Study of the Distribution System for the ITER Power Supplies Scheme

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ABSTRACT

The study analyses the distribution system for the ITER pulsed loads including HV switchyard, stepdown transformers, Intermediate Voltage (IV) switchyard, rectifier transformers and DC busbars. A comparative investigation amongst four different options for the IV system was carried out. Reactive power compensation and filtering requirements were defined in relation to the admissable voltage drops and distortion. A tentative layout for the complete system was also defined

INTRODUCTION

The pulsed loads of ITER (International Thermonuclear Experimental Reactor) will require an extensive power supply system capable of responding, during an ITER pulse lasting 2000 seconds, to a demand of active power varying from about -800MW to +400MW while the reactive power, in the absence of any compensation, can reach a peak value of approximately 800 MVAR (Fig. 1).

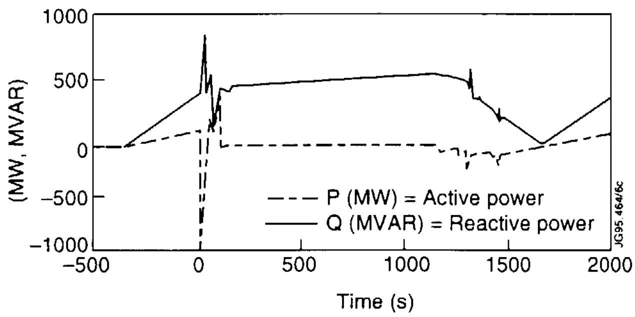

Fig. 1: Active and reactive power loading of the ITER pulsed loads

The experience gained in other large experiments [1] suggests that the supply of loads directly from the grid is, wherever the site conditions make it possible, the most convenient and cost effective solution. Ad hoc studies for the ITER case [2] show that the load can indeed be supplied in various European locations. The ITER pulsed loads are: seven superconductive poloidal field (PF) coils (P1 to P7), the set of twenty-four superconductive toroidal field (TF) coils and the additional heating (AH) loads. The total installed converter power is 3600 MVA [3]. The study (ITER Design Task 94/D51) was aimed at: identifying the schemes for the ITER pulsed supplies distribution system; defining the ratings of the main components and providing costs and delivery times.

The study was carried out taking into account the ITER design status described in [3] which was later substantially modified. An up-to-date description is in [4]. Standardised site conditions were also defined and agreed with the ITER Joint Central Team. The study involved several European manufacturers and included a wide survey of commercially available equipment.

AC DISTRIBUTION SYSTEM

The ITER pulsed loads were assumed to be supplied from an incoming HV grid double line via two circuit breakers X110 and X210 (Fig. 2). The assumed HV grid parameters, including the main limits to be complied with, are given in Table I.

Table I
Tentative HV Grid Main Parameters

Nominal voltage	380kV
Fault level	15-35 GVA
Frequency	50 Hz ±0.25Hz
Max. active pulsed power	1000 MW
Max. reactive power	500 MVAR
Max. allowed voltage harmonics (VMS)	1.5%
Max. allowed voltage variation	2.5%

Two HV busbar systems (BB1 and BB2) connect the two incoming circuits to four HV transformers (SGT1A, SGT1B, SGT2A and SGT2B). The two busbars can be connected together by means of the bus-coupler X013, in case one of the two incoming circuits is out of service.
The HV step-down transformers (400 MVA pulse power, 260 MVA continuous power) are provided with a tertiary winding (ca. 75 MVA) to reduce the zero-sequence impedance and with on-load tap-changers. The impedance voltage of 17.5% (400 MVA base) gives a fault level on the Intermediate Voltage (IV) busbars of 2.15 GVA and the three-phase short-circuit current, at 33kV, is 39.9kA, just within the capability of available vacuum circuit breakers. The primary star-point is solidly grounded; amongst the various methods of connection of the secondary star-point, eg. floating, low Ohmic, compensating (Petersen) coil and high Ohmic, the choice fell on the last option. This type of arrangement limits the fault current in case of single phase earth faults to a few tens of amperes and assures a good selectivity for the detection of earth faults even in

