A Technical Review on Classification of Various Faults in Smart Grid Systems

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Abstract. Increasing the technological developments of smart sensors, Information and communication tools (ICT) the traditional electric power systems have emerged with the improvement of Smart grids. Smart grid is defined as a modernized electric power grid with the integration of ICT tools and distributed generation (DG) resources into existing power system to provide continuous, stable and quality of power to all. Present smart grid electric power system network, the fault identification and mitigation is one of very critical task. Current power system structure transformed remarkably due to extension and integration of enormous amount of DG resources at delivery side. To confront the limitations of smart grids, existing fault identification and mitigation methods requires immoderate revision by making use of excellent facilities and tools. That will be useful to attain automation in fault detection, enhance the voltage stability, transient stability, and self-healing ability to perform the desired task. This paper is going to presents a detailed survey about target on various types of faults and fault detection methods in smart grids.

Keywords: smart grid, fault classification, fault diagnosis, renewable energy resources (RER), distributed generation (DG), protection.

1. Introduction

Power grids could be operating from the year 1882 onwards. Tesla was invented for long distance AC distribution was commercialized in competition against Thomas Edison’s short distance DC distribution system. Tesla invention has become not able to answer to power demand of present 21st century. It must be necessary to employ ICT in power generation, transmission and distribution systems in order to satisfy today's requirements and to deliver continuous supply. In smart grid point of view, from energy generation to distribution the real-time two way communication is access in all the levels and ensure its operate within the acceptable limits. Nowadays, the power industry has facing lot of challenges as follows: power demand, transmission and distribution power losses, power quality [1]. In order to conquer this demand, it must be essential to deliver the power to consumers in a secure, reliable and sustainable quality [2].

The smart-grid is a modernized digital power grid, it consists of smart energy systems, smart metering, Advanced Metering Infrastructure (AMI), smart sensors, phasor measurement unit (PMU), DG resources, smart communication and smart protection control etc. The advancement of the electric
power system structure will allow us to coordinate largeness amount of power generation, transmission and distribution, electric power markets, operators, customers, service providers and reduction of greenhouse effect and at the same moment, increase the quality of the power [3]. The existing power distribution networks were constructed to deliver power from centralized generation to fixed customers and expected loads. With the integration of distributed generation (DG) sources, micro-grid and energy storage technologies, the distribution systems become more decentralized nature and bilateral to reach system reconfiguration and self-healing capability of the network. There are many disputes, which come with this new advertising which involve regulate the bidirectional power flow, voltage and frequency damping oscillations in-balance way in the network. Under these situations, many types of faults may occur in the network like source and load side faults, converter faults (inverter and converter), cable faults, data communication faults, cyber security, Internet of things (IoT) protocol failure, data leakage, insufficient data, smart meter faults and so on, which are complicate to manage, detect and control. A increasing of faults in various elements of smart-grids is a major problem that comprises the elemental of energy generation and distribution framework. Furthermore, faults can exhibit via various failure modes in the same element. If appropriate detection and mitigation actions are not undertaken, then those faults can create instabilities and other severe problems in the network. Therefore, it is necessary not only to identify the different fault modes, and their main causes and problems, but also to implement real-time automated fault detection tools that can arrest the early stage of fault evolvement for diminishing actions [4].

The electric grid decentralization and its capability of interaction enact it more viable. The important aspects of the smart grid are electronic signal and power conditioning, control of the protection and distribution of electricity. They provide many advantages for supervising the distributed energy generation though remote sensing facilities and load dropping in case of contingency situations. In addition, the demand forecasting is built by using historical energy production, consuming details and energy supply, load demand balance is ensured properly [5].

