

Fault Location Detection Technique in a Smartgrid with Distributed Generation Sources

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ABSTRACT: In this paper, discussed an accurate and efficient method for fault distance calculation in electrical power distribution systems in a Smartgrid with Distributed Generation. Line faults have been a primary concern to networks as they affect the reliability of the service to the customer, the stability of the power system and the quality of the power delivered. Accurately locating the faults location is advantageous on many account but more important is making an easier task for maintenance, this is the main reason to go for new possibilities to a precisely estimate the fault location.

A fault produces a wide spectrum of signals that contains information about the fault distance. Synchronized voltage and current samples at both ends of a protected zone are used to calculate the location of the fault. The characteristic impedance and propagation constant of the line are determined by the line parameter.

KEYWORDS: Distributed Generation (DG), Smart Grid, Micro Grid.

I. INTRODUCTION

In power systems, high voltage transmission and distribution lines are vital links that achieve the essential continuity of service from the generating plants to the end users. The service continuity is one of the most important concerns to the utility company, but a fault is inevitable often resulting in power interruption. To improve the service reliability, it is necessary for the utility to identify the fault location as quickly as possible when fault is incident on the distribution network. Most of the research focuses on the fault location of the transmission lines. It is because transmission networks are generally under the balanced operation that enables the circuit analysis based on the symmetrical component. Note that the sequence component method generates three independent sequence networks only in case of the balanced systems and becomes a powerful tool in the circuit analysis. Although a direct circuit analysis of three phase network is another alternative but it has not been considered due to its high complexity and difficulty during the course of analysis. A fast fault location helps in reducing the interruption time, but conventional visual inspection not only takes a long time but also requires high manpower. Rapid restoration of service could reduce customer complaints, outage time, loss of revenue, and crew repair expense.

When faults occur in the power system, they usually provide significant changes in the system quantities like over-current, over or under-power, power factor, impedance, frequency and power or current direction. There has been much research in the fault location problem for transmission systems. In recent years, the digital protective devices are replacing the old type devices like the electromechanical or static devices. Those digital devices are generally equipped with fault recording function, which enables an automatic fault location. During the last decade, there has been much research on the fault location problem that is to calculate the distance from a protective device to the fault. Most of them deal with transmission networks, which are, in general, operated in a balanced manner. These methods can be classified into three groups: the first one is to use travelling waves, the second one is to use harmonics, and the last one

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is to use apparent impedance based on fundamental components of voltage and current. The last method can be further divided into two subgroups: to use one-end information or to use information from both ends of the faulted line. Among them, the latter method gives higher accuracy; however, it needs additional devices for communication and data transmission. Therefore, the former one is more widely used with some accuracy improving technique adopted. Location of faults in the distribution system is difficult due to its unbalance in phases, fault resistance, complex nature, variations in load and difficulty due to non homogeneity of line. However, the basic approach to calculate the fault location using voltage and current measurement is still the same as the transmission system case, which is to calculate the impedance using the fundamental component or harmonics. Fault location methods for the unbalanced distribution systems utilize harmonics, fundamental component of voltage and current. Additional calculation burden like recalculation of the voltage and current at each node is needed for the compensation of the characteristics unique to the distribution system. Fault location method for transmission lines cannot be directly used for distribution systems. Thus, various methods have been exclusively discussed for fault location in distribution systems. Generally, these fault location methods can be divided into two main categories: impedance based methods and travelling wave based methods. Most of the impedance-based methods estimate the distance of the faulted point from the distribution substation based on the impedance estimation as seen from the fault locator point [16].

II. CONCEPT OF SMART GRID

Smart Grid is today used as marketing term, rather than a technical definition. For this reason there is no well defined and commonly accepted scope of what smart is and what it is not. However smart technologies improve the observability and/or the controllability of the power system. Thereby Smart Grid technologies help to convert the power grid from a static infrastructure to be operated as designed, to a flexible, living infrastructure operated proactively [23]. Smart Grids is the concept of modernizing the electric grid. The Smart Grid is integrating the electrical and information technologies in between any point of generation and any point of consumption. The smart grid has advantage of two-way digital technology that enables efficiently managing end uses of electricity and grid to identify and correct supply demand mismatch instantaneously and self-healing process that improves service quality, reliability, and decrease costs. Thus, the smart grid is not limited to utilities only; it includes each stage of the power system cycle, from the electricity markets to customer's applications. The emerging vision of the smart grid encompasses a broad set of applications, including software, hardware, and technologies that enable utilities to integrate, interface with, and intelligently control innovations. Some of the enabling technologies that make smart grid deployments possible include:

- Meters
- Storage devices
- Distributed generation
- Renewable energy
- Energy efficiency
- Home area networks
- Demand response
- IT and back office computing
- Security
- Integrated communications systems
- Superconductive transmission lines

Potential Benefits of the Smart Grid

The smart grid presents a wide range of potential benefits, including:

- Optimizing the value of existing production and transmission capacity.
- Incorporating more renewable energy.
- Enabling step-function improvements in energy efficiency.
- Enabling broader penetration and use of energy storage options.

