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Key Aspects of Smart Grid Design for Distribution System Automation: Architecture and Responsibilities

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Abstract

In the conventional distribution network, systems designed for the control of individual constituents are autonomous with each other with respect to architectures and controlling. Thus, centralized control and integrated functionality are the major challenges faced by the distribution system operators. To overcome these issues, the term "distribution system automation" came into picture by using information and communications technology (ICT)as a resolution that integrate all the critical constituents of a distribution system. This develops a smart environment at power distribution level, called as "smart microgrid" that can optimize the system economy and improve the system resiliency. The major challenge lies in distribution system automation is the selection of proper architecture and communications. In view of all these aspects, this paper present an overview of distribution system automation as a part of smartgrid initiatives and its important features viz., architecture layout and responsibilities.

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1. Introduction

It is emerging fact that renewable energy based distributed power generation is playing an important role in reducing burden on utility grid and carbon emissions of conventional fossil fuel based systems. From utility grid perspective, these new power generation technologies require swell defined and/or improved monitoring and control of existing distribution network. To address these challenges, the distribution power systems has introduced the integration of ICT with local power system networks to make the system smart. The abilities of these smart

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distribution systems further enhanced with the concepts of demand side management (DSM) that enhances the energy efficiency, reliability, and decreases the unit generation cost. The real-time monitoring systems helps in prior estimation of equipment damage and blackouts, thus, helps in preventive and predictive maintenance, thereby improved the system reliability.

These evolutions in generation/demand side requires new and intelligent power grid at electric distribution side that can effectively manage the increasing energy needs efficiently. Besides, it should assist the utilities to adhere the country's regulations for power supply from both conventional utility grid and local renewable energy sources (RES).Deployment of smart grid technologies may appear in near future in all kinds of critical distribution systems by adding consecutive layers of capability and functionality onto existing equipment and systems. Technology is the vital consideration with certain technical characteristics (e.g. integrated, interactive, accessible, predictive, optimal, flexible, reliable, secure, and economic). In General, the smart grids include 3 major modules such as communication technologies, automated control systems, and distributed intelligence. So, automation plays an important role in these all kinds of new initiatives. With this intent, this paper presents some of the important aspects of automating distribution systems. The major benefits of these kind of systems for customers, utility, and as well as for the society are mentioned below.

- *Financial benefits*: pricing choices for consumers, lowering unit generation costs, and stabilized costs.
- *Efficient energy benefits*: optimum energy usage, reduced energy losses, demand management during peaks, and the possibility to operate the power system with maximum efficiency by energy management.
- *Power quality and reliability benefits*: reduction in number and duration of outages, "cleaner and reliable" power management in RES based power distribution systems or microgrids.
- *Energy conservation and environmental benefits*: minimizing greenhouse gases and other pollutants, minimizing power generation from uneconomic sources by enhancing the use of RES.
- *Safety and security benefits*: increasing visibility into insecure or unsafe situations, increased cyber security, physical system security, and privacy protection.

Various surveys on opportunities, technologies, etc., for the enablement of smartgrids for distribution systems were given in [1-9]. Where, the smartgrid design with respect to power and communication point of view was presented in [1]; an overview on smartgrid NIST architecture, standards, legislations, programs, projects, and trials were presented in [2]; Overview of challenges, solutions, and standard activities for smartgrid research were discussed in [3] and similarly, cyber security aspects were presented in [4]; survey on motivations, challenges, and requirements for the development of communication infrastructures for smartgrids were presented in [5]: survey on smartgrid applications, design, implementations, and communication technology requirements were discussed in [6, 7]; in spite of all the upcoming trends and technologies for smartgrids development for distribution systems, there are some critical open areas presented to be addressed. These upcoming challenges were discussed in [8, 9].Survey on various smart grid concepts, technological demonstrations and architectures implemented worldwide based on the initiatives taken by IEA (International Energy Agency - Europe) was presented in [10]. Similarly, survey on data analytics [11], comprehensive assessment systems [12], smartgrids for clean energy systems [13], and the developments in technology for smart substations [14] were presented.

