The Xenon1T Dark Matter Search: Experience with a Slow Control system based on industrial process control hardware and software

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***Abstract*—Xenon1T is the next generation Dark Matter search using 3.5 tons of liquid Xenon for direct detection of Dark Matter. A dual-phase Liquid Xenon Time Projection Chamber (TPC) shielded below 1400m of rock at the Gran Sasso underground laboratory in Italy serves as both target and detector. The TPC is inside a 10m high by 9.5m diameter water Cerenkov detector serving as an active muon veto. The Slow Control system is based on industrial process control hardware and software. It is now being used to commission the detector. The system provides secure monitoring and control by collaborators, shifters and experts at both local and remote locations. 3.5 tons of liquid Xenon requires extreme care to guard the safety of the instrumentation and to prevent the loss of any of the high value Xenon. To this end, the system makes use of guarded operations, redundancy and is fail safe at the SCADA level. The system consists of a distributed architecture of networked local control units (PACs) with touch panels for local control and redundant central Supervisory Control And Data Acquisition (SCADA) computers. All operating parameters and their history are stored and can be displayed. Alarms are sent by text messages sent by both email and cellular network and by recorded voice over land telephone lines. Experience with both the benefits and the disadvantages of using industrial process control hardware and software will be presented.**

***Index Terms*—Dark Matter, Slow Control, Distributed System, Programmable Logic Controller, SCADA Systems, OPC, Process control, Xenon1T experiment.**

I. INTRODUCTION

THE Xenon1T experiment is a direct detection dark matter experiment, consisting of a dual-phase time projection chamber (TPC) that uses ultra-pure xenon as detection medium. This TPC is shielded by 1400m of rock, at the Gran Sasso (Italy)[1] underground laboratory facilities, that serves as both target and detector. The successfull outcome of the XENON100 experiment, that published the worlds best upper limits to WIMP-nucleon cross-section [1] triggered the design and construction of a new detector (with ton-scale mass), Xenon1T, that is currently being commissioned in Hall-B of the LNGS laboratory. The data taking is expected to start still during late 2016.

Fig. 1. The Xenon1T underground facility at Laboratori Nazionali del Gran Sasso (LNGS), in Italy. At the left the water tank that holds the TPC inside and on the right the support 3 plan building.

II. THE SLOW CONTROL SYSTEM

Almost all the detector devices are monitored and controlled by an experiment-wide Slow Control System (SCS) that ensures a coherent, safe and efficient operation of the experiment. The operators interact with the SCS either through local interactive touch panels, devoted to specific functional sub-systems, or by means of a centralized control room, where an overall view and control of all the systems is available. In either case, the operators have clear and intuitive access to a graphical user interface and can visually monitor and control the values, state and history of the physics relevant variables.

The organization of the SCS is based on a hierarchical structure with distributed responsabilities. Each functional subsystem is responsible for the development and integration of their instrumentation's interface to the SCS, according to the base rules and following a detailed technical design report issued at the experiment early stages.

Given the dimension of the set of instruments to monitor and control, a scalable and distributed SCS topology is mandatory[2], evolving from the previous experience with the Xenon100 monitoring system [3]. The architecture of the SCS is based on a SCADA (Supervisory Control and Data Acquisition) paradigm very used in industrial instrumentation [4]. In the following sections, the SCADA layers of Xenon1T

