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Protection challenges on integration of renewable energy sources to power system network: A review

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Abstract: The demand for electricity to meet the 21st century requirement is increasing exponentially. This excessive demand is also forcing to increase the electricity generation limits. A huge amount of electrical energy is required to meet demands like EV charging, mobile communication networks, LED lights, non-linear loads etc. To meet this hunger for energy, renewable energy sources are being integrated with the existing grid. This integration of renewable energy with the grid extends from small scale integration to very large-scale integration. This integration results in smart grid technology with various new features like digitization, two-way communication, distributed generation, self-monitoring, self-mitigating and fully controllable compared to conventional grid. Although smart grid technology has various disadvantages over conventional grids, integration of renewable sources with the conventional grid has made the power system very complex. The smart grid has various protection challenges which are not present in conventional grid. This paper gives an insight of different protection issues which occur because of integration of renewable energy sources in the power system network at transmission, distribution, and Microgrid level. Along with these protection issues, some of the mitigating techniques are also elaborated in this article.

Keywords: Protection issues, Distribution network, Smart Grid, microgrid, islanded, mitigation techniques

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1. Introduction

In the power grid 70-80% of faults are line-to-ground (L-G) unsymmetrical faults. This fault occurs due to a failure of insulation between the earth and one of the conductors. Transmission and distribution lines are the important corridor of networks. Therefore, reliability and stability of transmission and distribution system are essential. In 21st century distributed generation and smart grid technologies are becoming popular due to increasing energy demand (Reddy & SreeBindu, 2019). The presence of renewable energy sources at transmission and distribution level weakens the performance of electrical power network due to uncertainty of the sources. Use of electronic components to convert DC to AC, DC to DC, Islanding concepts and Grid interfacing are the current issues of modern power systems. Use of converter will create problems related to power quality, over voltage, harmonics and voltage dip in the network. There are many challenges which need to be addressed to improve accuracy and reliability of power system network. This paper reveals various protection challenges of smart grid in presence of renewable sources and possible solutions as suggested by various researchers.

2. Literature review

The distributed generation concept has increased the amounts of non-synchronous and inverter-connected plants in the power system. These types of generation have different characteristics compared to conventional plant. The facts are given in the black out reports of few regions of different countries i.e. Black System in South Australia in 2016. AEMO (Operator, 2016) found number of factors behind this blackout, like trips of wind turbines due to high wind speed, operation of the five gas generators on-line at a time, settings of the relays that tripped the inter connector, settings of power line protection relays, Static var compensators (SVCs), etc. Black out in southern California was because of sudden unnecessary tripping of PV Inverters resulting in the loss of a nearly 1200 MW of solar photo voltaic (PV) generation (NERC, 2017). Uninterrupted and good power quality is our prime requirement. Many researchers are working on how to balance huge energy demand and protection challenges of it.

Article (Shahzad et al., 2017) has been summarized the major challenges such as variations in short circuit levels, blinding of protection, unsynchronized re-closing, single-phase connection, change in fault impedance, reverse power flow, loss of mains which can encounter while designing protection schemes for DG-connected distribution networks. Some possible solutions have also been given in the past, such as Symmetrical and Differential Current Components, Higher Rating Inverters which can differentiate between overloading and faulty condition. Other approaches are to use combination of various DG, smart or adaptive protection scheme, fault current limiter, centralized protection using SCADA or DCS. Article (Pazoki et al., 2020) has presented a general overview of pattern recognition to solve issues of distance protection in transmission line. The literature review has been confirmed that pattern recognition functions are effective in fault detection, fault classification, fault location identification, high impedance fault detection, power swing detection, and symmetrical fault detection during power swing.

Also, waveform monitoring of different complex and nonlinear power system parameters are included at relaying points.These parameters are also affected by different topology in fault condition, system configurations, compensation devices and involvement of DC grids. Different optimization techniques are discussed to achieve proper coordination of relay during abnormal conditions. Optimal sizing and location of DG is discussed in article (Katyara et al., 2018). Review articles (Brearley & Prabu, 2017; Muda & Jena, 2017; Namangolwa & Begumisa 2016; Telukunta et al., 2017;) have been discussed advantages and disadvantages of various existing protection schemes with the integration of renewable energy sources in power systems. Different methods to discriminate between power swing and actual fault are mentioned in the research paper (Patel et al., 2016). In arti-cle (B. Zhang et al., 2016), transient fault protection scheme has been represented using DSP processor and embedded system. Research article (Lin et al., 2015b) proposed coordinative PMU based adaptive distance protection technique. Distribution system model which has combined cycle power plant with three Gas turbine and three wind farms, was taken to test the algorithm. Auto reclosing scheme has been demonstrated and implemented using modified full cycle discrete fourier transform with adaptive dead time control. The fault detection logic was based on monitoring impedance trajectory in the R-X diagram of distance relay (Patel et al., 2019). Whereas research article (Patel et al., 2018a; 2018b) have represented impedance reach of numerical distance relay which was severely affected by various parameters of transmission line. This research paper proves adaptive settings of quadrilateral characteristics.

