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Coordination of Protection and Automation in Future Networks

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SUMMARY

The structure of the electric power grid is set to change dramatically over the coming years with the implementation of distributed generation and new technologies to improve efficiency and capacity. These will pose many challenges and opportunities. This paper looks at the likely model of the future grid and its prospective components, as well as identifying some of the requirements for protection and automation. It also offers some solutions for protection, automation, maintenance and communication, which will form a key part of the solutions.

The paper discusses issues for protection and automation related to Future Networks and then discusses envisageable solutions for these issues.

The picture of the future of the grid is beginning to take shape. The utility industry needs to be proactive and take steps to shape the network to best meet its needs. To accomplish this, the engineering community needs to predict what functions are coming to the grid and have the right tools and technologies available to best integrate everything together. This is easier said than done, and there will be challenges along the way to the network of the future, as several of the technologies may have only been used in trials so far. Whilst the principles and building blocks, such as IEC 61850 for communications are in place, the infrastructure, particularly in lower voltage system levels may not be and will require investment.

New changes are required also to provide the necessary education and knowledge for protection and automation engineers to cope with these technological changes. Specifically, new skills are demanded related to network and software engineering, as well as management proficiency and tools, in addition to traditional electrical and electronics engineering.

To cope with these demands, CIGRE Study Committee B5 has recently commissioned a Working Group to propose new curricula and training contents for protection and automation professionals, with focus on the needs of the future grids. SC B5 has also launched a Working Group to investigate the coordination of protection and automation for future networks.

KEYWORDS

Protection coordination, Future networks, smart grids, Distributed generation, FACTS, Metering, Communication and IEC 61850.

1. INTRODUCTION

The goal of making use of alternative energy resources is resulting in the restructuring of the electric power grid as we know it today. It is estimated that, over the next 20 years, a huge number of windfarms and big photovoltaic plants will be connected to the transmission network and that tens of millions of distributed energy resources will be connected worldwide to the grid. Existing storage technologies, like pump storage schemes, will be complemented by new technologies such as batteries and flywheels. Renewable Energy Sources (RES) and Dispersed Generation (DG) will be connected mostly at the lower network voltages, many of which were not designed to cater for embedded generation and pose challenges for conventional overcurrent-based protection schemes. This will create stability and power flow reversal issues to be resolved. Protection and control at all voltage levels, both locally and over wide areas must be co-ordinated and new applications are likely to emerge. With these additions and the changing face of generation, transmission and distribution, the network of the future poses a number of challenges and opportunities, not least to protection and control engineers.

Generation trends will likely change from predominantly large base load stations connected at the transmission level to a mix of large dispatchable stations at transmission level along with a large amount of embedded, generation with limited dispatchability, much of it from RES, and maybe some power storage. These embedded RES provide opportunities, or problems, depending upon one's viewpoint such as islanding of parts of the network under certain fault conditions. However, some RES do not possess the fault ride through capabilities of traditional generation sources and may compound stability issues during large fault disturbances. Despite the limited dispatchability of many RES the main control centres need their actual status to have a complete picture of generation connected to the network.

FACTS, SVC and HVDC devices aim to provide solutions to some of the problems encountered in transmission networks such as mitigation of faults or enhanced transmission of power, but also bring their own protection and automation issues and must be interfaced to the wider network.

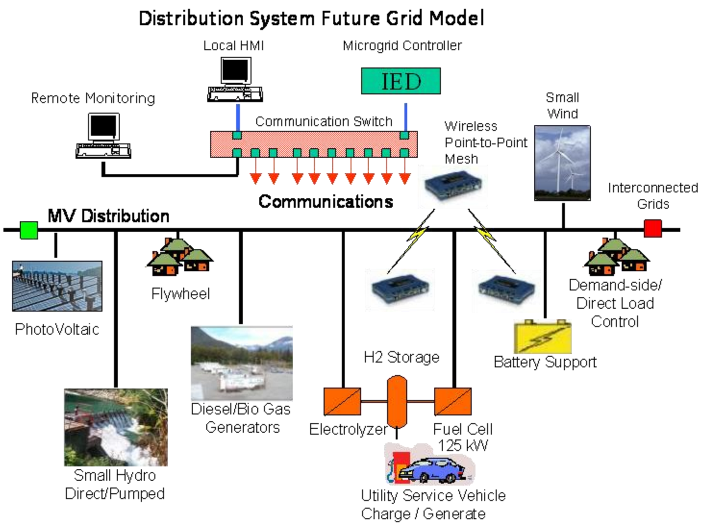
Key to many of the solutions within the network of the future will be communications – the ability to gather information with standardized semantics from remote parts of the network and make real time decisions. Greater use of synchrophasors may provide the ability to react to wider area events and minimise disturbances. Many transmission substations already have access to adequate communication networks but many distribution substations have limited communication facilities and bring additional challenges to be able to integrate them in the same way as transmission substations.
The standard IEC 61850 for “Communication networks and systems for Power Utility Automation” will also feature prominently. Originally developed for use inside substations, it has been extended to cover substation-to-substation communication. It also addresses sampled values of current and voltage in the process bus. This allows the realistic use of new technologies such as non-conventional instrument transformers.

