UPGRADE OF THE ISIS MAIN MAGNET POWER SUPPLY

S.West, J.W.Gray, W.A.Morris
Rutherford Appleton Laboratory, Chilton, Didcot, Oxon. OX11 0QX, UK.

Abstract

ISIS, situated at the Rutherford Appleton Laboratory (RAL) is the world's most powerful pulsed neutron source. At the heart of the ISIS accelerator is a proton synchrotron which uses a ring of magnets connected in series and configured as a "White Circuit" [1]. The magnets are connected in series with capacitor banks so that they form a resonant circuit with a fundamental frequency of 50 Hz. The circuit allows the magnets to be fed with an AC current superimposed on a DC current. The AC is currently provided by a 1MVA Motor-Alternator set and it is now proposed to replace this by a solid state UPS (Uninterruptible Power Supply) system. Tests on a smaller 80kVA unit have shown that it is possible to control the magnet current with a modified UPS system in such a way that both the frequency, phase and output voltage are under the direct influence of the control system. This paper discusses the issues surrounding the upgrading of the AC supply to the main magnets with a view to improving the system reliability, improving magnet current stability and reducing the risk of mains failure.

INTRODUCTION

The main magnet circuit is driven by two power supplies, one DC and one AC. The AC supply provides an oscillating current through the main magnets and this is superimposed on a bias current provided by the 1MW DC power supply. The current experienced by the magnets always flows in the same direction and swings from a minimum of about 260A to a maximum of approximately 1060A.

The current waveform covering one cycle of operation is shown in figure 1. The amount of AC power oscillating

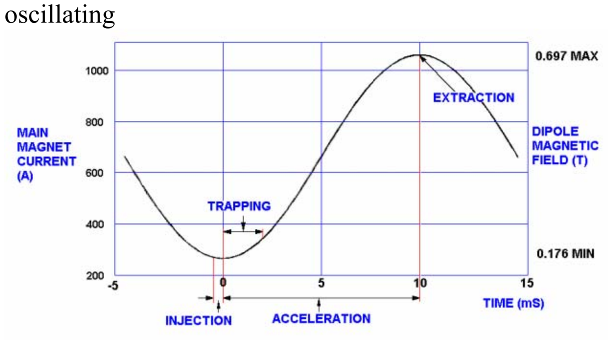

Figure 1: The current in the main magnets

back and forth in the circuit is considerable, of the order of 90MW. However, most of this is exchanged between the capacitor banks and magnets. The AC power supply

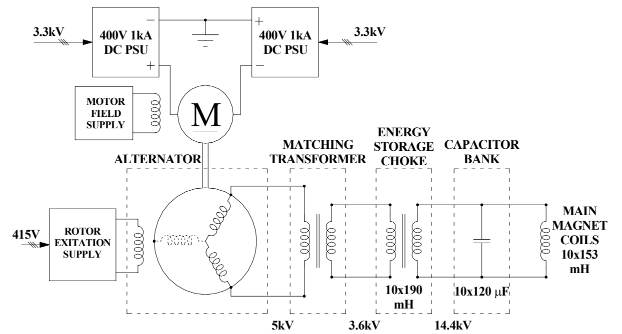

Figure 2: The ISIS main magnet AC power supply

that is the subject of this paper is required only to make up the losses in the circuit – approximately 560KW.

The motor-alternator set which currently comprises the AC power supply is shown on figure 2. The alternator was originally a three-phase machine but was modified to produce a single phase output by the removal of one of the phases and by connecting across the remaining two. The alternator then also required further modification to prevent overheating caused by circulating currents. Despite this the system has performed well over the years although there are increasing concerns regarding its continued reliability.

CONCERNS

The rotating machinery itself is old and wearing out and will eventually fail. In addition to this are the peripheral power supplies, some of which were inherited from ISIS's predecessor, NIMROD and date from the 1950's. Spare parts for these are no longer manufactured and the locally held stock of spares is dwindling. Attempts have been made to replace the excitation supply to the alternator but have been unsuccessful, as none of the prospective replacements have proved able to cope with the harmonics that are reflected back from the alternator winding. In this instance at least, the system has resisted modernisation.

