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The installation, testing and performance on the jet coils of the enhanced radial field amplifier (ERFA)

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ABSTRACT

The ERFA is a major part of the upgrade to the plasma vertical stabilisation system for JET. As well as improvements to the plasma controller, there was a requirement for a new power supply with increased voltage and current capability over its predecessor the Fast Radial Field Amplifier (FRFA). The ERFA had to be factory tested, installed at JET, power and signal connections made, all signals tested and then installed adjacent to FRFA. The connection to the JET coils had to be achieved in a planned 7-week pause in operation dedicated to this installation activity and perform to its full capability from the JET restart. The ERFA project achieved all of its aims and, following a minor upgrade, met or exceeded the performance specifications. This paper covers the site installation, signal testing, and power tests on dummy load leading to the final acceptance tests on the JET coils.

1. Introduction

The vertical position of the JET plasma is of critical importance during a JET discharge. Until 1991 stability was controlled by a (relatively) slow Poloidal Radial Field Amplifier (PRFA), which is now reassigned to other JET coils. A faster, more powerful amplifier, the Fast Radial Field Amplifier (FRFA), was used from 1992 until 2009 and was able to deliver ±10 kV; ±2.5 kA with a response time approaching 200 μs. The wider Plasma Control Upgrade project identified pulse types that would be beyond the stabilising capability of even the FRFA [1,2], and therefore a project to replace the FRFA with the ERFA was initiated in 2006. ERFA would be able to deliver more current and voltage to the JET coils (±12 kV; ±5 kA) and at speeds of up to 100 μs from an input reference request (see section 4.1 Waveform 6). The usual method for a fast amplifier to deliver energy in very short timescales to a load is from a DC stored energy source, typically high energy capacitors. In the ERFA a converter/inverter arrangement is used with the output voltage able to be switched from positive to negative using an H-bridge arrangement of Insulated Gate Bipolar Transistors (IGBT). Using four individual Units each capable of ±3 kV; ±5 kA connected in series the desired output is achieved (Fig. 1).

A significant constraint imposed upon the project was to connect the ERFA to the JET coils in a relatively short 7-week suspension of pulsing operations. Replacement included not only the output power section but also the many control, indication, protection, interlocks and data acquisition systems. All of this was achieved within the tight time frame available (Fig. 2).

2. Installation

ERFA had to be installed in such a way as to present the power output cables to the terminations in the FRFA connection box of existing load cables that run uninterrupted to the JET coils around ~200 m away. This connection box also contained the load earth switch and two output current transducers. The ERFA is constructed in a modular way for ease of factory testing, transportation and installation. This includes four main Unit shelters, two transformer shelters (each containing two transformers) and a dedicated connection box. The general arrangement of ERFA is shown in Fig. 1 with design details previously given in [3].

It made good economic and technical sense to avoid the use of large quantities of insulating/cooling oil within the ERFA, e.g. in HV transformers or large power capacitors. The technical specification dissuaded its use primarily in order that costly oil capture bunds in the civil works could be omitted. As such the site civil works

