JET-P(94)67

The JET Fast Power Supplies

R Claesen, T Bonicelli, R Öström,
H McBryan, G Zullo.

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK.

Preprint of a paper to be submitted for publication in the Proceedings of
EP^2 Forum 95 Electrical Power
Cern, Geneva, Switzerland, 2-3 March 1995

December 1994

1. INTRODUCTION

The JET Power Supplies can be divided into two main groups e.g. the power supplies to feed all the coils for the tokamak and the power supplies for the heating systems on JET. Most of these power supplies are of a conventional design with classical thyristor rectifiers either in the starpoint configuration or as a three phase bridge at the output of the transformer.
Over the last couple of years a few fast power supplies have been designed and installed using GTO's and IGBT's.
The first power supply is the Disruption Feedback Amplifier System(DFAS) which will be used in experiments to investigate disruptions and how they can be stabilised.
The second power supply is the Fast Radial Field Amplifier (FRFA) which replaces the old thyristor Radial Field Amplifier which is not fast enough to cope with the more demanding situations for the control of the vertical position of the plasma after the installation of the divertor coils.
The third power supply is for the Glow Discharge Cleaning. This power supply was installed last year to provide more power to the new Glow Discharge Cleaning System used for cleaning the inner wall of the vessel.
The paper gives an overview of these three power supplies.

2. THE DISRUPTION FEEDBACK AMPLIFIER

The Disruption Feedback Amplifier (DFA) is used to study plasma disruptions and to check experimentally on how they can be prevented. It has been observed that disruptions are preceded by a precursor characterised by a growing magnetic perturbation [1]. By using the processed precursor as an input signal to DFA it is hoped to stabilise the plasma by creating opposing magnetic fields to the perturbing one. The main requirements for the DFA PS are given in table 1. It has to be noted that the output current requirement decreases inversely with the frequency

Output Frequency	f	0 - 10 kHz
Output Current *	$I_{max.}$	3 kA for 0<f<1 kHz 3kA/f (kHz) for 1<f<10kHz
Output Voltage *	Vmax	1500V
Peak Power	S_{max}	4500 kVA
Duty Cycle	T_{duty}	I_{max}, 1s/600s 0.2*I_{max}, 25s/600s
Phase Shift	ϕ	<30°

* peak value of the fundamental

Table 1: DFA Design values

for frequencies between 1 kHz and 10 kHz. Another important factor is that the phase difference between the reference and the output current should never be more than 30^{o}.

Four pairs of saddle coils have been installed inside the vessel with which the opposing field is created. Each pair of these coils are supplied by one DFA (fig. 1).

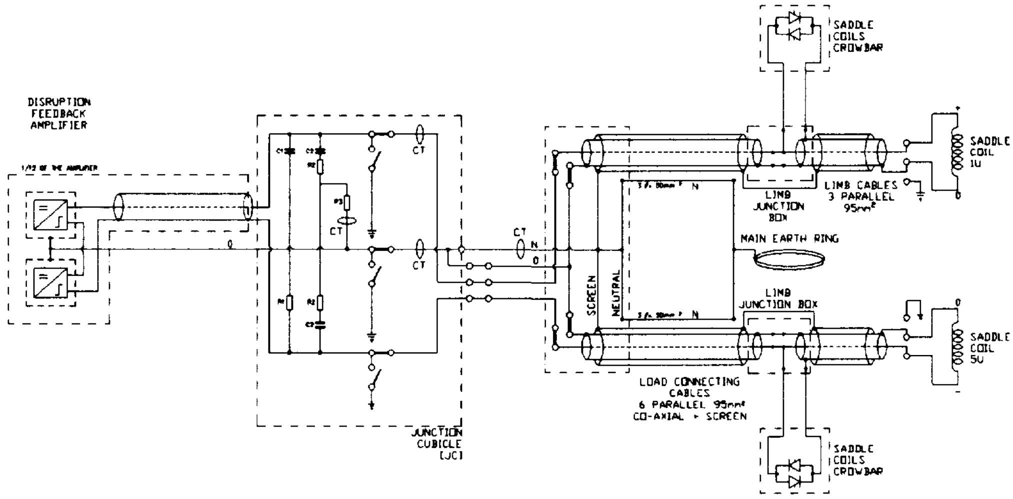

Fig. 1: DFAS Load connection

The measured impedance of the saddle coils is very frequency dependent (table 2).