Adaptive settings are preferred to avoid the effect of high resistance fault, DC component, power swing. MFCDFT algorithm has been implemented for fast and accurate phasor estimation of fault impedance for adaptive setting of relay followed by SVM classifier method for power swing detection. Author has implemented and tested auto recloser algorithm for transmission line along with fault detection technique MFCDFT (Patel et al., 2018c). Fault resistance compensation method and its MATLAB simulation for MHO type distance relay has been discussed (Idris et al., 2013). Researchers have proved that a small fault resistance value can make the relay to be under reached when it has used to protect short transmission line. The relay also might be under reached when the fault was near to remote substation terminal. Delayed tripping of circuit breaker due to under reaching of distance relay has generated stress in the power system for a longer time. Article (Mohammedsaeed et al., 2019) has represented performance of conventional distance protection scheme when PV plant connected to grid. Paper has also shown 'Fault ride through (FRT)' feature to control inverter operation during faulty condition and simulated system with PV plant to achieve accurate fault location using FRT. Article (Z. Zhang et al., 2016) has mentioned PV system integration with the distribution network. However, impact of PV plant and distributed generation on the transmission line has been discussed in article (Sun et al., 2016). IEEE 13 bus system along with RES has been simulated for distribution network, analyzed power flow and investigated performance of distance protection with various load condition and fault condition (Mortazavi et al., 2015). Microgrid net-work protection challenges and it's overcome methodology has been discussed in research papers (kumar et al., 2013; Lin et al., 2015a; Memon & Kauhaniemi 2015; Sudhakar et al., 2014). Research paper (Karpe & Kalgunde, 2016) has represented backup protection method of smart grids using synchronized PMU in a wide area protection. The protection design has effectively recognized the faulted line and faulted area of the interconnected system. Main goal is to detect different fault locations, the fault type on system and clearance of faults. Different techniques which are used for protection coordination of distribution systems without DER and with DER, sub transmission systemhas been discussed in (Singh, 2017). Author has also discussed impact and solution of DG sources in distribution network.

3. Protection challenges

Small, medium, and large-scale power generation and transmission utilities are facing different protection problems in microgrid, distributed and transmission networks. Protection challenges with DG integrated network are broadly mentioned in three sections: Microgrid, Distribution and Transmission.

3.1. Protection issues in micro-grid network interconnected with DGs

3.1.1. Coordination issues with DG

The presence of DG sources in the distribution system has converted simple unidirectional radial network to complicated bidirectional network. As a result, networks do not remain radial for long duration. Protection coordination is well established between relays, reclosers and fuse in radial network. DG sources in the distribution and microgrid network have lost coordination and the following effects can be seen in the network. Increase/decrease fault current level with connection/disconnection of renewable energy sources, overreach/under reach problems of over current relay, unwanted islanding, false tripping, blinding faults, avoid automatic reclosing.

3.1.2. Microgrid protection issued in grid connected mode

False tripping or unwanted interruptions occur between the microgrid and the utility grid, e.g., when a failure of a PCC device triggers a fault on the utility grid side or within the microgrid. False tripping may degrade power quality and increase the cost for restoration of normal operation. Major issues are speed of re-connection, synchronization of voltage, frequency and phase angle at point of common coupling of microgrid and main grid. The process of re-synchronization can be manual or automatic. It may take several seconds or minutes to re-synchronize depending on system characteristics. There are many synchronizations scheme available. In case of fault or abnormal event occurring at utility side, all individual DER protective device or relay should not give trip signal (Singh, 2017).

3.1.3. Microgrid protection issues in island mode

A major issue in island mode is that the short circuit current sensed by relay is very less in island mode, so relay does not operate or respond. If the protective device responds, then it takes longer time to trip and isolate faulty section from healthy line. Time to apply tripping signal is normally few milliseconds. Fault current level of conventional grid is approximately 10-50 times higher compared to full load current, whereas in standalone microgrid, it is 5-6 times higher compared to full load current. When converter based large number of distributed energy resources are connected in microgrid, level of fault current is 2-3 times full load current. So over current relay setting should be set different for each case (Karpe & Kalgunde, 2016).

3.2. Protection issues in Microgrid and Distribution System Interconnected with DGs

There are few protection issues which are common for microgrid as well as distribution systems, as discussed below.