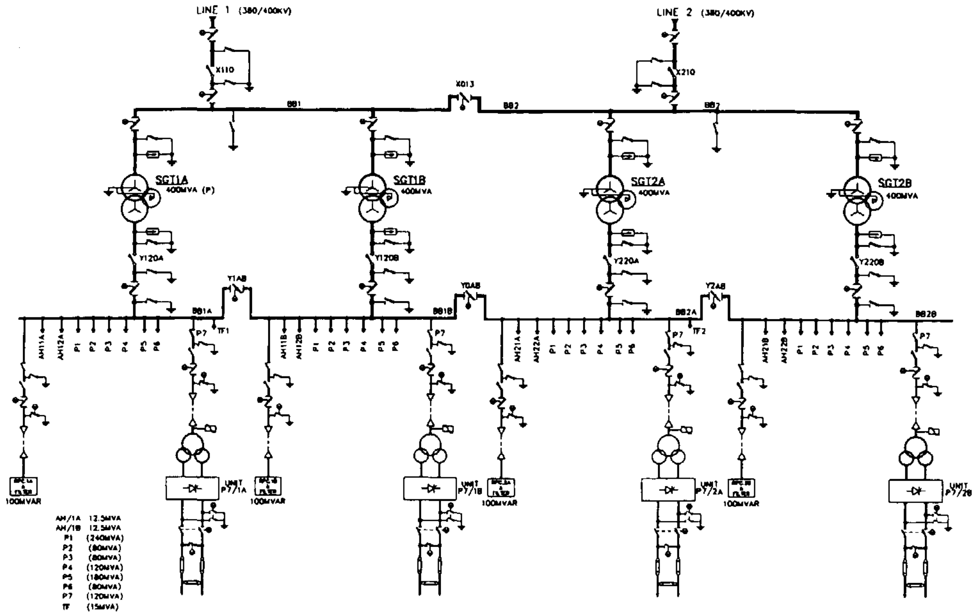

Fig. 2 Power Supply Scheme for the ITER Power Pulsed Loads

presence of imbalance of the system capacitances to earth. The supply can be maintained for up to 400s thus allowing an ordered termination of the ITER pulse.

The IV distribution system is based on four busbars (BB1A, BB1B, BB2A and BB2B), each of them normally fed from one HV transformer. Buscouplers (Y1AB, Y2AB and Y0AB) are available to connect the IV busbars in case one of the HV transformers is out of service. The loads are evenly distributed amongst the four busbars. Each PF power supply is composed of four units, series connected, one on each busbar. The units operate in sequential control with freewheeling action. The TF power supply is composed of two modules, series connected for redundancy. Two feeders on each busbar are dedicated to the AH loads (12.5 MVA each). A summary of the pulsed loads considered for the design is given in Table II.

Table II

Pulsed* loads on each IV busbar (MVA)

P1	P2	P3	P4	P5	P6	P7	TF**	AH
240	80	80	120	180	80	120	15	2x12.5

*Pulse factors: (ratio between pulsed and continuous power)
P1 to P7 = 1.5; TF = 1; AH = 2
**On busbars BB1A and BB2A only

Voltage drops during the execution of the ITER pulse (fig. 1) were calculated for a HV grid fault level of 15 GVA both in absence and with 400 MVAR of reactive power compensation (RPC). The most critical instants were found to be at t = 3s (plasma initiation) and t = 75s (X-point formation) (Table III).

Without RPC, the voltage drops on the HV grid exceeds by far the specified limits (Table I). On all the IV busbars, the voltage drop goes beyond 15% which was deemed to be the acceptable limit to ensure the proper functioning of the AC/DC converters. The situation improves when 400 MVAR of RPC are considered; though the voltage drops on the HV grid and BB1A are still not satisfactory, it would appear that additional 30 MVAR of RPC on each busbar would keep them within the desired limits. The

Table III

Voltage Drops on HV Grid and IV Busbars

	BB1A* (t=75s)	BB1B (t=3s)	BB2A (t=3s)	BB2B (t=3s)	HV grid (t=3s)
P(MW)	30	250	220	80	830
Q(MVAR)	305	230	230	150	820
V drop % (no RPC)	25.7	22	16.6	16.6	7.5
V drop % (with RPC)	16.8	11.4	6.2	6.2	3.6

*The voltage drop on BB1A is affected by the assumption that, when the required load voltage is low, all its AC/DC converters are still in operation (the AC/DC converters for the loads P2 to P7 on the other busbars being instead in freewheeling mode).

RPC system is sub-divided into four 100 MVAR units (one for each busbar) composed of two 50 MVAR modules. Two alternatives were considered: mechanically switched capacitors (point-on-wave switching of vacuum breakers) and static-var, the first one being less expensive but providing a more coarse and discontinuous compensation. For the 33kV scheme, the RPC units are directly connected to the IV busbars while, for the 66kV and 132kV schemes, a matching transformer is required. The voltage harmonic distortion, under some conservative assumptions and in the absence of filters and RPC, could reach (Table IV), at t=75s, 7.36% on the HV grid and 18.84% on BB1A. Filters are necessary to maintain the voltage harmonic distortion below 1.5% on the HV grid and below 5% on the IV busbars.

