EMERGENCY DIESEL GENERATORS: MODERNIZATION OF EXCITATION AND CONTROL SYSTEMS


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ABSTRACT

For the operation of any Nuclear Power Plant (NPP), it is mandatory to have a well-working and fully reliable emergency power system installed. In nuclear facilities, this emergency power is most commonly supplied by emergency diesel generator systems (EDG). Accordingly, EDGs are qualified based on the highest standards of safety and reliability. Although they are in stand-by mode most of the time, they need to provide the required power within a required time, mostly 10 to 15 seconds. A failure within the emergency power system can result in a shutdown of the whole plant which would have a strong impact for all stakeholders.

While the generator is mechanically driven by the diesel engine to transform mechanical electricity into electrical energy, a generator excitation system is required. This system builds up the required electromagnetic field to generate and regulate the necessary generator voltage for the emergency busbar. Such excitation is controlled by the Automatic Voltage Regulator (AVR). The functional interaction between the generator set and the associated mechanical auxiliary systems will be controlled by the safety and operational control supported by electrical protection.

In the case of modernization, qualification certificates and the fit-form function are of utmost importance. Essentially the spatial conditions, cabinet layout, cabling and the functional interrelationships must also be taken into account. This means that a functional upgraded EDG system can be developed from an existing system by individual solutions, in which forward-looking improvements are taken into account. It is feasible to reconcile the explicit requirements and challenges on the part of the power plant operator, e.g. the use of existing cabinets, interconnection cables and the responsible authorities for example in regard to seismic requirements.

Another key element of a successful modernization is the functional reproduction of the existing system or subsystem to be modernized. For this purpose, it is beneficial to rely, among other things, on the simulator platforms such as the ELVEES (Early Launch of Validation via an Evolving Engineering Simulator) in order to validate the design in an early project phase before commissioning.

With this simulation the functional equivalence of the revised EDG control system can be verified even before the start of the production phase. This gives the customer the certainty that there is a high degree of functional reliability with regard to commissioning, even if the EDG controls were originally supplied by another manufacturer. In addition, this system simulation can be extended as a training simulator for plant personnel for regular training.

Customer involvement in all phases of a modernization project is of central importance for the joint effective handling of the projects. Safety relevant components

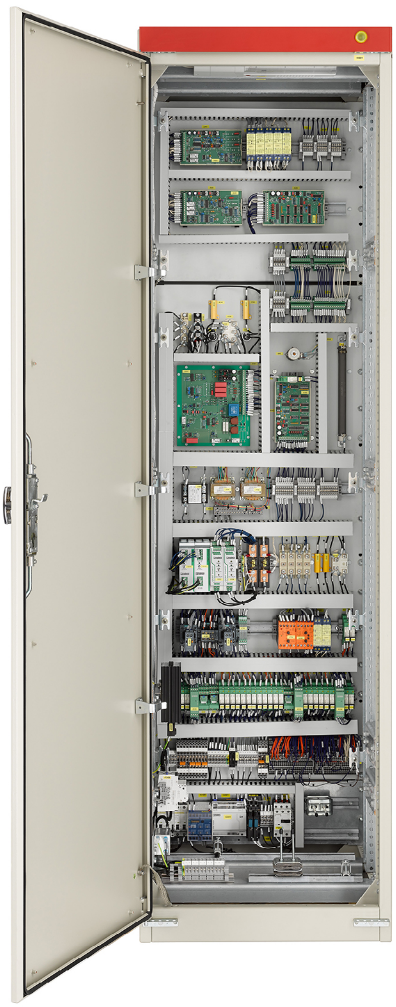

Figure 1. MAEX® Cabinet.

and systems have been successfully implemented in some modernization projects, in this article we will take the following products as an examples: ADCON (Advanced Diesel CONtrol) and TXS® (TELEPERM XS) for diesel control systems and MAEX® (Modular Analogous EXcitation) for excitation systems (Figure 1).

Generally, the modifications briefly described in this abstract and in more detail in the following paper are only examples of the possible upgrades to a EDG System, which include:

- Excitation Systems / Automatic Voltage Regulator
- Instrumentation and Control
- Electrical Protection and Synchronization
- Monitoring, Surveillance and Reporting
- Refurbishment (incl. Service and Life-Time Management) and studies of the complete Generator Set and its auxiliaries.