3.2.1. Variation in fault current level

Fault current level will be modified when large number of small capacity distributed generators are connected at transmission and distribution network. Some time, fault current is lower compared to load current, so relay did not sense the fault and fail to issue the trip command, when inverter-based PV sources had used in the network (Operator, 2016). Fault current value should be at least 5-10 times the nominal rated current for proper operation of over current relays. But in islanded mode, inverter-based DG limits the fault current around 2 times higher compared to the rated current. As shown in Figure 1, when DG interfaced with main grid at that time fault current is higher compared to islanded mode. Also, there is always uncertainty in availability of the wind and solar types of sources

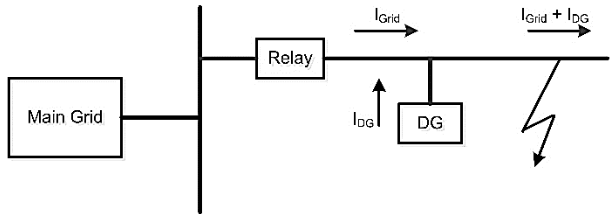

Figure 1. Fault current variation.

Location of DG connection, fault location, fault impedance in grid connected mode and island mode, magnitude, direction and duration of fault current are the parameters which modify level of fault current. As shown in Figure 1, fault current sense by the relay will be less in absence of DG source. Therefore, reduction in fault current results in no operation by relay. This is called blind operation of relay (Telukunta et al. 2017).

3.2.2. False tripping

False tripping of relay occurs due to bidirectional flow of fault current or faults in an outside the protective zone. DG source contributes towards the fault as shown in Figure 2. So, relay R2 operates in reverse direction along with R1 which reflects the maloperation of protective scheme. As a result, relay R2 unnecessarily operates because of fault on another line. This is also called sympathetic tripping (Sudhakar, et al., 2014).

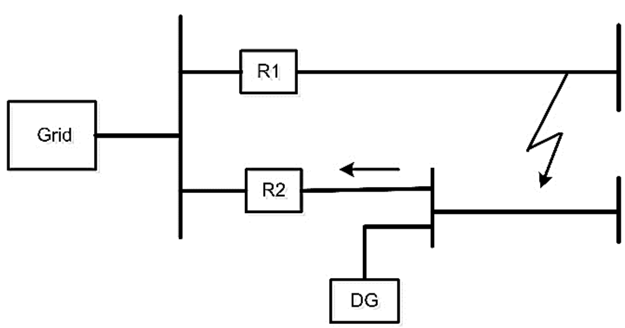

Figure 2. False tripping (sympathetic tripping).

3.2.3. Island mode issues

When fault occurs in a power system network as shown in Figure 3, relay R2 sense it and isolate the DG from the network. In this situation of islanding, the distributed generator (DG) continues to supply power to the local load L2 and L3. Under the situation of high load, it may lead to imbalance of the power in isolated network.

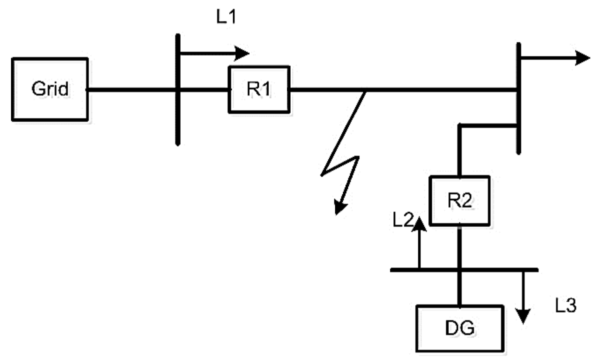

Figure 3. Islanding problem.

3.2.4. Single phase connection

PV sources sometime provide single phase supply to grid which may create an unbalance in three phase supply current. Due to unbalance system, current in neutral conductor may increase. As a result, the stray current to earth also increases. This current should be minimized to avoid overloading and hazardous effects to the system.

3.2.5. Loss of relay coordination

Due to blinding faults, false tripping, variation of fault current at distribution system, transmission system has also got affected. It creates overreach and under reach problems in the zone of protection of distance relay and in over current relay protection. As a result of which the overall system may lose coordination.

3.2.6. Unsynchronized reclosing

A recloser is a protective device used in distribution systems. Distribution system is not disconnected unnecessary for transient faults. If a fault remains for long duration (permanent fault), then recloser have three times open-close operation before lockout. As shown in Figure 4, fault current fed by the grid is enough to be detected by R1 relay and so the associated breaker will open. Current flowing from PV or DG source in small amount will continue feeding the fault. Eventually faults will clear or remain persist in the network and current will flow from the DG source. Circuit breaker at relay R1 will close after certain time interval, with PV continuously feeding the fault previously cleared. This will lose synchronism between the two systems. There will be voltage, frequency and phase mismatch that will damage the system.

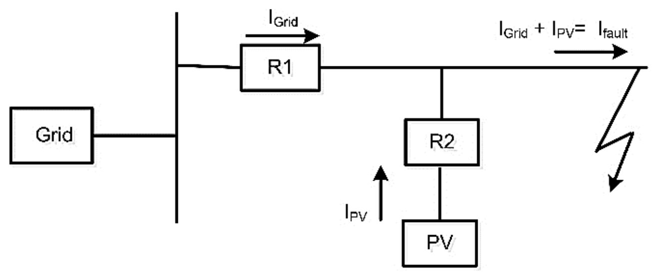

Figure 4. Unsynchronised re-closer.

