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Monitoring with Communication Technologies of the Smart Grid

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ABSTRACT

From the conception of the smart grid, a lot of attention has been paid to intelligent monitoring of the smart grid and monitoring of the power system. Condition monitoring of equipment such as transformer health has also been treated as priority together with distribution insulator monitoring, monitoring the applications for the smart grid technology, for example, locating the fault in the smart grid, monitoring of commercial electronic devices and monitoring for wide-area were under scrutiny. Monitoring in power system monitoring is associated with state estimation, seams between state estimates and instrument transformer calibration for all-PMU estimators. Next is the protection of the power system which involves the security and the capacity to be independent, monitoring the attributes of apparent impedances of relays, back-up zone supervision, loss-of-field adaption, load shedding using intelligent systems, islanding using intelligent systems and incorporation of schemes for system integrity protection. Two-way communication systems' deployment is one of the distinctive mark of the smart grid. The smart can gather and transfer monitored data from the power system elements to operators of the system using the smart grid monitoring system and form a two-way communication system via the grid power plant and the end user of electricity. The smart grid implementation is a gradual process to substitute the conventional power systems' elements built on the basis of existing systems and building brand new systems which would be very costly. Smart grid planning involves not only the consideration of these creative technologies but also respecting the interest of all the stakeholders involved. Decision making requires to be executed to analyze each smart grid component and its cost before investment and consequently deploying into the real grid. Considering the above mentioned issues, this project surveys an overall monitoring and communication structure. Information optimization is one the key strategies to obtain the benefits of the smart grid.
Keywords: Monitoring, Communication, Technologies and Smart Grid.

INTRODUCTION

There has been a significant growth of large industry and commerce which has brought the need for more power supply which in turn has created an energy supply deficit and pollution issues due to the power demand generated from fossil fuels. Smart grids have come into play to solve some of these issues in both developing and developed countries. Smart grids have more advanced construction, the best algorithms, and creative frameworks that are being enhanced [1]. The smart grid concept has been modeled for quite some time now such that a lot of power organizations across the globe are focused on explaining its functionality and its technical applications. Different countries and regions develop smart grids according to what best suits them, such as energy distribution and consumption. In addition, climate, industrial and commercial, etc. For example, people in Europe are inclined to develop renewable energy and distributed energy (distributed generation) systems whereas in the United States, the implementation of a smart grid is more of smart metering and demand response. The Chinese state grid Corporation wants to develop a strong and robust smart grid for High Voltage, Direct Current (HVDC), and Flexible AC Transmission Systems (FACTS) for transmission of electric power from west china which is rich in energy to east china. The difference between the smart grid and the traditional grid is that the smart grid deploys communication networks which are much more critical. Electricity delivery systems now incorporate a lot of computerized control, monitoring, and automatic operations from remote which form a two-way communication system link between power plants and the consumers such as domestic, industrial, commercial and agricultural. Furthermore, power systems can now share information with other systems such as petroleum, natural gas dispatch systems, weather forecast, and so on. The penetration levels of renewable energy resources such as wind energy, solar and demand response have become high and the effect of weather on the power system plays a significant role. Information exchange between the weather forecast and power systems is made possible using mechanisms such as the Load forecasting mechanism. Power economic dispatch and design of the right demand response or load shedding scheme for the prevention of loads from drawing too much energy from the grid may be as a result of accurate short term load forecasting. Long term load forecasting on the other hand helps to plan better for optimized allocation of energy. It is a gradual process of replacing the old power system elements with new computer-based elements in order to achieve the smart grid. Thus, the planning process for the smart grid does not only puts the effects of creative technology into consideration but also appreciates the diversity of the stakeholders' interest. To make correct and responsible decisions, carrying out a cost analysis may be the best way to go. Constructing a Decision Support System is one of the best and effective ways of estimating the cost of the technologies and implementation of smart grids. The decision support system is an information system that is based on the interaction of computers to support planning using decision making, management, and operations of the grid.

Power System and Smart Grid Monitoring

From the conception of the smart grid, a lot of attention has been paid to intelligent monitoring of the smart grid and monitoring of the power system. Condition monitoring of equipment such as transformer health has also been treated as priority together with distribution insulator monitoring [2], monitoring the applications for the smart grid technology, for example, locating the fault in the smart grid [3], monitoring of commercial electronic devices and monitoring for wide-area were under scrutiny have been discussed.