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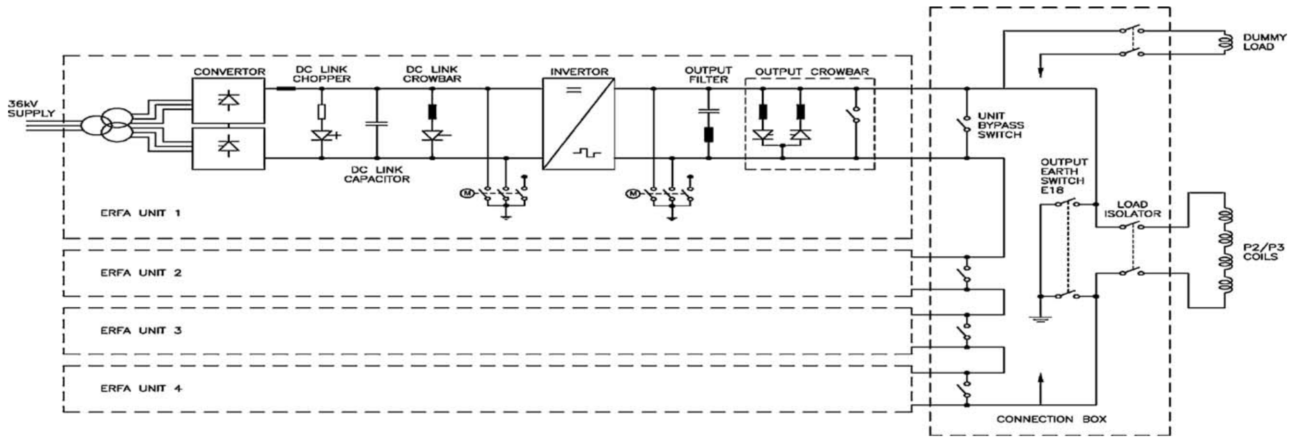

Fig. 1. General Arrangement of the ERFA with loads and connection boxes.

Fig. 2. Installation of the last power Unit of ERFA.

needed only to supply concrete plinths for the shelters to stand on and a short road with some linking pathways. Installation of the main components was completed in two days of delivery employing a 500 ton crane with sufficient reach to clear other power supply buildings in between. Careful planning ensured that as much of the ancillary infrastructure as possible was installed prior to the shelter delivery (new power connection box, signal patching cubicle, overhead cable trays, outdoor lighting, etc.), which significantly reduced the time to first energisation.

High voltage tests were performed on the final installation and some voltage breakdowns were found. The indoor power section electromagnetic screens (fitted after delivery to site) had insufficient electrical clearance; the addition of strategically placed insulating pieces resolved this. There were also breakdowns between the transformer secondary output tails and the transformer frame; additional insulating sheeting by the winding tails corrected this. The opportunity was taken to increase the rating of the transformer secondary output insulators to 20 kV giving a much greater safety margin.

3. Interfaces and signal testing

The ERFA contract demanded that all four Units making up the complete system be fully tested in the factory before despatch. However the interfaces to which it would connect at the JET plant were many and complex so whilst good preparation simplified the power connections there remained significant work in the area of signals, control, etc. The many interfaces employed by JET were manipulated to make ERFA insertion completely compatible with the FRFA it replaced and included:

- Central Interlock and Safety System (CISS) – back-up safety trip protection.
- Direct Magnet Safety System (DMSS) – trips in the event of load coil fault detection.
- CODAS (Control and Data Acquisition System) remote mimics and touch panels.
- CODAS analogue data acquisition – 40 high speed pulse data channels.
- CODAS alarm handling package – for the 700 new signals to and from ERFA.
- JET Coil Protection System (CPS).
- Central Timing System (CTS) – provided timing enable windows.

Plasma Position and Current Control (PPCC) – supplied in analogue (as with FRFA) but also in digital format for ERFA this being the (now) normal mode of operation.

In total 1047 new and existing signals were connected and commissioned with ERFA and in the remote interfaces; this significant task occupied around half of the 10 weeks from delivery on site to connection to the JET coils.

In addition the High and Low Voltages (HV and LV) supplies had to be redeployed including:

- Auxiliary electrical supplies.
- 36 kV power connections (two feeds).

3.1. ERFA testing

ERFA operates as part of a stability control system therefore the voltage reference from PPCC is somewhat random in its nature and cannot be accurately predetermined. In order to define performance requirements for ERFA the technical specification of the ERFA contract included a number of test waveforms that were designed to exercise the amplifier in a variety of ways thus ensuring the systems performance is fit-for-purpose, namely stabilizing the plasma's vertical position.

3.2. Tests with ERFA connected to the dummy load

The ERFA 36 kV supply was energised for the first time on 29th April 2009. There then followed a period of system commissioning