3.2.7. Selectivity issue

DGs integrated with main grid will make the current bidirectional. As the current direction is no longer unidirectional so fault current is not in one direction. Sometimes it is difficult to discriminate between healthy line and faulty line due to variation of distributed energy resource's fault current level. Healthy line with maximum current may be wrongly tripped and line with minimum fault current may not be tripped.

3.2.8. Loss of mains (LOM)

There is disconnection of microgrid from main grid at PCC or higher level. If there is disconnect at the point of common coupling, then microgrid works as isolated mode. It creates problems when DG is not generating enough power to feed local loads. This will lead to the problem of voltage dip and frequency instability during LOM. How to overcome or minimize time of loss of mains are discussed in article (Senarathna & Hemapala, 2019).

3.3. Protection issues in transmission system

Various system parameters are affecting the performance of transmission lines. As a result, these parameters are the cause of false tripping. These parameters are listed in Figure 5. Parameters can be the cause of under or overreach problem in distance protection of transmission line. Different distributed generators like induction generator and conventional synchronous generator have different short circuit behavior which affects the distance protection settings. Also, the penetration level of DG may create maloperation of relay in transmission line. The capacity and size of RES plant as well as number of plants in the network may modify the performance of distance protection of transmission line. Other parameters which influence the distance protection are faults occurring near to bus or away from the bus, location of the fault, transient fault, steady state fault, types of the faults. Also, various fault inception angle, power swing, voltage level, fault level, frequency mismatch, mutual coupling, FACTS devices used in transmission line to transfer maximum power are the different parameters which affect performance of distance protection.

4. Mitigation techniques to protection challenges

4.1. Micro-grid protection techniques

Different methods of micro-grid protection are available in the literature. Figure 6 summarizes different protection schemes implemented, simulated and suggested by researchers. The literature deals with providing sensitive and accurate protection schemes for small scale power generated systems so that it discriminates between small fault current and load current properly. Also, isolate the faulty section from the main power system to keep the rest of the system running smoothly and provide an uninterrupted supply. Below mentioned protection schemes are widely preferred for microgrid protection.

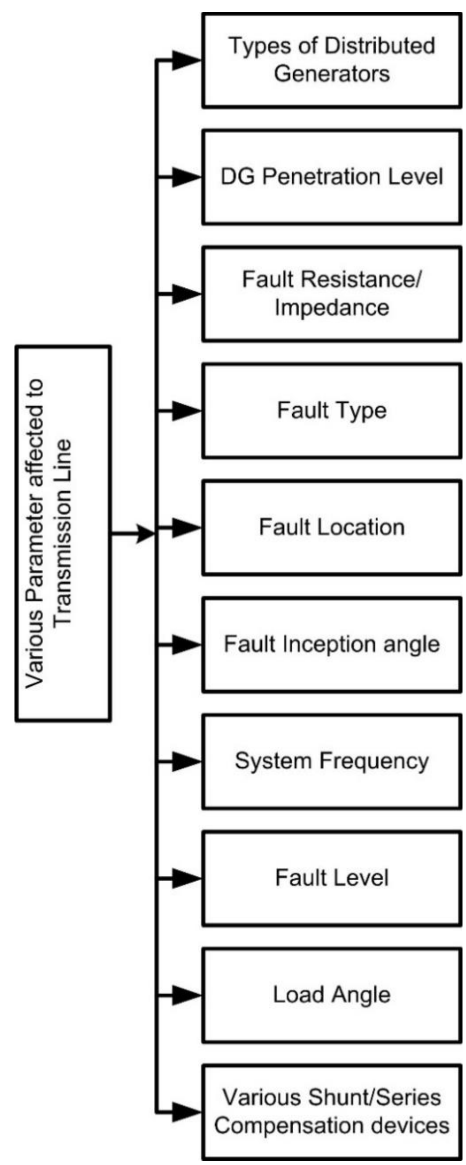

Figure 5. Parameters affected to transmission line protection.

1)Differential protection techniques compare the amplitude of fault current across the protected component. The technique is based on measurement of differential current at point of common coupling. Signal processing can be used to set differential relay setting for on grid and off grid small fault current detection and issue trip signal to break the faulty section. This technique works well in shunting and high impedance fault. It is not applicable for series faults because series faults are symmetrical in nature. Series faults do not have differential energy. Most of the series faults are converted to shunt fault after some time.

2)Fault current limiter-based protection scheme is applicable for micro-grid as well as distribution system integrated with renewable energy sources.