Frequency (kHz)	L (μH)	R (mΩ)
DC	115	110
1	68	220
5	59	360
10	55	500
100	50	1350

Table 2 : Load L and R (2 saddle coils plus cabling)

Because of this low load impedance and the relative high frequency requirements for the requested power, special attention was given to the layout of the amplifiers, to minimise stray inductance and capacitance, and to the cabling in order to keep the cable impedance low compared to the load. Each saddle coil is connected by means of 6 parallel coaxial cables to a point close (approx. 2 m) to the junction cubicle (fig. 1). The length of these cables is approx. 60 m. Each Amplifier consists of two identical units connected in series, the midpoint is connected to the common point of the pair of saddle coils. This midpoint is also connected to the central JET earth close to the vessel in order to detect earth faults in the saddle coils, and to keep the voltage of the saddle coils versus earth low, especially during fault situations.

Each unit consists of two identical H-bridges in series. The DC links of the two H-bridges are supplied from conventional two-quadrant 6-pulse thyristor converters fed from a stepdown transformer with two 30° phase shifted secondaries. Twelve of these units, which is one DFA, are fed from the same

DC rails with their outputs connected in parallel at the junction cubicle. The distance between the junction cubicle and the H-bridges is approx. 50 m. Each switch in the H-bridge consists of two IGBT's in parallel. The IGBT used is a Toshiba MG200Q1US1 (1200V, 200A). A more detailed description of the H-bridge layout is given in [2].

The DFA can be controlled either in current or in voltage, the normal mode being the current control mode. The control method is the so called " Delta Modulation " . This results in PWM for the lower frequencies and square waves with variable duty cycle for higher frequencies. There is an automatic change over point between the two pulse patterns at around 1 kHz. As two H-bridges are connected in series five voltage levels can be obtained (i.e. +2E, +E, 0, -E,-2E). The sequence at which these voltage levels are applied to the coils is computed by a state machine inside the DFA with a cycle time of 1/3 μs [3].

Where several combinations are possible (E_{DC}, 0, -E_{DC}) the states of the H-bridges are chosen cyclically to minimise IGBT's commutations. Operation on the dummy load as well as the early operation on the saddle coils have shown that the DFA fulfils the design values.

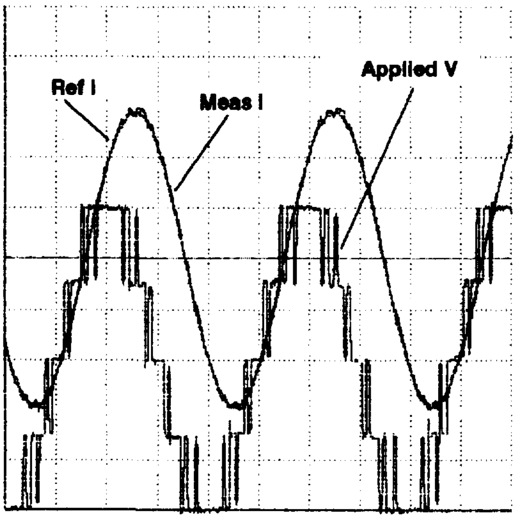

Fig.2: Response to a sin ref of 3 kA ampl at 500 Hz

Fig. 2 shows the response of the DFA to a sinusoidal reference current of 3 kA amplitude with a frequency of 500 Hz. As can be seen there is no phase shift between the reference and the measured current and the amplitudes are identical.

Fig. 3 shows the response to a sinusoidal reference current of 300 A amplitude with a frequency of 10 kHz. The measured current signal lags the reference by approx. 21°. In this case however there is a steady state overshoot of approx. 10 %.

