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CLASSIFICATION, CAUSES AND EFFECTS OF FAULTS IN POWER DISTRIBUTION SYSTEMS – A REVIEW

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Abstract:*The ability of power systems to maintain stability and to ensure continuous supply of electrical power to customers in the event of a disturbance is of critical importance. As the power system is spread over large geographic regions, the probability of facing different types of faults and failures is high. Unfortunately, unpredictable faults and cascading events usually lead to a blackout which might affect modern life. Thus, this paper provides the overview of faults and its causes in the power system. Additionally, we have discussed about different types of faults and their effects on the power distribution system.*

Keywords:Distribution system, faults, electrical power grid,

I. Introduction

Energy systems need to be adaptable in order to meet the fluctuating energy demand. Demand and supply must coincide at every time point in electric energy networks, making this requirement particularly clear. This requirement is met in a typical power system by a portfolio of various power plants that, when combined, may aggregately supply the required flexibility. New types of flexibility solutions are required if variable renewable electricity is introduced to the power system in sufficient quantities to balance the supply/demand imbalances, but problems may also occur in other parts of the energy system, such as in the distribution and transmission networks..

The component of the power system known as the distribution system is responsible for distributing electricity for local use. A distribution system is typically the electrical network that runs from the substation supplied by the transmission system to the consumer's meters. In the figure, a typical distribution system is displayed..

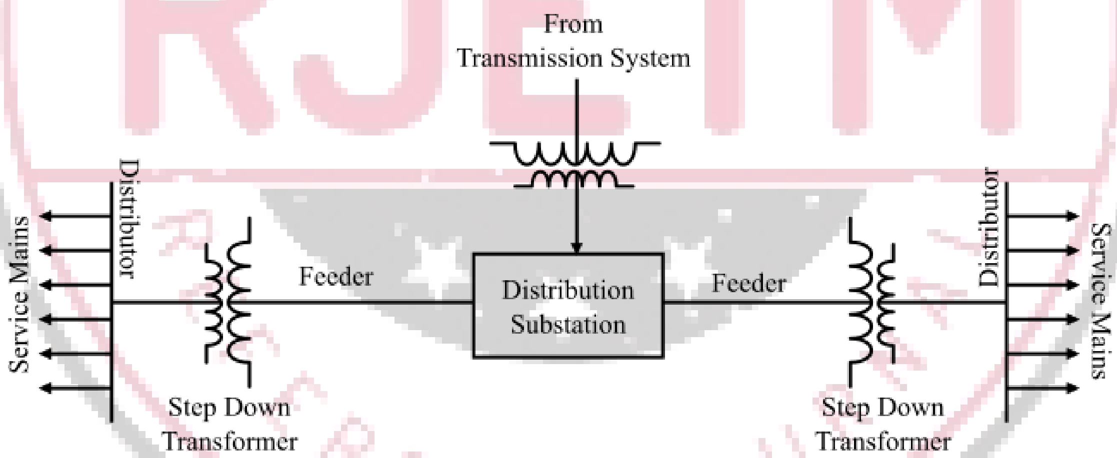


Figure 1 Distribution System

The use of renewable energy sources (RESs), such as micro-turbines, fuel cells, photovoltaic (PV) systems, and wind energy systems, has increased significantly in distributed power systems over the past few decades due to the increased penetration of distributed generation (DG) units on electrical grid systems. The DG units contribute significantly to the reduction of pollutants, the reduction of power transmission losses, and the improvement of local RES use, which strengthens the large-scale power grid. Inverse power flow, voltage deviations, and voltage oscillations are just a few of the difficulties that DG units could pose to the distribution network.. When several DG units are grouped together, they can create a microgrid (MG), which successfully addresses the issues brought on by high DG unit penetration and enables the large-scale implementation of DG systems. Wind turbines are linked to the AC bus using AC/DC/AC converters, and PV systems and energy storage systems (ESSs) are connected to the AC bus via DC/DC/AC converters. When operating on an island, RESs primarily supply AC power to the loads via local control. A tie line at the point of common coupling (PCC) connects the AC MG to the upstream grid in the grid-connected mode, allowing electricity to flow between the MG system and the grid.. The simultaneous sharing of the active and reactive powers of the DG units is necessary to guarantee the stability and cost-effective operation of MG. Droop controls, which are sophisticated control strategies without communication links that mimic the steady-state characteristics of the synchronous generator (SG) in islanded MGs, can be utilized to achieve power sharing.

