A NEW CONTROL SYSTEM FOR THE ISIS MAIN MAGNET POWER SUPPLY

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Abstract

The ISIS pulsed neutron and muon source at the Rutherford Appleton Laboratory in Oxfordshire is a world-leading centre for research in the physical and life sciences. At the heart of the ISIS accelerator is a proton synchrotron which uses a ring of dipole and quadrupole magnets connected in series and configured as a White Circuit [1]. The circuit allows the magnets to be fed with an AC current superimposed on a DC current.

A recent upgrade to the ISIS main magnet power supply (MMPS) [2] involved the replacement of the original AC supply, a motor-alternator set, with a bank of four 300 kVA UPS (uninterruptible power supplies) which had been modified to allow the output voltage to be varied using serial commands. However, when initially tested, this method was unable to produce the required stability in the main magnet current. This paper describes the further modifications to the UPS units to achieve the required stability and the development of a LabVIEW control system which manages the data acquisition and analysis, the communication to the UPS, interlock equipment and user interface, and provides a low latency control loop to the UPS and DC bias power supplies.

INTRODUCTION

The ISIS synchrotron main magnet circuit comprises of ten superperiods of bending dipoles and focusing quadrupoles connected as a resonant White Circuit [1]. The circuit is driven by two power supplies, one DC and one AC. The 660 A DC biases 400 A peak AC current to ensure a constantly positive magnetic field. The current waveform of one cycle is shown in Fig 1.

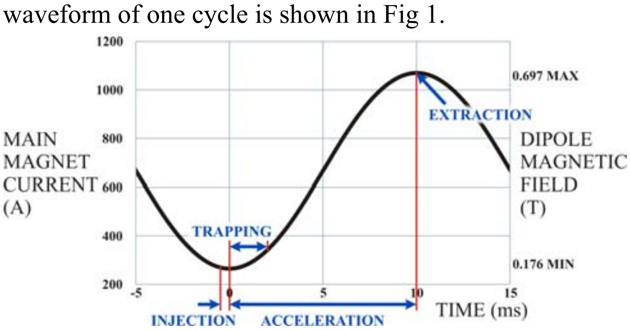

Figure 1: One cycle of the MMPS waveform.

The motor-alternator set that provided the AC power was superseded in 2009 by four 300 kVA UPS. Initial tests had shown that the UPS were capable of providing a stable current with little harmonic content when run at a fixed operating current, however, the limitations in the control method meant that the small changes in output necessary to correct for load variations were excessively coarse.

Through collaboration with Chloride, the supplier of the UPS units, modifications to the control boards and firmware were made so that the internal control loops were tuned to suit this application and an ability to control the output voltage with an analogue input was introduced.

The control system was developed using National Instruments hardware and software written using LabVIEW. The system provides control of the DC bias power supply by an analogue signal, and of the UPS by a combination of serial communications and analogue, to achieve the required stability to steer the ISIS beam.

ISSUES WITH CONTROL OF UPS UNITS

The S53300 UPS units were produced by Masterguard before the company changed ownership to Chloride (now Emerson Network Power). At the time of procurement it was obvious that our application would be somewhat unusual. The standard method of communication is via RS-485 which allows a user to set various parameters affecting the internal control, such as output voltage. A LabVIEW program was shipped with the units that would provide the ability for a computer to communicate to the units using ActiveX commands, and therefore a crude control loop could be implemented. However several problems were discovered with this method.

The ActiveX framework is intended to operate using the Microsoft Windows operating system (Windows). This operating system is notably unreliable for running control software. The time taken to send any single command could vary greatly and often took several seconds. At this time just one serial port was being used to communicate to all four units by polling round the addresses. This meant that for every change to a parameter the control loop could be hanging for near 15 seconds, by which time the magnet current could have changed significantly, leaving no option but to have large changes in output in an attempt to catch up.

The next problem was that each UPS output is connected in parallel; if one output is set to a higher voltage than the other three, then that one would be driving current back into the others. The difference in voltage demands had to be limited to just 2 V, and therefore when running up from zero to full operating voltage of 230 V, several hundred commands had to be sent. Combining this with the slow communication rate; the run-up time was a significant factor in the beam off time.

To control the magnet current accurately, the serial commands proved to be too coarse. To facilitate more precise control; an analogue input was incorporated that combined with the serial command inside each UPS unit to produce the voltage demand.