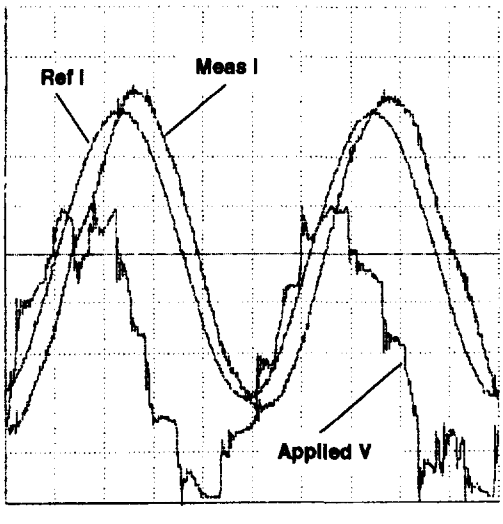

Fig. 3: Response to a sin ref of 300A ampl at 10kHz

3. THE FAST RADIAL FIELD AMPLIFIER

Until the beginning of 1992 an amplifier with a capacity of 4 kV at ± 3 kA has been used for the vertical stabilisation of the plasma. After the installation of the divertor coils inside the vessel this amplifier would not be fast enough nor powerful enough to stabilise the plasma in the vertical direction .
The required response time of the order of 200 µs at a peak power level of 25 MW GTO's seemed the obvious choice for such an amplifier.
The main requirements for the Fast Radial Field Amplifier (FRFA) are given in table 3. The amplifier is composed of two identical units which are

	Config. A	Config. B
Nominal Duty Cycle	30 s / 600s	
Max. output voltage	5000 V	10000 V
Base output current (29 s)	1000 A	500 A
Short time output current (1 s)	5000 A	2500 A
Output switching frequency at base current	2.5 kHz (2500 V step)	2.5 kHz (5000 V step)
Output switching frequency at short time current	1000 Hz (full voltage swing)	
Maximum response delay time	200 µs	

Table 3: FRFA Main Ratings

connected in series. Each unit has two subunits which can either be connected in series or in parallel (fig. 4).The connection in series or parallel is done in the connection box (fig. 4). The inverters are based on a H-bridge configuration. Two high power GTO's are connected in parallel in each arm of the bridge. The current sharing between the GTO's is ensured by means of passive as well as active methods. The configuration A in table 3 is for the

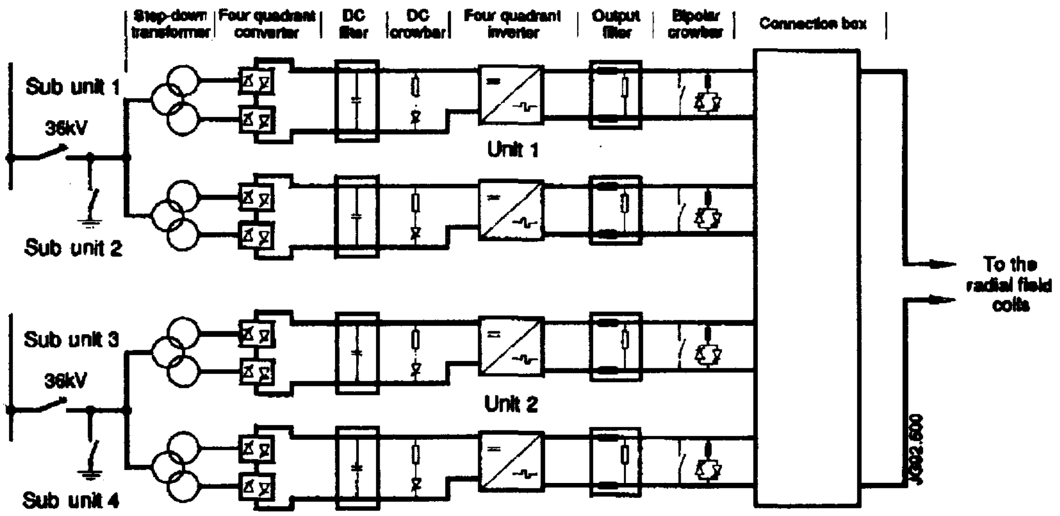

Fig. 4 : FRFA amplifier system

parallel connection of the two subunits in each unit while configuration B is for the series connection of all subunits. Each subunit can be configured independently and is controlled independently. In this way the output voltage of the FRFA can have 5 voltage levels for configuration A (e.g. -5000 V, -2500 V, 0 V, +2500 V, +5000 V) and nine voltage levels in configuration B equally spaced between -10000 V and +10000 V. The main components of the FRFA are described in detail in ref. [4].
Simulations were performed to check the losses in the GTO's [5]. Based on these calculations a protection scheme for the GTO's was implemented based on accurate on-line calculations of the junction temperature.
The load of the FRFA is highly inductive (L_{DC} = 43 mH). At full current the stored energy can be up to 537 kJ. This energy is recuperated and transferred back to the 36 kV supplying network via a four quadrant converter (fig. 4).
Three control methods are implemented, voltage control (open loop), current control and PWM; the one used so far for plasma operation is the voltage control mode. A typical example in open loop is shown in fig. 5.