2. VISION OF THE FUTURE GRID

Although somewhat incomplete, a picture of the future grid is beginning to emerge (see figure overleaf).

The largest impact on the power grid will probably be at the distribution level where most of the DERs (Distributed Energy Resources) will be installed. Identified DERs include Solar (Photo Voltaic and Concentrated), Wind, Reciprocating engine (diesel, bio-gas), Flywheel, Hydro (once-through, pumped storage), Hydrogen (electrolyser and fuel cell), and Battery (static storage, vehicle based). The physical topology of most distribution grids today is radial. The identified trend is towards looped feeders and tapped lines with dynamic switching of the various possible loops with the clear purpose of minimizing outages. The final state may be a meshed distribution network which allows creating virtual or, in case of emergency, real islands with balanced generation and consumption. In any case the transmission network is impacted also as backbone or bridge between the transmission systems.

Demand Side Management (DSM) and more sophisticated, Demand Response (DR) are the next steps in sophistication. These can be as simple as timers or flexible as ripple control to switch off heavy domestic loads like electric water heaters or washing machines during peak-demand periods, but such systems are unable to respond to contingencies. Future Networks will allow generators and loads to interact in real time, using modern information and communications technology. Managing demand to reduce the peak subsequently reduces the cost of peak generation, extends the life of equipment, exploits better limited power resources and should allow users to benefit from this enhanced management system by a lower energy price. Users will have to come to terms with the fact that there may be incentives as to what equipment they can use and when.

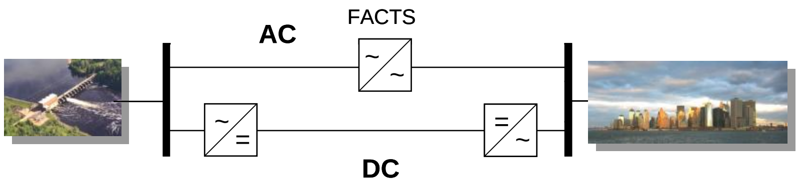


In general, these DERs can be grouped into two categories, namely, inertial and non-inertial based energy sources. The inertial sources (reciprocal, hydro, and to a certain extent certain wind devices) have mechanical systems that can provide fault current significantly above their full-load rated values. The non-inertial based DERs (solar, flywheel, hydrogen, and battery) are designed to limit both current and voltage output. Many wind generators also belong to this group because they are connected to the grid by power electronics in order to interface with the grid at the correct power frequency. In most cases today, the inverter-based devices are not designed to enable the dispatch of reactive power, however, a clear future trend is to enable such capability.

The integration of all of these devices requires the development of a communication infrastructure. Such communication availability enables advanced protection and automation for both transmission and distribution networks. Digital Relays can not only detect events on the grid but also respond to them in real time. A grid controller is envisioned that will coordinate the operation of the various elements. The functionality of this box will be defined in the “solutions” section of this document.

At the transmission level, the development of Large Networks for Bulk Transmission will provide more interconnections between the various countries and energy markets. Large Centralized Renewable Generation resources including offshore, intermittent sources and massive storage will be installed. Enhanced protection and communication systems will support the reliable operation of this super grid.

The future transmission level consists already today of AC networks and DC networks in parallel (see below). The AC links will be controlled by FACTS if applicable. It is likely that the DC links will be extended into networks when the DC breaker is available.