As highlighted, emergency diesel generators sets are important for any nuclear facility and can be described, due to the various different systems as a “plant in the plant”. Accordingly, all modernization design, installation and commissioning activities are based on high safety and quality standards in order to ensure the highest possible reliability of the emergency power system for the customer. The following article will explain the possibilities to exchange, respectively to implement, new excitation- and control-systems in existing configurations (Figure 2).

EXCITATION SYSTEMS IN NPPs

The excitation system is one of the key components for emergency diesel generators. The excitation system “provides the field current of a machine, including all regulating and control elements, as well as field discharge or suppression equipment and protective devices” [1].

In general, one distinguishes between static and dynamic excitation systems. In any case, the energy supply for the excitation system is delivered either by a permanent magnet generator (PMG), which is part of the generator, auxiliary windings of the generator stator, a voltage transformer or an uninterruptible power supply (UPS). This energy supply feeds the excitation system, whereas the required excitation current is controlled and regulated by the AVR. For static excitation systems, this excitation current is provided via brushes directly to the generator rotor.

For dynamic excitation systems, such as the MAEX®, the according generator has an additional exciter machine (called a main exciter) which is coupled via a shaft to the generator (Figure 3). The excitation current (field current) I_f is given to the stator of the main exciter. In the rotor of the

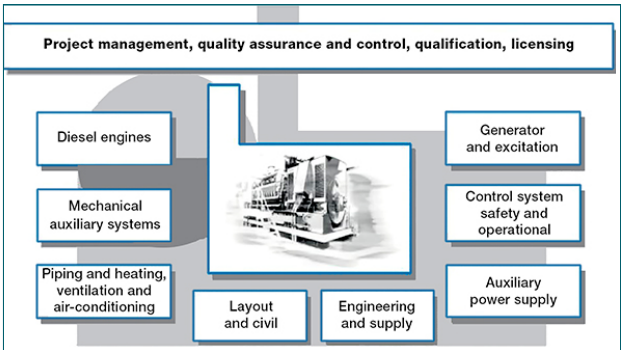

Figure 2. Different Scopes of diesel projects

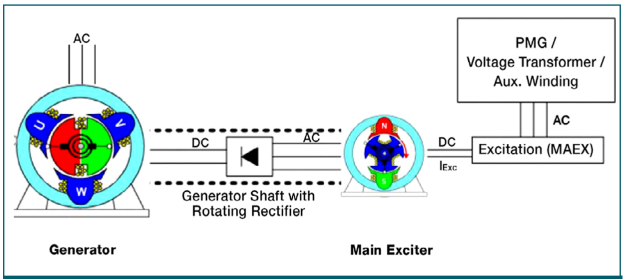

Figure 3. Excitation of brushless generators.

main exciter an AC current is generated, which is rectified via rotating rectifying diodes installed on the generator shaft to a DC current in the generator rotor. The generator rotor then produces the required AC generator voltage on the generator stator. Due to the main exciter, the necessary excitation current is relatively small (a few ampere) in comparison to static excitation systems.

Consequently, the excitation system is an important part of the emergency power supply and mandatory for the operation of the EDG. Accordingly, it requires the same high qualification standards.

In order to assure this high safety standard by internal know-how, Framatome has developed its own excitation system, the MAEX®. The MAEX® is a complete software-free modular excitation system for brushless generators, qualified by extensive testing on a prototype cabinet. Beside the existing qualification, based on KTA [2], IEEE [3] and RCC-E [4], a main advantage of the MAEX® is the simple integration in modernization projects, due to the modular and standardized design [5]

The MAEX® system is completely software-free and consists of 2 standardized modules, the

- Base Module, consisting of:
  - the AVR Printed Circuit Board (PCB)
  - the set point adjuster PCB
  - the field flashing
  - the booster detection circuit
  - internal switching logic
  - the interconnection to the Extension Module
  - all interconnections to external

and the optional:

- Extension Module, consisting of:
  - the Manual control and Balance Module
  - Cos ϕ - & Reactive power regulation
  - the according set point adjuster

Additionally, several required parts, which are individually customized to the project needs, are placed into the excitation cabinet, e.g.:

- Power converters,
- Rotating Diode Monitoring,
- Thermostat, Heating, lighting, etc.