1.1. Evolution of automation from needs perspectives

Initial stages of automation was focused on automating the existing manual operations in the industries, thereby gaining better yield and consistent product quality. The technologies available from the late 1970's made this needs fulfilled. Subsequently, the automation needs of the industry are driven by the standards and regulations for up keeping the environmental benefits. In 1990's, the safety of the equipment and people became another requirement in the plant automation that led to the widespread use of safety systems, emergency shutdown, and startup operations. In the subsequent years, the focus has been moved to improvising the plant revenue by achieving better efficiency in the plant operations. Evolution of the automation in terms of various needs is shown in Fig.1.

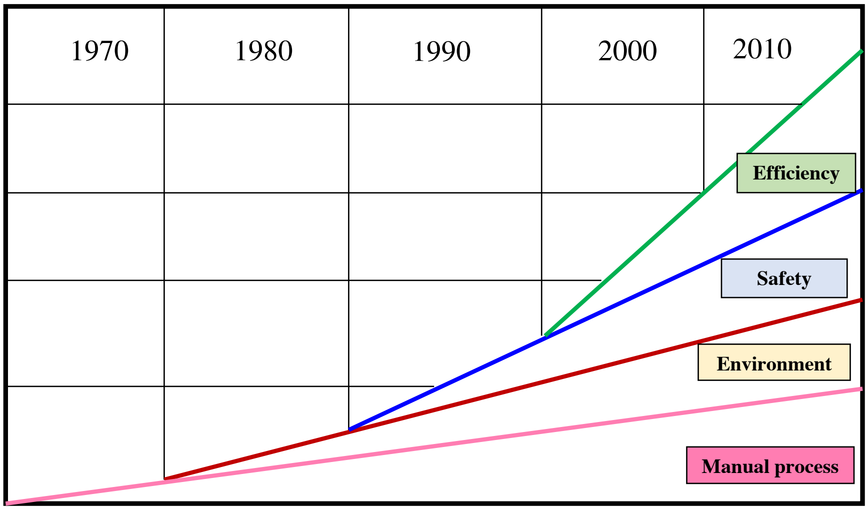

Fig. 1. Evolution chart of the automation from needs perspective.

1.2. Evolution of automation from technology perspectives

Evolution of the automation in technology perspective is shown in Fig.2.First generation automation systems were mostly used in the place where there is a need to replace human force by machines. The mechanization of the industries led to the automation by using mechanical gears and fixtures. The control signals and mechanisms were mostly hydraulic. The pressure of the liquid in small volume is used to transmit the signals from one place to another and is subsequently manipulated based on the requirement. However, due to the inherent nature of the liquid compressibility and the energy required to create the signals, the pneumatic systems came into existence. These pneumatic signals were used to drive the sensors and valves to transport the signals from one place to another. The next generation has seen the electrical signals in the form of voltage that is used as the technology choice for control systems. The fourth generation systems used the digital electronics technology for the control systems. Consequently, the manufacturers built a standard and customized communication interface on which their respective products were operate.

Later on, with the initiation of microprocessors, there was a shift from analog-to-digital technology usage in the development of automation solutions. This digital technology based instruments are known as "smart instruments" has many advantages such as, more and detailed information display, remote and local display, digital data communications, reliability, self-tuning and diagnostics ability, intelligence, economy, etc. The major applications of these instruments are in switchgear control, protection relays, variable speed drives, soft starters, etc.

