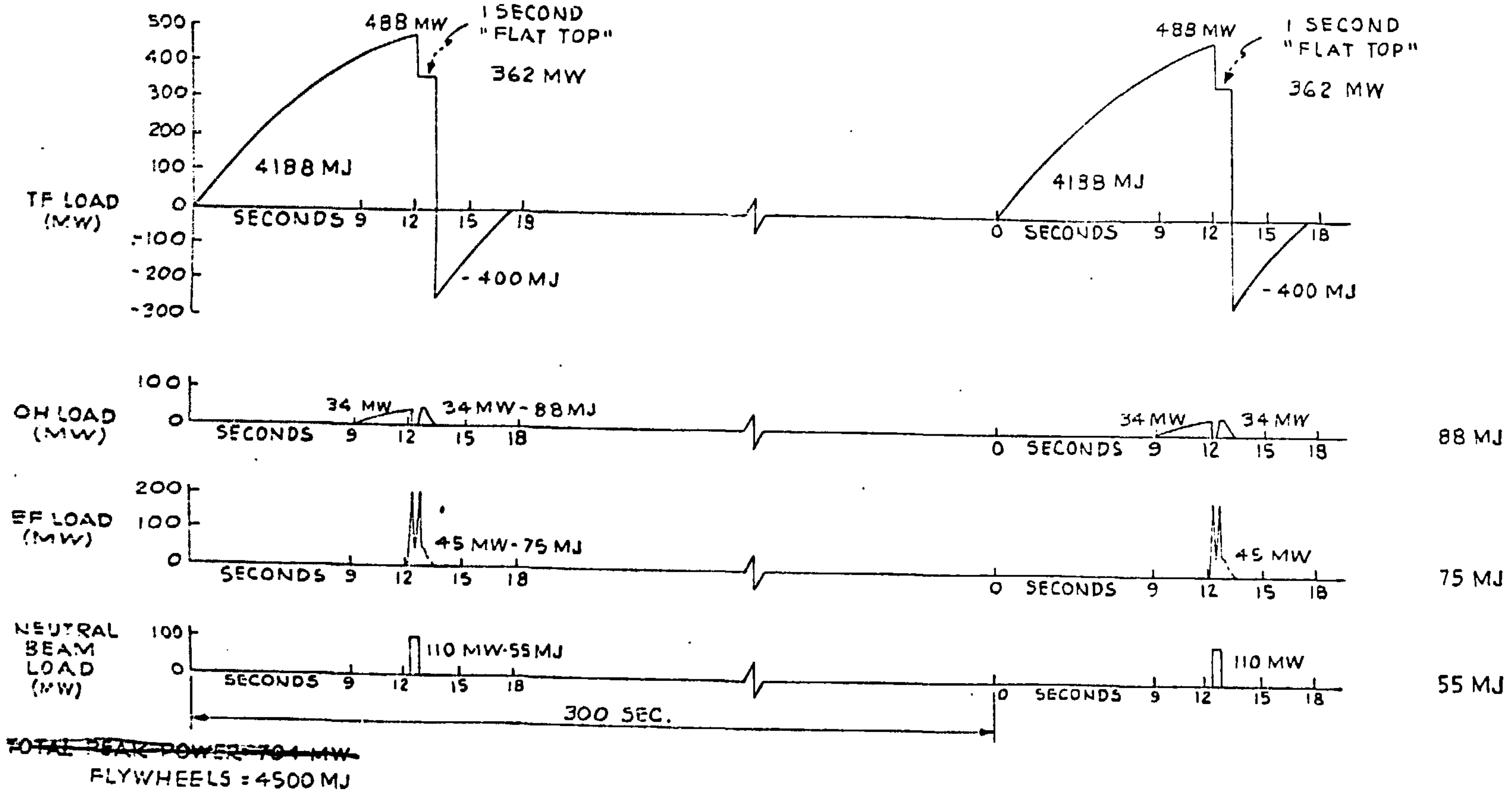
Fig. 1	Impedance Diagram
Fig. 2	Load Diagram
Fig. 3	Harmonic Content
Fig. 4	Symbolic TF Rectifier
Fig. 5	Symbolic OH Circuit
Fig. 6	Symbolic EF Circuit



