NEW ELECTRICAL NETWORK SUPERVISION FOR CERN: SIMPLER, SAFER, FASTER, AND INCLUDING NEW ADVANCED FEATURES

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Abstract

The CERN electrical network carries more than 235 MVA and is currently being consolidated and extended. From a consumption point of view, 1.2 TWh have been used in 2012, half of it for the LHC itself, which roughly represents the consumption of a town of about 250,000 people. In 2012, an effort started to replace the ageing current electrical supervision system (managing more than 20,000 devices and 200,000 tags) by a WinCC OA-based supervision system in order to unify the monitoring systems used by CERN operators, and to leverage the in-house knowledge and internal tools and frameworks. Along with the classical functionalities of a typical SCADA system (alarms management, event management, trending, archiving, access control, etc.), the supervision of the CERN electrical network requires a set of domain specific functionalities. Such functionalities include state estimation, power flow calculation, contingency analysis, etc. Moreover, as electrical power is a critical service for CERN operations, a high availability of its infrastructure is required, as well as of its supervision system. The new SCADA system is therefore redundant along with a disaster recovery system which is itself redundant (2x2 redundancy scheme) located in a different building. In this paper, we present the overall architecture of the new supervision system with an emphasis on the parts specific to the supervision of electrical network.

INTRODUCTION

The CERN electrical network is supplied by Electricité de France (EDF), the French national grid company, through a 400kV transmission line and by ALPIQ, the Swiss regional grid company, through a 130kV transmission line in case of emergency or maintenance. The LHC is supplied through a 66kV network and an 18kV network supplies the other accelerators (e.g. PS and SPS). With a total consumption of 1.2-TWh in 2012, which about 50% is dedicated to the LHC, the CERN annual consumption is equivalent to a medium size town of 250,000 inhabitants. From a supervision point of view, the CERN electrical network is made of more than 200,000 tags (measurements and controls) distributed across 20,000 devices (primary and secondary devices).

Since 2012, an ongoing effort to replace the current SCADA system has been started to bring better performances, better availability and new functionalities such as network simulation capabilities, network contingency analysis, events playback, outage management system, etc. While several industrial products may seem to fulfil most of the new SCADA's requirements, none of them offer the wide range of required functionalities with the needed flexibility: it was therefore decided after a thorough market evaluation to leverage the internal CERN expertise on WinCC OA [1] for an in-house development of the new SCADA for the CERN electrical network by reusing the tools and frameworks developed during the LHC era. The new SCADA is based on WinCC OA in order to unify the monitoring systems already developed and used by CERN operators and to benefit from the internal knowledge, and frameworks and tools already developed (JCOP [2], UNICOS [3], etc.).

Monitoring an electrical network requires two main types of functionalities: *(a)* the *generic* SCADA functionalities applicable to any or most type of process such as alarm management, event managements, trending, archiving, access control, network colouring, animated event replay, etc.; and *(b)* the *domain specific* functionalities which are dedicated to electrical network such as state estimation, contingency analysis, outage management system, etc. All of the *generic* SCADA functionalities were implemented directly in WinCC OA re-using or customizing already existing components (e.g. alarm screen, event screen, archiving) or from scratch if no development was done previously (e.g. network colouring, delayed alarm management, animated event replay). The domain specific functionalities have been mainly delegated to a third-party software (PowerFactory from DigSilent [4]) which behaves as a calculation engine transparently to the operators. Moreover, as electrical power is a critical service for CERN operations, a high availability of the electrical network infrastructure is required as well as of its supervision system. The new SCADA system is therefore redundant along with a disaster recovery system which is itself redundant (2x2 redundancy scheme) located to a different building.

The remainder of this paper is organized as follows. A first section presents the overall architecture of the new SCADA system with a focus on the redundancy scheme. The following sections focus on the generic SCADA functionalities which have been implemented specifically for the monitoring of the electrical network and then on the domain specific functionalities. Due to space restriction, the two sections focus on the implementation of delayed-alarms and network colouring for the generic functionalities and on the interaction between WinCC OA and Power-

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Factory for the domain specific part. Finally, a last section concludes the paper.