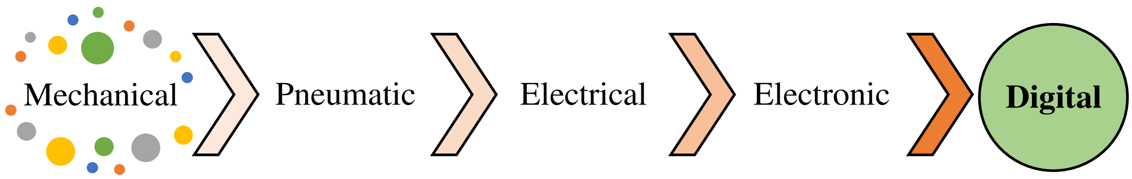

Fig. 2. Evolution chart of the automation from technology perspective.

1.3. Challenges in automation

Automation systems undergone a large change in the last three decades. Key challenges mentioned below are continuously being addressed for the design of efficient automation systems.

- Due to the limited communication systems, the interaction between the users and the system were restricted.
- The information flow from the plant floor to the executives is very limited, which requires high energy cost of operations due to non-coordinated systems.
- The information on new products and new solutions available in the market is very limited. There was limited information on the best practices of other peer industries and their performance with the automation systems.

All these key issues are being resolved now a days with the technology advancements and differently trained operators. The technology advancements made large data availability and storage, and communication revolutions made the data availability at any convenient location with much faster rate.

Current challenges in the industry are usage of fewer assets, increase in demand for more production with fewer human resources, demands for less wastage, more efficiency, better quality and improved tracking. Regulations and compliance aspects are increasing across all the domains of plant operations. Goals to reduce the energy consumption is the another key challenge. The challenges in automation and control are, demand for reduced engineering and commissioning costs, multi-disciplinary control systems development, improving machine uptime and reduction in machine down times, plant floor to enterprise connectivity, remote diagnostics, web access etc.

2. Architecture for System Automation and its Responsibilities

The concept of automation of a plant is the application of the control systems, information, and communication systems.Functional representation of the architecture of a generic industrial automation systemis shown in Fig. 3. Various constituents of the system are segregated and placed into various levels of the architectureas shown in Fig. 4, based on their purpose or responsibilities as mentioned follows.