The control of voltage, frequency and phase sequence is of major significance in power system control to maintain reliability and quality. Any change on those criterions could leads into the system collapse and failure. The DG integration in distribution side leads to occurrence of technical problems related to the present protection methods used in low and medium voltage. The designed protection schemes in distribution networks are usually based in released voltages able to react to transient over-voltages, and circuit breakers to react to faults. The protection system of smart grid increases the new significant challenges [3] are as follows;

- Developments in the infrastructure of distribution systems (two way information and power transfer capability).
- Capability of operating all the modes: Grid connected or autonomous mode.
- Topographical variations of generators, loads and storage devices connections and disconnections.

The traditional delivery networks were constructed for one way power, information flow, and not to usage a high diffusion of DG. The DG sources can create unbalance in the system, where power production exceeds the system capacity and can leads to negative impacts, like inversesible flows of power, high losses in transmission and distribution systems, voltage dip and swell, production of current harmonics in the network, system instability and oscillations in frequency [6]. The basic aim of this article is to study the different kinds of smart grid fault diagnosis and identification methodologies.
2. Fault classification methods in smart grid

2.1. Significance of fault management and fault investigation

Power monitoring system is play a major role to protect the smart grid from different kinds of faults and to maintain power flow without the disturbances. Sporadically, few inevitable, faults occur, such as: (i) natural disaster like lightening causes the transient faults (ii) Due to elements failures and criminal intervention causes the persisting faults (iii) Due to sudden change in load and short circuit inconsistency occurs. Figure 2. It clearly shows the various kinds of fault can be occurred in Electrical Power Monitoring System (EPMS) when transmitting of power from a generating station to distribution station. Such faults can be creating the negative disturbance to the entire grid system.
Figure 2. Various types of faults occurred in EPMS

In [9], fault detection and mitigation must be quick, in order to protect the power grid elements and sustain the normal functions. Fault detection and control techniques more relevant to the smart grid communication network. Also, fault control is necessary to minimize the synchronization issues and economically enhance the power supply system. Anyhow, many fault detection and management methods needs a control room to supervise, control and examine the behaviour of the network throughout the operation, as well as communication elements [11].
And also, it is very essential to identify the fault in the smart grid promptly enough to prevent an entire breakdown in the network [12] [13] [14]. In [9], there is few fault identification methods can be recommended in the smart grid inclusive of the intelligent electronic devices that control voltage and current waveforms in the network.

One more approach is used to detect the faults by using Markov model or wavelet transform to investigate the most recent sensing parameters throughout the network [15] [16] [17]. Markov model needs distributed smart meters between the systems, not only at the distribution side to detect the faults in the smart grid. So, smart grid needs to gives rapid detective information details and causes for faults in the network. In summary of this section, to discuss the various types of faults occurred in modern grid systems.

2.2. Common types of faults occurs in smart grid

In paper [20] [21], two types of externals faults occurs in the smart grid.
1) series faults will occurs in power system network due to open circuits or broken line conductors
2) shunt faults will occurs due to touching of two or more than two conductors to each other or touching with ground

Again the shunt faults are categorized into following two types.
- Symmetrical fault (also called as balanced fault)
- Unsymmetrical fault (also called as unbalanced fault)
75% - 80% of Single line-to-ground fault are the most commonly occurred in power system network [20] [22].

The lists of unsymmetrical faults are

- One line to ground fault (L-G Fault)
- Two line to ground fault (L-L-G Fault)
- Line to line fault (L-L Fault)
- Three line fault (L-L-L Fault)
- Three line to ground fault (L-L-L-G fault)

In Figure 3, shows various kinds of faults occurs in electrical transmission lines.

![Faults in overhead transmission system](image)

Figure 3. Possible faults that can occur within three-phase overhead transmission systems

According to the paper [23, 24, 25], smart grid faults are classified into following three types

- Incipient faults,
- Abrupt faults,
- Intermittent faults.