ARCHITECTURE

The new SCADA is based on a 2x2 redundancy scheme as illustrated in Figure 1. The first set of redundant servers is located in the CERN Control Room (CCR) along with most of the SCADA servers dedicated to the LHC infrastructure. Another set of redundant servers is located on another site (Disaster Recovery Center or DRC) in case the CCR becomes unavailable. The redundancy mechanism implemented in each set is the one provided by WinCC OA, i.e. hot-standby redundancy: only one server is active at a time and the other one being ready to take over the operation in case of failure. However, the redundancy between the CCR and the DCR servers is a hot-hot redundancy scheme with both center active at the same time. It is also worth noting that a set of additional redundant servers are dedicated to the execution of Digsilent PowerFactory to perform the domain specific functionalities and are only present in the CCR and not in the DCR. The rationale for not having PowerFactory in the DCR is a trade-off between cost and functionalities offered by the SCADA: the DCR is only supposed to be used under exceptional circumstances and thus only the core functionalities, i.e. mainly the alarms and events management, are really needed under these circumstances.

The archiving mechanism implemented is twofold: *(a)* the main archiving operation is performed on the central Oracle database provided by the CERN IT infrastructure and *(b)* a redundant local archiving which is file-based and stores data for the last seven days in case the main archive is not available.

All SCADA servers are connected to the CERN Technical Network (TN) to which the Remote Terminal Units (RTU), which act as data concentrator, are also connected. The system comprise more than 65 RTUs which are physically located in the substations. They provide most of the field measurements and controls through the IEC 60870-5-104 protocol [5] (abbreviated to IEC 104). An additional small amount of measurements are coming directly from some specific devices (e.g. time servers) located in the substation but connected to the TN through SNMP.

Finally, the SCADA also publishes some measurements to the overall CERN control infrastructure for global logging, alarms and supervision purposes.

GENERIC SCADA FUNCTIONALITIES

Most of the functionalities implemented for the CERN electrical SCADA fall into the category of generic SCADA functionalities, i.e. they are not tightly coupled to the nature of the process, even though some of them have never been implemented in the previous WinCC OA-based SCADA developed at CERN. It includes, but is not limited to, user management, archive and trends, devices and tags finder, alarm inhibition management, alarms and events management, and network colouring. In this section, we focus on two new functionalities which are the management of delayed alarms and network colouring. While these two functionalities were developed specifically for this project, the other functionalities are provided by already existing components of JCOP and UNICOS frameworks.

Delayed Alarm Management

A delayed alarm is an alarm which is active only when a measurement reaches a given threshold for a given period of time. As an example, an alarm should be activated if the oil temperature of a transformer reaches more than $100°C$ for at least 60 consecutive seconds. WinCC OA does not provide an *out of the box* mechanism to handle such alarms and thus a dedicated alarm handler has been developed. The handler is implemented as a WinCC OA CTRL script which relies on the duplication of measurements. For each measurement requiring a delayed alarm, which represents about 100,000 measurements, one measurement holds the value coming from the field and one measurement contains the filtered value according to the alarm definition. The CTRL script is in charge of updating the filtered values. First, an event-triggered based part of the script is a callback function registered to the field measurements and executed whenever the values of the measurements change. It then determines if the measurement exceeded its threshold(s) or not. Second, a time-triggered part of the script is executed every 2 seconds and evaluates if the tags which have reached their threshold have their period expired. If the period is expired, the filtered measurement is then updated to its new value, i.e. value of the field measurement when it first reached its threshold, which automatically triggers a *standard* WinCC OA alarm. The design of the delayed alarm management in two parts allows WinCC OA to cope with high data rates.