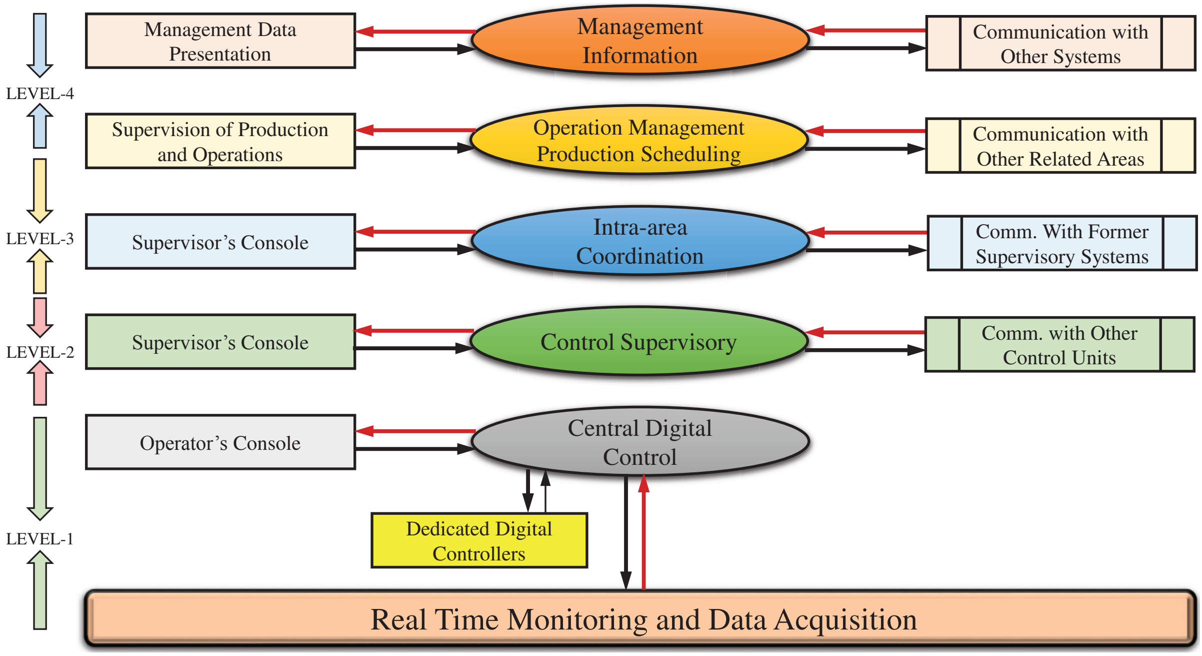

Fig. 3. Functional representation of a generic automated system architecture.

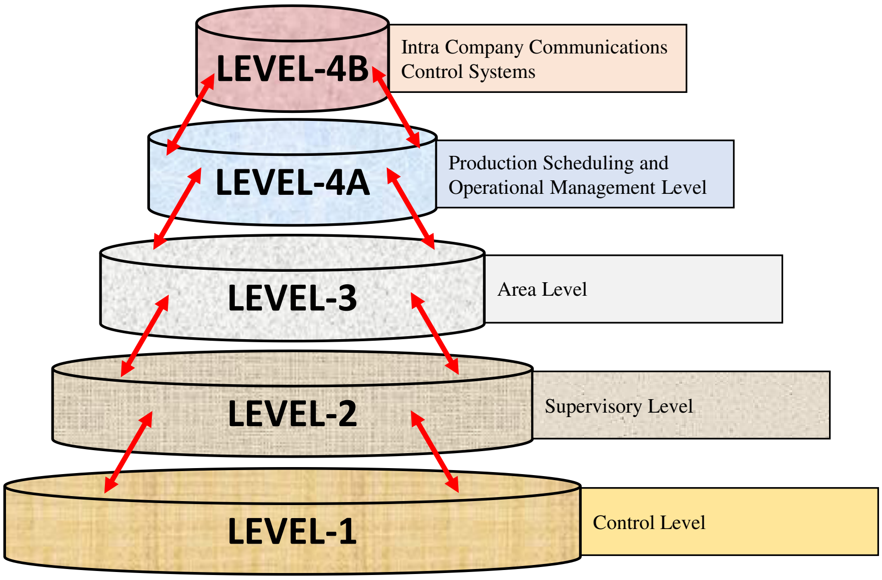

Fig. 4. Segregation of automation architecture levels based on responsibilities.

- Level-1 performs the actions involved in sensing, manipulating the physical processes, and emergency protection. This is mapped to the transmitters, control valves, solenoid valves and limit switches etc.
- The level-2 layer will have a communication network and is connected to other systems through a network router. The network router will provide a separate LAN for the process communication network and interconnects the different systems that are secure, separate and are logically connected together.Level-2 performs the monitoring and controlling activities in the automated system by using the real-time responses measured in sub seconds. These systems are typically implemented on distributed control systems (DCS) and programmable logic controllers (PLC).
- Level-3 performs the activities that coordinate all the resources to produce the desired end results. It includes, "procedural control" and "work-flow control" through standard methodologies. The other responsibilities includes maintenance activities, quality assurance, and inventory movement activities, etc., which are collectively called as "Manufacturing Operations Management".
- The leve-3 is connected to the level-4 separated by a firewall and DNS server. Some of the systems/nodes that are accessible from both the levels will be placed in DMZ (De-militarized Zone). The typical systems placed in the DMZ are wireless access points, plant history access, web access, data access from plant wide LAN etc.
- Level-4 is called as "Business Planning and Logistics level" that defines business-related management activities. These includes establishing the plant's schedule (such as material delivery, usage, and shipping), logistics control, and material control (ensuring material is delivered to the right place and on time for production). Enterprise resource planning logistics are used to automate Level-4 activities.

