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AUTOMATIC RECONFIGURATION OF CERN 18 kV ELECTRICAL DISTRIBUTION – THE AUTO TRANSFER CONTROL SYSTEM

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Abstract

Availability is key to electrical power distribution at CERN. The CERN electrical network has been consolidated over the last 15 years in order to cope with the evolving needs of the laboratory and now comprises a 210 MW supply from the French grid at 400 kV, a partial back up from the Swiss grid at 130 kV and 16 diesel generators. The Auto Transfer Control System has a critical role in minimizing the duration of power cuts on this complex electrical network, thus significantly reducing the impact of downtime on CERN accelerator operation. In the event of a major power loss, the control system analyses the global status of the network and decides how to reconfigure the network from alternative sources, following predefined constraints and priorities. The Auto Transfer Control System is based on redundant Programmable Logic Controllers (PLC) with multiple remote I/O stations linked via an EtherNet/IP ring (over optical fiber) across three major substations at CERN. This paper describes the system requirements, constraints and the applicable technologies, which will be used to deliver an operational system by mid-2020.

MOTIVATION

Three of the main 18 kV substations, ME9, SEM12 and BE9, located in different CERN geographical sites, are involved in the Auto Transfer control system. These are three key substations supplying the SPS (Super Proton Synchrotron), the North Area experimental areas, the Prevessin site (stable network), the LHC (Large Hadron Collider) 18 kV loop, the Meyrin site, the ATLAS Experiment, the LHC1.8 site (general services and machine networks) and the safety networks. The three substations are, under nominal condition, supplied via the French grid at 400 kV but they can also be supplied by the Swiss grid at 130 kV in case of problems on the French grid.

The ME9 substation is obsolete, more than 40 years old. It is currently undergoing a major renovation, in line with the electrical network consolidation plan and in conjunction with CERN accelerators shutdown phase. The renewal of ME9 implied a complete redesign of the substation and therefore of the 18 kV network, bringing improvements in terms of availability and flexibility of the network.

Additionally, with the existing Auto Transfer being obsolete, difficult to maintain and evolve, it was the right time for re-engineering and replacing the existing, 20 years old Auto Transfer control system.

The system was only partially mastered in terms of hardware and software, as its development and implementation had been outsourced to an external company. This limitation often created difficulties in case of major power outages that involved an auto transfer requiring post-mortem analysis. For this reason, it was decided to go for an internal implementation of the new system.

The project specification was developed in direct contact with the operation team, who has the expertise about the system expected behavior in every possible configuration scenario. The specification covers all the operation needs and allows future evolutions of the network with minor modification at the software level.

SPECIFICATION

The Auto Transfer control system main function consists in automatically reconfigure and resupply the three 18 kV substations in case of a power outage due to failures on the French grid (400 kV), the Swiss grid (130 kV) or internal failures related to transformers, bus bars or inter-substation liaison cables. See Fig. 1 for details. However, resource limitations and system operational constraints shall be taken into account. Examples are the power availability of each source, limited by its upstream transformer, and the maximum power accepted by the inter-substation liaison cables. Theoretically, up to six sources can be used to supply the seven bus bars composing the three substations; none of them can be left in parallel with another, particularly between the French and the Swiss grid. The Auto Transfer control system shall be able to reconfigure the network by opening/closing breakers with a minimum of maneuvers, maximizing the number of supplied bus bars by their nearest source, according to a predefined configuration set by the user (operation team).

THE SOLVER APPROACH

In order to cover the specified requirements, several solutions were envisaged. Former system used a *domino* approach, which consisted in supplying each bus bar as a separate entity of the network: a *domino*. Using this approach, each bus bar had one main (nominal) source and one or several backup sources. The control system managed each *domino* so that it could be powered by one of the breakers directly attached to it, according to predefined priorities. This approach created dependency between *dominos*, leading to unnecessary maneuvers and a need of synchronization between substations. Furthermore, it was tailored to the existing network configuration, limiting its evolution.

