STATIC VAR POWER FACTOR CORRECTION FOR THE ISIS MAIN MAGNET POWER SUPPLY

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Abstract

ISIS sited at the Rutherford Appleton Laboratory (RAL) is the worlds brightest pulsed neutron source. Intense pulses of neutrons are produced at 50 Hz when a heavy metal target is bombarded with a beam of high energy (800MeV) protons. Energy is imparted to the protons by accelerating them in a synchrotron, the magnets of which are connected in a configuration known as a “White Circuit” [1]. This White Circuit suffers from problems arising from drifting values of capacitance and inductance which affect the resonant frequency. This paper provides a review of Static VAr technology, and focuses on the design and simulation of the implementation of this technology to regulate the resonant frequency of the White Circuit.

INTRODUCTION

Background Information

The White Circuit configuration of the ISIS Main Magnet Power Supply consists of ten superperiods of magnets connected in a resonant circuit with ten large capacitor banks. As part of the original capacitor bank design specification, the capacitors used would be of two different types; one type with a negative temperature coefficient, and the other with a positive temperature coefficient. Any changes in the ambient temperature therefore were cancelled out by the opposing coefficients. This capacitor bank was altered due to the fact that the negative temperature coefficient capacitors contained a PCB dielectric. These capacitors were replaced with a non-PCB, positive temperature coefficient dielectric alternative. The bank was then all positive temperature coefficient, however the capacitors did not suffer from noticeable changes due to ambient temperature because they were in fact quite lossy, putting around 150kW of heat into the capacitor room which meant that they all stayed at a fairly consistent temperature. In 2002 the capacitor bank was fully replaced with a more modern equivalent which is a lot more efficient. Unfortunately, this increase in efficiency does now mean that the temperature coefficient of the bank is more influential and we now see both a daily change and a seasonal change in capacitance, in line with ambient temperature.

A previous attempt to solve this problem was the installation of an auxiliary bank of 12 switched capacitor units which were individually switched into circuit by a control system when needed. This system was not successful, as the step changes of 40kVA in reactance as the capacitors were switched into circuit caused unacceptable stability issues with the beam. Since this time the control system has been removed, and the auxiliary capacitors are now manually switched in and out of circuit, however this can only be done during ISIS beam downtime. This is clearly not a satisfactory state, and a better solution allowing control over the circuit reactance during an ISIS beam cycle is required.

Static VAr Technology

The Static VAr Compensator is a static device which controls the flow of reactive power in a system by generating or absorbing reactive power. Static VAr compensation is achieved by the use of shunt connected reactive elements, which are controlled by thyristors. These shunt connected elements can generally be split into two types: the thyristor switched capacitor (TSC), and the thyristor controlled reactor (TCR). The TSC is simply a shunt connected capacitor in series with a bi-directional thyristor valve, which works as an on/off switch providing extra capacitance into the system. The TCR however, is not operated as an on/off switch but rather as a variable supply of inductive reactive power supplied by a shunt connected inductor in series with a bi-directional thyristor valve. Control is achieved by variation of the firing angle of the thyristors. Fig. 1. shows the operation of a TCR branch, where the inductor begins to conduct current upon the application of a firing pulse to the thyristors, and stops when the current crosses zero. It is through control of this firing angle, that the TCR can be used to provide a continuous range of reactive power to the circuit. The TCR can be used in conjunction with TSC branches by ensuring that as the TSC is switched into circuit the TCR firing angle is set to initially counteract the extra capacitance and then can be gradually altered to smoothly add the extra capacitive reactive power.

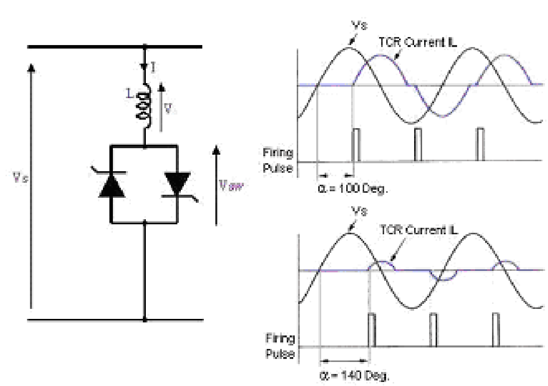

Fig. 1. TCR Configuration and Operation

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IMPLEMENTATION INTO ISIS

Position in White Circuit

There are currently 2 large projects under way which will drastically alter the layout of the White Circuit Main Magnet Power Supply. The first of these is the replacement of the AC supply, which in its current form is provided by a single phase AC generator driven by a DC motor. This is being replaced by 4 off 300kVA UPS' connected in parallel and feeding into phase shifting equipment to give 720V single phase (480V-0V-240V). The second project is the replacement of the energy storage choke which connects the power supply into the synchrotron superperiods. This job is currently done by one large, ten winding, 1MJ choke, and the ongoing project is to replace this with ten smaller individual chokes.

