© April 2020 | IJIRT | Volume 6 Issue 11 | ISSN: 2349-6002

Smart Distribution Systems

Swapnil Namekar[1], Shubham Gupta[2]
[1]Assistant Professor, Department of Electrical Engineering, Bharati Vidyapeeth Deemed University, College of Engineering, Pune, India
[2]Student, Department of Electrical Engineering, Bharati Vidyapeeth Deemed University, College of Engineering, Pune, India

Abstract- **The increasing importance of system reliability and resilience is changing the way distribution systems are planned and operated. To achieve a distribution system self-healing against power outages, emerging technologies and devices, like remote-controlled switches (RCSs) and smart meters, are being deployed. The higher level of automation is transforming traditional distribution systems into the smart distribution systems (SDSs) of the longer term. The availability of knowledge and remote capability in SDSs provides distribution operators with a chance to optimize system operation and control. In this paper, the event of SDSs and resulting benefits of enhanced system capabilities are discussed. A comprehensive survey is conducted on the state-of-the-art applications of RCSs and smart meters in SDSs. Specifically, a replacement method, called Temporal Causal Diagram (TCD), is employed to include outage notifications from smart meters for enhanced outage management. To fully utilize the fast operation of RCSs, the spanning tree search algorithm is employed to develop service restoration strategies. Optimal placement of RCSs and therefore the resulting enhancement of system reliability are discussed. Distribution system resilience with reference to extreme events is presented. Test cases are used to demonstrate the benefit of SDSs. Active management of distributed generators (DGs) is introduced. Future research during a smart distribution environment is proposed.**

INTRODUCTION

Electric power distribution systems are designed to deliver power from substations to customers. Efficient delivery and reliability of service are crucial measures for distribution systems. However, extreme events, such as Super storm Sandy and derecho, threaten the reliable operation of distribution systems, and cost the economy billions of dollars, e.g., an estimated loss of $52 billion due to Super storm Sandy. Destructive hurricanes, winter storms, and other extreme weather events, resulting from global climate change, may further challenge the reliable operation of distribution systems. To minimize the impact of these events on reliable power supply, governments and utilities are making an effort toward smart distribution systems (SDSs) through grid modernization.

Traditionally, limited information is acquired along distribution feeders with few deployed sensors. Crews are sent to gather field data and operate devices on site. The lack of remote monitoring and control capability limits distribution operators' ability to monitor system operations and take control actions promptly in response to extreme events. It may take those hours to determine fault locations through field crews and trouble calls from affected customers.

The observability and controllability of distribution systems can be enhanced by adopting emerging intelligent devices and smart grid applications. With the ongoing smart grid development, smart meters and remote control switches (RCSs) are deployed nationwide in the U.S. According to, a total of 7661 RCSs have been installed by 2013. It is estimated that 65 million smart meters have been installed by 2015. These devices with bidirectional communication are accelerating the transformation to SDSs of the future. In a SDS, a large amount of data, gathered by smart meters and intelligent electronics devices (IEDs), provides sufficient information to monitor system operations in nearly real time. Smart grid applications, such as advanced outage management and fault location, isolation, and service restoration (FLISR), are developed and integrated into Outage Management Systems (OMSs) and Distribution Management Systems (DMSs). These tools assist distribution operators in determining optimal system operation strategies and taking control actions promptly in response to a disturbance.

This paper is focused on the state-of-the-art applications of smart meters and RCSs in SDSs.

The impact of extreme events on distribution systems is analyzed to highlight the importance of developing SDSs. With the availability of numerous smart meters, applications based on data gathered from these meters are discussed. A new method, called Temporal Causal Diagram (TCD), is presented for enhanced outage management by incorporating outage reports from smart meters.

Fault isolation and service restoration are implemented to restore service to the interrupted customers [1]

A state-of-the-art survey is conducted on service restoration techniques. Specifically, the spanning tree search algorithm, which determines service restoration strategies that restore the maximum amount of interrupted load with a minimum number of switching operations, is illustrated with examples.