3. CAPABILITIES AND NEEDS REQUIRED FOR THE NETWORK OF THE FUTURE

A number of identifiable grid capabilities and needs for the Network of the Future are outlined in this section

3.1 Requirements for Protection

The implementation of generation in MV (and possibly LV) networks and the evolution of the topology of these networks away from radial feeders towards meshed networks requires modification of their protection system [1].

Most distribution systems are today protected by simple and economic overcurrent protections, completed in some cases by fuses. A feeder often has only one main protection. The selectivity of fault elimination is basically assured by selection of proper trip time, protections and fuses situated downstream having a shorter trip delay. The upstream protections thus act as back-up protection and also may have a greater sensitivity for resistive faults. In meshed networks with generator infeed, a selective protection based on simple overcurrent protections is not feasible.

The new functions and features of the future grid will induce higher constraints regarding the reliability and selectivity of the protection system. These include the selective elimination of a line fault, implementation of overload protections and also the disconnection of generating resources during faults, voltage drops, over- or under-frequency conditions, isolated network conditions, etc. Some of these criteria are directly related to safety issues.

Depending on the network regulations that apply, the generating resources have to stay connected in some of these network conditions for a limited time. With respect to conventional distribution networks, a completely new class of protection systems is thus required for the generating resources.
In most cases, the protection schemes of the sub-transmission system are already designed for varying load and generation conditions and should not need major modifications. This is different on the transmission level, where the changing context and composition of generating resources and resources providing network service may require additional new protection schemes to assure regional or system-wide stability.

In the framework of future networks, new long distance bulk transmission infrastructures based on HVDC technology or meshed HVDC networks to transmit energy from RES areas to load areas are under discussion. The protection system for this type of network requires new developments and approaches.

3.2 Requirements for Automation and Grid Management

Demand-response management – Load varies significantly over time. Typically, generators provide “spinning reserve” to meet the dynamic changes in demand. Generally, a grid level application has to level out the load e.g. by increasing the consumer prices of electric power at times of high demand in some areas or carry out load management based on mutually agreed contracts with the consumers. The related features of future networks have to be consumer controlled equipment to enable better use of consumed power by “smart appliances” and “intelligent equipment”. This is valid for homes (“smart house”) and businesses (“smart building”). The incentive for the consumer will be reduced energy budget. This equipment may be set automatically with the consumer profile and contract. In emergencies direct load control may be needed in order to avoid instability for load changes greater than the available spinning reserve. Advanced communication capabilities have to enable both demand and direct load control.

Topology Management - Rapid diagnosis and precise solutions to specific grid disruptions or outages are required. This is demanded in a highly dispersed generation grid, with a large number of agents and stakeholders, and a huge amount of data to be collected and processed during contingencies. Their rapid analysis and use in decision making will require innovative techniques yet to be implemented.

Active and reactive power control - Load and generation has to be measured and controlled everywhere in the grid. With increasing decentralized generation, voltage and reactive power, frequency and active power have to be controlled at an increasing number of points. Continuous monitoring of the system and equipment status is also required. Power quality has to be monitored as part of power delivery contracts. With multiple DERs on a feeder, there is a challenge of active and reactive power dispatch and voltage balance. The open issues are how active power is either dispatched or stored and whether the voltage balance is done centrally or is distributed throughout the feeder. Voltage balance will also require the ability to dispatch reactive power. The clear requirement is for robust communications throughout the length of the feeder to wherever the decisions are performed.

Monitoring This function has to supervise the power grid, power and electronic components assisting in real time operation and providing the basis of asset management. The sheer number of new devices that will be located on the grid poses an asset management challenge.These automations have to perform a wide range of applications that include monitoring, reporting, and tele-maintenance.

Islanded operation – Intentional islanded operation opens new opportunities for improved reliability and continuity of supply to customers. However a number of technical, economical and regulatory issues have to be addressed first. There are three fundamental requirements which need to be satisfied; safety, statutory power quality requirements and prevention of out of phase switching. In this regard, new island management automation function will be required including island detection, dynamic islanding, self-healing, island merging and synchronization.