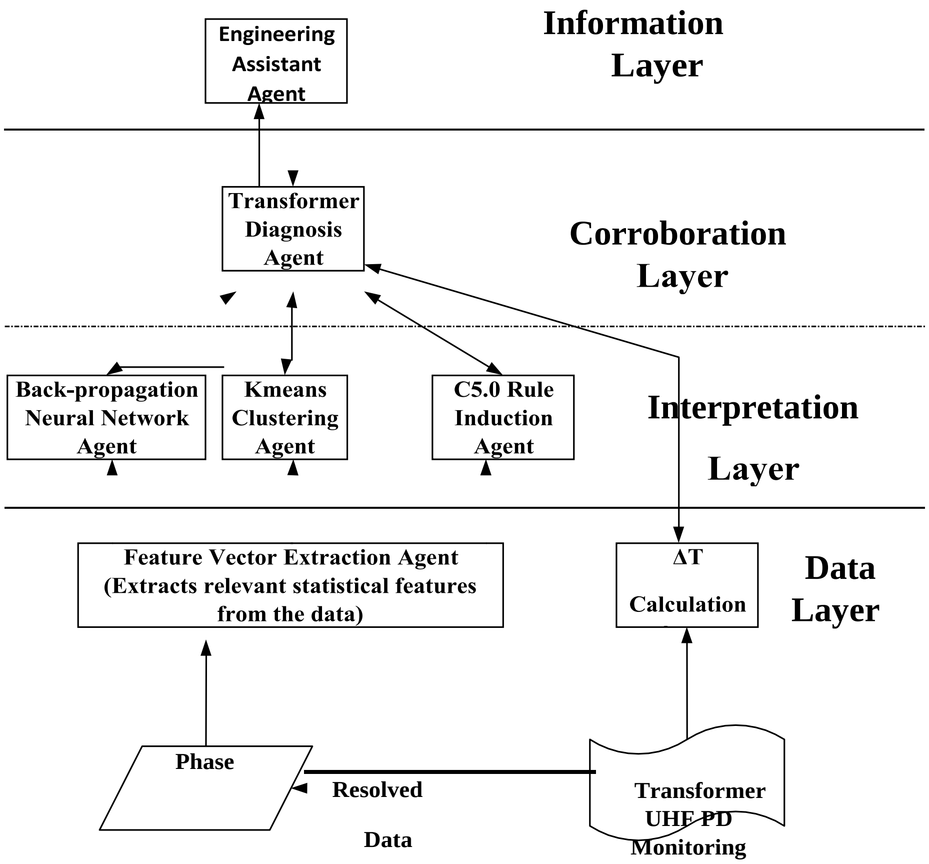

Fig. 1 the architecture of the COMMAS

In the early 21st century, before the smart grid concept was proposed, there was a report of power quality monitoring using intelligent systems in reference [4]. In the 20th century, a survey was conducted in a paper concerning power quality using intelligent systems. The author realized that indicators of power quality that were developed in 80's of which most of them were low-priced and did not provide data and information which was accurate for decision making due to several LED indicators which could remain ON. There were two outstanding problems of the indicators there were mentioned and these were; the only way to obtain information was when the indicators are plugged and are able to communicate with other parts and secondly, the users did not understand how to handle the information that was collected. There was four characteristics that were suggested by the authors for system monitoring of intelligent power quality. Firstly, there was need to gather data such as currents, voltages, time plus any other parameters. Secondly, the data has to be transferred to where it's necessary. Thirdly, the aggregation of any other sources of data with the power quality was also important. And lastly, the conversion of data into information for action to be taken.

Condition monitoring is a very important topic in many areas of the electrical power system. (*Stephen D. J. McArthur, Campbell D. Booth, J*, n.d.), the authors demonstrated an architecture of an agent based detection for the operation of a power plant and monitoring the maintenance. Figure 3 shows this proposed architecture in which the agents were classified into four groups according to their functionality, abstraction of data, processing of data, presentation and analysis and administration. The authors suggested that the agent be deployed into the power plants to provide constant change of linking the source of data to the functions of data processing. The connection between various measurements, the knowledge to do with data and behavior for plant models would be improved using a continuous detection scheme. This proposed architecture was flexible and accomplished agents that were reusable with abilities of data processing.