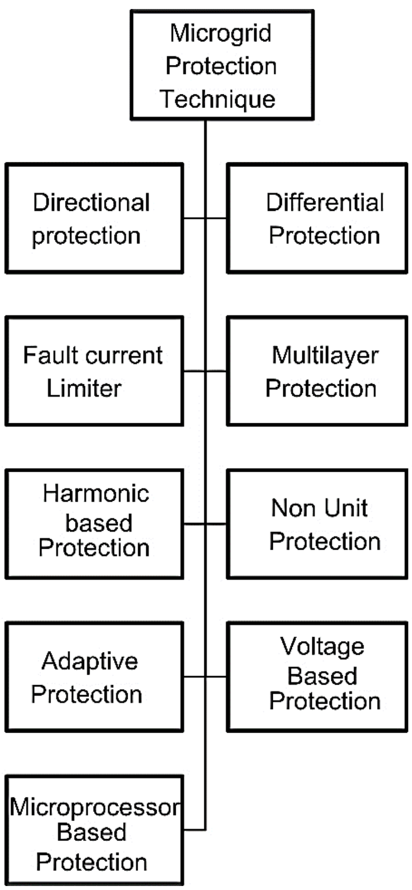

Figure 6. Different schemes used for micro-grid protection systems.

FCL is placed in series with power line or at optimal location of interconnected network to limit the fault current. The size of the FCL will depend on the number of small capacity DER available in the system or on the fault current level. Tuning of FCL parameter, location and size of FCL are challenging aspects of the power network.

3)Harmonic component based over current protection scheme is widely used in the presence of RES. Generation of electricity with renewable energy source uses converters like DC-to-DC boost converter and DC-to-AC inverter. These converters introduce harmonics in the system. Total harmonic distortion (THD) is calculated using FFT or DFT method. THD content helps to identify abnormal conditions and separates out healthy and faulty sections. Protection scheme fails to operate with increase in dynamic load or increase in non-uniform DGs in the system.

4)Voltage/current based protection scheme uses positive sequence component of fundamental quantity to detect different types of microgrid faults. The voltage measurement method is faster and more reliable compared to the over current relay. Time-inverse over current relay coordination fails for limited fault current of renewable energy sources of microgrid. Terminal voltage of distributed energy sources goes below its operating range for small increment of current during fault in microgrid. Current based overcurrent relays can thus be used for both microgrids and distribution networks

5)Non unit protection scheme calculates impedance of DC micro-grid using local measurement. This scheme is only applicable for DC microgrid, as it may not work for other different microgrid typologies.

6)Directional over current protection has provision of directional element. When a greater number of RES are available in microgrid mesh network, reverse current will flow in the microgrid. To avoid the malfunction of the relay due to bidirectional current, directional element is required. Magnitude and angle of negative sequence impedance relay is used to detect the magnitude of asymmetrical fault. Current and torque angle of negative sequence impedance relay is used for symm-etrical fault, but it may not work for different network typologies.

7)Adaptive protection scheme works for different microgrid structures. It is applicable for grid connected and islanded network. It works based on programable logic. Different relay setting selections are available at various protection stages. Relay communication protocol is used to communicate between master relays at control stations and slave relays in the field. Different relay settings are set by the master relay according to structure of microgrid. Future scenarios will increase a greater number of dynamic faults depending on the level of RES penetration in to microgrid. Adaptive protection schemes are more effective and reliable in the presence of Distributed Generation sources (DGs).

8)Multi-layer Protection scheme is applied for current protection, differential protection, back up protection, anti-islanding protection. Due to more layers, flexibility, reliability and accuracy of the protection is improved, but simultaneously communication between these four layers becomes complex.

Table 1. Distribution and microgrid protection scheme summary.

System	Parameters effect	Techniques applied to overcome the effect	Software Tool
Grid connected PV (Sudhakar, et al., 2014)	i)Power reversals change in fault current level of the network ii)Possibility of sympathetic tripping iii)Reduction in reach of distance relays iv)Loss of relay coordination v) Unintentional islanding vi)Harmonic distortion	Inject scheduled amount of real and reactive powers into the grid while maintaining the balance between input and output powers	MATLAB Simulink
Grid Integrated PV (kumar et al., 2013)	i)Fault current level of the network. ii)Sympathetic tripping iii)Reduction in reach of distance relays iv)Loss of relay coordination. v)Unintentional Islanding	i)Adaptive microgrid protection system ii)Protection based on symmetrical components and differential components of currents	-
220 KV IEEE-5 Bus System without DG (Karpe & Kalgunde, 2015)	i)Backup protection system was one of the main causes of unwanted cataract trips. ii)Detect fault type. iii)Identify fault location	Backup protection method using synchronized PMU in a wide area protection	MATLAB Simulink
IEEE 6 BUS with /without DER (Alkaran et al., 2015)	Exact critical fault point instead of empirical CFP for coordination of over current relay	Modifies the impedance matrix of the network using the analytical approch. Used GA method	MATLAB Optimization Toolbox
IEEE 30 BUS with Solar DER (Tejeswini et al., 2019)	i)Radial network distribution system converted to meshed network ii)Fault current fed by DER from multiple sides iii)Relay coordination calculation will become complex	i)Voltage-current based inverse relay model. ii)considering the logarithmic function rather than exponential function to improve in service time to overcome the low fault magnitude level.	MATLAB
110kV Bus connected to PV (Sun et al., 2016)	i)Short circuit current phase difference between system side and PV power station side is different when fault occurs ii)Phase selection failure. i) malfunction of transmission line distance relay protection	i)Modified adaptive distance protection scheme to avoid unwanted trip of transmission line with PV ii)To avoid wrong phase selection, voltage based phase selector instead of current based suggested	DIgSILENT/ Power Factory
IEEE 13 node with PV Integrated (Ram Ola et al., 2020)	Various locations, different fault incident angles, fault impedance, sampling frequencies, hybrid line consisting of overhead (OH) line and underground (UG) cable sections, different types of transformer winding and the presence of noise	Wigner distribution (WD) index and alienation (ALN) index used, and it gives better performance compared to DWT, WPT and stockwell transform	MiPower & MATLAB