The standardized modules are installed together with the individual customized parts into a seismic enforced 600 mm wide standard cabinet (8MF6, Figure 1). Due to the extensive in- and output signals and relay logic, covering a vast array of possible requirements, an easy and fast adaptation to customer interfaces and requirements is possible.

For the works directly on the spot, the analog design enables simple commissioning done only by analogous potentiometers. To achieve customers' schedule requirements and especially for a quick reaction in the case of potential customer system problems, a replica of each sold MAEX® is available on the manufacturers site.

Furthermore, a customer specific simulation of start and load sequences, with a new MAEX® system or the comparison between existing and new excitation system can be offered. This gains confidence in the new system and shortens commissioning time and amount of motor starts due to identification of optimal parameters in advance.

The safety classified (1E) system is already qualified according to common standards [2], [3], [4], in terms of seismic, electromagnetic compatibility (EMC), aging and extreme operating conditions, surrounded by an initial and final reference test (closed loop with generator) [5]. The qualification was done on a prototype cabinet incl. all possible options. The tests were performed in various test laboratories according the RCC-E sequence, covering KTA and IEEE requirements.

MAEX® MODERNIZATION IN SWISS NPP

In the following, the latest MAEX® modernization, installation and commissioning in a Swiss NPP will be described in more detail.

In this Swiss NPP, two "Special Emergency Heat Removal (SEHR) Diesel Gensets" and their according excitation systems are installed in the controlled area. They are part of the emergency cooling system and are started when the normal Emergency Diesel Generators (EDG) are failing. They supply the emergency busbar, which is necessary for the important feed-water pumps.

The task for the supplier was to exchange the existing excitation system, together with the synchronization device and the operator panel, installed in the existing swing frame (Figure 4). Thereby only the components should be exchanged, but all interfaces to the existing I&C, protection and generator should stay and all existing cables should continue to be used.

In contrast to the manufacturing and delivery of the standardized excitation cabinet, another approach had to be taken. Due to the different dimensions of the excitation system, the project individual cabinet parts had to be arranged and customized to this application. Furthermore, the operator panel logic had to be implemented on the cabinet module and a matching transformer was installed to adapt to the existing generator supply. Temporarily, the modules of the MAEX® were installed in a new transportation cabinet, as well as the new operator panel and synchronization in its swing frame (Figure 5).

On site, the equipment of the existing excitation cabinet had to be demounted. The new equipment had to be taken from the transportation cabinet and was installed into the empty existing excitation cabinet (Figure 6). The removal of the currently installed excitation and synchronization and the integration of the MAEX®, needed to be handled in due time. For the hot commissioning itself, a maximum of just ten hours was required.

A further challenge was the working conditions in the controlled area and the cabinet location directly next to the generator. Additionally, only limited working times were permitted.

Figure 4. Existing excitation system and synchronization (in swing frame) in existing cabinet.

Figure 5. MAEX®, synchronization and operator panel in transportation cabinet.

In summary, due to the standardized logic of the existing interfaces all cables could be further used and connected directly. The project specific logic as the operation panel and synchronization was designed individually and connected to the standardized interface of the MAEX® Base Module. In terms of qualification, all generic qualification certificates could be used and only a short delta report regarding seismic qualification was necessary.

After several modernizations in China, this project was the first implementation in a European NPP, coming along with very high seismic requirements and successful acceptance by Swiss authority ENSI (*Eidgenössische Nuklearsicherheitsinspektorat*), the Swiss Federal Nuclear Safety Inspectorate.