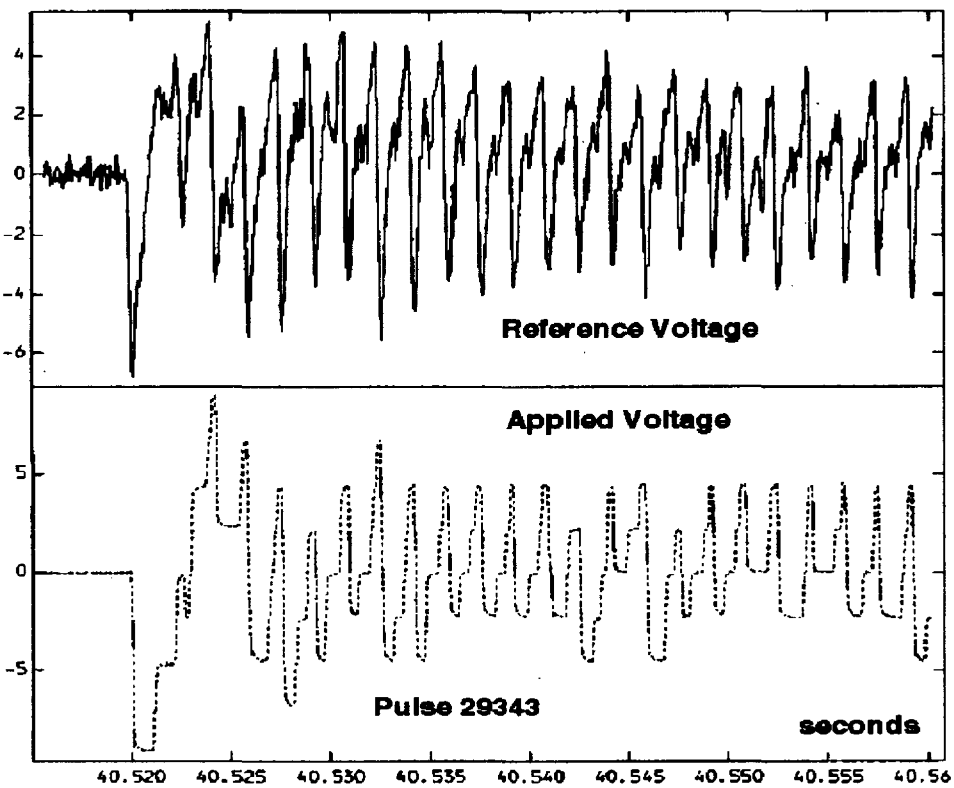

Fig. 5 : Typical FRFA response

The FRFA system control and the fast protections are based on Logic Cell Arrays (LCA's) while the slow controls and protections are handled by a system of Programmable Logic Controllers (PLC's). When more bridges are series connected (e.g. four in configuration B), the inverter controller rotates cyclically amongst the subunits in order to share the load. If a subunit becomes unavailable it is immediately by-passed by means of an output

bipolar crowbar. The plasma position control is maintained by the remaining healthy subunits.
The FRFA was commissioned on dummy a load up to the full performance indicated in table 3 during the summer of 1993 and has been successfully operated during the plasma experimental campaign since then.