4.2. Distribution network Protection Scheme

Distributed energy resources are increasing at distribution level to meet the future energy demand. This will make system operation and control complicated and will create issues related to power quality and protection. Most of the protection schemes which applied for microgrid protection are also suggested for distribution power systems. Over current protection scheme is used for primary and backup protection in distribution feeder network. But over current protection relaying scheme becomes non-functional in presence of converter based distributed energy resources. Again, the over current protective scheme works for unidirectional flow of current in radial network, but distribution network fails to remain radial network when large number ofe DG sources are interconnected to main grid. As current flows bidirectional, directional element with over current relay will help to avoid malfunction of OC (Over Current) relay in case of reverse direction flow of current. Due to slow response of over current scheme in sub transmission level, distance protection is used as primary protection and over current is used as backup protection. To provide proper relay coordination at distribution networks, several protection schemes are mentioned in this article. Table 1 shows the summary of the protection issues and mitigation techniques.

1) In curve fitting technique, normal inverse current relay scheme is mathematically modeled. This technique is very simple. The drawback of the technique is that it does not work for current setting 1.3 times less than pick up current.

2) Graph theory technique is quite useful for interconnected or mesh distributed network. Computational time of solving OC relay coordination is higher.

3) Analytical method takes large number of iteration and not able to provide optimal relay setting in distributed network to solve relay coordination issues.

4) Optimization techniques are also used to provide relay coordination and optimal relay setting. Mathematical based optimization techniques in which various mathematical optimization are used starting from simple linear programming techniques to complex techniques for non-linear networks. Optimization techniques are fixed as well as variable for distributed power system network.

5) Artificial Intelligence based optimization techniques are used to find global optimal solution of relay setting of interconnected power system. Different techniques have been proposed by many researchers, like Genetic Algorithm, PSO, BBO, artificial bee's colony etc.

For radial network mathematical optimization technique is preferred but for large number of interconnected distributed energy sources network, artificial optimization techniques are preferred. The requirement of proper tune optimization parameter to find optimal global settings of the relay is the only limitation of the machine learning techniques.

Adaptive or non-adaptive different protection schemes are discussed in article (NERC 2017), during high level of distributed energy sources are present at distributed power system. Fault current levels are different in grid connected and island mode. To limit high fault current and to reduce the miscoordination, fault current limiters are used in the network. FCL are connected in series with each DER to limit the fault current in the system. Main purpose of providing FCL in the system is to avoid the change in fault current setting because of addition of a greater number of DER in the system. Super conducting fault current limiter (SFCL) and Solid-state Fault current limiter can also be used for quick blocking of higher value of fault current. Optimal location of FCL can provide proper relay coordination in distribution network. Size and setting of the FCL is designed differently for grid connected and island mode. Harmonic limiter and node voltage limiters are required on each DER when majority DER are based on photovoltaic inverter. Multi-agent algorithm also works in mesh network as well as in radial network. It provides dual setting of the relay coordination. Evolution algorithms are also implemented by scientists for transmission line protection. Voltage-current based protection scheme is discriminated between loading and short circuit fault current. Fault current of synchronous generator is 6 to 8 times higher than the normal rated full load current as discussed earlier. Inverter based PV sources generate fault current 2-3 times rated full load current. Small increment in load current is decreasing the voltage level of photovoltaic source in microgrid mode. Voltage-current based inverse time relay discriminates between short circuit and overload condition. This type of normal inverse characteristics of voltage-current relay are not used for transmission line protection, only used for microgrid protection.

Distance relay elements are less affected by dynamic changes in the network compared to over-current. For transmission line high set instantaneous over current element is replaced with quadrilateral element and low set instantaneous over current element is replaced with MHO element. Characteristics of the distance relay are inherently directional. Distance protection offers three zones of protection. Zone-1 covers 80% of the line and provides instantaneous protection. Zone-2 and Zone-3 protection provide definite time protection. Zone-2 protection covers 10 to 20% of the protected line which was not covered by zone-1 and provides backup protection for an initial 50% of adjoining line. Zone-3 provides backup protection to the remaining 50% of the adjoining line. Zone-3 covers a larger area compared to zone-2. Zone-3-time settings are higher than zone-2. As shown in Figure 7, DG which is connected at Bus-3 is also fed the fault current at point F. Impedance of DG connected transmission line is added with the impedance of mail line, so impedance seen by R1 is higher compare to set impedance. If the measure impedance is higher compared to set impedance, false tripping occurs in the network. To minimize the impact of DG at upstream and downstream, the network is required to recalculate the set of impedance values. Thus, the selectivity and relay parameter settings must change dynamically as the network changes (Patel et al., 2016).