Unlike the normal operation of mains fed UPS; in this application the voltage output is locked to an accurate, fixed frequency reference. It was therefore possible to improve the output stability by suppressing the frequency control loop and allowing the voltage amplitude control loop to dominate.

CONTROL SYSTEM HARDWARE

National Instruments (NI) hardware has been used to implement the control system. A PXI [3] with Windows XP operating system is used to run the host software with local user interface. This computer communicates using Modbus over TCP/IP to the VISTA Vsystem used for overall control of ISIS and the remote user interface for this system. A NI-8353 2.4 GHz quad-core controller runs the target software, including data acquisition and control loops. This computer uses the NI Real Time Operating System (RTOS) [4], specifically designed for increased reliability, low interrupt latency and high determinism.

Included in the LabVIEW software package is a variety of communication libraries that simplify the process of creating distributed applications. Shared variables are used to pass data around the application, between local programs running on the real time (RT) target and across the network to the host PC.

The RT machine has two remote drops that house the data acquisition modules; one located near the DC power supply and the other near the UPS units. NI MXI-Express modules (NI PXI-PCIe8362) are used to provide a 110 MB/s bridge that extends the PCI backplane of the RT machine so that this and the two remote PXIs appear as one system. Data acquisition (DAQ) is performed by NI PXI-6289 modules that have high accuracy in amplitude, used for measuring the DC current transformers (DCCT) and outputting control values to the power supplies, and PXI-6133 modules that have high accuracy in time. The communication to the UPS units is via RS-485, provided as four ports using PXI-8432. Figure 2 shows a schematic of the connectivity of the control hardware.

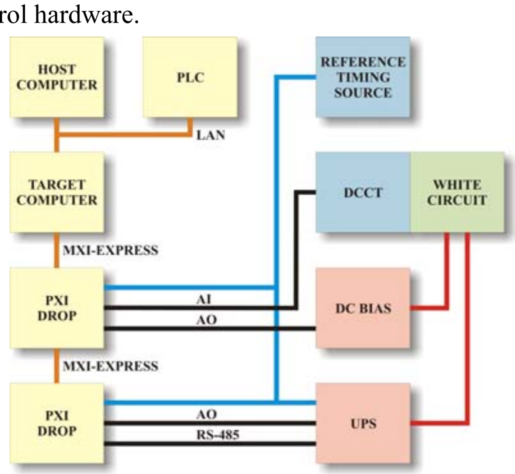

Figure 2: Control system hardware.

In addition to a beam permit system and a personnel protection system; a PLC supervises the power supply interlocks. Its function is to prevent the power supply from energising if an interlock is not present and to turn the power supply off if an interlock is lost whilst operating. The PLC is used instead of the LabVIEW system because it is considered less prone to failure, from either software or hardware, and at lower risk of programmer error. The PLC was also part of the old control system and is therefore a trusted and proven technology. The LabVIEW system does communicate to the PLC in order to send On/Off commands to the power supplies and also to get status information.

METHOD OF CONTROL

The control software was written using LabVIEW, for its in-built ability to communicate to the equipment being used and for the ease at which code can be viewed and maintained.

The host program runs on the Windows PXI and has no functions that are critical in order to control the power supplies current levels or interlocks, and therefore the performances of the PXI or operating system are not detrimental to the system.

The RT machine runs the target program which contains several tasks running in parallel and are shared over the machines four processor cores. In this paper attention will be given to the tasks that acquire data from the DCCTs and then process the values to generate a control output. The other tasks that are concerned with the motor-alternator set, status of power supplies, interlocks, program watchdogs, error handling and remote user interface will not be discussed in detail.

The magnet current is measured by two DCCTs which, through transducers, provide 0-10 V signals representing 0-1200 A. Only one of the two DCCT measurements are used, manually selected by the user although the controller will automatically switch to the other if an error is seen with the primary selection. Each signal is read continuously at 10 kHz and is represented as a waveform data type containing 800 samples, a timestamp of the first sample and the sampling rate. The DAQ loop is run every 80 ms in order to obtain all acquired samples. Despite the low jitter of an RTOS, it is possible that the loop will finish early, in which case it would wait for the required samples to become available, or finish late, in which case the DAQ module would use on-board memory to store the last samples, in this case up to 4095 samples.

After 80 ms the acquired data is available for the control loop to use. A ‘producer-consumer’ architecture has been employed so that the DAQ loop is allowed to repeat immediately, and the control loop can run in parallel. The data acquired in the ‘producer’ loop is placed in a reserved memory area ready for the ‘consumer’ to read. The control loop is delayed so that a constant phase between the two loops is maintained.