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- Reducing carbon emissions by increasing system, load and delivery efficiencies.
- Improving power quality.
- Improving a utility’s power reliability, operational performance, asset management and overall productivity.
- Enabling informed participation by consumers by empowering them to manage their energy usage.
- Promoting energy independence.

Key Characteristics of the Smart Grid

- Self-healing: The grid rapidly detects, analyzes, responds, and restores.
- Empowers and incorporates the consumer: Ability to incorporate consumer equipment and behaviour in grid design and operation.
- Tolerant of attack: The grid mitigates and is resilient to physical/cyber attacks.
- 21st century power quality needs: The grid provides quality power consistent with consumer and industry needs.
- Accommodates a wide variety of supply and demand: The grid accommodates a variety of resources, including demand response, combined heat and power, wind, photovoltaic’s and end-use efficiency.
- Fully enables and is supported by competitive electricity markets.

Comparison between Current Grid and Smart Grid

Table 1: Current grid and smart grid : A comparison

<i>Current State</i>	<i>Modern Utility</i>
Analog / Electromechanical	Digital / Microprocessor
Centralized	De-centralized
Reactive (Prone to failures / blackouts)	Proactive
Manual (field restoration)	Semi-automated, automated (self-healing)
One price	Real time pricing
No / limited consumer choice	Multiple consumer products
One way communication (if any)	Two way / Integrated communication
Few sensors	Ubiquitous monitors, sensors
Manual restoration	Condition / Performance based maintenance
Limited transparency with customers and regulators	Transparency with customers and regulators
Limited control over power flows	Pervasive control systems
Estimated reliability	Predictive reliability

III. MICRO GRID AND DISTRIBUTED ENERGY RESOURCES

As one of the fundamental structures in Smart grid concept, Micro grid has critical effort on maintaining user’s power quality and efficiency therefore reduce energy consumption and carbon emission. The Distributed Energy Resources (DERs) have emerging potential that can independently operate the customers from the bulk electric power system. This brings about a new concept called ‘microgrid’ together with customers’ power quality and reliability problems. A microgrid is defined as an aggregator of several micro generation units, storage devices and controllable loads operating as a single system that provides electricity and thermal energy, i.e. combined heat and power (CHP). Microgrid is a concept that incorporates distributed energy resources (DER), including distributed generation (DG) and distributed storage (DS).

To manage the DER, a network of communication devices must provide the microgrid with the necessary intelligence to allow customers and utility companies to collaboratively manage power generated, delivered, and consumed through real-time, bidirectional communications. Thus, communication is essential in order to ensure the proper operation of all the microgrid components. Microgrids are closed small power networks equipped with distributed generation (like diesel generator, wind turbine and Photovoltaic Panel etc.) and battery storage on the generation side. While on the consumer end, a small group of customers is connected to the microgrid. Depending on

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customer's requirements, microgrid may be connected to the large upper grid through a tie line or can work in isolated mode. Micro grid is a state of the art technology and a number of micro grids are operational in different parts of the world like the one at Kythnos Island, Greece. Balance of demand and supply is vital for the safe operation of a micro grid. Energy balance must be ensured in real-time otherwise the fluctuating voltage may cause a serious damage to the appliances and critical situation of energy shortage may collapse the whole system leaving behind the entire area in darkness. At present, the energy balance in a micro grid is only maintained by taking measures on generation side, either by increasing the generation capacity or by connecting it to the higher grid. Whereas, at the consumer end there is no infrastructure to optimize energy utilization on demand side. Under the decentralization of power generation system, the thrust is on utilizing small (50 kW to 500 kW) capacity DERs such as micro-turbines, fuel cells, diesel generators, solar PV, wind energy systems, storage batteries etc, for eliminating transmission line congestion during peak hours, blackouts etc.