3. Key Objectives of the Smart Grid for Power Distribution System Automation

IEEE-1471 has given the definition of the typical system architecture for the first time [15, 16]. This architectural representation has been further extended by IEEE-1547 [17], ISA-95 [18], IEC-61850 [19], Open System Interconnection (OSI) [20], and U.S. Department of Defense (DoD) [21] guidelines. For an electrical energy system, the objectives of a distribution system network automation can be derived as primary level and secondary level objectives as shown in Fig. 5. These level are further derived specifically with respect to various elements in the system. All the sub-systems are grouped under various categories shown in Fig.6 to achieve the plant objectives.

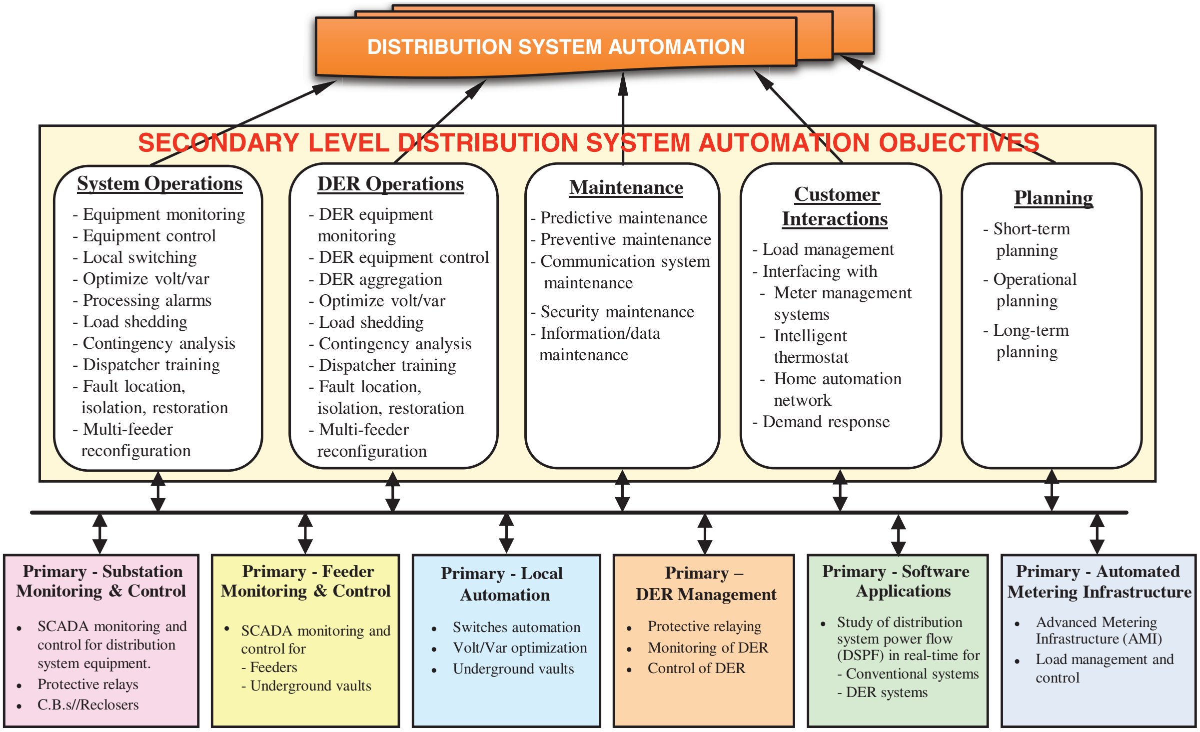

Fig. 5. Primary level and secondary level objectives of power distribution system automation.

Smart Grid system is a group of various sub-systems that collectively achieves the objectives of the power distribution system automation. These sub-systems can be categorized as follows.