Authors in [23] reported that, incipient fault generates the fire and harmful effects in the smart grid. Authors in [24] reported that, an abrupt fault creates power losses in the smart grid network due to abrupt variation of signals magnitude. According to [25], intermittent fault creates in very minimum time period transients and this transient may leads to permanent failure in power network. It was many factors reasonable for occurrence of the above faults such as loose connection, conductor deterioration or severed conductors. This faults can occurs in different points in smart grid at transmission and distribution lines, transformers, induction motors, or at underground cables and its lead to create serious problems such as fires or bursting of fuel tank due to spark ignition, permanent damage to the system etc. This temporary incident faults is a step-by-step incident and it may requires several months to build in to a permanent fault. If no problems occur in the system, after minimum time duration of transient period the smart grid will act normally. This fact gives an experience to detect the above-mentioned variety of faults in early levels [23] [24] [25] [26] [27].

Various techniques which reports the earlier detection of faults. Author in [23], suggested that the wavelet transform analysis to identify and categorize the incipient faults by controlling the magnitude, total time period of an interruption of the events. Author in [26], reported that to diagnosing of incipient fault for underground cable by using the impedance-based distribution approach. Author in [24], reported that to monitor the disturbance in intermittent faults through distance relays and in paper [25] reported that to identify the intermittent fault by calculating the carrier signal magnitude between the two lines in smart grid. In paper [24] suggested the wavelet transformation, adaptive filter technique and numerical relays to diagnosis the abrupt faults in the smart grid. In paper [28], to detect the arc fault through monitoring the temporary variations and changing in wiring parameters in the network. In paper [27], to detect the arc fault via by distinguishing the variations in load currents and reference load currents in between the buses.
From the above discussions, smart grid faults are categorized in to three types. In this section briefly explained the various existing techniques available to detect the smart grid faults.