4. THE GLOW DISCHARGE CLEANING POWER SUPPLIES

The Glow Discharge Cleaning power supplies (GDC) consist of four independent power supplies. Each one is connected to one electrode inside the vessel. The system is used to clean the inner wall of the vessel of

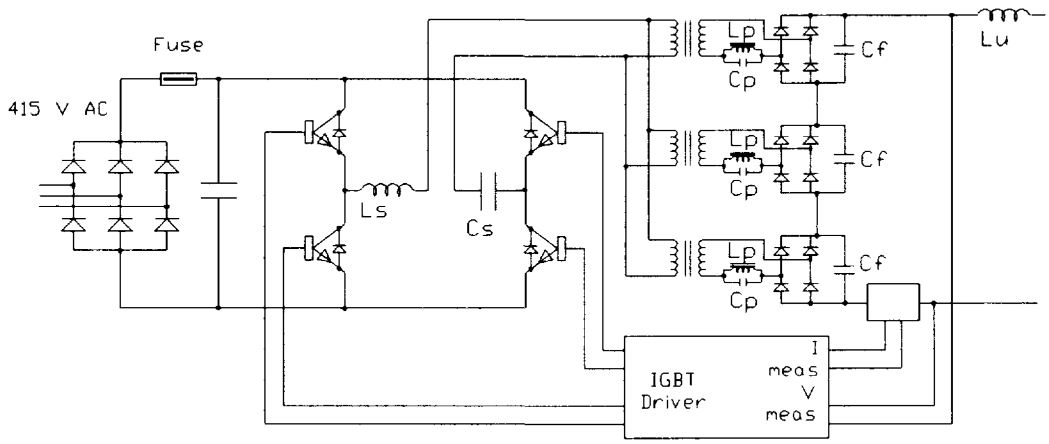

Fig. 6 : The Glow Discharge Cleaning PS principle

impurities embedded in it [6].
The overall schematic of the power supply is given in fig. 6. The power supply is a current source based on a full bridge series and parallel resonant power converter working in discontinuous current operation [7], its output is fully floating. Table 4 gives the main ratings of the power supply.

Max. output V	1500 V
Max. output I	20 A
Max. energy in arc before trip	10 J
Output	Floating
Output isolation level	10 kV
Duty cycle	continuous
Control Mode	current

Table 4: GDC main ratings

The series resonant circuit is composed of Ls and the parallel connection of the three Cp. Cs is used only as a de-coupling capacitor. The parallel resonant circuit is formed by the three Lp and Cp circuits in parallel. Table 5 gives the values of the main components of the circuit
The load is protected by two voltage protections e.g. minimum and maximum voltage level.
The minimum voltage level is used to protect against arcing and is set just below the actual voltage level during operation. If during operation the voltage drops below this set value the power supply trips, only the energy in the bridge Cf and output Lu is transferred to the load. No significant energy is

added from the inverter because the under voltage detection circuit reacts within 10 μs.

The maximum voltage level prevents the voltage going too high in case the glow extinguishes.

The power supplies were fully tested on a resistive dummy load up to full current. They are now used routinely for cleaning the vessel.

Series res freq.	±100 kHz
Parallel res freq.	±20 kHz
IGBT	Fuji 1MBI200L-120
Working freq. range	20 kHz - 50 kHz 0 A - 20A
Intermediate DC volts	560 V

Table 5: Circuit values of the GDC

REFERENCES

1. J. Snipes et al., " An analysis of Plasma Ion Rotation during large Amplitude MHD Activity in JET", Proceedings of 16th EPS Conference, pp 513-516, Venice, Italy,1989

2. P.L. Mondino et al., " The high power, wide bandwidth disruption feedback amplifiers for JET" , Fusion Technology 1990 pp 194 - 198, 16th Soft Conference London 1990

3. M Marchesoni et al., "A nonconventional power converter for plasma stabilization", IEEE transactions on power electronics vol. 5, No 2, April 1990, pp 212 - 219

4. P.L Mondino et al., "The new fast radial field amplifier for the control of the plasma vertical position in JET" Fusion Technology 1992 pp 907 - 911, 17th Soft Conference Rome 1992

5. T. Bonicelli et. al., "On-line simulation of the junction temperature for the thermal protection of the high power gate turn-off thyristors used in pulsed duty inverters", 5th European Conference on power electronics and applications, vol. 2 pp 413 - 418 Brighton 1993

6. P. Andrew et. al., "The JET glow discharge cleaning system", 18th Symposium on Fusion Technology, Soft conference, Karlsruhe August 1994

7. R.J. King et. al., "Modelling the full-bridge series-resonant power converter", IEEE transactions on aerospace and electronic systems, vol. AES-18,No4 July 1982 pp 449 - 459