Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

The ITER Pulsed Power Electrical Network (PPEN)

Ashok MANKANI [a*], Ivone BENFATTO [a], Joël HOURTOULE [a], Electrical Engineering Division [a]
[a]*ITER Organization, 13067 St Paul-lez-Durance Cedex France*

[*]*Corresponding author: Ashok.mankani@iter.org*

1 Abstract

ITER's ac power is derived from the 400 kV, 6.5 – 12 GVA, Double Circuit Grid and transformed to an intermediate voltage level (66 kV) via three step down transformers of 300 MVA (continuous duty), 400/66/22 kV, YNynd11 each. Each transformer feeds one interconnected 66 kV distribution bus. Most of the large and dynamic loads are directly fed from the 66 kV bus. Loads with relatively lower power (normally less than 20 MVA/unit) and more or less steady duty are fed from the 22 kV bus, are powered from the 66 kV bus via three step down transformers of 50 MVA (continuous duty), 66/22 kV each (**Scheme I**) OR through 22 kV Delta connected tertiary windings on the 400kV transformers (**Scheme II**).

The loads are primarily thyristor rectifier AC/DC converter power supplies that supply DC power to the ITER superconducting magnet coils to produce magnetic field to confine and shape the plasma and heating and current drive power supplies to supply DC power to neutral beam and radio frequency plasma heating systems to heat the core of the plasma.

The ITER pulsed power electrical network (PPEN) is capable of supplying 500 MW of pulse power and consumes around 1 Gvar of reactive power. In addition, the conversion plant is always operated in dynamic conditions in terms of the plasma control requirements. Abundant harmonics generated by the pulsed power supply, large installed power compared with the short circuit capacity and complicated interaction with the grid means that stability of the power system becomes a significant issue.

This paper focuses on the merits and demerits of the above two possible schemes to be adopted for the ITER PPEN. The Scheme I is defined in the ITER 2001 Baseline design whereas Scheme II is derived from system and value engineering. The analysis results: load flow, short circuit, harmonics, reliability, under/over voltage and cable sizing, are compaired for both schemes and consider the initial and extended phase of ITER operation.

2 Introduction

2.1 Concept

The ITER pulsed power electrical network will be connected to a powerful high-voltage (400 kV) grid capable of providing the large pulsed power needed to feed the superconducting coils, the heating and current drive (H&CD) systems. The grid is assumed to provide large active (positive or negative transfers from the grid) and reactive power, as well as fast power variations and occasional power steps. The proposed technical parameters for the grid are given in Table – 1. The ac power received from the grid will be distributed to the consumers at the two lower voltage levels: intermediate, 66 kV, and medium, 22 kV.

Table – 1

Parameter	Grid Capacity (proposed by RTE for ITER)
Max. active power	± 500 MW pulsed +120 MW for auxiliaries
Max. reactive power	200 Mvar pulsed + 48 Mvar for auxiliaries
Max. active power rate	up to ± 200 MW/s
Short circuit power	6.5 – 10 GVA (no plasma operation) 10 -12 GVA (plasma operation) 40 kA (for sizing the components)
Flickering Pst_max	0.6
Max. Imbalance Rate	0.6 %
Frequency variation: permissible expected max	 50 mHz 28 mHz
Voltage variation at 400 kV	2-3%

2.2 Typical Pulsed Load Profile and Data

The total load is composed of the following major components: power required for the scenarios, power needed for the plasma current, position and shape control, including the vertical stabilisation, and power to supply the H&CD system. In addition, power to supply the correction coils (CC), in-vessel coils (ELM) and in-vessel vertical stabilisation coils have also been taken into account. The maximum values of these components and the total load are shown in Table – 2 for the following three cases:

i. during plasma current ramp-up phase
ii. during burn with the basic H&CD power (initial phase)
iii. during burn with the increased H&CD power (extended phase)

The typical load profile is shown in Graph – 1

The power required for fast transient plasma control (pulses up to ± 100 MW of ≤ 10 s duration) is superimposed to the profile shown in Graph – 1. The speed of the active power variation can be very high, and, therefore, such a variation should be considered as a power step. The amplitude of this step may exceed the 60 MW. This is the subject for further analysis as well as for future discussion with the HV Grid Operator.

3. Schemes for Pulsed Power Electrical Network

Based on the ITER 2001 baseline design and present actual operating conditions two possible schemes are identified and assessed.