II. Different types of faults in power distribution system

The difference of currents or voltages from rated value or states is referred to as an electrical fault. Under normal operating conditions, power system equipment or lines carry normal voltages and currents, resulting in a safer system operation. However, when a fault occurs, it causes excessively high currents to flow, causing equipment and devices to be damaged. Detection process and analyzation are required when selecting or designing suitable switchgear equipment, electromechanical relays, circuit breakers, and other protection devices..
Electrical power system consists of two types of faults. i) symmetrical
ii) unsymmetrical faults.

1. Symmetrical faults

These are extremely serious faults that occur infrequently in power systems. These are also known as balanced faults and come in two varieties: line to line to ground (L-L-L-G) and line to line to line (L-L-L).

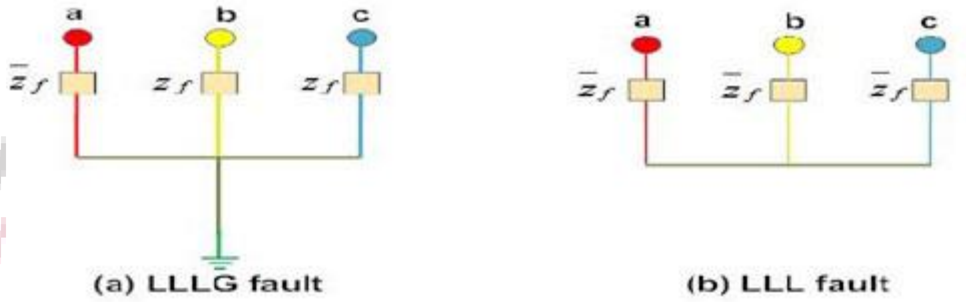
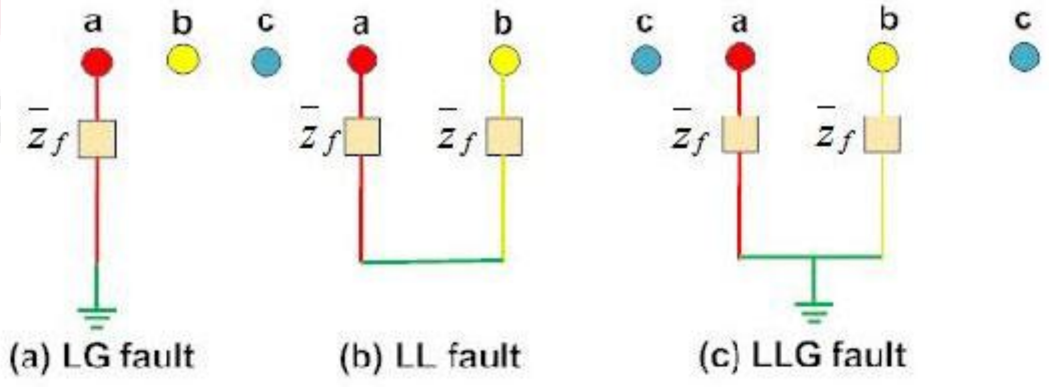


Figure 2 Symmetrical Faults

Only 2-5 percent of system faults are symmetrical. If these faults occur, the system remains balanced, but the electrical power system equipment suffers severe damage. The diagram above depicts two types of three-phase symmetrical faults. The analysis of these faults is simple and is usually done on a per-phase basis. For selecting set-phase relays, rupturing capacity of circuit breakers, and protective switchgear rating, three phase fault analysis or information is required.

2. Unsymmetrical faults

These are far more common and less dangerous than symmetrical faults. There are three types of faults: line to ground (L-G), line to line (L-L), and double line to ground (LL-G).



The most common fault is a line to ground fault (L-G), which accounts for 65-70 percent of all faults.
It brings the conductor into contact with the earth or ground. 15 to 20% of faults are double line to ground, causing the two conductors to come into contact with ground. Line to line faults occur when two conductors come into contact with each other, most commonly when lines swing due to wind, and account for 5- 10% of all faults.
These are also known as unbalanced faults because their occurrence causes system unbalance. The system is unbalanced if the impedance values in each phase differ, causing unbalanced current to flow through the phases. These are more difficult to analyse and are carried out on a per phase basis, much like three phase balanced faults.

III. Effects Of Faults In Power Distribution System

A power system typically operates under balanced conditions, with all equipment carrying normal load currents and bus voltages within the prescribed limits. This condition can be disrupted if there is a fault in the system. The consequences

can be disastrous if the electrical fault current exceeds the interrupting rating of the protective device. It poses a serious threat to human life and has the potential to cause injury and extensive equipment damage.
The short circuit fault current is many orders of magnitude greater than the normal current. A short circuit is simply a low resistance connection between two conductors that supply power to a circuit. This causes an excessive amount of current to flow in power systems through low resistance paths, potentially destroying the power source and causing additional heat and fires.
ach component of a power distribution system, like any other piece of equipment, has the potential to fail at some point. Even when properly installed, there are several factors that can cause failures, including high currents and voltages, animal interference, inclement weather, and so on.