Network dynamic stability-The bulk interconnected grid will require extremely high levels of reliability and flexibility, in particular regarding system stability. On the other hand with large penetration of DG, some system events may lead to the disconnection of large generation capacity. An integral approach is needed in order to take advantage of the opportunities of the new generation technologies regarding transient stability (angle, voltage, frequency and small signal stability). Advanced Wide Area Protection and Control system will support these new functionalities.

3.3 Requirements for Communication

Communications needs

As seen generally from the characteristics of the future Grid and more specifically from the related protection, automation and monitoring issues, the key requirement is that all active components are able to communicate which each other. Both the operator control and the automations i.e. all functionalities discussed for protection and automation need a powerful communication system. The communications system has to work seamlessly over all grid levels and to support non time critical bulk data exchange for power system operation and to guarantee the management of data exchange for few but very time critical automation or protection functions.

Such a comprehensive communication system with components from many suppliers calls for a global standard with powerful communication services and a data model with standardized high-level semantics (interoperability) avoiding any risk for misinterpretation both by operators and IEDs. It is clear that each vendor will have different algorithms for feeder management and re-deployment. In order to achieve interoperability, the physical interfaces at each of the protection and control devices and the logical interfaces between the concerned functions will have to be standardized.

Based on the task to be performed (control, protection, etc.) different communication *performance* requirements for the different basic data types (binary data like position indications and trips, analogue data derived from voltage and current) have to be fulfilled. In the substation LAN both binary data and analogue samples have to be transmitted within some few ms. Between substations over dedicated links or over the utility WAN the requirements are about a factor of 10 less demanding.

To obtain coherent analogue values that can be compared or evaluated, the samples or phasors from different sources have to be created and transmitted synchronously or with an absolute time stamp with accuracy of the order of 1 µs. Time critical communication has to be valid for any automation or protection function. Data for network operators need not be transmitted faster than the response time of an operator which is in the order of 1 sec. With this framework of communication requirements, future applications will also be possible. Regarding the key role of communication for the future grid cyber security is of utmost importance but not allowed to block operation and maintenance.

Communication over all grid levels needs to cope with links of physical layers and different bandwidths. Available bandwidth is normally higher at transmission (HV) level and lower at distribution (MV, LV) level. Therefore, different stacks may be needed and accepted at different grid levels but without deviation from the models to avoid the classical semantic problem of protocol converters.

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4. AVAILABLE SOLUTIONS FOR THE NETWORKS OF THE FUTURE

4.1 Network Protection

In order to achieve selective tripping in MV networks of the future, protections schemes (distance- and differential protection) comparable to those employed in meshed transmission networks will be used. This means use of distance- or line differential protections. In the former case, the short line lengths will frequently induce the need of a blocking scheme. In both cases, a communication link between the line ends is required, the link for the line differential protection requiring greater bandwidth.

The implementation of these protection schemes implies access to phase voltages and also may require current transformers with a higher performance. In addition to more powerful communication links, the installation of voltage transformers in the feeders (both at the ends of the feeders and at strategic places in the feeder) and the upgrade of current transformers are thus necessary. These constraints would also apply if overcurrent protections with directional comparison scheme were used, which are globally less selective than the two schemes mentioned above. Non-Conventional Instrument Transformers with process bus interfaces might offer an economic solution for this challenge.

Concerning integration of generating resources in MV or LV networks, the need of improving the associated protections has clearly been identified [2]. This concerns detection of islanding conditions, under- or over frequency trips, etc. Improved communication schemes will help to improve detection of islanding. They also may be required if the dispersed generating resources were to be addressed by zone- or network-wide stability protection schemes. In some applications, trip commands for a group of DER may be remotely generated and have to be transferred. Overload protections schemes taking into account the network topology may be required.

Utilities ask for harmonisation of requirements, standards and for guidelines on these issues. Adaptive protection schemes or the use of PMU (Phasor Measurement Unit) might offer a solution for some of them. Synchrophasor (PMU) based monitoring, control and protection may also be used for system-wide monitoring or protection schemes for network stability or the detection of wide-area generator oscillations. Dynamic state estimation can help reduce the probability and effects of wide area disturbances. These systems may have to be developed or enhanced.

In the future, all these functions will support the operation of the three-phase AC grid. Phasor measurements can provide a complementary view into the operation of all levels of the AC grid and enable advanced protection and automation functions. This approach is applicable both to large scale stability issues and small scale protection and synchronization.