The magnet current waveform is expected to be a positive offset sinusoid with 20 ms period, and so four waveforms should be captured in each iteration. The DC component is found by taking a mean of all samples in the waveform. This is equivalent to a fast Fourier transform (FFT) but takes fewer calculations.

Before calculating the AC component of the waveform a Butterworth bandpass filter is applied. The RMS value is then taken and included in a running average of previous values with a Hanning window applied. The result is scaled to give a measure of peak amplitude rather than RMS. This method has been shown through testing to be more accurate than a FFT method, as the period of the measured waveform varies and does not always factorise into the sampling period, and therefore does not fit exactly into any ‘bin’.

Both the DC bias supply and the UPS control loops operate by a similar method. The DC has some complexity removed as the control output is simply an analogue signal which the power supply follows. The UPS also requires a serial command to set the desired output voltage, known as the register value, as well as the analogue output.

The run-up procedure is handled in a part of the program with pseudo state machine architecture. The state selection is dependent upon the error between the setpoint and the current reading. The aim is to allow the power supply to reach full current as quickly as possible, whilst maintaining close control at operational levels. For example; if the setpoint is much greater than the current reading then the output will be increased in open loop towards the maximum output possible. As the error becomes smaller the control state changes to provide different parameters that prevent overshoot and eventually a state using feedback is engaged and the output is controlled by a PID loop.

There are special states that provide addition protection and diagnostics of the power supplies, one of which controls the initial ramp up. In this state the output is limited to a low level; once the control system has confirmed that the power supply and magnet current are varying in agreement then the limit is removed and the next state may be selected.

Each state uses the previous output and the parameters for that state to generate an analogue output value, and for the UPS, a setpoint register value and a register rate of change value.

The UPS values are then passed to a program that handles the serial communications. This program is also a state machine; changing between normal operational state, to initialise and close communication ports states when first running the program or when the controller detects a communication fault. In normal operation the state of the UPS outputs are monitored to confirm that the units are working correctly, outputs are balanced and that the absolute maximum ratings are not being exceeded. If necessary the register value setpoint will be reduced to prevent damage to equipment.

The previously imposed limit of 2 V difference between all UPS outputs is still valid. Therefore after each register value command is sent, the status of each UPS is checked. Once all have confirmed that the new value has been accepted and the output voltage has followed the change then another register value command can be sent. The current register value, the register value setpoint and the time taken for all UPS to equalise is used to generate the next register value command.

The analogue output value is fed into a rate of change limiter program that prevents the output from changing faster than the predetermined limits, and then compared to absolute limits before being output to the UPS units. Inside each UPS, the analogue is converted to a register value, which is added on to the register value set by the serial command and can change the magnet current by up to 20 A. This is adequate to correct for errors due to load variations and compensates for the effects to the circuit components caused by temperature fluctuations.

Using this method of combined serial communication and analogue control loop gives the fine adjustment needed to operate the UPS successfully and control the ISIS beam. However the time taken to achieve full current was still limited by the serial communications having to check the status of each UPS before sending the next register value command. To improve this, the task of the serial port was split between four separate ports operating independently. It is still necessary to wait for the UPS to equalise before sending the next command, but with a dedicated serial port communicating to each UPS then the read back delay was significantly reduced. The UPS can now ramp from zero to full operating current in a controlled manner within thirty seconds, however for the benefit of old equipment this has been limited to five minutes.

CONCLUSION

The new ISIS MMPS control system has been implemented using National Instrument hardware and programmed using LabVIEW. It is capable of controlling both the DC bias and UPS power supplies that provide the magnet current to achieve an improved stability and desired performance in order to control the ISIS beam.

REFERENCES

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

[2] S. West, J.W. Gray, W.A. Morris, “Upgrade of the ISIS Main Magnet Power Supply”, Rutherford Appleton Laboratory, EPAC 2004 p1467.

[3] “PXI [PCI eXtensions for Instrumentation] combines the Peripheral Component Interconnect (PCI) electrical bus with the rugged, modular Eurocard mechanical packaging of CompactPCI and adds specialized synchronization buses and key software features.” What is PXI?, http://zone.ni.com/devzone/cda/tut/p/id/481

[4] National Instruments, “What is a Real-Time Operating System (RTOS)?”, NI Tutorial 3938, http://zone.ni.com/devzone/cda/tut/p/id/3938