Methodologies for placement of RCSs to enhance service restoration capability are discussed.

The enhancement of system reliability through added remote control capability is demonstrated.

Distribution system resilience with respect to extreme events is discussed and demonstrated using numerical simulation results of the Pullman-Washington State University (WSU) distribution system.

In addition, worldwide development of SDSs, especially in Europe, and active management of DGs are summarized.

SGIG

Smart Grid Investment Grant (SGIG) program, which is aimed at modernizing electric power grids with advanced tools and smart grid techniques. The projected SGIG expenditures at completion are summarized in Figure 1.

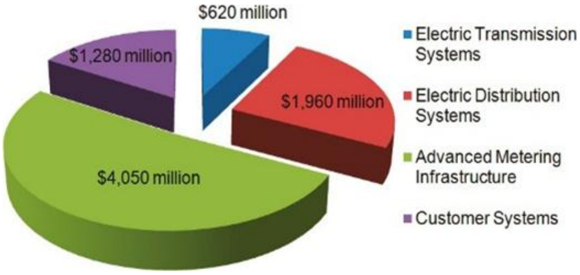

Figure 1. Estimated expenditures of the SGIG programs

SMART METERING TECHNOLOGY

In a SDS, smart meters play an important role in acquiring data and enhancing the situational awareness of system operators. A smart meter is an electronic device with two-way communications that can automatically transmit customers' energy consumption data as well as system operation information to the distribution operating center.[2] The available information includes the values of voltage and real and apparent power. A large amount of data from smart meters provides distribution operators with near real-time monitoring of system operations. The architecture for integration of smart meters in the distribution operating center is illustrated in Figure 2. Smart meters are set up to collect data every 5 min and transmit the information via a Local Area Network (LAN) to a Meter Data Management System (MDMS) as often as 15 min or more infrequently according to the data usage. Peer-to-Peer (P2P) and Zigbee technologies are widely used in a LAN. To pass on the data to the central collection point in the distribution operating center, a Wide Area Network (WAN), e.g., Power Line Carrier (PLC), is adopted. The data is then processed at the distribution operating center for customer billing, outage management, and other operational purposes

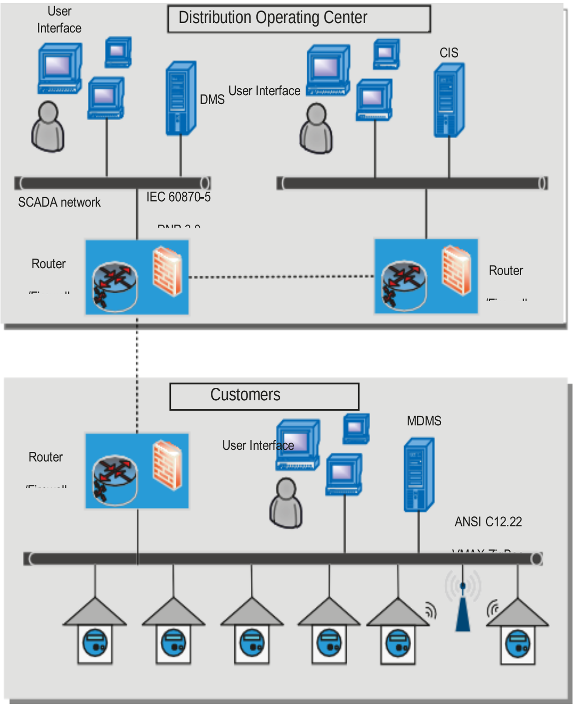

Figure 2. The architecture for integration of smart meters in the distribution operating center