4.2 Network Automation and Grid Management

Network automation on transmission and distribution has evolved to cover a wide range of applications that include monitoring, control, reconfiguration, reporting, tele-protection, and maintenance. These functions will have to be enhanced and new functions will have to be developed for the future networks. The functions to be implemented provide a solution for the automation issues identified in the previous paragraph. They include:

- Remote monitoring only - fault detection for both overhead and underground circuits; load measurements - distributed generation meters, etc.
- Remote monitoring and control (typically using SCADA protocols such as IEC 61850) – voltage and VAR control; or generation control (e.g. power measurements and generation mode of distributed generation).
- Remote monitoring and circuit reconfiguration (typically using SCADA) - equipment status (e.g. open or close of station or circuit switches); fault detection and isolation (e.g. fault detection, power measurements and open or close with line reclosers or switchgear with fault interrupters).
- Reporting (typically using file transfer protocols) - power quality measurements (e.g. harmonic content from high-end meters or monitoring/control devices); disturbance recordings (e.g. fault signatures or oscillographics from high-end meters or monitoring/control devices).
- Evaluation (either remotely or locally) - accurate fault location (e.g. based on analysis of fault currents, voltages and/or disturbance recordings); or spare capacity for circuit reconfiguration (e.g. based on assumed equipment capabilities and historical power measurements).
- Tele-protection (typically using high-speed protocols such as IEC 61850) – prevent operation of high-speed protective relays that are further upstream of the first upstream protection device (e.g. directional comparison blocking – DCB).
- Tele-maintenance (typically using internet protocol – IP) – maintenance records or configuration of devices.
- Automatons to enhance system stability both on local and transmission level.
- Network automation to allow power restoration in case of faults through automatic service restoration. In future network applications, many possibilities exist to reconfigure an optimised network restoration.

Many of these applications can share functions, sensors and especially communications with other applications. This integration, when properly planned, can save cost and improve benefits to the global transmission- and distribution system.

The solution for the automation and grid management tasks required in the context of the Future Networks will be based on advanced control methods like: distributed intelligent agents (control systems), analytical tools (software algorithms and high-speed computers), and operational applications (SCADA, substation automation, demand response, etc.).
State of the art Interfaces and Decision Support to provide operators and managers with the tools and training required to operate the grid, both on distribution- and on transmission level. Complex data is converted into easily understood information for decision making. Such decision support tools include visualization techniques that reduce large quantities of data into easily understood visual formats, software systems that provide multiple options when systems operator actions are required, and simulators.

The use of real-time information from embedded sensors and automated controls will allow anticipation, detection and response to system problems in advance, minimizing or eliminating power outages. Automatic fault location and system reconfiguration will allow the improvement of the continuity of supply to customers.

Microgrids are small network areas where consumption and decentralized generation are balanced under normal operating conditions. The operation of such Microgrids will require functions such as microgrid islanding and resynchronization, Energy Resource optimization, dynamic load shed, and protection coordination. To elaborate on two of these functions, Energy Resource optimization is optimal dispatch of the generation and load resources on the microgrid level and protection coordination involves determining the optimal protection strategy to implement based on the connected generation types and loads.

It is envisioned that the implementation of the functions will be performed by a localized Microgrid Controller. Localization is desirable in that it limits the communications to the local area and subsequently provides a more robust system performance.

4.3 System maintenance

An automation system is a significant part of a utility's efforts to maintain the power system and provide reliable service to its many varieties of customers. SCADA systems save time and money by eliminating the regular need to visit each remotely controlled location to inspect, gather data, perform adjustments, and review actions taken by the protective relaying and/or the remote terminal unit (RTU). Important developments can be anticipated concerning the maintenance of the protection and automation system itself. While the maintenance for conventional automation systems almost always requires the physical presence of maintenance staff in the substation, the development of digital automation and protection systems, combined with the availability of high-performance telecommunication structures, will enable a great part of the maintenance to be done remotely. This includes analysis of incidents, monitoring of the systems and equipments and analysis of failures, remote modification of settings and parameters and, eventually, even remote firmware- or configuration updates.

Another aspect of remote maintenance will be the remote assistance, by high-level experts, for local operator or maintenance staff in case of complex problems or maintenance operations.