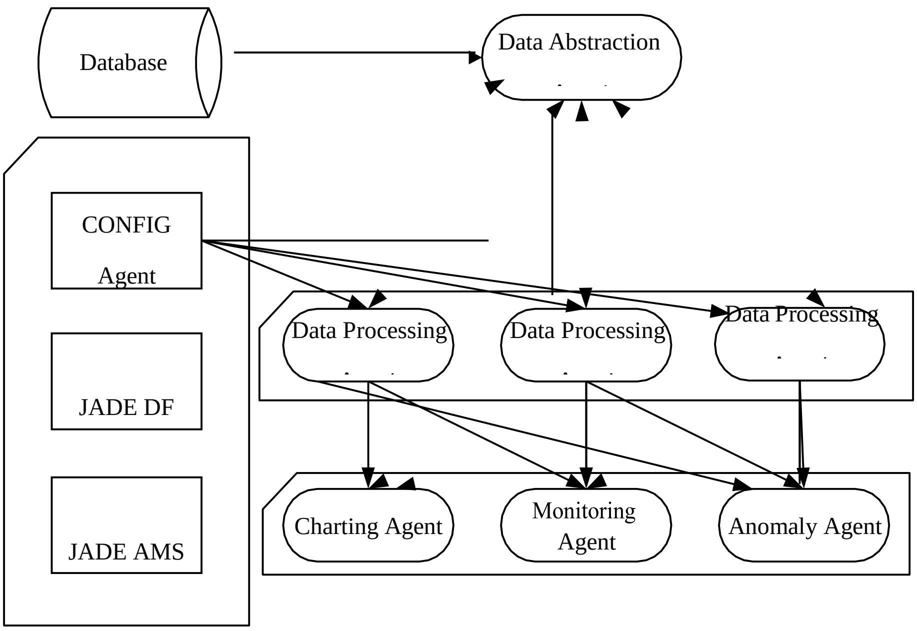

Fig. 2: Anomaly detection agent architecture (Stephen D. J. McArthur, Campbell D. Booth, J, n.d.)

From around 2010, a lot papers and researches have their attention on intelligent system monitoring of the smart grid. The implementation including power System Frequency Monitoring Network (FNET) applications on wide-area monitoring systems were reviewed [4]. The FNET system building blocks are shown in Fig. 2. Figure 3 shows a demonstration of an FNET system of consisting modules with its application. Because of the framework with hierarchical procedure, the elements can be arranged easily. The FNET system applications have been explored in various aspects of electrical power systems such as monitoring of constant changes, estimation of the stability, solutions of the smart grid and control in real-time. [5] Proposed characteristics of a wavelet-based technique for accomplishing frequency and voltage derivatives for the purpose of analyzing the disturbance. [6] An energy efficient algorithm for security for smart grid WAMS was developed. Three theorems were generated in this paper. Firstly, the consumption of energy is considered as important. Secondly, energy, security and time factors have to be balanced. Algorithms with encryption could have an increase in the efficiency of implementation and have a reduction in the consumption of energy by optimizing the code. Lastly, the strength of encryption of security algorithms is associated with the operation model, the length of the key and the number of repetitions which when changed, could affect the consumption of energy [7] describes the monitoring functions as the next generation. The authors suggested that the next generation monitoring functions should provide essential information to the operators as opposed to raw data. Besides, it is the data that is needed compared to information. For the operators to get information efficiently, advanced visualization methods have to be deployed. Communication systems technologies such as high resolution meter reading, sensor network for the local area and wireless sensor network have an important role to play in the delivery of data and information to accomplish online real-time monitoring. However, the deployment of wireless communication networks would bring new challenges such as cyberattacks and fault disturbance. Transmission and distribution technologies on the smart grid monitoring was surveyed. Also monitoring of equipment such as the transformer and wind generators were also demonstrated. A survey on the standards of the smart grid control, monitoring and protection applications were referenced from [8].