It is required that system vendors comply with new requirements to address remote access, authentication, encryption, and privacy of metered data and customer information. Besides these guidelines, research related to cyber security of smart meters is being conducted to prevent metering infrastructures from cyber-attacks. Issues concerning health effects of radio frequency exposure from smart meters are also raised. It is reported by California Council on Science and Technology that radio frequency exposure resulting from smart meters, when installed and maintained properly, is lower than common household electronic devices, such as cell phones and microwave ovens [2]. To standardize the radio exposure from transmitters, the Federal Communications Commission (FCC) has issued Maximum Permissible Exposure (MPE) limits for field strength and power density of radio frequency electromagnetic fields. All smart meters are mandated to comply with the FCC rules. Smart meters enable near real-time data collection and remote control capability, which provide great opportunities for utilities to improve distribution system management and operations.

APPLICATIONS OF SMART METERS INCLUDE

1. Automatic customer billing: compared with kilo-watt meters, which need tedious on-site meter reading work, smart meters automatically send energy consumption data to the utility. It is reported by Avista Utilities, based in Spokane, WA, that developed customer billing portals using smart meter data reveal significant benefit to utilities as well as customers. The benefit includes recording the billing history, analyzing the bill to identify ways to increase energy efficiency, and acting as online home energy advisor to outline ways to save energy
2. State estimation of distribution systems: numerous data from smart meters can be used for state estimation of distribution systems
3. Volt/VAR management: voltage and reactive power management is essential for utilities to minimize power losses while maintaining an acceptable voltage profile along the distribution feeder under various loading conditions. The near real-time voltage measurements from smart meters can be used as inputs for Volt/VAR controls to support decision-making, such as switch-on/off of capacitor banks and adjustment of voltage regulator tap positions.
4. Remote connect/disconnect: two-way communications of smart meters enable distribution operators to remotely connect and disconnect meters. If a customer defaults on electricity payment, a command to the smart meter can quickly cut the customer's power supply. Connect/disconnect functions of smart meters provide distribution operators with more remote control capability to reduce dispatching field crews.
5. Demand response: demand response is aimed to reduce the peak load, which avoids utilities from purchasing electricity at a high cost and delays the construction of new power substations. These demand response programs can be implemented through smart meters to control appliances so as to change customers' energy consumption patterns.

For example [3], the leaf connected to vertex F1 represents three smart meters that do not report an outage. The attribute t of an edge entering a leaf indicates the outage reporting time of a smart meter. Using the Escalation method, the number of smart meter outage notifications correlated with each protective device is determined. Three indices, i.e., Noutage, Nmeter, and Cred are associated with each vertex that represents a protective device. Another two indices, i.e., T and Δ T, are defined for each edge connecting protective devices. These indices are defined as follows: Noutage: number of smart meters downstream the protective device reporting a power outage; Nmeter: total number of smart meters downstream the protective device; Cred percentage of downstream smart meters reporting an outage, Cred. =Noutage/Nmeter;

T: time of occurrence of a fault;

Δ T: time window to select the smart meter notifications corresponding to an outage