In addition, applications implemented in the network- or substation automation system contribute to the maintenance of other assets installed in the network (e.g. cb operation count, etc.)

4.4 Communication

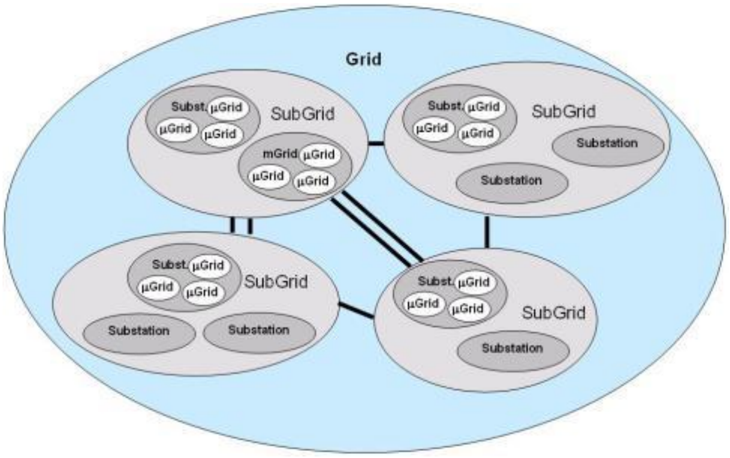
IEC 61850 is the standard which provides a data model on high semantic level, and services with high performance and high reliability. It was successfully designed and accepted for substation automation. In addition, the standard has already been extended beyond the limits of substations e.g. for distributed energy resources (DER), hydro and wind power, where first applications are going into operation. Therefore, IEC 61850 is the key communication solution for the future grid.

The communication potential of IEC 61850 provides for non-time critical communications, the common *client-server* solution of which provides high reliability but with limited response performance (typically ≥ 100 ms) especially for event reporting and switchgear control. Time critical information like binary trips, blockings and releases are provided by the 61850 GOOSE service. Samples of voltage and current - time critical by definition - are transmitted with the same performance by the SV service.

Communication to receivers outside the substation are provided either by tunnelling the SV and GOOSE service across some high speed communication networks like SDH and SONET or via IP networks if their communication delay and delay jitter are acceptable by the application. For the second method both the SV and GOOSE service is enhanced by UDP/IP resulting in R-SV and R-GOOSE respectively. A typical solution is the transmission of phasors for wide-area applications.

In the substation LAN, the bandwidth for IEC 61850 is typically implemented as 100 MBit/s Ethernet, utility WANs at transmission level may provide reasonable high bandwidth also. Since the network of the future needs communication down to LV, the communication has to work also over links with low bandwidth like power line carrier as already defined. In addition, IEC 61850 remains generally the favourite for communication solutions also at lower voltage levels since the value is in the standardized data model and services also if the application areas needs another stack

The figure below shows the expected interaction between the various levels of the electric power grid. An example of these interactions is when a generator at the high-voltage grid level is lost, load may be shed or generation augmented at the SubGrid or MicroGrid level. The extension of IEC 61850 to system wide communication was indicated clearly by the title of Edition 2 i.e. “Communication Networks and Systems for Power Utility Automation”. This specific interaction chain may need some extensions of IEC 61850 but the basic concept of IEC 61850 will be maintained.



The formal description of “system of systems” i.e. of large systems was also included in the Edition 2 indicated by the renaming of SCL into System Configuration Language. The requirement of managing the huge amount of IEDs in a large system is already addressed by creating a related Task Force in TC57 WG10.

5. CONCLUSIONS

The picture of the future of the grid is beginning to take shape. The utility industry needs to be proactive and take steps to shape the network to best meet its needs. To accomplish this, the engineering community needs to predict what functions are coming to the grid and have the right tools and technologies available to best integrate everything together. This is easier said than done, and there will be challenges along the way to the network of the future, as several of the technologies may have only been used in trials so far. Whilst the principles and building blocks, such as IEC 61850 for communications are in place, the infrastructure, particularly in lower voltage systems may not be and will require investment.

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To cope with these demands, CIGRE Study Committee B5 has recently commissioned a Working Group (B5.40) to propose new curricula and training contents for protection and automation professionals, with focus on the needs of the future grids. SC B5 has also launched a Working Group (B5.43) to look at the coordination of protection and automation for future networks.

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