Network Colouring

Network colouring aims at assigning colours to the primary equipment of the process according to some given properties (e.g. temperature, voltage, pressure, etc.) in order to display synoptic views with enhanced information to the operators. While the colouring can be performed for different processes, e.g. cryogenic or cooling and ventilation, in the context of the electrical network the properties considered are voltage classes, network types, energization state and sources of energization. Two types of network colouring are identified: static and dynamic network colouring. Static network colouring relies on properties which do not evolve over time and therefore does not require any computation. This is the case for the colouring by voltage classes and network types, which are the rating or classification of the primary equipments. Unlike static colouring, dynamic network colouring depends on the current connectivity of the electrical network, i.e. on the status of the switching equipment, and requires to be updated continuously. Dynamic network colouring has been imple-

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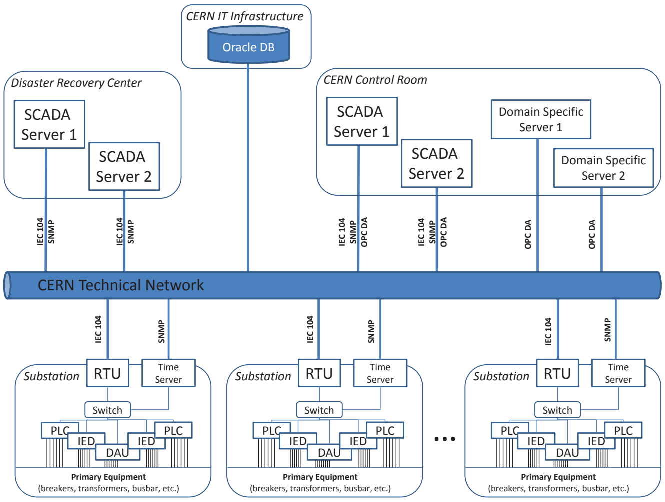

Figure 1: Overview of the architecture of the new SCADA for the CERN electrical network.

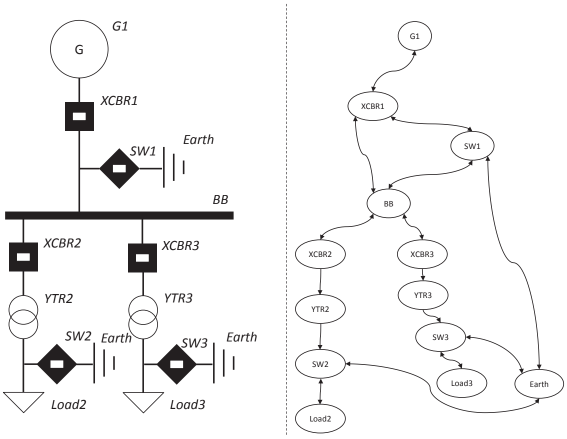

Figure 2: Example of the mapping between the electrical network connectivity and its graph representation.

mented as a WinCC OA CTRL script which periodically analyses the entire network. To do so, the electrical network is represented internally as a directed graph as seen in Figure 2: the nodes represent the primary equipment and the edges represent the physical connection between the primary devices. The direction of the edge represents the possible flow of power: for example switching equipment can have power flowing indifferently from one end to the other, whereas transformers can only have power flowing from the primary to the secondary windings, i.e. back-feed is not considered. Nodes representing generator devices, such as the interconnection with the external grids (RTE, EDF and EOS), the diesel generators and the UPS, are considered as sources in the graphs. Nodes representing switching equipment have properties depending on their status which make them blocking or passing. Finally, node representing the earth is also considered as a source the same way generators are. Each node has properties which are calculated dynamically and corresponding to the two types of dynamic colouring. For example, the busbar node has a property *ENERGIZATION* which can be either *ENERGIZED, NOT ENERGIZED, EARTHED* or *UNDEFINED*. The CTRL script is run every with 5 seconds and implements the following basic steps:

1. Initialize each node of the graph to *NOT ENERGIZED*
2. Update the status of each source node according to the status of the generators (e.g. *ON* or *OFF*)
3. Update the status of the switching nodes according to the status of the switching equipment (i.e. blocking or passing)
4. For each source node, and starting by the earth, explore all accessible nodes and assign the calculated properties (e.g. *EARTHED* if the source node if the earth)