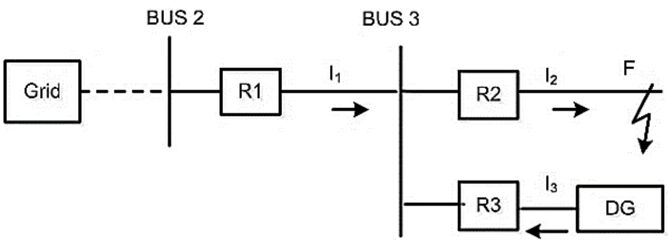

Figure 7. Distance protection scheme.

DG integrated power network, distance protection technique has not worked properly due to various influencing parameters as discussed in Figure 5. In research article (Ram Ola et al., 2020), the researcher has applied Wigner distribution function on IEEE-13 node test power network interconnected with PV plant. This function detects the types of faults from the faulty phases with the help of fault index. Performance of the model has been checked for different fault location, various fault inception angle, high fault impedance, types of faults, different types of transformer winding. The algorithm has worked effectively for all the above parameters variations. Fault characteristics of PV have been different from the conventional transmission line characteristics. Phase current differences based technique has been analyze and simulated in PSCAD software for 150mw PV interconnection with grid (Alsafasfeh et al., 2019). There are many other techniques simulated and tested by researchers like multi agent, Artificial Neural Network, Fuzzy logic, Pattern recognition, modified distance protection techniques, Adaptive techniques etc. Adaptive technique and modified distance protection technique, PMU based adaptive distance protection techniques are preferred and suggested by researchers. Different protection techniques, its features and limitation with their corrective action are discussed in Table 2.

5. Findings & future challenges

In this review article, the research gap and future protection challenges of power systems in the presence of renewable energy sources are discussed. They are mentioned as below:

1) Microgrid, distribution and transmission line protection challenges and it's mitigation techniques summary, which were described by many researchers, have mentioned in Table 1 and Table 2.

2) Distribution system no longer remains radial because of large number of small-scale PV system integrated in the network. As a result, complex network has been faced the over current relay coordination issues. Maloperation of the backup protection may occur in the network. To avoid this coordination problem, direction element is required in the system.

3) Due to unpredictable behavior of renewable energy zsources and high penetration of DER, the fault levels are modified every instant of fault. If the fault current setting has not changed accordingly, then the relay may operate incorrectly. FCL are used at appropriate location to limit the fault current.

4) It has been observed that large scale penetration of renewable energy sources has been affected by transmission line distance reach settings, which needs to be addressed properly.

5) Research articles (Javadi et al., 2013; Lim et al., 2012; Lee et al., 2011; Z. Zhang et al. 2016) indicate that the multiple settings of over current relay or adaptive relay setting are required for small penetration of PV or large-scale integration of wind or any other DG to overcome the issues of overreach and under reach.

6) Renewable energy sources are used to feed local network in islanded mode. Fault current level is different in islanded mode compared to grid connected transmission and distribution line fault level. So, detection and classification of fault is the biggest challenge. Many researchers are working on those challenges.

7) Many machine learning and deep learning techniques like Artificial neural network, probabilistic neural network, decision tree, fuzzy logic are used for fault detection and classification at transmission line. Each method has its own characteristics and also its limitations. To identify the best suited method for detection and classification of faults is tedious and challenging task when renewable sources are integrated in the network or series /shunt compensated line in the network.

Table 2. Protection methodology features and its limitations.