If any of the components that comprise the power supply fail, it is likely that the ISIS synchrotron would be out of action for a very long time. Therefore it is considered that an alternative power supply should be developed before the present one suffers a catastrophic failure.

Other issues

The AC current in the main magnet circuit shows some instability, showing a variability of up to ± 0.2A about a normal operating mean of 400A. The variations appear random but are fairly slow, typically taking tens of seconds per cycle. The reasons behind this effect are not fully understood but it is suspected that interference between the nominal 50Hz of the mains and the crystal controlled 50Hz of the ISIS circuits may be partially to blame. The motor-alternator set is not easy to control and runs under a simple proportion feedback system. A more sophisticated PID control loop was developed but proved to be ineffective. It has not therefore been possible to use feedback controls to iron out the instability.

The motor-alternator is itself powered by the mains supply. This is subject to occasional failure, and "brown outs", where the mains voltage dips or fails for a short period of time, are not uncommon. A "brown out" of even a couple of cycles requires that the motor-alternator trips out. This of course results in unscheduled down-time for the ISIS accelerator. It is likely that interruptions to the mains supply will become more common as pressure on the national grid increases.

Opportunity

The Main Magnet Power Supply has been critically examined, [2], and recommendations were made about component replacement. The first phase of development saw the replacement of the synchrotron capacitor banks. The new ones have a considerably smaller ground footprint than the old ones and this has freed up a sizable area of the building adjacent to the plant-room where the motor-alternator set is housed. This has provided room to develop a replacement main magnet power supply without disturbing the existing system.

DISCUSSION

In order to avoid radical changes to the way in which power is fed into the main magnets it is desirable that the replacement AC power supply should emulate the characteristics of the motor-alternator set. In addition it is intended that the new supply should be, as far as possible built up out of "off the shelf" components. We would prefer to buy in equipment that has already been proven elsewhere and for which there is a ready supply of maintenance expertise and spare parts.

Consideration has also been given to the type of technology to be used to replace the motor-alternator set. Electronic inverters have now reached a stage of development whereby they may be considered a viable alternative to the rotating machines. Preference has been given therefore to electronics over a new electro-mechanical generator.

Inverters are readily available on the market as the output stage of uninterruptible power supplies or "UPS's". These are widely used to protect and condition electrical supplies in a very wide range of applications and industries. In view of this it was decided to concentrate on using UPS's as the basis for building a replacement for the ISIS motor-alternator set. A further advantage of choosing UPS's is their ability to continue to provide power during temporary failures of the primary mains supply. This would address one of the issues identified previously. With this in mind a set of basic requirements for the AC supply can be drawn up.

Requirements

- Approximately 560KW are needed to make up the losses in the magnet circuit.
- The supply must be phase-locked to the ISIS 50Hz timing pulse
- The magnet circuit has to be "Soft started" with the driving voltage and current gently run up from zero.
- The output voltage must be controllable "on the fly"
- The circuit is single-phase.

The last three points above are of particular note. Most UPS's on the market have been designed to provide an output equivalent to the mains supply. They are therefore set to run at a steady voltage depending on the local standard. In addition, at the power level specified here, the vast majority of UPS's are three-phase.

UPS ALTERNATIVE TO THE MOTOR-ALTERNATOR SET

Having settled on UPS's as the basis for the new power supply it was decided that a bank of four 300 KVA machines would be purchased and run in parallel to drive the main magnet AC circuit. With this arrangement any three of them would be able to power the system. There would thus be a redundancy of one and even the catastrophic failure of a UPS would not disable the ISIS synchrotron. With the requirements detailed a specification was drawn up and put out for tender. From the responses that were received it was clear that for most manufacturers the demands were difficult to meet. In particular, the ability to vary and control the output voltage was apparently difficult to achieve. However, one company, Chloride Power, through their German subsidiary, Masterguard, did offer a product that met the specifications.

It had been recognised that any high power UPS's that would be offered would be three-phase and so it was not part of the specification that the UPS output should be single-phase. This left a problem: how should the three-phase be converted to a single-phase?

SOLUTION

The solution for the three to single phase conversion problem is the circuit shown in figure 3. This circuit, if the reactor components L2 and C3 are correctly chosen, places a balanced, unity power factor, three-phase load on the supply.

