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A study on Intelligent Control for Smart Grid

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Abstract - **This paper gives us a better understanding of the intelligent control of Smart Grid and its potential advantages. Smart grids are the modern electric power grids for the enhancement of power system efficiency and reliability through automated control, high-power converters, sensing and metering technologies, modern communication infrastructure and modern energy management techniques based on the optimization of energy, demand, network availability and so on. Also the identification of faults and the control of fault current were studied. In this paper we have explored various failure protection mechanisms which improve the reliability of the Smart Grid as well as the security and privacy issues in the Smart Grid.**

***Keywords*— Smart Grid (SG), Advanced Metering Infrastructure (AMI), Fault Current Controller (FCC), Intelligent electronic devices (IED), Power line communication (PLC)**

I. INTRODUCTION

The entire power system has been the same for several decades and there has to be a change that makes it updated. Smart grid is a term referring to the next generation power grid and it delivers electricity between suppliers and consumers using two-way digital technologies. It controls intelligent appliances at consumers' home, building or industries so as to save energy reduce cost, increase reliability, efficiency and transparency. Smart grids have capabilities that would enable it to deal with the power outages by balancing both supply and demand. This is achieved by the intelligent balancing of the consumption between peak and off-peak periods.

The smart grid on the whole makes the power system to use all available information, providing a two-way, cyber-secure communication and computational intelligence in an integrated fashion over generation, transmission, distribution and loads to achieve a system that would be much more clean, safe, secure, reliable, efficient and sustainable [1].

According to the report from NIST, the benefits and requirements of a smart grid are the following

- Improved power reliability as well as power quality
- Optimized facility for the deployment and averting the construction of back-up (peak load) power plants
- Enhanced capability and efficiency of existing systems
- Enable automated safeguarding and self-healing responses
- Facilitates deployment of renewable energy
- Provides opportunities to improve grid security

II. EXISTING COMMUNICATION TECHNOLOGIES

Different communication technologies supported by the two main communication media, viz., wired and wireless, can be used for data transmission between smart meters and electric utilities [2].

Two types of information infrastructures are mandatory. The first one is from the sensor and electrical appliances to the smart meters and the second is between the smart meters and the utility's data centers. The very first data flow can be accomplished through the power line communication or the wireless communication, say ZigBee. The second information flow is through the internet or the cellular technologies.

A. ZigBee

ZigBee is one among the wireless communication technology which has relatively low power usage, data rate, complexity and cost of employment. It is an ideal technology for smart lightning, energy monitoring, home automation, industrial automation, automatic meter reading, etc., It enables the utilities to send messages to the owners so that they can get the information of their real-time energy consumption.

B. Wireless Mesh

A mesh network is a flexible network which consists of a group of nodes, where we can add new nodes to the existing group and each node can act as an independent router. The self-healing characteristics of the network enables the communication signals to find another feasible route via the active nodes if any node be supposed to drop out of the network.

C. Cellular Network Communication

Existing cellular networks can be a good option for the communication between the smart meters and the utility and also between the far nodes. The existing communication infrastructures prevent utilities from spending operational costs and additional time for building a keen communication infrastructure. Cellular network communication also enables smart metering deployments spreading to a wide area environment. 2G, 2.5G, 3G, WiMAX and LTE are some of the cellular communication technologies available to utilities for smart metering techniques. When a data transfer interval between the meter and the utility of typically 15 min is used, then huge amount of data will be generated and a high data rate connection would be required to transfer the data to the utility which can be well established using this technology.

D. Power Line Communication

Power line communication (PLC) is a technique that utilizes the existing power lines to transmit high-speed (2–3 Mb/s) data signals from one device to the other. PLC has been the first choice for communication with the electricity meter due to the availability of direct connection with the meter as well as the successful implementation of the Advanced Metering Infrastructure (AMI) in urban areas where the other solutions struggle to meet the needs of the utilities. PLC technology is chosen for data communication between the smart meters and the data concentrators, while GPRS technology is used for transferring the data from the data concentrator to the utility's data management center.

E. Digital Subscriber Lines

Digital Subscriber Lines (DSLs) are one among the high-speed digital data transmission technology that uses the wires of the voice telephone network. The existing infrastructure of DSL lines reduces the installation cost. Hence now a days many companies choose DSL technology for their smart grid projects.