Protection Scheme	Features	Applicable For	Operational Method	Limitation
Adaptive protection Technique (Chandraratne et al. 2020)	i)Compatibility relay setting with power system conditions, online system ii)Less complicated approaches with reasonable implementation of cost	Microgrid, distribution and Transmission line network	Relay setting changes according to network state	Requires having prior knowledge of power network configurations in order to perform power flow and short circuit calculations
Differential Protection Technique (Lei et al., 2019)	i) It is more suited to detect downstream earth faults ii)Immune to current flow direction and magnitude variations iii) High performance for high impedance fault	Islanded Mode, Lower fault current network will prefer	Comparison (Difference) of input and output current of a zone	i)Cannot suited for upstream faults ii)Problems due to unbalance and transients
Voltage based Protection	i)Applicable for Internal and external Fault i) Perform abc-dq0 transformations on voltage waveform to identify the short circuit fault type and location ii) Designing load shedding and preventing blackout system	Microgrid	Voltage symmetrical component	i)may not be viable with reconfiguring networks ii)Voltage drops can create errors, may operate incorrectly in any voltage disturbances iii)HIF cannot be detected iv)Poor accuracy in the grid-connected and varying power systems
Current-Based protection	Over-current relay can be modified with direction element	Micro-grid, Islanded, Distribution system	Symmetrical current components.	i)Requirement of infrastructure upgrade, including communication channels ii)Backup protection is required for safe operation during communication failure, iii) Costly compared to conventional system
Impedance based Protection (Distance Protection)	To identify the fault location of radial systems	Micro-grid, Distribution network	Measured impedance with threshold values	i)Relays are equipped with impedance element and directional element to identify the occurrence and direction of the fault ii)Accuracy affected by harmonics and transients iii)Errors due to the fault impedance iv)Not effective for short lines
Multi-agent protection	i)This technique developed for over-current and frequency problems ii)Utilizes the IEC 61850 GOOSE communication protocol	Micro-grid, Distribution system	Operate using distributed agents which could be either software or hardware known as IDE	The number of agents increases, the complexity and the cost of communication protocol also increases

Wide-area protection	Employ supervisory control and data acquisition (SCADA) and Intelligent Electronic Devices (IED) to collect measured values in a wider area and perform protective actions based on the data	Micro-grid, Distribution system	SCADA & IED device used	Adaptive or multi agent protection method requires as a backup protection method in case of a communication failure
Differential energy	Used data from both ends of the faulty feeder and subjected it to the S-transform to obtain the differential energy Used to identify fault patterns and compare with predefined patterns for different fault scenarios	Micro-grid	Comparison (Difference) of data at both end of the Fault zone	It requires more data set to formulate differential energy contours and to make a decision
SVM Classifier	i)Bulk penetration of DG ii) Different types of maloperation conditions iii)Intelligently differentiate between mal operation and Fault	Distribution and Transmission line	Operate by drawing decision boundaries between data points and targeting the decision boundary that best separates the data points into classes	More costly
PNN	i)Multilayered feed forward network with four layers ii)PNN networks generate accurate predicted target probability scores	Fault classification and analysis	Using the parent probability distribution function of each class	PNN are slower than multi-layer perceptron networks at classifying new cases. PNN require more memory space to store the model
ANN (Prasad et al., 2018)	i)Distributed parameters of the transmission line is considered ii)Wind farm loading level iii) Fast, accurate and adaptive in nature	Distribution, Transmission Line	Artificial neurons for classification, Pattern recognition, Nonlinear statistical model	i)Require Large storage space requirement. ii)Impacts of fault resistance have not been taken into consideration
Decision Tree include Fuzzy ruled based on differential protection	i)Very low fault current contribution by DFIG ii)Focused on speed of operation iii)Reliable for complex network	UPFC connected with transmission line	Differential Feature Extraction	Communication wire is required.
Fuzzy based Technique.	A fuzzy logic can continuously monitor the status of the RES source, voltage phasor based on DFT technique and update the pickup & TDS settings based on the network changes	Distribution and transmission system	Fuzzy rules and select proper membership function	i)The identification of all potential network typologies is difficult ii) Approach suitable for limited network topology

6. Conclusion

This paper shows the studies, research and simulation carried out for transmission, distribution and microgrid system protection issues and its solution. This paper focuses more on fault identification and classification in PV integrated microgrid, distribution and transmission network. Summary of the fault identification issues its mitigation technique and limitation are given in Table 3. To achieve reliability, to reduce mal-operation and to protect the device, proper technique or algorithms are required to implement. For long transmission lines, distance protection is the most promising protection method but in presences of solar and wind energy accuracy of fault detection may reduce. To improve accuracy of fault detection and smooth functioning of power system network, it is required to select modified distance protection or adaptive protection scheme. Various parameters like penetration level of DG, size and location of DG system, dynamic behavior of renewable energy sources is responsible to modify optimization techniques. Comparative evaluation of different techniques used in smart grid is also undertaken for identification of most effective technique as required by specific application.

Table 3. Summary of power system protection challenges, its mitigation and limitations with RES (Sahebkar Farkhani et al., 2020).

Protection Challenges	Mitigation Techniques	Limitation
False tripping/ Sympathetic tripping	Directional relay	Inefficient mesh network and non-uniform RES structure
Variation in fault current (Increase/Decrease fault current)	Fault current limiter (inductive, resistive, thyristor-controlled series capacitor)	Increase size, cost and number of FCL with more penetration of DG
Unsysnchronized reclosing/ Auto recloser issue	Anti islanding protection	Applicable for microgrid and distribution system with small scale DGs
Reverse current flow	Directional element with over current relay	Not efficient for large network
Blinding protection	FCL, Under voltage protection	Complexity will be more with the size of network
Overreach/ Under reach protection	Adaptive distance protection scheme/ Multilayer protection	In multilayer coordination and comm-unication between each layer is tedious

Conflict of interest

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