The motivation behind implementing a time-triggered network colouring instead of a event-triggered one (e.g. colouring calculated only when the status of a generator or a switching device changes) is to prevent overloading the system in case of a major outage. Moreover, it also increases consistency as the colouring is applied on a snapshot of the network connectivity instead of trying to *follow* in real-time. From the operator point of view, the consistent calculation avoids *blinking* synoptic views in which different part of the view is updated asynchronously. The downside of the approach is that a constant load is imposed to the system as even if nothing changes the colouring is still calculated. This drawback is anyhow mitigated as only the changes observed between two successive calculations are actually applied.

DOMAIN SPECIFIC FUNCTIONALITIES

The domain specific functionalities are dedicated to the electrical process and encompass state estimation, contingency analysis, simulation and, in the future, it may also include optimal power flow calculation. State estimation aims at calculating the most probable state of the network, i.e. the voltage phasor at each bus, given a set of measurements by using the redundant measurements to filter out errors due to sensor inaccuracy, imprecision and sensor failures. The contingency analysis performs periodically a *what-if* scenario to evaluate the impact of a failure of one or more equipments to identify the weak points of the network. Finally the power flow simulation is similar to the contingency analysis but is performed on-demand: for example, before a maintenance operation of a transformer the operator needs to see what is the impact on the network of the transformer being down in terms load on the other transformers placed in parallel.

The domain specific functionalities are executed by the external software Digsilent PowerFactory but all configuration and results are performed and shown from the WinCC OA SCADA interface. PowerFactory is thus a black-box and is not seen by the operators nor the administrators. Similarly to the network colouring functionality, PowerFactory requires the knowledge of the network topology and the status of its components. The network topology is sent from WinCC OA to PowerFactory to identify the different components, their connection but also their ratings (e.g. for a cable it includes its rated voltage and current, its *pi* modelling with its resistance, reactance and suspectance and length). This exchange is file-based and is done only when the structure of the network changes (e.g. adding, removing or replacing an equipment). The file is text-based and formatted according to the proprietary PowerFactory representation, but an evaluation of using the IEC 61968 [6] (CIM Standard) is foreseen. During the normal operation of the SCADA, the status of the switching equipments and the generators is sent from WinCC OA to PowerFactory through OPC DA [7]. Similarly, the results of the different calculation (e.g. state estimation and contingency analysis) are sent from PowerFacory to WinCC OA through OPC DA. Unlike the network colouring, the sending of status information from WinCC OA to PowerFactory is event-based, thus calculations are performed whenever the status of an equipment changes in the network. Indeed, even in the case of a major outage, the SCADA system is only slightly impacted as all the load is handled by the server dedicated to PowerFactory.

The reason for choosing PowerFactory has been highly motivated by the fact that all operations can be triggered pro-grammatically through an extended API and thus does not require the user to interact with its HMI allowing it to be executed as a black-box. Therefore a set of WinCC OA CTRL script and PowerFactory scripts are being implemented to format the file containing the network topology and equipment ratings, set the OPC addresses on both sides and trigger the different calculation.

CONCLUSION AND OUTLOOK

This paper gave an overview of the new SCADA system for the CERN electrical network by presenting its main architectural principles and some innovative functionalities (delayed alarm management, network colouring and Digsilent PowerFactory integration for domain specific functionalities). A full proof of concept including the integration with PowerFactory was implemented and demonstrated in 2012 on a small subset of the network. The first half of 2013 was dedicated to the development of the new SCADA with a focus on the core functionalities (alarms and events management, delayed alarm, alarm inhibition, device and tag finders, network colouring, archive, trend), while the second part of 2013 is dedicated to the deployment which is performed gradually (as of September about 30,000 tags are integrated). The goal is to have the whole electrical network supervised by the new SCADA by the end of 2013. The second half of 2013 is also dedicated to the development of the integration of Digsilent PowerFactory to envision a deployment in 2014.

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