III.DATA INTEGRATION FOR SMART FAULT LOCATION

A. Transmission Line

A smart integrated substation is normally equipped with various types of Intelligent Electronic Devices (IEDs) which can be used for monitoring, controlling and protection purposes. Substation analog signals which are measured at high power level are transformed to instrumentation level (using current and voltage instrument transformers) and then filtered and digitized for being processed using the IEDs. The basic idea of integration of data is to gather all the IED data in a substation database and use it for extracting the information automatically and then utilizing the extracted information for several power system applications [6]. The functional diagram for the substation data flow is depicted in Fig.1.

The substation database consists of the following data:

- Measurements received from RTUs
- Measurements received from other IEDs
- Static system data containing the topology ie., the description of the system's components and their connections
- SCADA EMS PI Historian data, which may be used to tune the static system model with the real-time data available
- Substation interpretation data that allows one to correlate the prehistoric as well as the present information.

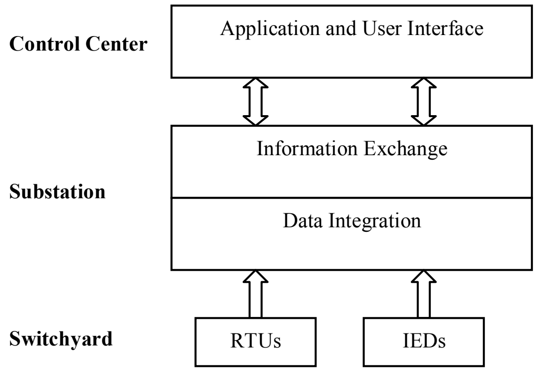

Fig. 1 Functional diagram for the substation data flow

B. Distribution Feeder

As a part of the smart grid employment projects, the IEDs for monitoring, controlling, protecting and other purposes including the smart metering systems, power quality monitoring and distributing automated system has emerged in the distribution systems. These smart sensors are installed all over the system, the very first one from substation down to the customer location. Their types vary accordingly and some provide samples (say digital protection relays and digital fault recorders) and synchronized phases (say digital protection relays) and some provide energy measurements and power quality indicators (say smart meters and power quality meters).

Availability of additional feeder data may help in improving the accuracy of the fault location methods. However, there are certain standing concerns that should be taken into account: for example, how the different types of IEDs available in the network may affect the fault location method selection, what are the factors that influence the quality of the recorded data and how the feeder automation's architecture influence the final availability of data.

C. Data Sampling and Processing

In the scanning method, each and every analog input channel is sampled for a given time and then converted to a digital word. This then creates a time skew between the corresponding samples on different channels. In synchronous sampling method, all the input signals at each channel are sampled at the same time and these sampled values are converted to a digital word. Hence in this case there is no time skew between the corresponding samples on different channels. This can be accomplished either by using one ADC serving all channels but having separate S/H circuits on each channel and a multiplexer that feeds another S/H in front of the ADC or by using a separate S/H circuit and ADC on each channel.

IV. SELECTION OF OPTIMAL SOLUTION FOR TRANSMISSION LINE FAULT LOCATION

After gathering all the information and updating the system data, the location of the fault can be estimated using the optimal fault location algorithm with the help of the following architecture shown in Fig. 2.

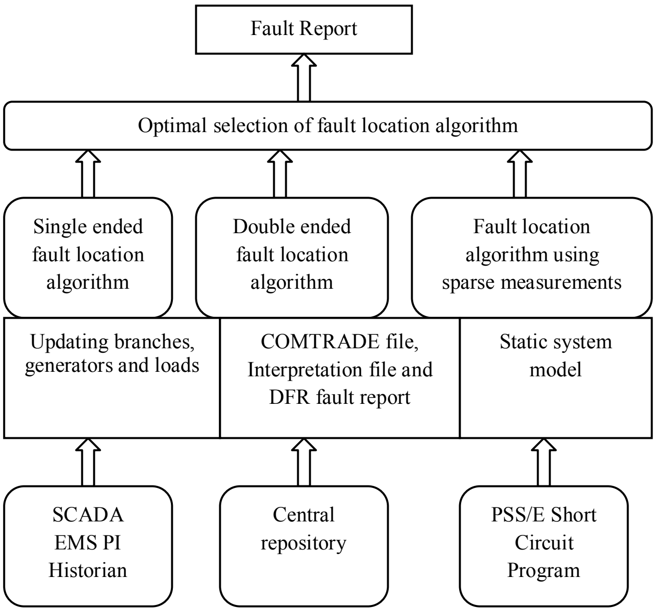

Fig. 2 Architecture of optimized fault location algorithm

An optimal fault location approach which will opt for the most appropriate fault location algorithm depending on the Availability of data and the location of the fault measured is explained below [3].