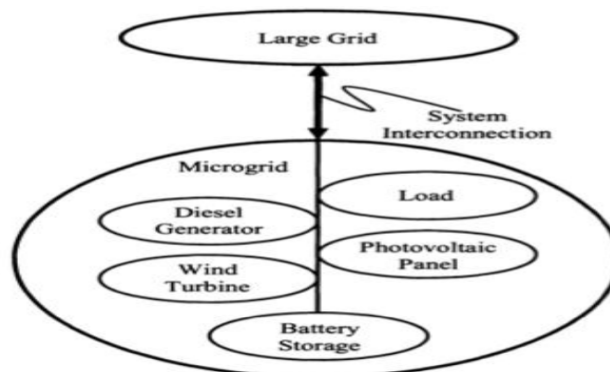


Figure 1: Basic concept of a micro grid.

Major Advantages of Micro Grid can be summarized as follows

- Micro Grid can provide an efficient way to integrate distributed energy resources and loads for taking full advantage of them (including CHP).
- Micro Grid can be a "grid-friendly" entity and does not give undesirable influences to the connecting distribution grid. That means the operation policy of distribution grid does not have to be modified.
- Micro Grid can achieve a flexible way for distributed energy resources to connect and disconnect as they like, which is called as "plug- and-play" feature.
- Micro Grid can independently operate without connecting to the upper distribution grid when a fault occurs (islanding mode).

The environmental and economical benefits of the microgrid, and consequently its acceptability and degree of proliferation in the utility power industry, are primarily determined by the envisioned controller capabilities and the operational features. Depending on the type and depth of penetration of distributed energy resource (DER) units, load characteristics and power quality constraints, and market participation strategies, the required control and operational strategies of a micro grid can be significantly, and even conceptually, different than those of the conventional power systems. The main reasons are as follows [24]:

- Steady-state and dynamic characteristics of DER units, particularly electronically coupled units, are different than those of the conventional large turbine-generator units
- A micro grid is inherently subject to a significant degree of imbalance due to the presence of single-phase loads and/or DER units
- A noticeable portion of supply within a micro grid can be from —noncontrollable sources; e.g., wind-based units
- Short- and long-term energy storage units can play a major role in control and operation of a micro grid
- Economics often dictate that a micro grid must readily accommodate connection and disconnection of DER units and loads while maintaining its operation
- A micro grid may be required to provide pre specified power quality levels or preferential services to some loads

- In addition to electrical energy, a micro grid is often responsible for generating and supplying heat to all or parts of its loads.

IV. THE DISCUSSED FAULT DETECTION TECHNIQUE

Fault location index are combined with PMU configuration to form the adaptive fault locator system. The overall diagram of the adaptive PMU based fault location technique is shown in Fig. 2. PMUs can be utilized to process the data measured at both ends. In order to evaluate the performance of the discussed fault location technique, the simulated voltage and current waveforms were directly taken as the synchronized sampled data (voltages and currents) from respective ends. The next step is to estimate line parameters. At this stage, the technique has generated the correct modal components that can be utilized to calculate the index. This method has ability to locate the fault of transmission and distribution line. It is worthy to note that the discussed technique is recursive. Hence, the discussed technique is very suitable for the online monitoring applications [6].

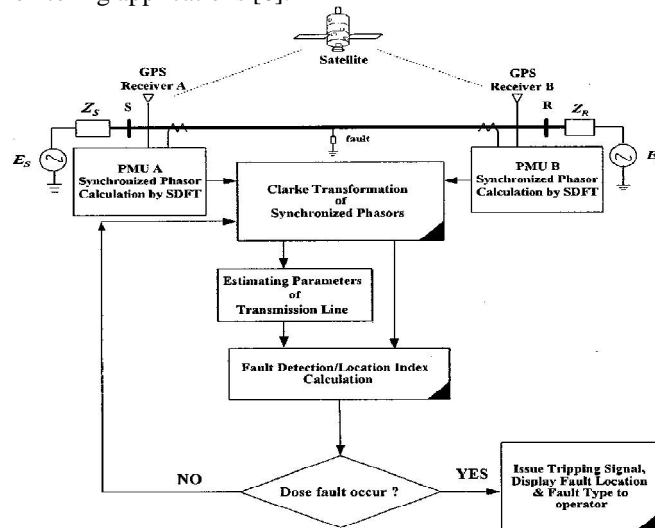


Fig. 2. Configuration of adaptive PMU based fault location system [2,4].

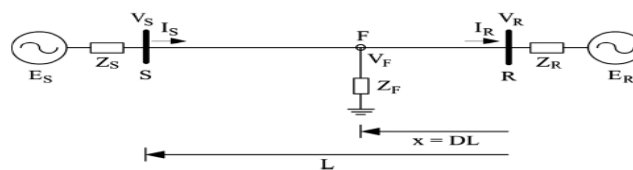


Fig.3. One line view of a single circuit transposed transmission line with a fault at a distance $x = DL$ away from the bus R [6].