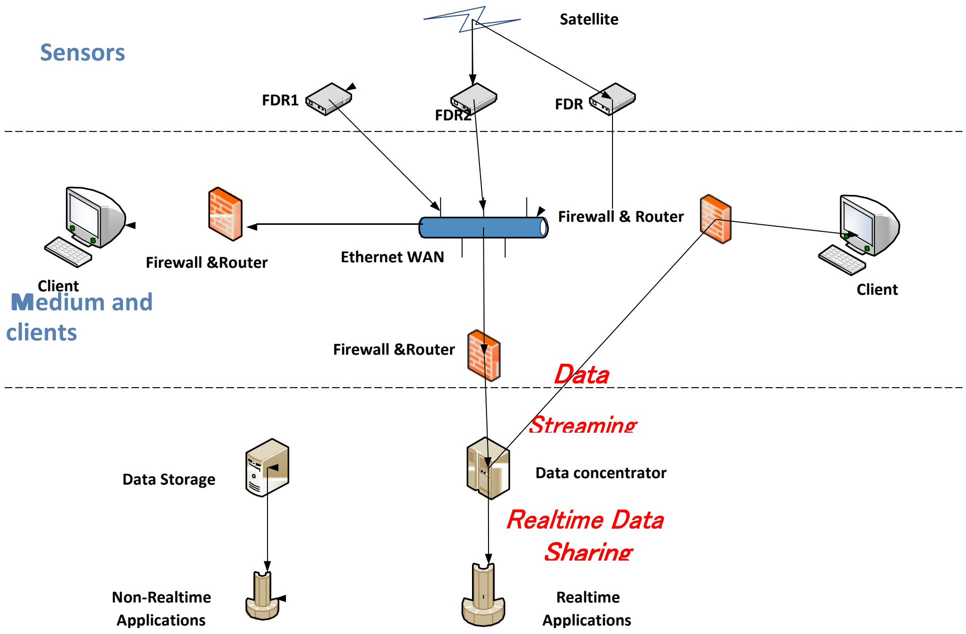

Fig. 3: Building blocks of the FNET system [5]

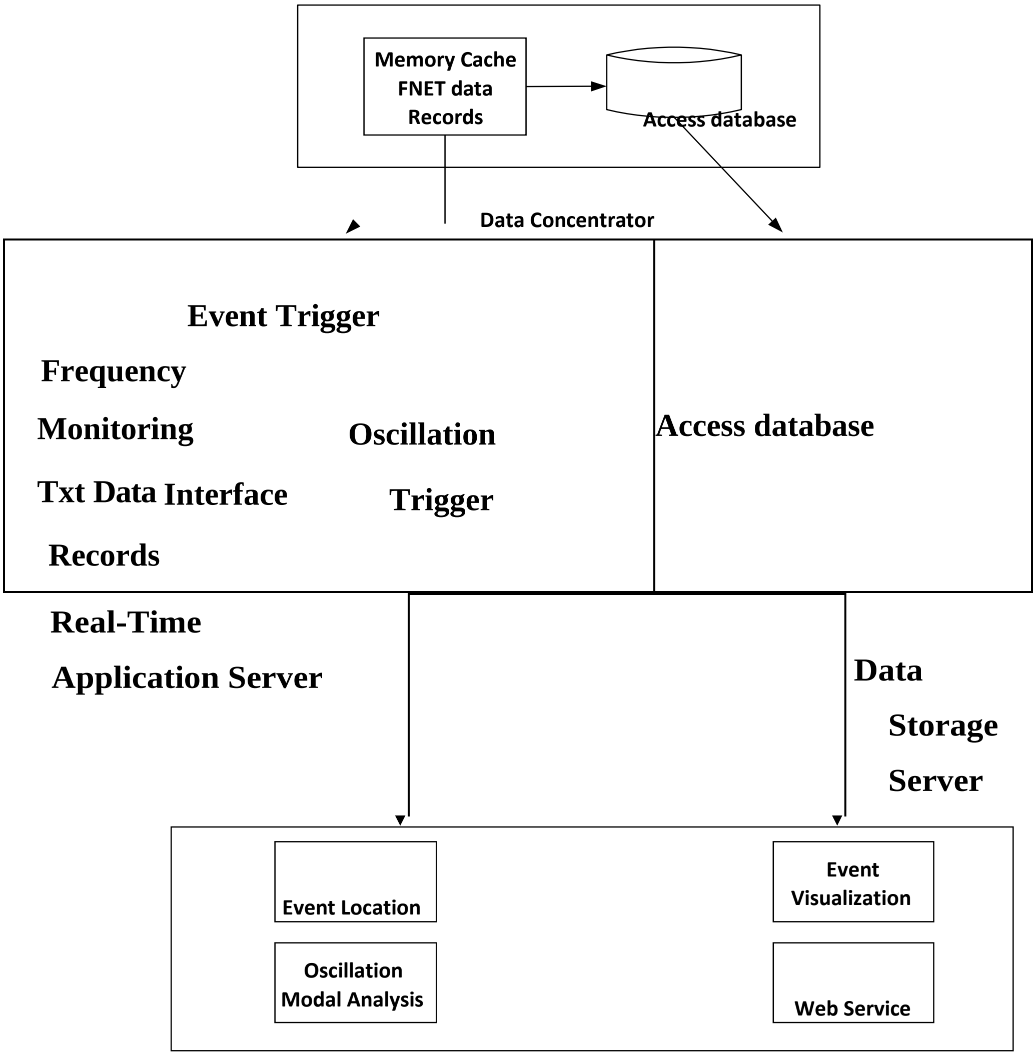

Fig. 4: FNET application hierarchy and data flow paths [9]