A. Single-End Method

Estimates the location of fault using the measurement from only one end of the faulted line.

B. Double-End Methods

Estimate the location of fault using either the unsynchronized phasor measurements or the synchronized samples from both ends of the faulted line.

1) System wide Sparse Measurement Method

This method uses the phasor measurements which may be sparse, i.e., which are recorded from few substations located in the region where the fault has occurred. This method works on comparing the measured data versus the simulated data generated by the short circuit simulation of possible fault locations, while the location of the fault is changed in the short circuit program. This process is repeated automatically until the measured and the simulated values have minimal difference, i.e., it indicates that the fault location used in the short circuit program is the actual one.

System Level Data: These data include the power system model data and the data reflecting real time changes in power system. The power flow input data contains the power flow system specification data for the establishment of a static system model used by the PSS/E software to run the power flow analysis.

Extraction and Synchronization of Phasors: The disturbance events obtained from the IEDs are processed to gain the phasors from the samples of the recorded analog signals

Tuning of the Power System Model with Real-Time Power System Conditions: The system model obtained from the PSS/E software may not reflect the prevailing operating conditions of the system when fault occurs. Thus to obtain the simulated phasors corresponding to the time when fault occurred, the static system model should be tuned with the real-time power system conditions. This tuning procedure consists of updating the power grid topology (i.e., the switching status) and then updating the generation as well as the load data near the substations of particular interest. The topology update is thus performed by using the information of the prefault circuit breaker status and the prefault current magnitudes of the monitored branches.

V. CONCEPT OF SMART FAULT CURRENT CONTROLLER (FCC)

The smart FCC is based on the solid state superconducting technology. It consists of a superconducting coil (with a freewheeling diode if necessary), four thyristors and a control unit. Since the main topology is similar to a full-wave rectifier called as a bridge rectifier, its operational principle can be explained as a rectifier. The superconducting coil has no resistance but possess large inductance. Since the coil is a kind of an energy storing device, the current flowing through the coil should be accumulated, i.e., almost direct current (dc). It means that there is no voltage drop across the coil in a normal operating condition. Note that the line current is ac and the coil current is dc. Since the dc coil current makes all thyristors turned on, the nominal ac current behave not to flow in the coil. In this case, the voltage drop is caused by just thyristors or any other solid state if replaced, since the coil is in superconducting state and has almost zero ac loss [4].

The most important part of the smart FCC system is its control unit. All the information about the grid network related to the smart FCC can be transferred to the control unit as depicted in Fig.3. The so obtained information can be converted to an equivalent value such as Thevenin impedance and load current in the line. Thus the control unit can calculate the optimal fault current level based on the collected data.

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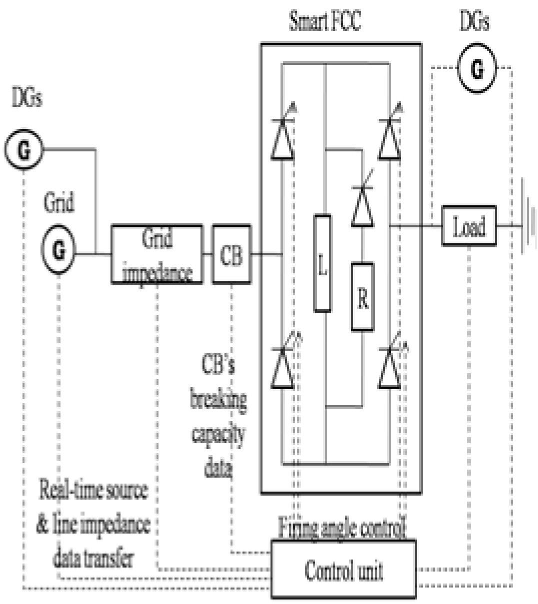

Fig. 3 Schematic representation showing the smart FCC and the fault location in a grid with grid-connected Distributed Generators (DGs)

The existing power system protective devices viz., over current relays and circuit breakers, should be considered while calculating the optimum fault level. Since the generating source capacity experience a temporal variation when DGs are connected to the grid, the optimum delay angle should be calculated at every stages in the collection of the information. i.e., the real-time optimal firing angle is calculated and is being ready to be supplied to the gate signals.