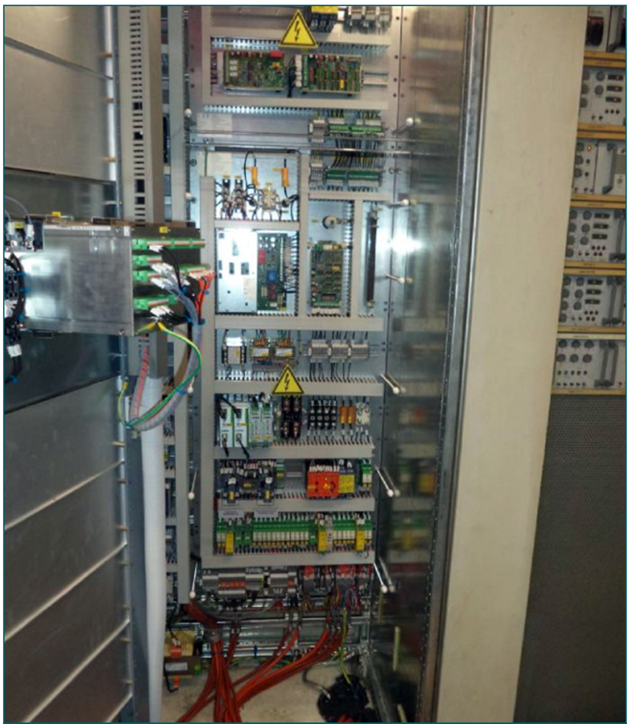

Figure 6. MAEX®, synchronization and operator panel installed on site.

MODERNIZATION PROJECTS OF EDG CONTROL

Beyond the MAEX® and other excitation systems, it is often necessary to replace further sub-systems of the EDG Sets due to aging and no longer available spare parts. Most demanded are, next to complete new Form-Fit and Function (FFF) Generator Sets, solutions for the diesel control systems. While digital solutions are available as well with the TELEPERM XS platform (TXS®), in addition a hardwired integrated safety- and operational control was developed specifically for EDGs. This is called Advanced Diesel CONtrol – Safety (ADCON-S) respectively Advanced Diesel CONtrol – Operational (ADCON-O). ADCON-S operates the EDG in emergency mode fully software-free while the ADCON-O solution works with already well-proven software. It can be implemented in new buildings as well as in existing configurations, independent from the type or brand of the Generator Set. This product was already integrated into installed Nuclear Power Plants considering IEEE [3] and also RCC-E [4] requirements.

This safety control mainly consists of a hardwired 19” rack, (Figure 7), with completely software-free plug-in cards and a Human Machine Interface (HMI). Due to its modular design, it can be also extended by several modules and functions during the component’s lifetime.

ADCON-S can be adjusted to each customer’s requirement within the hardware interconnections of the individual plug-in cards. The plug-in cards are available with different functions (e.g. “AND”-gates, “OR”-gates, limits for analog values, timer, pulses or frequency measuring). If the control is more extensive, it can also be expanded with a second rack.

In addition to the customer-specific logic, the interfaces to external controls can also be adapted to the requirements of the existing conditions (e.g. voltage levels, active/ passive trigger). Furthermore, the control cabinet size can also be customized to the existing conditions and additional hardware such as protective devices or switching outlets can be installed.

Also the HMI, which is integrated into the cabinet’s front door, can be adjusted according to customer needs, e.g. in terms of switches, push buttons or a mosaic panel instead.

A mobile test station is available in order to check the proper functions and settings of the plug-in boards (Figura 8).

ADCON-O can also be adjusted to each customer requirement. The operational control consists mainly of a Programmable Logic Controller (PLC) and a HMI. The type of the PLC and the HMI (e.g. Siemens, ABB, National Instruments) can be adapted to the requirements of the customer.

All safety signals handled by ADCON-S or the operational signals could be displayed and recorded. It is also possible to expand the operational control with a monitoring system for advanced data evaluation. As with the ADCON-S plat-

Figure 7. ADCON-S.

Figure 8. ADCON-O.

form, the control cabinet size can be customized to the existing conditions and additional hardware such as protective devices or switching outlets can be installed (Figure 9).

Due to the high degree of adaptability for ADCON-S and ADCON-O, a replacement of an existing control (safety and operational) while maintaining the existing interfaces is possible and feasible.

The implementation into an existing configuration makes also use of the benefit of the already existing qualification according the common nuclear standards, e.g. in terms of EMC and seismic [6] [7].