Fig. 3 shows a single circuit transposed transmission line. In Fig. 3, L is the total line length between buses, and $V_s, I_s, V_R,$ and I_R are the synchronized voltage and current phasor measured on buses S and respectively. Using symmetrical components transformation to decouple three phase quantities and to consider only the variation of a distance variable (km), the relation between the voltages and currents at a distance x away from bus R can be expressed by the following sequence equations,

$$\frac{dV}{dx} = Z I \tag{1}$$

$$\frac{dI}{dx} = Y V \tag{2}$$

Where, Z and Y are per unit length sequence impedance (Ohm/km) and admittance (Mho/km) of the transmission line, respectively. The matrices of Z and Y are all diagonal matrices, and the diagonal entries of matrices

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Z and Y are (Z_0, Z_1, Z_2) and (Y_0, Y_1, Y_2) , respectively. The variables with the subscripts 0, 1, 2 denote the zero, positive, and negative sequence variables, respectively.

The solutions of voltages and currents of the three decoupled sequence systems can be written as,

$$V_{xi} = [A_i \exp(\tau_i x) + B_i \exp(-\tau_i x)] \quad (3)$$

$$I_{xi} = \frac{1}{Z_{Ci}} [A_i \exp(\tau_i x) - B_i \exp(-\tau_i x)] \quad (4)$$

Where, $Z_{Ci} = \sqrt{\frac{Z_i}{Y_i}}$ denotes the characteristic impedance, and $\tau_i = \sqrt{Z_i Y_i}$ is the propagation constant. The constants A_i and B_i can be obtained by the boundary conditions of voltages and currents measured at bus R and bus S, respectively. Therefore, voltage (3) can be further rewritten as

$$V_{xi,R} = \frac{(V_{xi,R} + Z_{Ci} I_{i,R})}{2} e^{\tau_i x} + \frac{(V_{xi,R} - Z_{Ci} I_{i,R})}{2} e^{-\tau_i x} \quad (5)$$

$$V_{xi,S} = \frac{1}{2} e^{-\tau_i L} (V_{i,S} + Z_{Ci} I_{i,S}) e^{\tau_i x} + \frac{1}{2} e^{\tau_i L} (V_{i,S} - Z_{Ci} I_{i,S}) e^{-\tau_i x} \quad (6)$$

Equations (5) and (6) represent the voltages at point x, which are expressed in terms of the two data sets $(V_{i,R}, I_{i,R})$ and $(V_{i,S}, I_{i,S})$ measured at the receiving end R and sending end S of the line, respectively.

A fault is assumed to occur at point F with a distance $x = DL$ km away from the receiving end R on a transmission line shown in Fig. 3, where D is termed as the per unit fault location index. Using the relationship $V_{F,R} = V_{F,S}$ and equating (5) to (6), the index can be solved as follows,

$$D = \frac{\ln\left(\frac{M}{N}\right)}{2\tau_i L} \quad (7)$$

Where M and N are given by,

$$M = \frac{1}{2} (V_S + Z_C I_S) e^{-\tau_i L} - \frac{1}{2} (V_R + Z_C I_R) \quad (8)$$

$$N = \frac{1}{2} (V_R - Z_C I_R) - \frac{1}{2} (V_S - Z_C I_S) e^{\tau_i L} \quad (9)$$

With a fault occurs between buses S and R, the calculated complex value of D will lie between 0 and 1. When no fault or an external fault occurs, the value of D is indefinite. It is worth mentioning that there is no assumption made in the procedure of derivation for the fault location index D. Thus, the index D is unaffected by the variations in source impedance, loading change, fault impedance, fault inception angle, and fault type.

The performance index in terms of the error percentage is defined as follows [6],

$$\text{Error}(\%) = \frac{|\text{Estimated location in km} - \text{actual location in km}|}{\text{Total line length in km}} \times 100 \quad (10)$$

V. CONCLUSION

In this paper, we discussed an adaptive fault location technique in a Smartgrid with DG sources. The discussed index does not need any assumption, so it is a very robust index. With the advent of these algorithms the discussed method can achieve an excellent performance for locating the fault of distribution line. The accuracy of fault location estimation may achieve even up to 99 % for many simulated cases. A phasor measurement unit (PMU) with high performance is designed and implemented in the paper. Combining robust fault location index, parameter estimation algorithm, and the well-designed PMU, the discussed technique will be an adaptive, high performance, and low cost fault location technique.

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