Operational Phase	Plasma Current Ramp-up		Plasma burn with Initial Heating Power		Plasma burn with Updating Heating Power	
	P (MW)	Q (Mvar)	P (MW)	Q (Mvar)	P (MW)	Q (Mvar)
Poloidal Field: • scenario • plasma control	80 100	650 0	30 100	750 0	30 100	750 0
Heating and Current Drive	230	150	230	150	390	200
Correction Coils	10	10	10	10	10	10
ELMs	20	20	20	20	20	20
In VV VS	20	20	20	20	20	20
Losses	20	20	20	20	20	20
TOTAL	**480**	**900**	**430**	**950**	**590**	**1000**

Table - 2

3.1 Scheme I

The three step-down transformers each rated at 300 MVA continuous power, are used to convert voltage from 400 kV to 66 kV. Each transformer is operated and protected by its own circuit breakers. The Y connected secondary winding (66 kV) with neutral earthed of each transformer forms 66 kV busbar. These three 66 kV busbars are coupled with coupler disconnectors in case of a step-down transformers being out of service. All the loads are subdivided among the three 66 kV busbars as equally as possible. A reactive power compensation & harmonic filtering (RPC & HF) unit is connected to each busbar. The 22 kV distribution has a similar configuration. The loads are distributed among three busbars each of them normally fed from one 66 kV/22 kV step-down transformer rated for 50 MVA.

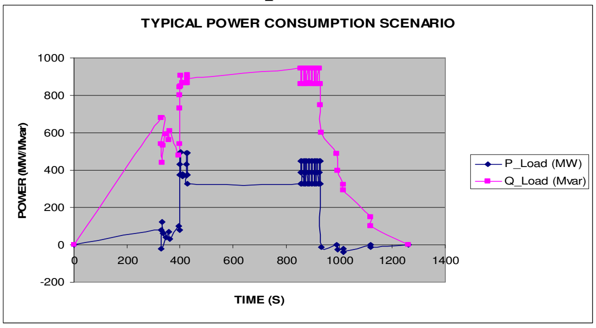
In addition, these transformers are equipped with a tertiary winding (22 kV, 100 MVA) which have two functions: to allow the circulation of the third harmonic current and to provide the medium voltage to connect units for active power shedding (APS) to smooth large negative active power steps, which may occur after a plasma disruption. Each unit of APS consists of 3 phase resistor banks connected to the tertiary winding of the transformer via 3 vacuum circuit breakers.

3.2 Scheme II

Owing to formal site adaptation for ITER machine at Cadarache in France and interaction with Local Grid operator (RTE – Réseau de Transport d'électricité) supplying power to pulsed power electrical network, it is considered that the Grid is stable enough and capable of accommodating the large negative active power steps, which may occur after a plasma disruption. Hence the APS (active power shedding) units designed to perform the above function are no longer required.

In addition, in order to optimize the site layout and system in general, the 22 kV loads are assessed for supply from the tertiary winding (22 kV, 100 MVA). This scheme is a more economic solution compared to Scheme I resulting from the removal of 3 units of 66/22 kV, 50 MVA transformers.

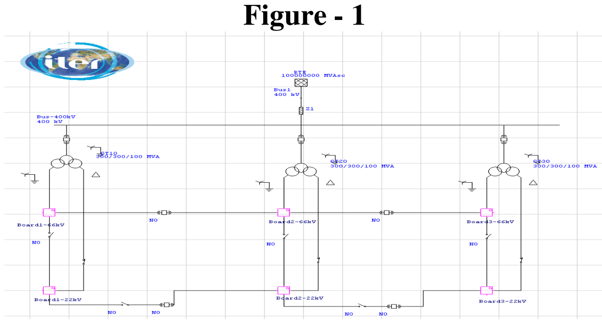
Graph – 1



4. Results

The analysis is carried out by creating an ETAP model for both the above schemes for initial and extended phase of operation. The analysis is focused on load flow, short circuit, computation of under/overvoltage at each voltage level, harmonic analysis, reliability analysis, cable sizing, and overall cost estimation. The summary results are shown in Table – 3 and the ETAP model in Figure – 1.

Figure - 1



Argument	Scheme 1	Scheme 2
Quantity of cables / Cable cost	Ø	Ø
Cost of circuit breakers	Ø	Ø
Sizing of boards / Board cost	+	–
Voltage surges on 66kV busbars	Ø	Ø
Transformer cost	–	+
Voltage drop on 22kV busbars	–	+
Over voltage in case RPC only connected	–	+
Overloading of 2-winding transformers	–	+
Harmonic voltage rate on 400kV level	+	–
Harmonic voltage rate on 66kV level	Ø	Ø
Harmonic voltage rate on 22kV level	–	+
Reliability of supply of 66kV loads	Ø	Ø
Reliability of supply of 22kV loads	–	+
Sizing of reactive power compensator	–	+ (not significant)

Ø: Neutral Point, -: Weak Point, +: Strong Point

Table-3

5. Conclusions

Based on the analysis, Scheme II is shown to be preferable as it optimises layout and overall system cost. Discussions with transformer manufacturing companies on the above results and its feasibility support this scheme for the ITER Pulse Power Electrical Network (PPEN).