When a fault occurs, the coil current should be increased so that the controller can recognize an event of the fault. Thus the gate signals can be controlled based on the updated optimal firing angle delay. Fig. 4 represents the flowchart of the controlling procedure. The firing angle can be modified even during the instance of fault in order to satisfy the optimal fault current level by considering the interrupting duty of breakers and time delay before the interruption.

VI. PROOF OF CONCEPTS OF FAULT CURRENT CONTROLLER

A. Modeling and Simulation

To simulate the proposed power system circuit, a commercialized circuit simulator viz., CASPOC2003 is used. The main variable used in this simulation model is the firing angle which can be varied from 0 to 180 degrees [4].

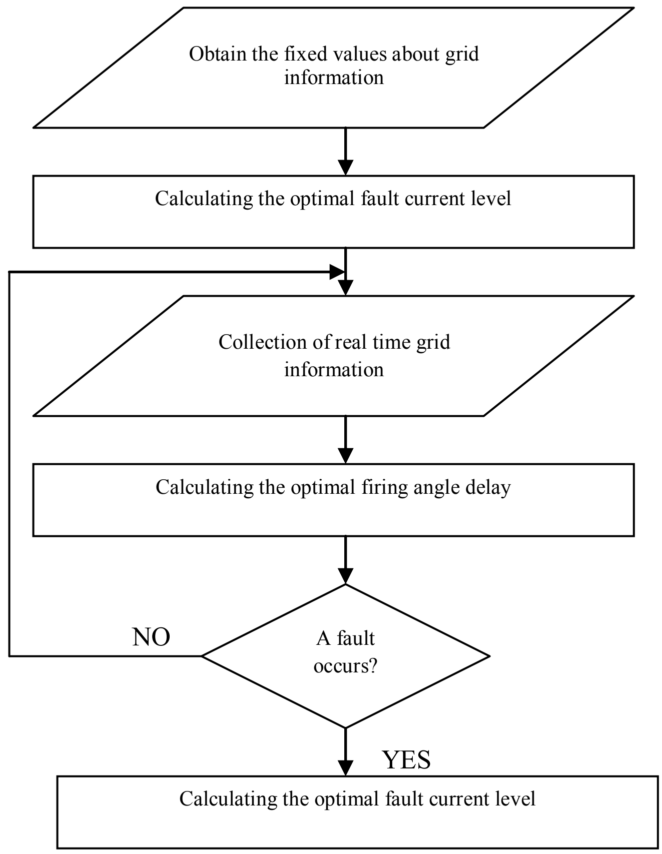

Fig. 4 Flow chart of the controller operation

B. Proof of Controlling

Even though the control unit is supposed to calculate the optimal phase angle in real case, we can vary the firing angle values manually to prove the function of the fault current controlling. Thus the variation of the delay angle can adjust the fault current to the fixed target level.

A. Effect of Freewheeling Circuit

In case of with the freewheeling, the coil is charging and discharging repeatedly during the occurrence of fault. Hence after the clearance of the fault, the freewheeling case is much easier to return to the initial status, i.e., the state before the fault. In summary, a freewheeling circuit is necessary so as to recover the superconductor.

VII. CONCLUSION

The smart grid has been considered as an evolution of the electric power systems due to the increasing diffusion of distributed generation by renewable sources and also with the additional aim to enhance the efficiency, reliability and safety of the existing power grid. This paper discusses the existing approaches and future trends in determining the fault location methods for both transmission and distribution systems and also discusses the smart grid technologies and sources of data that could be utilized to improve fault location methods. As a new solution of dealing with the fault currents, we have proposed the smart fault current controller. In summary, there is no doubt that the emergence of Smart Grid will lead us to a more environmentally sound future with better power supply services and eventually revolutionize our daily lives.

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