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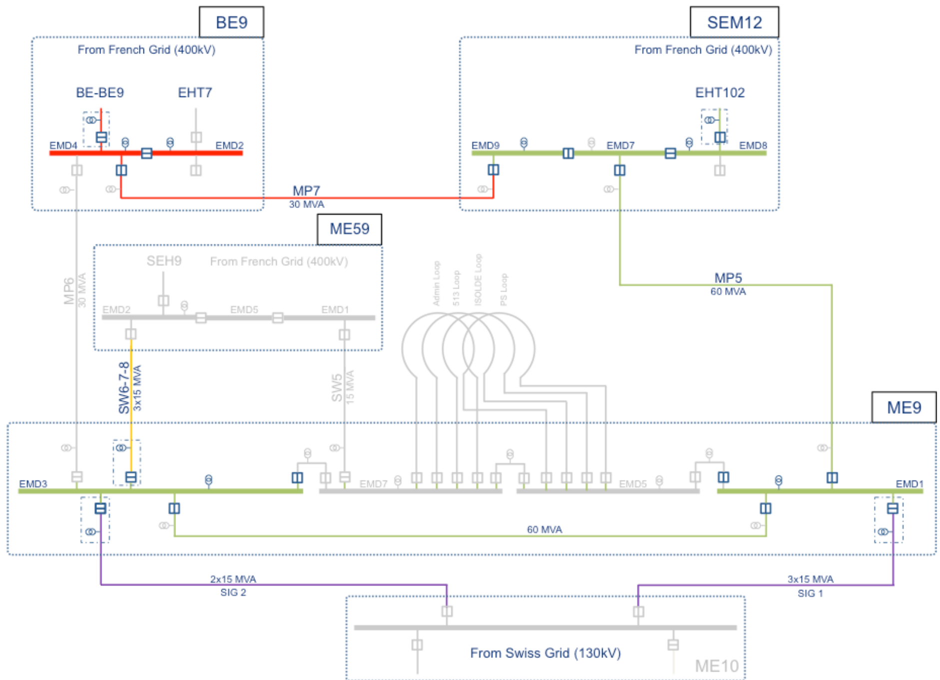

Figure 1: CERN 18 kV single line diagram representing the six sources capable of supplying the seven bus bars spread over the three main substations ME9, SEM12 and BE9. Breakers in bold are operated by the control system.

The new 18 kV network being redesigned in ME9 to bring extra redundancy and availability has made this approach no longer suitable to the needs. The new network layout can create rings via switchgears that are not controlled by the control system and therefore the *dominos* can no longer be managed. In order to solve this problem, the *Solver* approach was proposed. This approach was initially based on G. Dantzig's simplex algorithm [1] for maximizing a linear function but its implementation on a PLC would become very complex due to the high number of variables needed to describe the maximization functions, restrictions and the intermediate calculations to achieve the optimal result. Based on this algorithm, the *Solver* approach was designed and implemented.

The *Solver* approach consists of analyzing the entire network as a single entity and calculating dynamically the possibilities of supplying it entirely. These possibilities are calculated based on the status of the electrical path needed to connect one source to a given bus bar. These paths are based on settings predefined by the operation team and live status of the network elements (availability, faults, etc.). With these possibilities the *Solver* has two main objectives to achieve:

- Maximize the number of supplied bus bars
- Maximize the score[1] of the entire network

Operators configure the system by assigning to each bus bar, its main (nominal) source and the backup sources to be used in order of priority. Once the configuration is set, a pre-check is made by the control system to guarantee the specified restrictions are respected. Restrictions are imposed by the physical architecture of the network. Once the configuration is validated, the Auto Transfer control system analyzes the current status of the network and evaluates if the two main objectives can be improved or not. If improvement is possible, the control system will act on the concerned switchgear in order to reconfigure the network for the new optimum. If not, the system remains in a *surveillance* mode.

In order to validate this approach, a simulator has been written in Excel (using VBA). This simulator allows the operation team to graphically set the 18 kV network in different scenarios (including power outages, fault, etc.) and define configuration recipes for the network (Table 1). Once the simulation setup is ready, operators can run the solver and evaluate the optimal calculated solution.

This tool became a technical communication tool between the operation team (user) and developers, allowing a better understanding of the system and the identification and solution of multiple problems, prior to final implementation of the software.

ARCHITECTURE

PLC and HMI

Schneider M580 redundant PLC will be used to run the control application. This PLC is composed by two redundant CPUs, physically separated (CPU A in ME9 substation and CPU B in SEM12 substation). The two CPUs are connected via a dedicated single mode optical fiber allowing the exchange of data in real time between the primary and standby CPUs. This architecture provides redundancy to the system in case of a major hazard involving ME9 or SEM12. See Fig. 2 for details.

[1] The score is calculated based on the source priority supplying a given bus bar. The nominal sources have the highest score and the backup sources with the lowest priority have the lowest score.