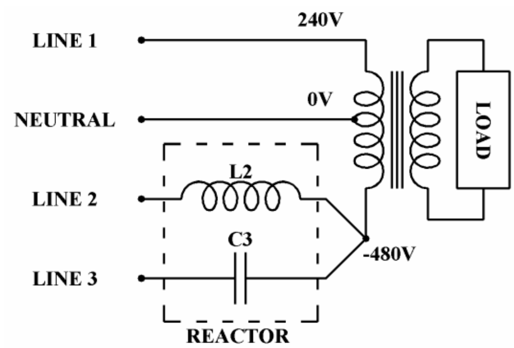

Figure 3: The three to single phase converter circuit.

A detailed analysis will not be attempted here but suffice to say that if the components are chosen according to the equation below then the circuit balances correctly.

$$R'_{LOAD}=\sqrt{3}.X_{L2}=\sqrt{3}.X_{C3}$$

In this equation R'_{LOAD} is the resistance of the load referred to the primary side of the transformer. This assumes that the load is purely resistive although variations in load power-factor are referred back to the supply (and are borne entirely by line 1). This circuit has been tested using a small UPS with the synchrotron main magnet circuit running at reduced power. The results were encouraging and we believe that a full size version is practicable.

Of particular note is the split primary of the transformer. The arrangement shown, with the primary connected to neutral a third of the way along the winding means that the converter circuit acts as a voltage source. In conjunction with the UPS's it can therefore directly replace the motor-alternator set. However, if the link to neutral is removed then the circuit behaves as a current source. It is possible that the current-source configuration will give better magnet current stability and this will be trialled once the system is installed. If this proves unsuccessful the voltage-source arrangement will provide a fall-back. The overall arrangement of the supply including the feeds will be as shown in figure 4.

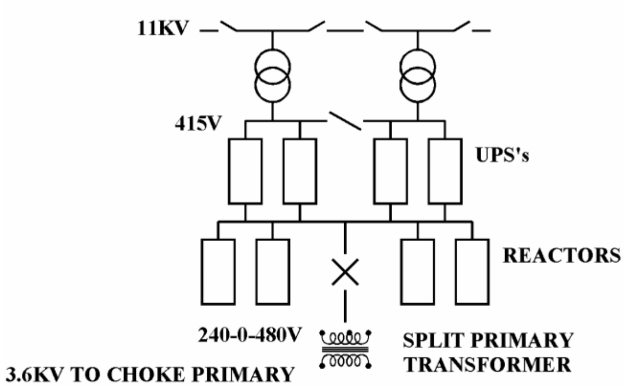

Figure 4: Arrangement for the UPS-based replacement for the motor-alternator.

Figure 4 schematic shows two 11KV-415V transformers and a split low voltage switch panel. This has already been installed (early 2004) and replaces the original single transformer and switch panel. Although the supply normally uses both transformers it can be quickly reconfigured to use one only in the event of a failure or for maintenance. This increases the robustness and tolerance of individual component failure of the feeds.

Control

Masterguard, who have developed the UPS's, has provided a means to control the output voltage of the inverter via a serial link. The required output voltage can be directly written into the internal RAM of the UPS. This allows the voltage to be controlled by a computer system using a program written in a language such as LabVIEW and in fact a LabVIEW driver already exists for the Masterguard UPS's. It is intended to integrate the driver into a PID-loop to better control the AC current in the min magnets. This would allow the possibility to iron out the AC current instability previously noted.

As a standby the UPS's have also have an analogue control input. This would allow for integration into a faster analogue control loop. However, as the instability waveforms are slow it is hoped that the relative slowness of the serial link will not be a disadvantage in comparison to the analogue system.

CONCLUSION

We believe that the new system should be able at least to equal the motor-alternator set in performance. Once the issues that surround the causes of current instability in the main magnet circuit are better understood then it may well be possible to negate them and improve the performance by judicious control of the UPS's. we also believe that the redundancy offered by the UPS's and their more comprehensive condition monitoring will greatly increase the overall reliability of the system and thereby reduce the risk of lengthy and expensive loss of operating time.

REFERENCES

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