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[1] http://www.lngs.infn.it

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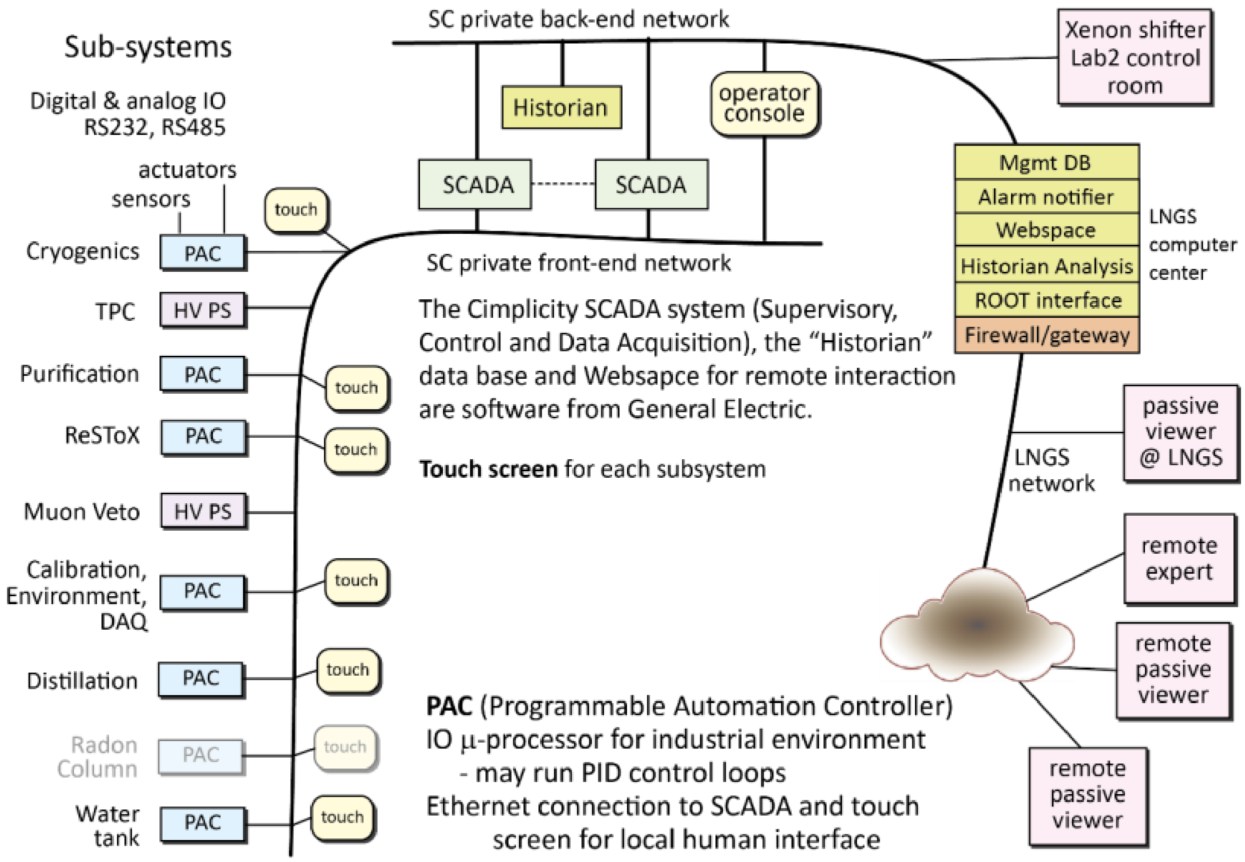

The Cimplicity SCADA system (Supervisory, Control and Data Acquisition), the "Historian" data base and Websapce for remote interaction are software from General Electric.

Touch screen for each subsystem

PAC (Programmable Automation Controller)
IO μ-processor for industrial environment
- may run PID control loops
Ethernet connection to SCADA and touch screen for local human interface

Fig. 2. Diagram of the physical layout of the Slow Control System for the Xenon1T. A private front-end network of PACs and touch panels is isolated from the back-end network being the fail-over SCADA server the only point of contact of these two networks. supervisory components are all alocated at the back-end.

are described (supervisory, front-end and devices) and a global analysis, on the benefits and pitfalls of the use of industrial off-the-shelf instrumentation, is presented.

A. Architecture and Components

The Xenon1T experiment is composed of several functional sub-systems (Cryogenics, Purification, Recovery and Storage, Distillation, Calibration and Water Loop). These subsystems are closely interconnected and in some cases dependent on the operation or state of the others. Each subsystem has a devoted controller or PAC (Programmable Automation Controllers) along with a touch-panel that allows local operation through an intuitive graphical interface. The local controllers are the RX3i family of Programmable Automation Controllers (PACs) and input/output modules from General Electric. Each touch panel allows control of the corresponding subsystem even if the central SCADA system is unavailable or the subsystem is *off-line*. The local controllers can also communicate directly with each other via EGD[2] protocol. Control loops are implemented at both the instrument and PAC level.

CAEN HV voltage controllers for the TPC and Muon Veto photomultipliers are integrated into the system by means of their OPC (OLE for Process Control) servers. The DAQ system can query Slow Control variables and supply DAQ status values via dedicated webservices developed by both workgroups.

The central SCADA units, running Cimplicity-HMI[3] 8.20 from General Electric, provide real-time visualization of all monitored sensors, control of equipment, alarms, long term data recording and interfaces to the outside world. Two SCADA servers run in active-passive failover mode. The Historian database records all the operating parameters and can be queried to produce trends, reports and correlations. Excluding the $\approx$350 HV channels, there are over 1000 sensor/actuator data points tracked in the database. Besides the commercial solutions adopted, a few more were developed to enhance the supervisory layer functionalities: Xe1tViewer (a passive cross platform web server tool for data visualization on computers, tablets or mobile phones), the Alarm Notification Server (an alarm broadcast tool via email and SMS channels) ot the ROOT tree interface scripts.

The Xe1tViewer is a cross-platform web server that was designed from scratch in order to allow generalized monitoring of the experiment status without platform or number of simultaeneous users logged in. The server synchronously queries the Historian database via an OLEDB data source

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[2] Ethernet Global Data a producer-consumer memory shared protocol from GE used to communicate between PACs and with the SCADA or Historian servers