EQUIVALENT WYE REACTANCE
FOR 3 WINDING TRANSFORMER

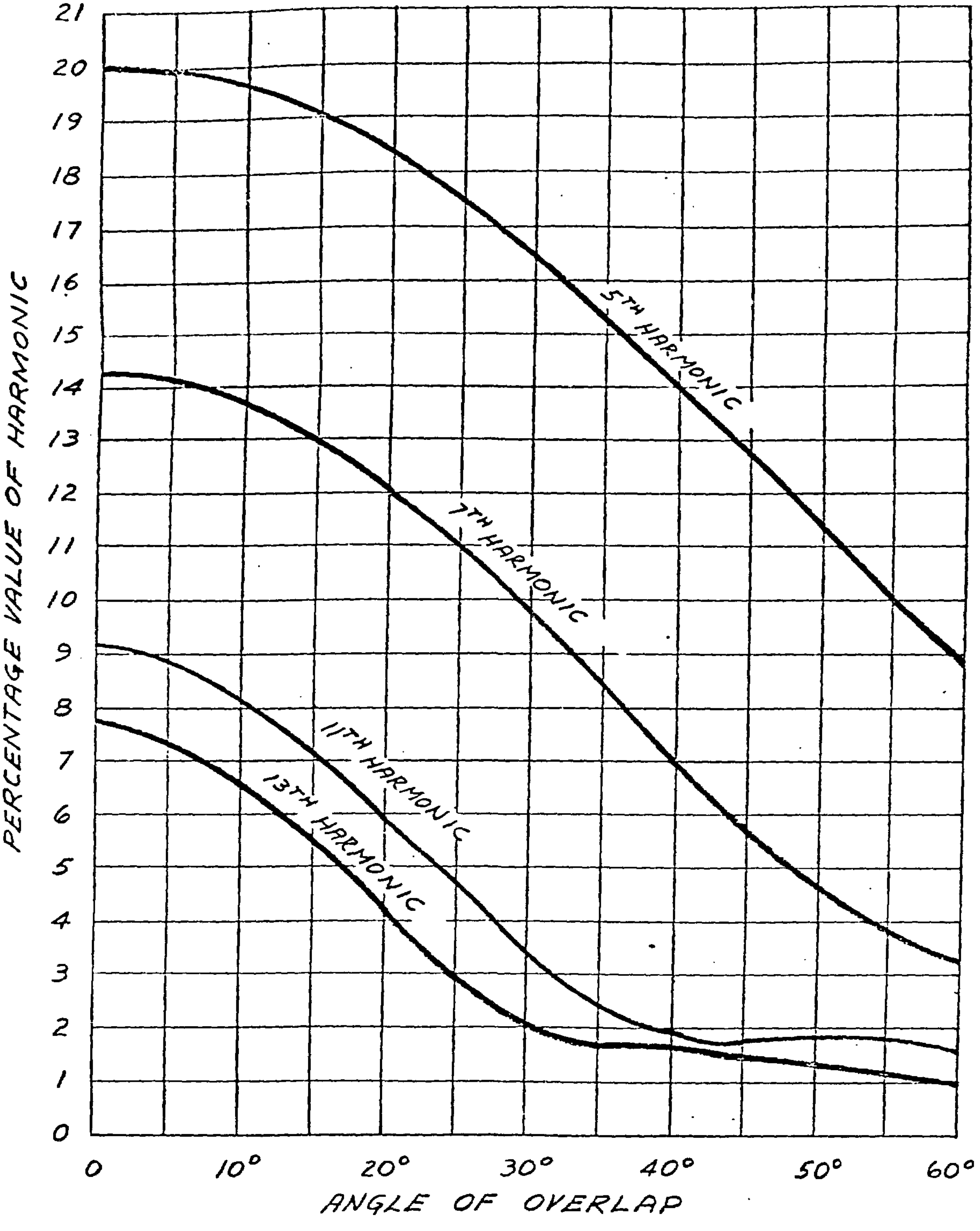
REACTANCE
FOR 3 WINDING TRANSFORMER

FIG. 1



TF LOAD (MW)
500
400
300
200
100
0
-100
-200
-300
488 MW
1 SECOND "FLAT TOP"
362 MW
4188 MJ
SECONDS
0
9
12
15
18
-400 MJ
OH LOAD (MW)
100
0
34 MW
34 MW - 88 MJ
34 MW
88 MJ
EF LOAD (MW)
200
100
0
45 MW - 75 MJ
45 MW
75 MJ
NEUTRAL BEAM LOAD (MW)
100
0
110 MW-55 MJ
110 MW
55 MJ
300 SEC.
~~TOTAL PEAK POWER = 704 MW~~
FLYWHEELS = 4500 MJ