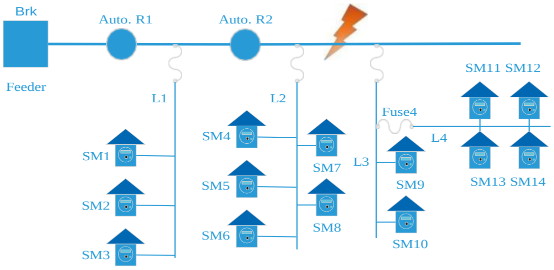

Figure 3. Configuration of a simple distribution system

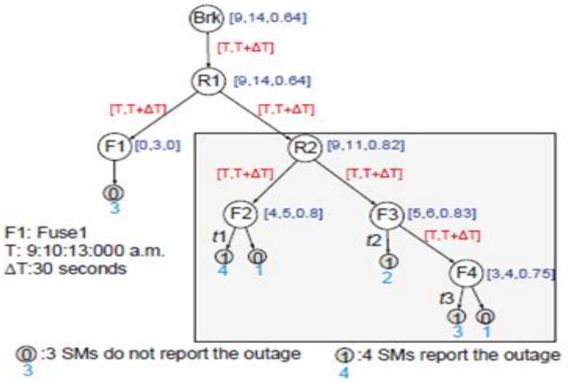

Figure 4. Temporal Causal Diagram (TCD) for outage management

The timing attribute of the edges in the TCD establishes the temporal relationship of the outage scenario and evidence for outage management. The fault occurrence time can be obtained from the digital event recorder at substations with a resolution of half a cycle. For the given outage scenario, T is equal to 9:10:13:000 a.m. The time window, Δ T, defines the length of a time period used to filter outage reports from smart meters. Only outage reports with t falling in the range of T to T + ΔT are used in the TCD for fault scenario identification. In the example, ΔT is chosen to be 30 s. Assuming there is an outage report with time stamp t at 9:01:13:000 a.m., the outage report is abandoned as it is not in the range of 9:10:13:000 a.m. to 9:10:43:000 a.m. By assuming that only one fault occurs and all protective devices operate correctly, it can be concluded that recloser R2 opens to isolate the fault, and the fault location is downstream recloser R2 and upstream fuses F2 and F3. Meanwhile, with communication capabilities, the status of automatic reclosers as well as the current flowing through is transmitted to the distribution operating center.

The data can help to validate the activated protective device identified from smart meter outage reports. In the example, recloser R2 reports an open status to the distribution operating center, which is consistent with the inference based on smart meter data. In addition, two missing outage reports are identified based on the fact that only nine out of 11 smart meters report an outage correctly. Note that the TCD alone cannot identify the fault scenarios if protection miscoordination is considered. For example, if fuse F3 and recloser R2 are not coordinated, a fault downstream fuse F3 may cause recloser R2 to open. In this case, information from fault indicators will be useful. Study on integrating fault indicators with communication capabilities in the TCD is needed.

DISTRIBUTION SYSTEM RESTORATION

Distribution system restoration is intended to promptly restore as much load as possible in areas where electricity service is interrupted following an outage. It plays a critical role in SDSs. By operating normally open tie switches and normally closed sectionalizing switches, system topologies are altered in order to restore power supply to interrupted customers. A well-designed service restoration strategy can restore the maximum amount of load with a minimum number of switching operations. Thus, the outage duration is shortened and system reliability is enhanced.

SERVICE RESTORATION PROCEDURE

Following an outage, the fault is located using the methods described in Section 4. Faulted zones are isolated by opening adjacent switches. Then the actuated breaker or recloser is reclosed to bring service back to the customers upstream the fault.[4]The loads downstream the fault are picked up by other feeders, distributed generators, or microgrids through feeder reconfiguration. Constraints, such as limits on bus voltages and capacity of transformers, need to be evaluated. After the faulted component is repaired, switching actions will be taken to bring the distribution system back to its normal topology.

SERVICE RESTORATION ALGORITHMS

Distribution system service restoration is a multi-objective, mix-integer non-linear optimization problem with a number of constraints, including topological and operational constraints. Due to its combinatorial nature, the service restoration problem is NP-hard. It is a challenge to develop an efficient algorithm to develop service restoration plans, especially for large-scale distribution systems with numerous components. Various methods have been proposed, including mathematical programming, heuristic search, expert systems, fuzzy logic, and multi-agent systems, to determine a final system configuration that restores the maximum amount of load.

The flow chart of the spanning tree search algorithm is shown in Figure 5

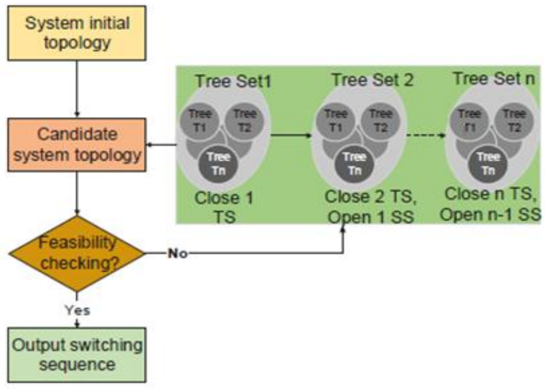

Figure 5. Flowchart of the spanning tree search algorithm

A distribution network is formed by interconnected distribution feeders. The feeders are connected with each other through normally open tie switches. [6]If a zone is modeled as a vertex and a switch is viewed as an edge, the distribution network can be represented as a connected graph.