The existing energy storage choke is currently supplied at 3.6kV, whereas the replacement chokes will be supplied at 960V. It is required that the UPS supplies will be able to supply both choke arrangements, therefore the 480V-0V-240V will supply the primary of an autotransformer which will also have tappings at 480V-0V-480V to give the required 960V. This transformer will also have a secondary winding which will give 3.6kV.

Considering these changes in the White Circuit, it is believed that the best position for the Static VAr device will be on the low voltage side of the matching transformer, as the components can be rated for the lower voltage, and the device will be active for both choke configurations.

System Design

Static VAr technology has traditionally been used in applications such as large scale power transmission or for high power applications such as arc furnaces. In such high power applications it is necessary to use several TSC branches to allow for a smaller inductive element to be used. The TCR is then used with phase angle modulation to smoothly add each TSC as needed. For this application on ISIS, the power involved is much lower as there is only 0.5MW being generated by the AC supply to make up for the resonant circuit losses. For this reason the system to be used on ISIS will not use any TSC branches, and will instead be a reduced complexity fixed capacitor-TCR system.

As the device is planned to be used on the low Voltage side of the matching transformer, the centre tap of the 480V-0V-480V winding can be utilised to allow 2 TCR branches to be connected, one across each half of the winding. The capacitors to be used in the system will be the existing auxiliary capacitor banks, which will be fixed into circuit instead of switched. Also, it is planned to use chokes of the same specification as in the phase shifting cabinets in order to standardize this part. These chokes are 4mH each.

SIMULATION

Circuit Schematic

The White Circuit incorporating the proposed Static VAr system has been simulated using Saber Circuit Analysis program (Fig. 2). For this simulation, the energy storage choke inductance and magnet inductances are both assumed to be 160mH, which is appropriate for the final system of replacement chokes. The transformer turns ratio is 16:1, with the primary supplied at 960Vrms using a circuit model of the UPS driven supply. When seen from the power supply circuit, the 10 synchrotron super-periods appear to be parallel connected. The choke and magnet inductance can therefore be combined to give

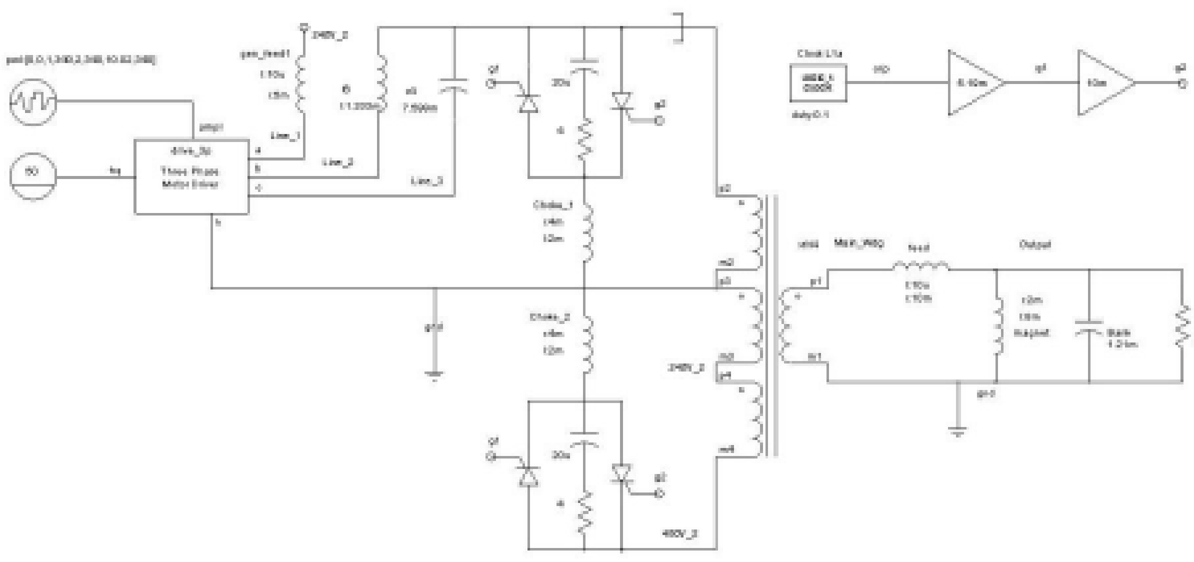

Fig. 2. Saber Schematic for the ISIS White Circuit with Static VAr Power Factor Correction

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a single value of 8mH when seen at 16:1. Losses are represented by a shunt resistor that will dissipate 0.5MW at 15kV. The magnets and choke were crudely resonated to a frequency near to 50Hz. TCR branches were connected across each half of the primary winding and operated with several different firing angles.