To ensure the "First Time Right" for EDG projects, the design can be validated by dynamical simulation by the so-called ELVEES (Early Launch of Validation via an Evolving Engineering Simulator) [8]. This additional tool is able to simulate the designed system before the start of the commissioning. This leads to a significant minimization of risk during the commissioning phase and consequently ensures that no complete design changes are necessary while the commissioning is already ongoing. Otherwise, possible faults in the design would be detected at latest during commissioning, which could lead to additional costs and possible prolongation of the outage. Especially for modernization projects, it is a must to implement the system in short time. This ensures also a high quality, cost and time-optimized project implementation without significant mitigation measures late in the project (Figure 10).

CONCLUSION

To ensure high reliability and fulfilment of the overall requirements for an emergency power system, the EDG Sets are considered as key components for any NPP. In order to achieve these high standards during the complete lifetime of the plant and in consideration of the obsolescence topic, several modifications and modernizations are recommended. These modifications are challenging for all stakeholders as all remaining interfaces need to be considered. Furthermore, a modernization project usually has a tough schedule, meaning that the installation and commissioning needs to be done in a specific short time slot as otherwise outage duration could be prolonged. This requires a detailed preparation, including i.e. from technical point of view:

- Site walk down with inspection of the current configuration
- Review of the current design respectively documentation
- Check of the feasible technical options
- Studies for implementation, also considering existing obstacles
- Design, manufacturing and testing (Factory Acceptance Test) of electrical cabinets
- Detailed planning of installation and commissioning
- Simulation of design (e.g. by ELVEES)
- Definition of the clearance times
- Installation and commissioning

During these updates, the nuclear qualification of the new parts has to be ensured, especially for safety relevant parts of the Generator Set, as well as their functionality in combination with the existing interfaces.

Exemplary with the MAEX® and the (analog) ADCON systems described in this article, or Teleperm XS if full digital solutions are preferred, modernizations are challenges for a running plant. Nevertheless, being well prepared with the right components, these challenges can be tackled successfully and lead to the improvement of the emergency power system and consequently to a safe operation of the NPP.

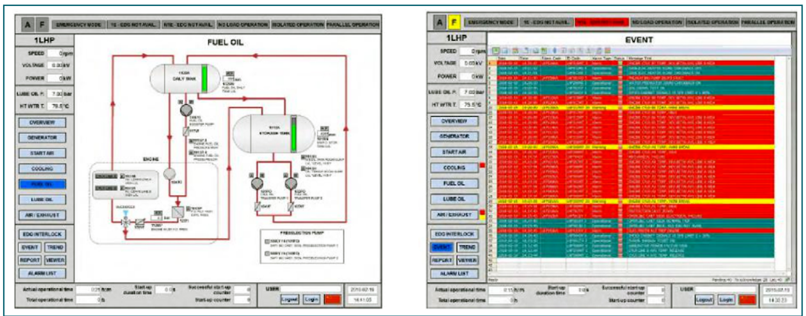

Figure 9. Display Sample.

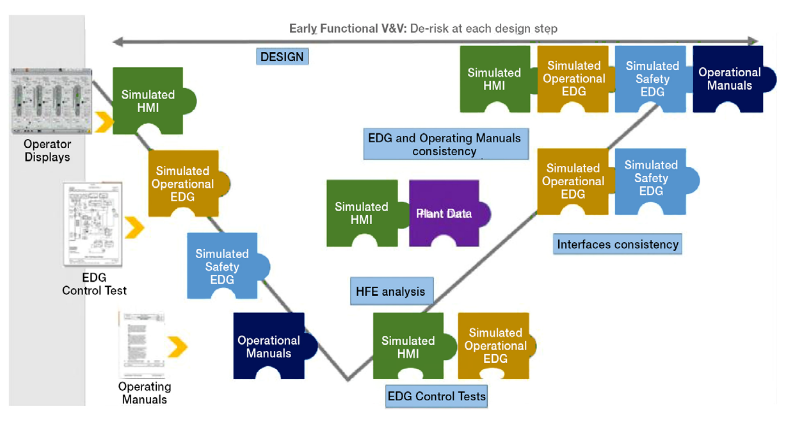

Figure 10. ELVEES Structure.

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