For each IV busbar, the filter arrangement is composed of two LC tuned branches (all the components values are

Table IV

Voltage harmonic distortion (%) on HV grid and IV busbars (t=75s - X-point formation)

	No filters/ No RPC	With filters/ No RPC	With filters and RPC
HV grid	7.36	1.29	1.17
BB1A	18.84	3.10	2.70

given for the 66kV option) at 550 Hz (L=15.2 mH, C=5.5μF) and 650 Hz (L=16.4 mH, C=3.67μF). An additional high pass branch (L=32 mH, C=0.25μF, R=400Ω) is added to damp the high frequency oscillations generated by the resonance between the cable capacitance and the stepdown transformer reactance. The additional, filtering effect of the RPC units (L=4.74 mH, C=134μF for a 50 MVAR module) was also considered.

Four options for the IV distribution system were analysed and compared in detail (Table V):

a) 33kV indoor substation;
b) 66kV indoor Gas Insulated substation (GIS);
c) 66kV outdoor substation;
d) 132kV outdoor substation.

66kV appears to be the most convenient voltage level; the availability of components makes it preferable to the 33kV option, while cost (for the outdoor switchyard solution) and less difficulties for the construction of small rectifier transformers give it an advantage over the 132kV option. While the 66kV GIS alternative could be considered in case of particular site conditions, it is thought that the 66kV outdoor switchyard option is the most effective choice.

RECTIFIER TRANSFORMERS

The rectifier transformers are provided with two secondaries to supply 12-pulse AC/DC converters. Pulse factors were as in the note to Table II. Two main sizes were identified: 80 MVA (P2, P3 and P6 loads for a total of 12 units) and 60 MVA (P1, P4, P5 and P7 for a total of 44 units). Smaller transformers were in addition required for the AH, TF loads and for AC/DC converter boosters. For the smaller transformers and the higher primary voltages (66kV and 132kV), it was reported that the construction may be critical and that matching auto transformers in the same tanks were required. The impedance voltage for the main rectifier transformers was fixed at 12% (pulsed power basis). The connection between transformer secondaries and AC/DC converters is characterised by high currents and aluminium isolated phase busbars were adopted. The busbars account for an additional 3% impedance voltage.

DC SYSTEM

The DC system encompasses the DC busbars and limiting reactors at the output of the AC/DC converters, the main DC busbars connecting the power supplies to the Electrical Termination Building and all the associated switchgear. Each power supply is provided with a disconnector, an earthing switch and a by-pass switch (all motorised) to allow the unit to be isolated in case of faults. Each 12-pulse AC/DC converter is made up of two 6-pulse modules parallel connected; two air-cored water-cooled limiting reactors are required to reduce the 300 Hz circulating ripple current and the current imbalance, especially during transition to freewheeling mode and to limit the peak DC short-circuit current within 250kA. The design was standardised and two types of reactors were devised: the first one of 100μH for the PF power supplies and the second one of 10μH for the TF system. Each pole of the main DC busbars is constructed of four 500x30mm aluminium bars (Fig. 3) for a DC steady current of 50kA and a peak short-circuit current of 250kA. The busbars are cooled by natural circulation of air; the sections of busbars are welded.

LAYOUT AND DELIVERY TIME

For all the four options considered for the IV distribution system, a general layout was produced (Fig. 4), covering the HV switchyard and transformers, the IV distribution system including cable trenches, rectifier transformers bays and AC/DC converter buildings The layout includes enough space for additional feeders on each of the four busbars as well as bays for rectifier transformers for future

Table V
Comparison amongst the four options for the IV Distribution System

	33kV indoor	66kV GIS	66kV outdoor	132kV outdoor
Circuit Breaker Type	Vacuum	SF_6	SF_6	SF_6
Technical Feasibility	The 33kV scheme presents some difficulties: the rated current for the incomers (700 A) is beyond the capability of available circuit breakers and non-standard arrangements (eg. the use of one three-pole circuit breaker per phase) must be adopted. For the feeders a cabinet including the circuit breaker and two isolators should be developed. The other three options can be implemented with standard equipment. The higher voltages (66kV and 132kV) might entail some problems with the smaller rectifier transformers.			
Reliability	An assessment of the reliability was possible only in general terms in view of the particular operating regimes which are unlike standard applications. The number of connections for the 33kV scheme is about twice than for the 66kV and 132kV options, with consequently higher risk of failure.			
Maintainability	Indoor substations should result in less demanding maintenance requirements (easier access, no external insulators). Maintenance of GIS normally requires specialised teams from the Supplier with longer down-times. Vacuum breakers require less frequent maintenance than SF_6 breakers			
Performances	Performances are equivalent to a great extent. The 33kV option entails higher faults current with higher energy released. Switching overvoltages are in general higher for vacuum breakers than for SF_6 breakers			
Area required (m^2)	2450	2400	13760	23460
Cost IV switchyard only	1.18	2.13	1	1.44
Cost (AC syst. incl Rect. Tx)	0.96	1.19	1	1.18