Simulation Results

The first simulation carried out was to observe the phase relationship between the supply voltage and current on one phase with no correction from the Static VAr system. The result of this simulation is shown in Fig. 3. where the upper graph shows the current flowing in the Static VAr choke, and the lower graph shows the supply voltage and current on phase “A” of the supply.

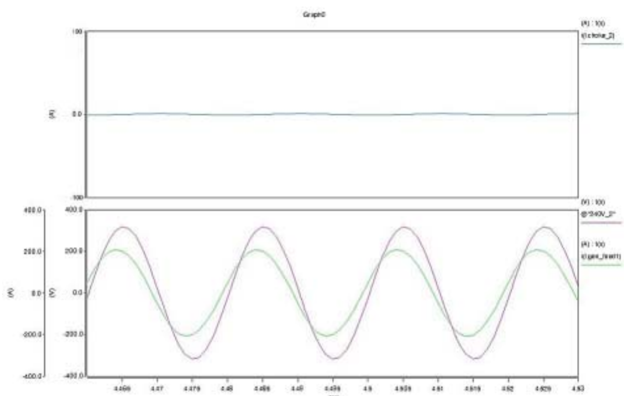

Fig. 3. Static VAr system “phased off”

The second simulation performed was to observe the phase relationship between the supply voltage and current on one phase when the firing angle was such that the Static VAr choke was in circuit continuously. The results are shown in Fig. 4. Again, the upper graph shows the Static VAr choke current, while the lower graph shows the supply voltage and current on phase “A” of the supply.

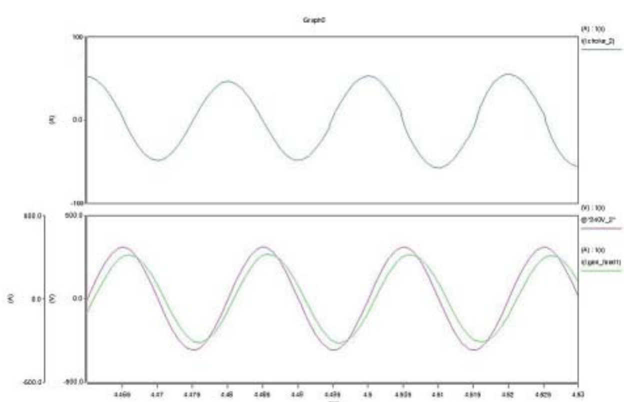

Fig. 4. Static VAr system fully conducting

The final simulation performed was to observe the operating characteristics of the circuit with the Static VAr system operating as intended, and bringing the supply current into phase with the supply voltage. It was found that for the circuit values used a firing angle of 7.22ms was needed. The results are shown in Fig. 5. As in the previous graphs, the upper graph shows the Static VAr choke current, while the lower graph shows the supply voltage and current relationship.

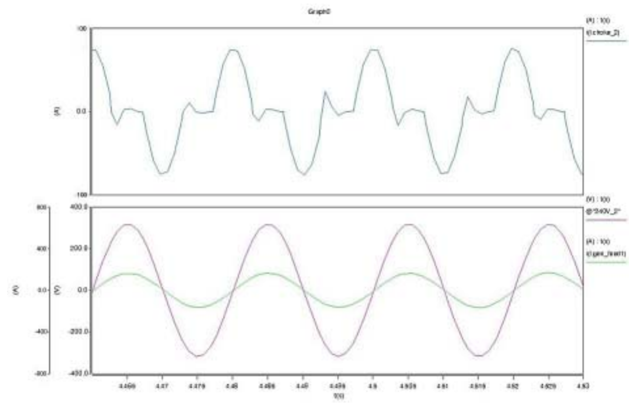

Fig. 5. Static VAr system tuned for unity power factor

Discussion of Results

The simulation results show Static VAr technology to be capable of performing the task required of it on the ISIS Main magnet power supply. The only real area of concern is the amount of harmonics injected into the system by the thyristors. Increased harmonics could cause overheating particularly in the transformer windings, and could potentially cause problems for the UPS supply. The true extent of this problem will only become apparent during the testing phase, so provision will be left for the installation of harmonic traps if necessary.

FUTURE WORK

Further to this design and simulation work, a Static VAr system for ISIS has been specified and manufactured. The system design is as stated in this report, based on a dual 400A thyristor regulator system to connect across the two halves of the 960V transformer winding. The choke elements have been purchased to the same 4mH 480V specification as used in the phase shifting equipment, while the capacitors to be used are the existing bank of 12 off 40kVA units.

The Static VAr system is currently on-site at RAL, and will be installed and commissioned during the ongoing shutdown period.

REFERENCES

[1] M.G.White et al., “A 3-BeV High Intensity Proton Synchrotron”, the Princeton-Pennsylvania Accelerator, CERN Symp. 1956 Proc., p525.