A. Overhead Line Sag

Because overhead lines are exposed, they are susceptible to damage from outside forces. You'll frequently see damage caused by severe weather, such as high winds, vegetation growth, or animals moving along the lines themselves. However, because bare conductors can withstand high pressure and temperatures, they are less of a concern.
High currents, on the other hand, can cause a variety of issues. The most serious issue here is line sag. Thermal inertia causes this to happen over time. Lines will typically have thermal time constants that allow for temporary overloading without issue. These are usually between five and twenty minutes long, but if the overload is not cleared quickly enough, it will cause sagging.
When the lines sag, it reduces ground clearance and increases the likelihood of phase conductors swinging into contact. The high currents will also cause the conductors to anneal, increasing the likelihood of a break.

B. Transformer Failure and Overloading

Transformers cause problems with power distribution in two ways. They can either fail or overheat, resulting in a major power outage. When one transformer fails, the others must pick up the slack. In some cases, you may not have enough spare transformer capacity and will have to make a decision on the one that is having problems. You can overload your operating transformers, but this will reduce equipment life faster than expected. Still, it can ensure that dependable service is available in the short term, so it's a decision that should be made case by case.

C. Underground Cable Treeing

One of the most serious issues with underground cables is electrochemical and water treeing. Treeing occurs when moisture penetrates cable insulation in the presence of an electrical field, reducing its dielectric strength. When moisture infiltrates most cable insulation materials, it creates a tree-like pattern. This causes issues because, if the insulation has degraded sufficiently, it will result in dielectric breakdowns. These typically occur as a result of lightning or switching. The severity of the damage is related to thermal age, because moisture absorption occurs faster at higher temperatures. This can be avoided, however, by using tree retardant insulation.

D. Circuit Breaker Failure

Circuit breakers are complex pieces of machinery that can fail in a variety of ways. The key will be determining what caused their failure in the first place. They may, for example, open when they should not, fail while opening, become damaged while closing, and so on. The most common problem with circuit breakers is that they open when they should not, a condition known as false tripping. The most common problem will be spontaneous internal faults.
If there are any problems, we should look for faulty control wiring, uncharged actuators, or breakers that are simply stuck. To reduce all of these issues, you should test circuit breakers on a regular basis to ensure that they are less likely to cause problems.
Also, keep in mind that circuit breakers are prone to contact erosion, which occurs when a small amount of contact material vaporises when the current is interrupted. This, too, can be reduced through regular testing.
These are the most common issues encountered in power distribution. If you are aware of them, you can monitor for issues and maintain systems before they fail. Most of the time, good maintenance will reduce downtime.

IV. Literature Review

(Guo et al., 2017)provides a summary of cascading failure analysis and categorises the most relevant literatures and analysis models various aspects of cascading failures have been demonstrated and discussed. Comparisons of various models have been presented. The benefits and drawbacks of these models are summarised.
(Panteli&Mancarella, 2015) The first section looks at how weather and climate change affect the reliability and operation of power system components. Because weather modelling is difficult due to its stochastic and unpredictable nature, a review of existing methodologies is provided to gain an understanding of the key modelling approaches, challenges, and requirements for assessing the effect of extreme weather on the frequency and duration of power system blackouts. The emerging concept of resilience is then discussed in the context of power systems as critical infrastructure, including several defence plans to improve power system resilience to extreme weather events.
(Zhang et al., 2013) examines cutting-edge technologies for assessing the reliability of large-scale PV systems, as well as the impact of PV interconnection on the reliability of local distribution systems. The discussion is expanded to include

emerging research topics such as time-varying and ambient-condition-dependent failure rates of critical PV system components, accurate operating models of PV generators in both interconnected and isolated modes, and the reliability evaluation of active distribution networks with PV penetration and transmission level Giga-PV systems.

(Aftab et al., 2020) examines the most recent advancements in travelling wave-based fault location techniques Because travelling wave transients have a high frequency, signal processing methods play an important role in information extraction. A critical examination of these methods as reported in the literature is provided. The use of travelling wave-based protection techniques is investigated, with a special emphasis on distribution systems with a high penetration of renewable energy-based generators. Traveling wave-based protection techniques have enormous potential for future use in smart grid scenarios such as microgrids and active distribution systems.