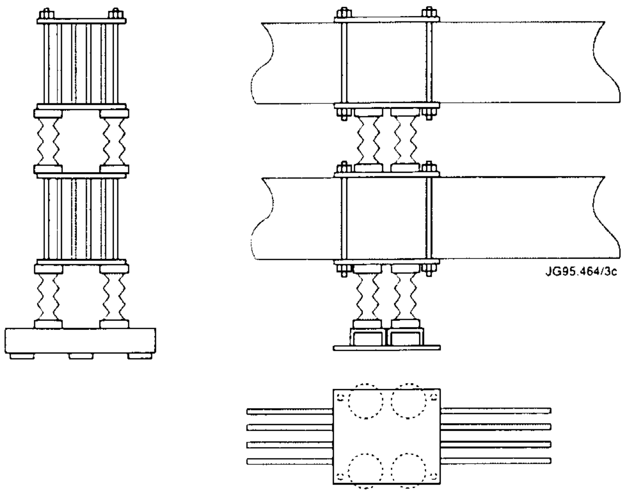

Fig. 3 Arrangement of the main DC busbar

loads and an area for the installation of further four 100 MVAR RPC units. The items with the longest delivery times are the rectifier transformers and the DC busbars (36 months) partly due to the large number of pieces.

CONCLUSIONS

The AC distribution system for the ITER pulsed loads does not require, with the exception of the 33kV option, any non-standard components. The study produced a large amount of data on the components and equipment including ratings, cost, sizes, delivery times which can be utilised as a data base for the investigation of new power supplies schemes. Outline specifications were produced which can be used as a basis for the procurement contracts. Some areas of further investigation were also identified. The reliability issue might require some additional scrutiny. The layout of the DC busbars system will also require an additional effort, especially for the study of the routing in the Switching Hall. A possible design for the DC busbar connections has been established though it should possibly be reviewed taking into account the later modifications at the coil connection circuits.

ACKNOWLEDGEMENTS

The authors would like to thank the various Manufacturers who contributed to the study by providing indispensable information and data on the equipment.

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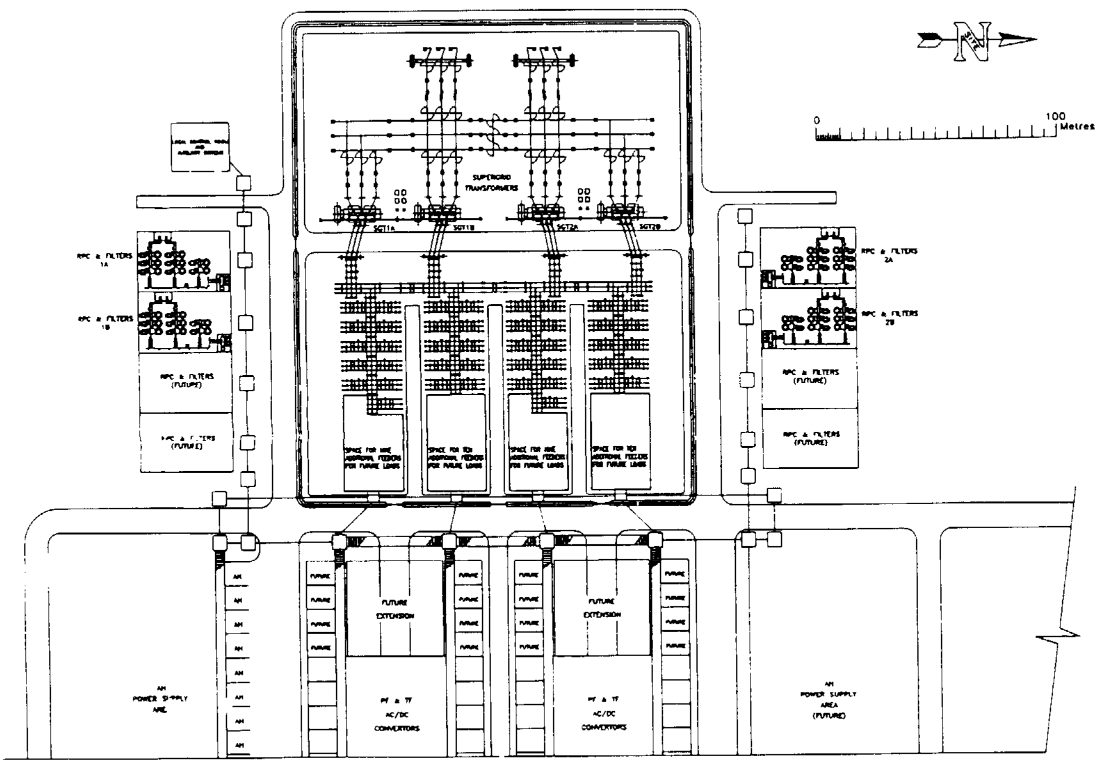

Fig. 4 General layout for the ITER Pulsed Power Supplies Distribution System (66kV outdoor IV substation)