1) Process control and safety systems
2) Communication networks
3) Process optimization systems
4) Database management and maintenance systems
5) Process improvement and decision support systems

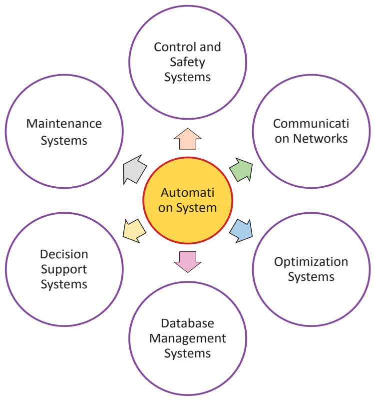

Fig. 6. Functional sub-systems of a smart grid system.

3.1. Process control and safety systems

Process control systems are automated-computer based digital control systems those can monitor and control all the critical processes in the plant. This technology advancements enhance the capability of conventional control systems and focus towards achieving the following objectives.

- Minimizing the manual recording of the measurements and tracking of operational assessments to reduce the human errors and accelerate the data acquisition.
- Enhancing the productivity of system engineers by developing efficient, comprehensive, readily accessible, design and analysis tools.

- Simplifying the operational and economical studies in the plant to permit quick analysis and prediction of emergency/unusual operating conditions well ahead.
- Increasing the accessibility to history data to permit comprehensive analysis of operational andprocess issues and expedite the system growth and expansion to meet the future requirements.

3.2. Communication networks

Communication networks enables plant-wide information exchangesusingcoordinated work stations and provideplant information access to all users readily. It focus on the following objectives.

- Connectivity and interoperability among different systems in the plant those works on different technologies. Also providing adaptability and expansion capabilities easily.
- Minimizing transmission delays/latencies for the analysis and decision making on time.
- Providing integral and secure data transmission with access to central databases for reliable operation.
- Image transmissions through data, voice, and video should be integrated that provides consistent information.
- Gateways, routers, etc inter-network bridges must be provided with efficient connectivity.

3.3. Process optimization systems

Process optimization must provide and expand the capabilities of system simulation, operations scheduling, and optimization. It majorly focus on the following objectives.

- Supporting process execution and modeling tools to enhance their usage that allows more comprehensive analysis across the plant.
- Providing the ready and more comprehensive information on dynamic acquisition of material balance to optimize the raw-material utilization and thereby reducing overall plant's running costs.
- Productive resource management timely with the available demand/supply data and real-time inventory data.

3.4. Database management and maintenance systems

Database management system must act as a global entity in the plant that can integrate and interrelate all the sub-system's databases in the plant. This supports business, marketing, and research strategies as well as control of production and plant operations. These systems mainly includes the following supporting goals.

- Maintaining data integrity through high-speed network access instead of extensive collection and copying.
- Providing data integration easily by employing standard industry relational database systems and structures.
- Providing security to the data that is accessed by various classes of users in the plant.
- Supporting plant-wide information gathering for taking managerial and operational decisions in the plant.
- Providing concurrent accessibility to all individual users across multiple databases in the system.

3.5. Process improvement and decision support systems

Process improvement and decision support systems can modify the overall processes running in the plant by using real-time instantaneous plant-wide data available. This helps in reducing the unnecessary processes and consumption of raw-materials. Also, provides critical decisions under emergency situations to avoid productivity damage in the plant. These systems focus on the following supporting objectives.

- Enabling complete control on product quality by collecting and analyzing the product-related data from all sub-systems in the plant.
- Implementing control feedback mechanisms for the automatic online manipulation of plant operations in order to improve the output product quality.Also, provides the report on those results obtained.
- Enabling the use of statistical analysis methods and tools to determine and analyze quality trends of the products.
- Decision support tools assist people in accessing, manipulating, analyzing, displaying and documenting data.

4. Conclusion

In this paper, various aspects of smart grid such as distribution automation, its technologies and levels of automation and the responsibilities of each level were discussed in detail.

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