FIG 2



21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
PERCENTAGE VALUE OF HARMONIC
5TH HARMONIC
7TH HARMONIC
11TH HARMONIC
13TH HARMONIC
0
10°
20°
30°
40°
50°
60°
ANGLE OF OVERLAP

FIG. 3

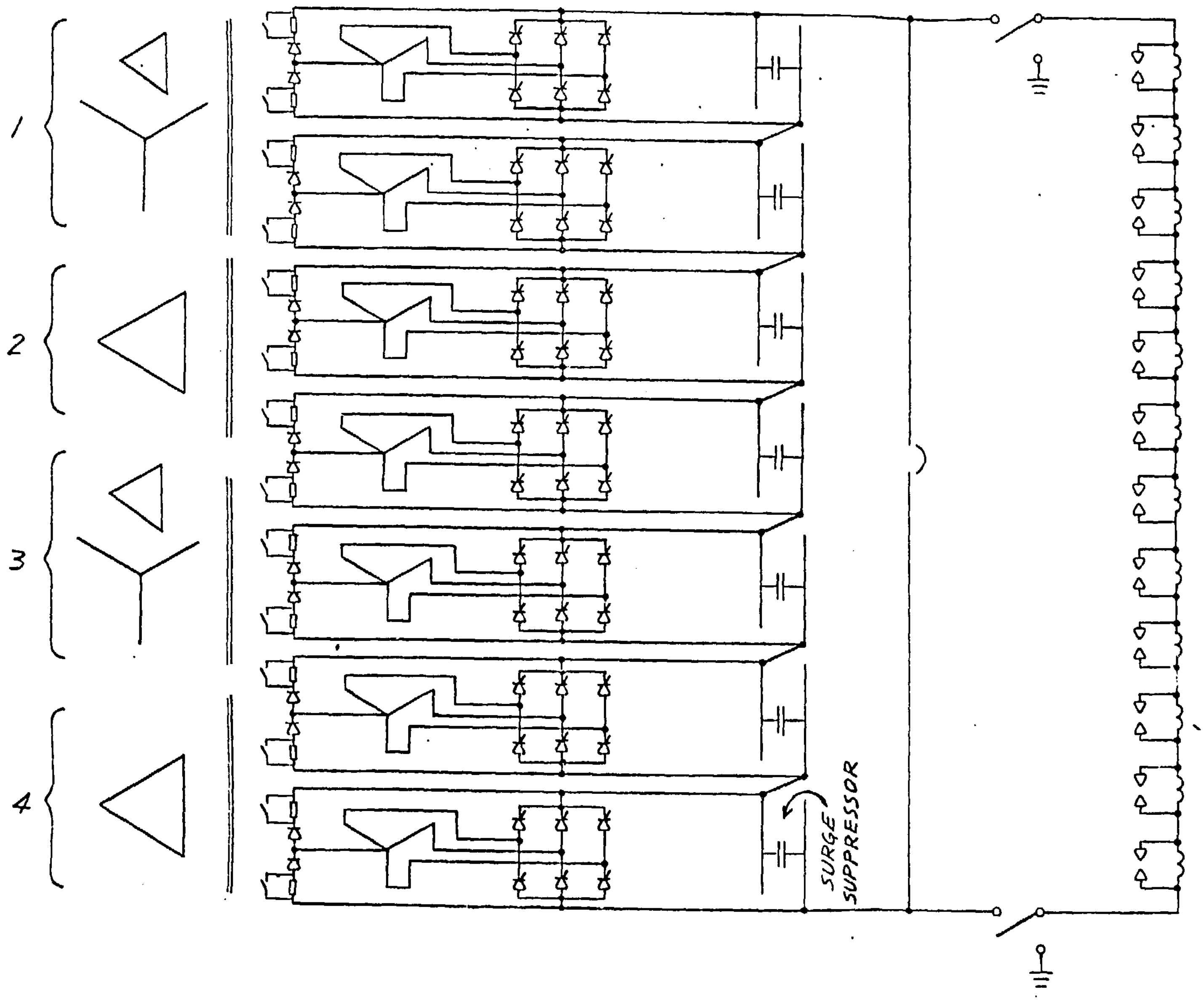


FIG. 4

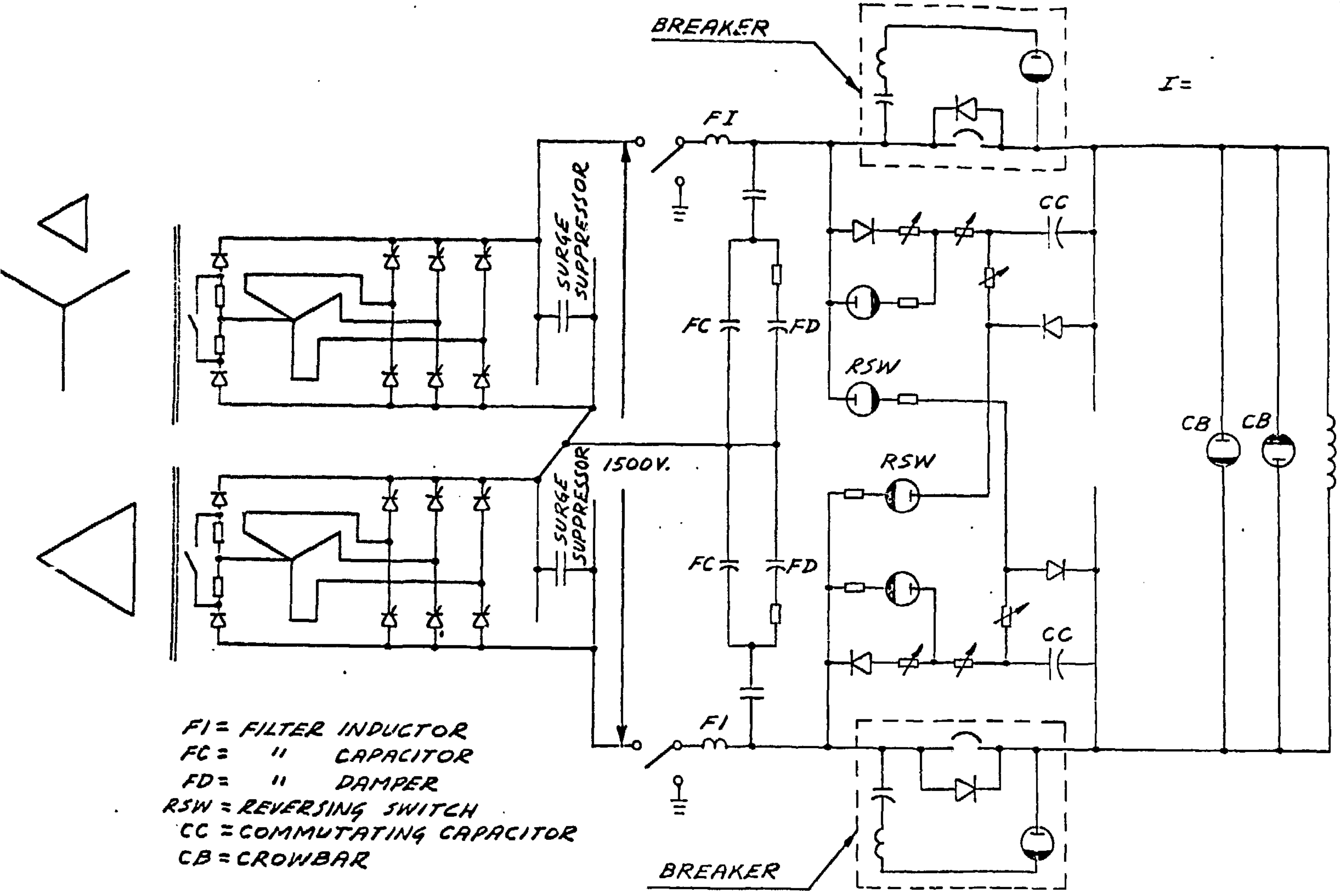
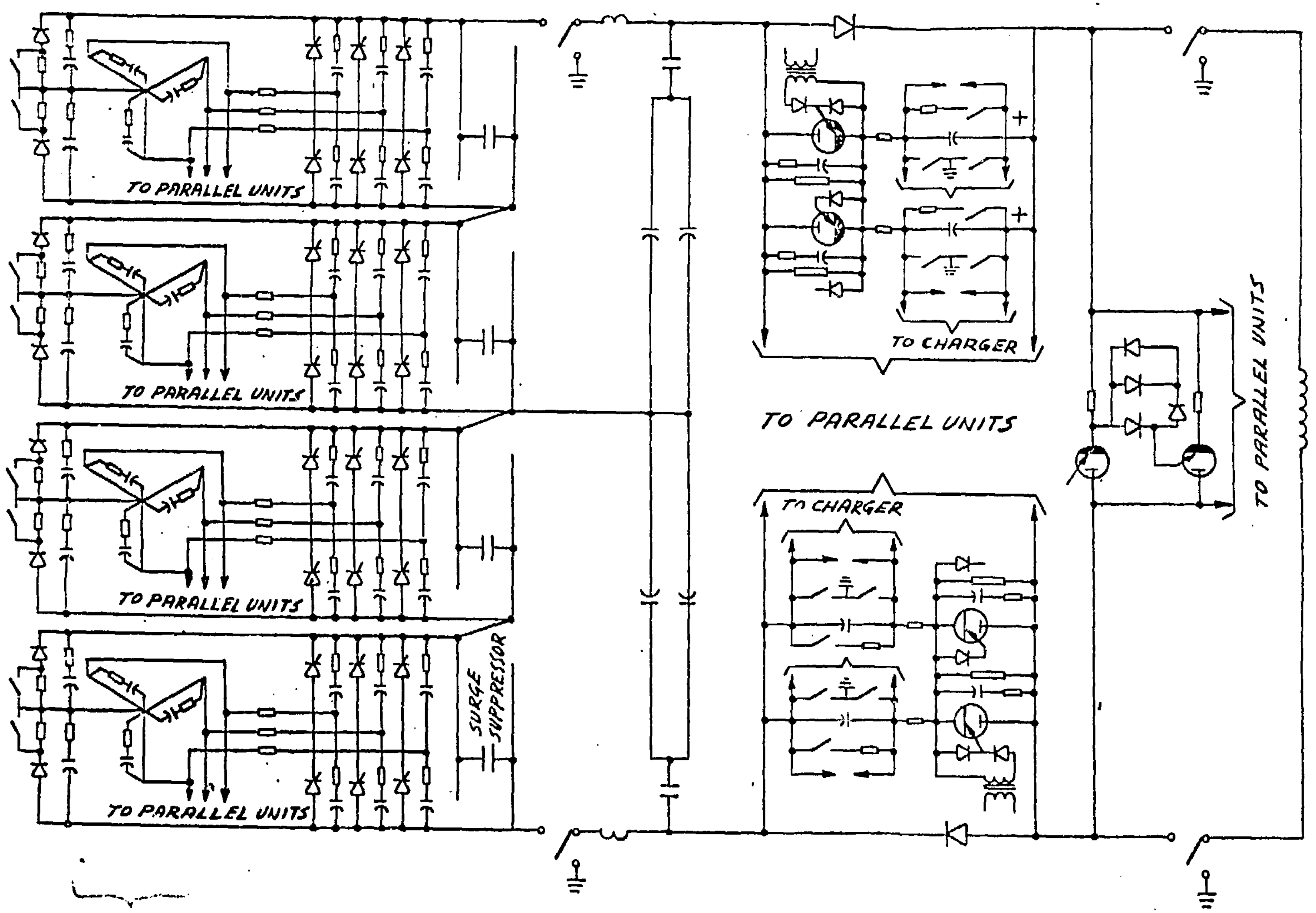

BREAKER
I=
FI
SURGE SUPPRESSOR
FC
FD
CC
RSW
RSW
CB
CB
1500V.
SURGE SUPPRESSOR
FC
FD
CC
FI
FI= FILTER INDUCTOR
FC= " CAPACITOR
FD= " DAMPER
RSW = REVERSING SWITCH
CC = COMMUTATING CAPACITOR
CB = CROWBAR
BREAKER

FIG. 5



TRANSL, SECTION

E.F CIRCUIT

FIG 6