**Table 1.** Common types faults occurs in the traditional and smart grid

| S. No. | Fault type | Causes | Effects | Diagnosis methods |
|--------|------------|--------|---------|--------------------|
| 1.     | source side faults (in solar, wind etc.,) | 1) intermittent variation of input  
2) enormous dc-link voltage and ac currents;  
3) loss of synchronization in grid voltage | Discontinuity of power flow occurs and the resistance at that fault point becomes zero. | Ensure the reliability of power conditioning device |
| 2.     | converter faults (inverter and converter) | 1) defect due to malfunctions of valves and controllers  
2) Commutation default  
3) Short circuits fault | (i) Fire return  
(ii) Fire trench  
(iii) Misfire  
(iv) Arc extinction | Regulate the rectifier and inverter station the firing angle and minimizes harmful effects. |
| 3.     | load side faults | Abrupt or continual load variations, overvoltage, uncompensated issues. | Its create power quality problems like voltage sags/swells, voltage flickers, harmonics etc. | To interconnect custom power compensating devices like DSTATCOM, DVR and UPQC etc. |
| 4.     | cable faults | Some of the major causes for cable faults are:  
✓ Deterioration  
✓ Wrong selection  
✓ Electrical puncture  
✓ Heating of cable  
✓ Fire and lightning surges  
✓ Mechanical failures  
✓ Corrosion of sheath  
✓ Moisture in the insulation. | Cable faults are leads to effect of resistance and breakdown voltage. It persists, which may destroy the entire cable. | Appropriate design of the cable, cable earthing methods, cable bonding and power network earthing systems, installing an earth fault current limiting protection device, such as a neutral earthing resistor/reactor or peterson coil |
| 5.     | data communication faults | Data communication faults occurs due to misconfiguration is the cause of as many as 80% of unplanned outages like  
✓ Hardware failures  
✓ Power failures  
✓ Human error  
✓ Old equipment  
✓ Incompatible changes  
✓ Security breaches | Improper communication and mismatching of parameters like text, programs, images, audio, and telemetry etc. | Monitor and use the various advanced high performance communication networks like wide-area wireless data systems, satellite systems and Mobile Ad Hoc Networks etc. |
| 6.     | cyber security | Many causes of cyber security attacks are  
✓ By using own software tools individuals can initiate the attack  
✓ Criminal organizations running with more enterprise with many employees creating the | Theft of valuable, sensitive data, hacking etc. | maintain software up-to-date, install anti-virus protection software, implement multi-factor authentication, secure system infrastructure, backup the critical data, provides the training to workers to face the cyber |
| 7. | Internet of things (IoT) protocol failure | Expired software and hardware, Employ powerless credentials, Difficult to identify if a device is damaged, Predicting and preventing attacks, Data protection and security challenges. | Effect of system architecture, security protocols, energy efficiency, and quality of service can be affected by IoT protocol failure. | Use the priority-based energy-efficient routing method. |
| --- | --- | --- | --- | --- |
| 8. | smart meter faults | smart meter display is not updating | Improper measurement leads to high tariff | Energy savings and consumption reduction as a result of smart use and the optimal. |
| 9. | One Phase-to-ground (LG Fault) | Unpredictable or incidental contacts between the single conductor to the ground. Failure of insulation also leads to LG fault. | Create minimum impedance path and maximum current flows to the ground. It persists the loss of output voltage permanently. | Install the earth fault protection devices and fault current regulating devices. |
| 10. | Phase-to-phase (LL Fault) | Interconnection between two conductors with unequal potential differences. | Create minimum impedance path and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and install fault current regulating devices. |
| 11. | Two phases-to-ground (LLG Fault) | Interconnection between two conductors to ground with unequal potential differences. | Create minimum impedance path between two conductors to ground and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and install fault current regulating devices. |
| 12. | Three phases (LLL Fault) | Interconnection between three conductors with unequal potential differences. | Create minimum impedance path between the three conductors and creates reverse current flow in the faulted section. It leads to results in fire hazard. | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and install fault current regulating devices. |
| 13. | Three phases-to-ground fault (LLLG Fault) | Interconnection between three current carrying conductors and ground with different potential variations. | Create minimum impedance path between three conductors to ground and creates reverse current flow in the faulted section. It leads | Install the earth fault protection devices, blocking diodes to avoid the reverse current flow and install fault current regulating devices like ELCB. |
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14. Open circuit fault
The most common causes of open circuit fault include disconnection of overhead lines, cables, loss of one or more conductors of circuit breaker and damage of fuse. It is also called as series faults.
Due to open circuit faults discontinuous path from and back to the source of EMF. It leads to change of its resistance to an extremely high value will cause current to drop.
Check-up affected portion potential on wire 1 at the bottom of the control fuse and at the top of the neutral link.

15. Transformer failure
The main reasons that cause this fault in the transformer are the poor maintenance, corrosion, manufacturing defect, improper adjustment, mechanical and vibration movement within the transformer.
Leads to increases the risk of fire and explosions.
Preventative maintenance is required for this issue should include routine oil filtration.

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| 15. | Transformer failure | The main reasons that cause this fault in the transformer are the poor maintenance, corrosion, manufacturing defect, improper adjustment, mechanical and vibration movement within the transformer. | Leads to increases the risk of fire and explosions. | Preventative maintenance is required for this issue should include routine oil filtration. |

2.3. Fault protection in smart grid
Fault protection in smart grid is very essential to improve the reliability of the grid. Author in [4], reported that the architecture of the smart grid is designed capable to detect the over-current and over-voltage faults especially converter circuits and battery energy storage systems. And also stated that smart grid should operate in an autonomous mode during high impedance faults to maintain the protection of the network. Author in [18], reported that to isolate the faulty elements of smart grid, used the combination of numerical relays and global positioning systems. To prevent from the bigger failure three stages of protections schemes are used. Thus the protection system of the smart grid can be classified into three stages as shown in Table 2.