[3] https://www.ge.com/digital/products/cimplicity

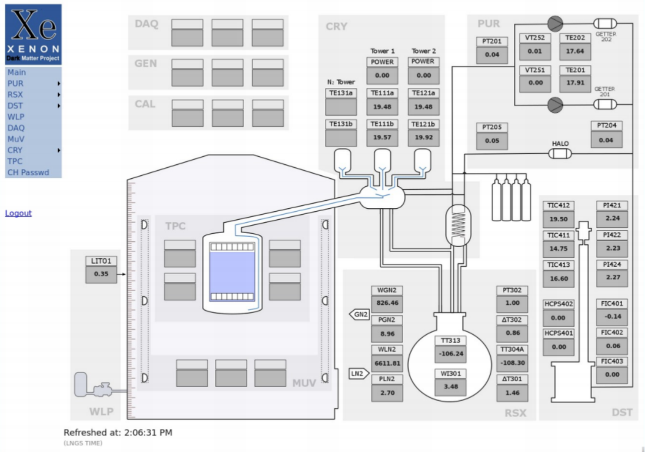

Fig. 3. Layout of the main screen of the web client Xe1tViewer. A global overview of the Key Performance Indicators allows a overall glance of the experiment status.

connection and creates a graphical user interface similiar to that provided by SCADA (and also available at touch-panels level). Data is updated almost in real-time and has no browser or major computational client limitations. Xe1tviewer also allows graphical and data export on the fly. For security reasons, the access to the Xe1tViewer is only possible inside the LNGS internal network, or via LNGS VPN from the external world.

The Alarm Notification server is another of the developed tools to increase SCS functionality by providing universal alarm notification (via email and SMS). Alarm conditions at the PAC level are signalled and captured by an Alarm and Event Express (AEX) subscription[4] and an internal message from AEX is produced. A dedicated C# application broadcast and logs the alarm messages through email and SMS using a third party SMS gateway webservice (Nexmo)[5].

Data can also be exported by means of a Python scripting ROOT[6] interface that allows queries to the Historian database and returns a properly formated ROOT tree with the queried data for further analysis.

B. Infrastructure and Security

All the components of the supervisory layer of SCS run on a native virtualization platform (VSphere) over several Dell[7] PowerEdge R420 and R620 servers (with Intel[8] Xeon family processors). The different virtual machines (VM) are devoted to specific roles. The SCADA, Historian or Webspace are independent VMs. All the machines run Windows Server 2008 R2[9].

The security architecture has two layers controlled by a firewall/gateway. Xenon collaborators authenticate themselves to the Virtual Private Network (VPN) and are given access to monitoring and control applications according to their roles. Experts may gain access to the Slow Control networks. A dedicate backup network connects directly from the Slow Control underground to an internet point-of-presence independent from the Gran Sasso laboratory network.

III. ON THE USE OF INDUSTRIAL INSTRUMENTATION

There are many clear and compelling benefits to using industrial hardware and software. Just to name a few let's state the available portfolio of hardware modules, with many different roles and protocol interfaces, along with a set of mature software tools are amongst the more relevant. This ensures a much short development and setup cycle and allows to focus on the high-end experimental control rather than dealing with low level technical debugging. However, this choice still presents some challenges when it comes to the implementation of additional functionalities to the system because these solutions are naturally protected and not allways suitable to an easy interface. Besides, companies supplying industrial process control hardware and software are not accustomed to working with research groups and have constraints that must be taken into account in order to work successfully with them. Nevertheless, the installed SCS suites all the functionality initially requested keeps the pace for unavoiable add-ons.

IV. CONCLUSIONS

A Slow Control System for the Xenon1T dark matter search experiment, currently commissioning at LNGS, in Italy, has been presented. The system in based on a commercial SCADA tool, Cimplicity, but several other functional add-ons where required and build as components of the supervisory layer of the SCS.

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REFERENCES

[1] E. Aprile *et al.*, "Dark matter results from 225 live days of XENON100 data," *Phys. Rev. Lett.*, vol. 109, p. 181301, Nov 2012. [Online]. Available: http://link.aps.org/doi/10.1103/PhysRevLett.109.181301

[2] P. Bordalo *et al.*, "Control systems: An application to a high energy physics experiment COMPASS," in *Proceedings of 2012 IEEE International Conference on Automation, Quality and Testing, Robotics*. Institute of Electrical & Electronics Engineers (IEEE), may 2012. [Online]. Available: http://dx.doi.org/10.1109/AQTR.2012.6237669

[3] E. Aprile *et al.*, "The distributed slow control system of the XENON100 experiment," *Journal of Instrumentation*, vol. 7, no. 12, p. T12001, 2012. [Online]. Available: http://stacks.iop.org/1748-0221/7/i=12/a=T12001

[4] A. Daneels and W. Salter, "Selection and evaluation of commercial SCADA systems for the controls of the CERN LHC experiments," in *Accelerator and large experimental physics control systems. Proceedings, 7th International Conference, ICALEPCS'99, Trieste, Italy, October 4-8, 1999*, vol. C991004, 1999, pp. 353–355, [,353(1999)]. [Online]. Available: http://www.elettra.trieste.it/icalepcs99/proceedings/papers/ta2o01.pdf

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[4] AEX is a tool provided by GE to deliver alarm notification but with limitations on the configuration of messages and destinations

[5] http://www.nexmo.com

[6] https://root.cern.ch/

[7] http://www.dell.com/

[8] http://www.intel.com/

[9] https://technet.microsoft.com/library/dd349801