In the first iteration, it searches for candidate network topologies that can be obtained by operating one pair of switches. Unbalanced three-phase power flow calculations are performed to check the feasibility of candidate network topologies If all potential network topologies are explored and there is no configuration that satisfies all operational constraints, the partial load restoration in the out-of-service area is selected. The minimum amount of load to relieve the overload is identified for the network topology with the least severe overloading condition. Based on the previous power flow calculation results, if the lowest node voltage in the system is defined as the minimum node voltage for this network topology, the network topology with the highest minimum node voltage is the least severe overload topology.

Test Case

A 4-feeder, 1069-bus system, as shown in Figure 6, is used as the test case. The test system is based on the Taxonomy "R3-12.47-2" developed by Pacific Northwest National Laboratory (PNNL). The voltage level of the unbalanced system is 12.47 kV. The real and reactive load on each feeder is 17.467 MW and 2.362 MVar, respectively. The four feeders are interconnected through seven normally open tie switches. Four microgrids are connected to the test system, as shown in Figure 6. The real power limits for microgrids 1–4 are 5.15, 1.65, 2.5, and 1.0 MW, respectively, and the reactive power limits are 2.25, 0.95, 1.75, 0.55 MVar, respectively.

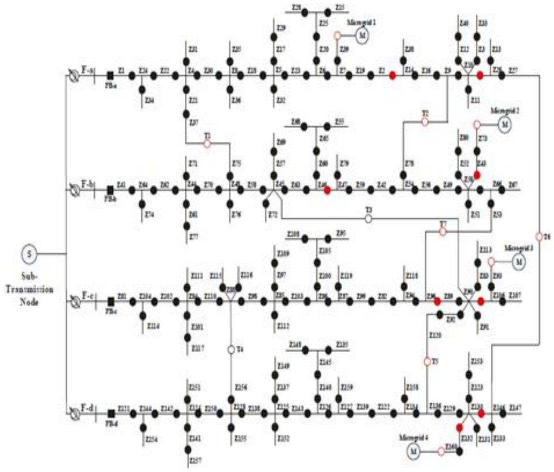

Figure 6. One-line diagram of the 4-feeder 1069-node test system

SMART DISTRIBUTION SYSTEM DEVELOPMENT IN EUROPE

In 2007, the Europe Council set up the 20:20:20 objective of reducing greenhouse gas (GHG) emissions by 20%, increasing the share of renewable energy to 20%, and making 20% improvements in energy efficiency by 2020. To meet this goal, two primary efforts are made by European countries, i.e., the deployment of smart meters and integration of DGs into distribution networks. The European

Union (EU) aims to deploy around 200 million smart meters for electricity and 45 million for gas by 2020. These smart meters will help save energy consumption. For example, Greece expects 5% energy saving by deploying and making proper use of smart meter. Supported by the EU Research Framework Programmer (FPs) 5–7, contributions have been made in the corresponding projects to design and validate new system architectures and advanced components towards the future European electricity networks with a high penetration level of DG. For instance, a demonstration project, Active Distribution Networks with Full Integration of

Demand and Distributed Energy Resources, is aimed to explore active demand management and integration of DGs into distribution networks.

ACTIVE MANAGEMENT OF DGS IN SMART DISTRIBUTION SYSTEMS

Renewable-based DGs, such as PV modules, and energy storage systems (ESSs) are connected to distribution systems through power electronic converters and interface protection systems (IPSs).