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Table 1: Auto Transfer Control System Configuration

	Source Name						
Bus Bar	**BE/BE9**	**EHT7/E9**	**EHT102/1E**	**SW**	**SIG1**	**SIG2**	**SIG1+2**
EMD4/E9	Backup 1	Nominal	Backup 2	Backup 3	Backup 5	Backup 6	Backup 4
EMD9/1E	Backup 1	Nominal	Backup 2	Backup 3	Backup 5	Backup 6	Backup 4
EMD7/1E	Backup 2	Backup 1	Nominal	Backup 3	Backup 5	Backup 6	Backup 4
EMD8/1E	Backup 2	Backup 1	Nominal	Backup 3	Backup 5	Backup 6	Backup 4
EMD1*9	Backup 6	Backup 5	Nominal	Backup 1	Backup 3	Backup 4	Backup 2
EDM3*9	Backup 6	Backup 5	Nominal	Backup 1	Backup 4	Backup 3	Backup 2

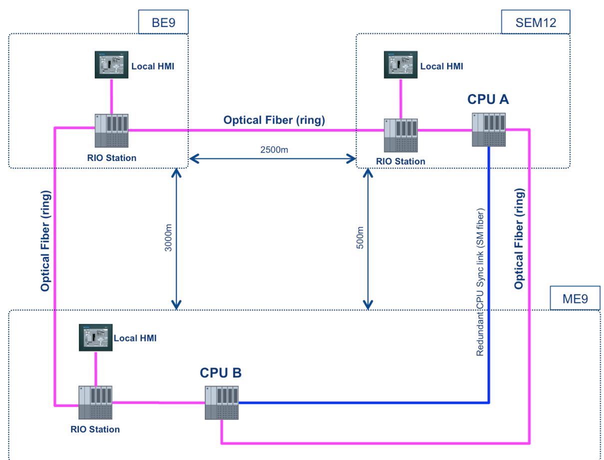

Figure 2: Auto Transfer control system PLC architecture.

A dedicated single mode optical fiber ring will be used to interconnect the CPUs and the remote I/O stations, installed on each substation. Each remote I/O station hosts the dedicated I/O cards used to collect the switchgear and other field information from the protection relays (from Arcteq and Schneider). CPUs collect the data from the I/O stations using industrial communication protocol EtherNet/IP.

One local Human Machine Interface (HMI) will be installed on each substation, sitting on the same EtherNet/IP ring used for the I/O stations. The embedded switches allowing Quality of Service (QoS), will assure the critical data packets between PLC, CPUs and I/O stations will be treated with higher priority than data packets to be used by the HMI.

EtherNet/IP is part of the Common Industrial Protocol (CIP). It is an application layer protocol transferred inside the TCP/IP packet. This means EtherNet/IP is just a way of organizing the data inside the TCP or UDP packets [2].

SCADA Supervision

The CERN Electrical Network Supervision (ENS) system will monitor the Auto Transfer control system so the CERN Control Center (CCC) can supervise it 24h/day, 7 days a week. In case of a major event, hundreds of events are triggered simultaneously and since the PLC does not have the capability of sequencing and time stamping the events locally, a solution has been proposed in order to allow a reliable post-mortem analysis. The operation requirement for the time stamping is to record the events with a sampling period below 20 ms. To fulfill this requirement, the proposed solution consists of using an intermediate gateway collecting the data from the PLC and dealing with the time stamping separately. This function is assured by a Modbus/TCP to IEC 60870-5-104 gateway, the WAGO 750-880/025-001. This industrial controller reads the data from the PLC memory at a cycle time below 2 ms, time stamps and buffers it in sequence and converts it to IEC 60870-5-104 messages to be sent to the supervision. The IEC 60870-5-104 gateway time synchronization is assured via a clock synchronization command (message 103). This message is periodically sent by the RTU (Remote Terminal Unit), which is synchronized via CERN NTP servers. With this solution, at supervision level, the data source time stamp is preserved, allowing a reliable post mortem analysis.

PROBLEMS ENCOUNTERED

Planning

Projects of this size, having an impact on the organization operation, must be phased and coordinated with the global CERN accelerators schedule. Furthermore, the commissioning phase of the project requires a complete availability of the network, which is not easy to achieve. In order to cope with this limitation, the operation team manually reconfigures the network in order to reduce and possibly avoid any power cut. The drawback of this solution is that the system is tested on a semi-real situation, meaning, the loads connected to the network are not nominal. This commitment is considered acceptable since this system is not classified as a safety system. Nevertheless, the potential in-rush currents problems have been taken into account during development, meaning the automatic transfer is done in a specific sequence and includes delays between commutations.

Hardware

While evaluating the hardware modification needed to implement the new control system, cables between the protection relays and PLC crates and 18 kV switchgears

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were found damaged. Cable insulation was degraded due to cables aging, UV exposition from the fluorescent lighting bulbs, differences of temperature, etc. These findings led to additional cost as well as time schedule limitations.

CURRENT AND FUTURE WORK

The Auto Transfer control system is currently in development phase. This includes the PLC and HMI software applications. The simulator has been used to test the different scenarios and the logical equations are now validated for implementation. The preliminary tests are foreseen to be completed before the end of 2019. On site installation is foreseen to be completed in the first quarter of 2020 with final commissioning in April 2020.

REFERENCES

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[2] An Overview of EtherNet/IP™, https://techstep.com.au/wp-content/uploads/2014/07/EIP_Overview1.pdf