Table 2. Various protection levels in smart grid

| Parameter | Warning | Isolating | Shutdown |
|-----------|---------|-----------|----------|
| Indication | Abnormal behaviour that remains. But does not create immediate damage to the network. | Disconnect the faulted components to maintain the protection in smart grid. | Prevents fault, the may cause if left uncorrected. |
| Needed Equipment | Communication devices | Protective relays, circuit breakers and power switches | Protective relays, circuit breakers and power switches. |

According to [19] [20], There are various reasons leads to produce the faults in smart grid. The few causes are lightning strokes, overloads, direct physical contact by humans and animals, degrading of insulators, poor insulation, high-speed wind blows, movable objects, trees falling, snow storms, human errors, and failure in protection. The three-phase symmetrical fault is the most severe faults and creates major disturbances in the smart grid [20].

3. Existing research techniques is available to detecting various types of faults in smart grid
To maintain the stability and reliability of smart grid, fault diagnosis and protection schemes must be operate faster rate. Various methods are proposed that some researchers studied to detect and protect the faults in smart grid. Measuring instrument may be used to monitor various parameters and to diagnose transient behaviour of the smart grid. All the parameters should maintain within the
prescribed boundaries during normal and faulty operations and it should automatically controllable to sustain the stability during the abnormal situations.

Fuzzy control system using discrete wavelet transform was discussed in [8], to detect different types of disturbance in an asymmetrical power network. It was described that the fuzzy logic algorithm is able to locating faults and ignoring the impact of inception angle. In Paper [8] is used the artificial neural network to categorizing and identification of faults in electrical overhead lines. Here used the feed forward neural network along with back propagation algorithm. The pattern recognition technique used to locate and categorizing faults. It is suggested that ANN is the best method due to the following characteristics [29]:

- Capable to withstand the progressive variations in the electric grid.
- Based on the training, the result is quick and accurate. Also, its operation is very easier.
- It is an effective and reliable for a smart grid fault identification and assortment.
- It is powerful, opportunity is broad and its gives beneficial to explore more.

Author in [30] was reported that multi-Agent system is capable to provide reliability and quality of services by employing reconfiguration solutions. Multi-Agent system develops a reconfiguring architecture depend on fault classification rule to search appropriate and powerful solutions. This technique is suitable for self-restoration of smart grid during the fault occurrence. Author in [31], was reviewed and reported that a model-based fault detection and isolation (FDI) method is more suitable for complicated power networks and is design depends on unknown input observer (UIO) with unknown inputs. The output and load variations of DER are designed as unknown value inputs of smart grid. Author in [32], was reviewed and reported about wavelet transform for analysing the travelling waves. He is obtained the detailed coefficients for single line to ground fault. Various techniques in [33], [34], [29] reviewed including genetic algorithm, particle swarm optimization, expert systems, heuristic methods, ant colony algorithm, tabu search, reactive tabu search, hybrid methods and NSGA-II. The limitation for these is that they are centralized.

The drawback of all the above technique is, it should need an intelligent smart metering system in order to precisely diagnosis the variations in the system [35]. However there are a more number of researchers investigate fault diagnosis and mitigating methodologies to enhance the stability of the smart grid. Still have few drawbacks that can be improved for betterment.

4. Discussion

Many researchers investigated the various types of fault and detection methodologies of smart grid by using artificial neural network. Anyhow its does not considered the integration of distributed energy resources to the smart grid. Fuzzy logic control using discrete wavelet is tested when more consideration is paid on variation in energy, even though few parameters like voltage imbalance were ignored.

5. Conclusion and future work

Fault identification and mitigation of smart grids is most important to enhance the stability, quality and reliability of modern electrical system. Earlier detection of faults of smart grid promotes self restoration and condition based monitoring to cut down overhauling time, expenses and reducing cascading faults. This article reviewed about various types of faults occurred in the smart grid infrastructure with large penetration renewable energy sources and detection and mitigation methods currently available. In spite of various approaches have been reported, there are still few faults that requires upgraded diagnostic strategies to really make the current electrical systems makes into smart. And also ICT is very important for smart grids for the improvement, fast and exact fault detection. Still, few more research is needed for ICT for the betterment of smart grid fault detection.

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