The power electronic converters can be used to control the real and reactive power of a DG or ESS,

e.g., the maximum power point tracking (MPPT) for PV. The IPS protects the DG from abnormal conditions, such as faults on the distribution feeders and unintentional islanding. Traditionally, the IPS monitors voltage and current at the point of common coupling (PCC) of the DG and makes decisions with local information. Such a passive scheme can cause problems. For example, the DG may continue injecting power into the distribution feeder when an unintentional islanding or external fault condition occurs.

Energies 2016 by introducing communication between DGs and the distribution system control center, active management of DGs can be achieved [5]. Distribution system operators can be aware of status of DGs in the distribution system by collecting information from the DG IPSs and send control commands to DG IPSs via the communication infrastructure. Consequently, a distribution system operator can remotely disconnect DGs in the network when an abnormal condition occurs. In addition, with the communication capability, the power electronic converters of DGs can also be remotely controlled regulate voltage or reduce the net load seen by the utilities. An economic and effective solution for active IPS of DGs is proposed in. An IPS and a communication bridge are designed. The narrow-band (NB) power line communication (PLC) technology is used to build the communication links between DGs and distribution system control center at a low cost for installation and no cost to communication providers. The effectiveness

NB-PLC-based solution has been evaluated by on-site experiments.

CONCLUSIONS

The worldwide development of SDSs are introduced, particularly the progress in the U.S. and

Europe. Several state-of-the-art smart grid technologies are reviewed. Smart meters and their potential applications are summarized. For enhanced outage management, TCD incorporates outage reports from smart meters to accurately identify the fault location. Service restoration strategies are determined by the spanning tree search algorithm to restore as much load as possible after an outage. A novel method for placement of RCSs to enhance distribution system restoration capability is introduced.

Improved system reliability from the installation of RCSs is reported. By using microgrids to serve critical loads, the resilience of a SDS with respect to extreme events is enhanced, which is illustrated by numerical simulations of a real distribution system. Technologies for active management of DGs are presented. Technologies for cyber-attack detection and defense should be developed and implemented to protect utilities and customers from malicious intrusions.

ACKNOWLEDGEMENT

We would like to express our special thanks of gratefulness to Dr. D.S. Bankar, Head Department of electrical engineering for their Guidance and support for completing the research paper. I would like to thank the faculty member of the department of electrical engineering who helped us with extended support

REFERENCES

[1] U.S. Department of Energy. Economic Benefits of Increasing Electric Grid Resilience to Weather Outages. Available online: http://energy.gov/ sites/prod/files/2013/08/f2/Grid%20Resiliency% 20Report_FINAL.pdf (accessed on 30 August 2013).

[2] The Grid Wise Alliance. Improving Electric Grid Reliability and Resilience: Lessons Learned from Superstorm Sandy and Other Extreme Events. Available online: http://www.gridwise.org/ documents/ Improving Electric Grid Reliability and Resilience_6_6_13 webFINAL.pdf (accessed on 30 June 2013).

[3] U.S. Department of Energy. Smart Grid Investments Improve Grid Reliability,

Resilience, and Storm Responses. Available online: http://energy.gov/oe/downloads/smart-grid-investments-improve-grid- reliability-resilience-and-storm-responses-november (accessed on 31 November 2014).

[4] Southern California Edison. Southern California Edison Smart Grid Strategy & Roadmap. Available online: https://www.smartgrid.gov/document/southern_california_edison_smart_grid_strategy_roadmap (accessed on 30 November 2010).

[5] Liu, Y.; Schulz, N.N. Knowledge-Based System for Distribution System Outage Locating Using Comprehensive Information. IEEE Trans. Power Syst. 2002, 17, 451–456.

[6] Eric Bogatin, Signal and power integrity simplified, Prentice Hall, U.S.A (2009).

[7] OnlinePCBcalculator,https://www.eeweb.com/toolbox/microstrip-impedance