Non Real Time Application Server

Information and communication technology (ICT) is one of the major key technology in regards to the smart grid. This is according to the United States Department of Energy. The micro-grids' service-oriented architecture with monitoring integration was suggested (*Alfredo Vaccaro, Marjan Popov, Domenico Villacci*, n.d.). The main element of the architecture is an engine for the micro-grid which is used for implementing the functions of the micro-grid. [10] Proposes changing decision and monitoring system to enable sustainability in energy services. It as well addresses the issue of dependence and also issues to do with reconnections in the micro-grids and DGs. Authors in reference [11], realized that utilization of Phasor Measurement Units (PMUs) require low values of Total Vector Error (TVE). A PMU that is on the basis of the estimation algorithm of a synchro-phasor was developed specifically to attain the standards of the monitoring in active distribution networks. The author stated that, the information provided by PMUs can improve the management and control systems in a way that is reliable and easily applied. On the other hand, the information obtained from the PMUs can help the operator of the distribution systems to make decisions in the event when there is a critical moment being experienced in the system.

	First Category	Second Category	Third Category
Motor	Washing Machine, Fan, Mixer	Air Conditioner, Freezer	**Smoke exhauster, Frequency-alterable AC, Refrigerator, Microwave ovens**
HR	Rice Cooker	Rice Cooker	**Heater, Hair dryer, Cooker**
EC	**NULL**	**PC, TV**	**NULL**

Table. 1 Application classification list (*Marcelo Matus, Doris Sáez, Mark Favley, Carlos*, n.d.)

A non-contact technique founded on magneto-resistive sensors which includes the measurement of derived magnetic field out of the line conductor that utilized to observe short duration in the reduction of the rms voltage as well as the current in HV transmission line in reference to [12]. The author illustrated that the technique was low-cost, accurate, applicable and non-contact. The current in the phase conductor and the position of the line were described by the measurement of the derived magnetic field of the transmission line. Furthermore, the optimal use of stochastic can allow handling of different configurations such as artificial Immunity System (AIS) used to handle complicated scenarios.

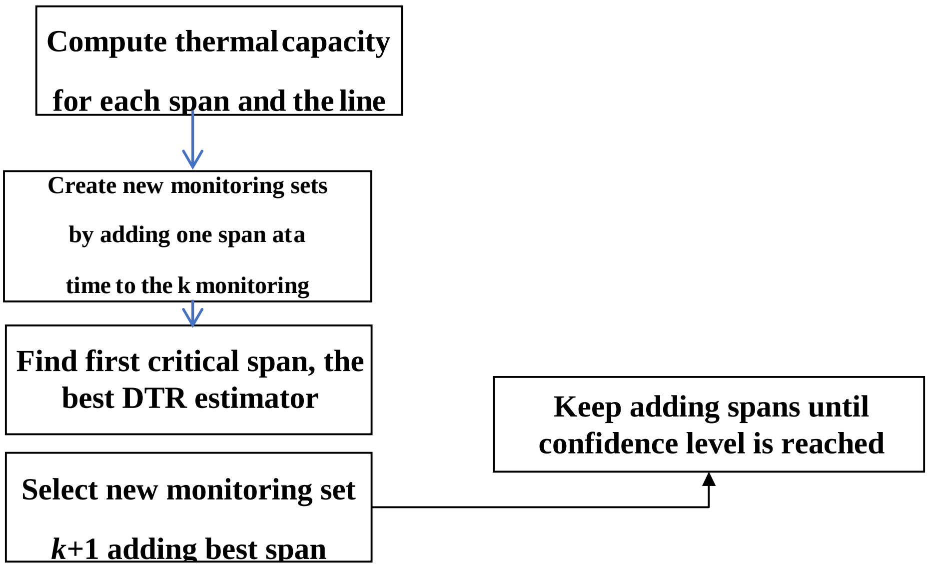

Fig. 5: Heuristic flow diagram (Marcelo Matus, Doris Sáez, Mark Favley, Carlos, n.d.-b)

Apart from condition monitoring the grid itself, the monitoring of the smart grid also includes monitoring the Dynamic Thermal Rating in the planning of the power system and industrial electronic devices. Figure 6 illustrates the flow diagram of a heuristic novel proposed in (Marcelo Matus, Doris Sáez, Mark Favley, Carlos, n.d.-b) in order to recognize the amount and position of the monitoring spans for the establishment of dynamic thermal rating (DTR). Statistically, the thermal capacity analysis from each span and a Mesoscale weather model generated a historical-simulated weather data. A new non-intrusive load monitoring method (NILM) [13] demonstrated the identification as well as monitoring of domestic appliances. Domestic applications were put into three groups according to their functionality and were classified into three categories according to working style shown in

Table 1. Three steps have been done to establish the platform of the appliance identification. Step 1 is the identification of a detection event with the benefits of the analysis of transients and steady-state. Step 2 is classifying the loads into categories in three aspects. And step 3 is generally multi-dimensioning of linear discriminate that has function features used for the assessment of power. The author also discussed the advantages of NILM techniques. First of all, the sample study is not required. Secondly, the sensor is used in a multi-functioning meter. Thirdly, the internal non-working part of a microcontroller unit in multi-functioning meter can provide a system in real-time using event detection, and the raw data does not require large space for storage. And lastly, in as much as it was under noisy measurements, the NILM still worked. A summary of techniques and algorithms in regards to the smart grid are shown in Table 2.

Table 2: Techniques and algorithms that apply in the smart grid monitoring

	Purposes	**Algorithms, key characteristics, hardware and software**
Protection Relays	Allow new power system problem-solving, cost saving	Microprocessors and intelligent electronic devices
Local area sensor network	Provide benefits to power quality, grid efficiency and health monitoring	Smart meters, Telephone Terminal Unit (TTU) local area network, IP address, Logging
Cyber security, fault detection, and Communication	Facilitate the linear quadratic Gaussian control of power system, collect gas flow data, and detect small leaks and theft.	Discrete-time linear state space model, new locally optimum method, high-resolution meter reading, Wireless sensor network,
Smart grid control center	Implement parallel computing infrastructure	Human-centered, comprehensive, proactive coordinated, self-healing
Distribution networks	Improve customer satisfaction, improve the delay of the network, improve the control and management system of the active distribution Network	Proactive approach, quality of Service, a synchro-phasor estimation algorithm for PMU
Transmission networks	Monitor and optimize the electric transmission, real-time monitoring of changes in the characteristic signature of electromechanical oscillations	Wireless network based architecture, smart wireless transformer sensor node, smart controlling station, smart transmission line sensor node, smart wireless consumer sensor node, data aggregation and synchronization algorithm, remote monitoring and control, Rule Identification Algorithm, Negative Data Oriented Compensation Algorithm, Magneto-resistive Sensors, empirical mode decomposition (EMD) method with masking technique, and the non-linear Teager-Kaiser energy operator (TKEO)
Micro grids	Incorporate micro-grid modeling, monitoring and control	The service-oriented architectures
Power quality and Stability	Track the modes of voltage collapse and identify areas vulnerable areas	Eigen-decomposition on Thevenin impedance matrix

Operation and Communication Business of the Smart Grid

The entire system of the smart grid has deployed communication technologies in various levels and for various consumptions. From the operation and business communication point of view, it is mainly implementing technologies in Automation in Advanced Distribution, Automation of the feeder, Wide-area control and monitoring, automatic systems for substations, self-healing technologies, DGs, storage of electricity, operations of non-conventional energy and micro-grid.

Automation of Advanced Distribution

Automation of Advanced distribution is dependent on widespread communication from the controlled devices to at least on control unit (Mcgranaghan & Goodman, n.d.). The deployment of communication network in distribution system has three major categories associated with Wireless, Landline and Power Line Carrier (PLC) (Scott Schoenherr, "Wireless Technologies, n.d.). According to the Electric Power Research Institute (EPRI), PLC performs well when applied in functions such as automatic meter reading and load control. But, when the PLC is deployed as the communication channel, the applications of automatic distribution are vulnerable to the challenges of open circuit (Mcgranaghan & Goodman, n.d.). The two categories of Landline communication are fiber optics and telephone. The fiber optics' characteristic of Electromagnetic Interference (EMI) or Radio-frequency Interference (FRI) and the dielectric immunity to noise allows it to work in high voltage environment. However, the price of fiber optics is very high for to be applied in distribution systems. Then, the telephone lines are rented out or rather, they are leased for the communication from the SCADA system to the remote terminal unit (RTU). To achieve automation of distribution, Wireless network is one of the cheapest and most popular communication technique for communication to anywhere. In as much as public wireless network such as cellphone network will have no cost on the capital and maintenance, security for network providers still remains as top priority to prevent leakage of customer information into wrong hands (cyber-attacks). From the Electric Power Research Institute's point of view, security threats can be disregarded if security features such as secure socket layers (SSL), encryption of 128-bit and frame relays are deployed.

Automation of Feeders

The automation of feeders includes the following:

Locating the fault, isolation from and service restoration

Optimizing the network reconfiguration

Planned islanding, a situation where a DG continues to supply power to a location even when the power grid is off (R. W. Uluski, "The Role of Advanced Distribution, n.d.).

Wide-Area Control and Monitoring

Transmission systems as well as distribution systems are areas in which wide-area network can be applied. Wide-area Management Systems (WAMS) can transmit information on voltage and current to the control center at very high rate using PMUs on power system. Normally, Phasor Data Concentrators (PDC) obtain data from PMU through wide area networks to the control center. [1] Gives a description of three applications of wide-area management associated with communication network. First of all, monitoring in power system monitoring is associated with state estimation, seams between state estimates and instrument transformer calibration for all-PMU estimators. Next is the protection of the power system which involves the security and the capacity to be independent, monitoring the attributes of apparent impedances of relays, back-up zone supervision, loss-of-field adaption, load shedding using intelligent systems, islanding using intelligent systems and incorporation of schemes for system integrity protection. Then finally, control of power system is comprised of oscillations that are uninterrupted for some time, control contains sustained oscillations, large oscillations control, action plans as remedies and the restoration of the system.

Automation Systems for Substations

A scheme for the automation of a substation needs features such as monitoring and control of every electrical component of the substation from a central location, SCADA systems remote interface, observing the status of the substation equipment connected, management of the database system, management of the energy as well as condition monitoring of electrical components including transformers, switchgear, relays and IEDs [14]. To accomplish this, communication network with high-performance and of international standard such as IEC 61850 is needed for the connection of all IEDs to that part of the substation which is interfaced with the humans. Unlike automation for distribution systems, the automation for substation is deployed inside the substation to monitor and control the electric components.

Self-Healing Technology

The processors installed in the equipment of the substation enable communication between the substation devices such as circuit breakers, transformers, switches, isolators, bus-bars is made possible by the use of self-healing technology. A parallel connection of information must be established on the connection of the high voltage to the device, of which, the parameters, the status have permanent information from the sensors. In the event where a new device is brought into the substation, the central computer will automatically update the data after being received from the new device (Massoud Amin "Challenges in Reliability, n.d.). The idea is that, the self-healing strategies should ensure that there is frequency and changing voltage stability, a contingency must be followed [15]. The rate at the devices communicate with each other and switching actions determines the rate at which the tripping action will occur in the load shedding scheme in regards to self-healing in real time [16].

Distributed Generation, Electricity Storage, Renewable Energy and Micro-Grid Operation

Distributed generation (DG) incorporated with islanding functions needs a communication infrastructure to achieve practical solutions [16]. When a proper communication infrastructure is in place, distribution systems and consumption that is meant to save and shift electricity using digital power electronics for control can evolve and form a grid connection of the distributed power components such as DGs and storage and many other loads that are able to be controlled [16].

CONCLUSION

Two-way communication systems' deployment is one of the distinctive mark of the smart grid. The smart can gather and transfer monitored data from the power system elements to operators of the system using the smart grid monitoring system and form a two-way communication system via the grid power plant and the end user of electricity.

The smart grid implementation is a gradual process to substitute the conventional power systems' elements built on the basis of existing systems and building brand new systems which would be very costly. Smart grid planning involves not only the consideration of these creative technologies but also respecting the interest of all the stakeholders involved. Decision making requires to be executed to analyze each smart grid component and its cost before investment and consequently deploying into the real grid. Considering the above mentioned issues, this project surveys an overall monitoring and communication structure. Information optimization is one the key strategies to obtain the benefits of the smart grid.

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