(Javadi&Nobakht, 2011) surveys on the reliability technique known as Fault Tree Analysis (FTA). FTA is a top-down approach to failure analysis that begins with a potential undesirable event (accident) known as a TOP event and then determines all of the possible outcomes. The analysis then determines how individual or combined lower level failures or events can cause the TOP event. In power system analysis, this approach could keep the system's static analysis intact. The TOP event's causes are "connected" via logic gates and modelling of the corresponding system. The main features and applications of this technique are discussed in this paper.

(Panahi et al., 2021) investigates various transmission network fault location techniques in depth as a critical requirement for making the modern power system more secure and reliable. Various new fault location methods, such as I distance relay algorithm, ii) travelling wave, iii) artificial intelligence, iv) wide-area, v) time reversal theory, vi) differential equations, and vii) impedance calculation methods, are reviewed and investigated in this survey to demonstrate the benefits and drawbacks of inaccurate fault location for complex modern power networks.

(Alhelou et al., 2019) There is a comprehensive review of the major blackouts and cascading events that have occurred in the last decade. Because the United States is one of the world's leading power producers, and because data for previous events is readily available, a special emphasis is placed on power system outages and their causes. The paper also discusses the underlying causes of various blackouts around the world. Furthermore, the methods of blackout and cascading analysis, as well as the consequences of blackouts, are discussed. Furthermore, the shortcomings of existing protective schemes and research gaps in the topic of power system blackouts and cascading events are identified.

(Lopes et al., 2007) overview of the most pressing issues concerning the integration of distributed generation into electric power systems today The primary drivers driving the focus on DG integration, particularly renewable DG integration, in many countries around the world are discussed. A summary of the major challenges that must be overcome during the process is provided. The need to transition from a fit-and-forget approach to connecting DG to electric power systems to a policy of integrating DG into power system planning and operation through active management of distribution networks and the application of other novel concepts is emphasised.

(Saeedifard et al., 2010) The penetration depth of Distribution Energy Resources (DER) and the development of power electronics devices have a significant impact on the development of DC power transmission and distribution systems. This paper provides an overview of recent advancements as well as projected research and development on DC grids, with the goal of identifying and discussing the corresponding issues. Brief descriptions of DC grids at various voltage levels are presented and discussed, as are their benefits. Different DC grid layouts are presented, as well as the associated technical issues.

V. Electrical Power Grids

An electrical power grid (EPG) is a dynamical system that consists of four major operations: generation, transmission, distribution, and control. Over the last decade, technological advancements, particularly the increased use of information and communication technologies (ICTs), have exposed EPGs to an entirely new set of threats. An EPG, like any other system, is not completely fault-proof. A fault can occur at any point along the grid, due to natural causes, operational errors, cyber attacks, or physical attacks, among other things. When a fault occurs in any part of the EPG, different levels of consequences are generated for the grid as a whole. Faults that affect only a small portion of the EPG and are easily and quickly resolved do not imply a redirection of energy flow through other transmission lines. Catastrophic events, on the other hand, may imply the isolation or overloading of other sections of the EPG due to load redistribution, which can result in a cascade failure.

VI. Resilience Concept Under Electrical Power Grid Analysis

There are various definitions used in the literature when discussing resilient systems and taking into account authors who use the term resilience in their research areas. Resilience is defined as "the capacity of a body to recover its original shape after shock or deformation" or "the ability to overcome or recover from adversities." Some authors argue that the broadest definition of the resilience concept must be assumed, because it has evolved into a term with multiple definitions over time. Various terms, such as robustness, risk assessment, reliability, and adaptability, among others, are frequently used interchangeably, which can be misleading because these concepts can be partial characteristics of a resilient system without replacing the concept of resilience itself. Some of these terms are as follows:

1. Robustness/Resistance refers to the ability to resist changes without losing stability; for example, a robust system continues to operate during attacks or failure events, and can withstand low-probability events with large consequences. If damage occurs in a robust system, the system will resist, but the damage will remain until it is repaired. As a result,

and from an engineering standpoint, the robust system may be more vulnerable than others in terms of various features such as the ability to recover after an event.
2The ability of a system to ensure component performance under specific conditions and over a specific time period is referred to as reliability. The accuracy of the system is related to reliability, and if the components work in a variety of conditions, the system security is ensured.
3. Control system adaptability aims to ensure proper operation by adjusting control parameters and algorithms in response to uncertain changes. At the process layer, these disturbances can be regarded as undesirable incidents, and the system is expected to adapt to those changes.
The integration of the aforementioned concepts is the criterion used to define a system's resilience in some knowledge areas, such as scientific, social, or physical fields.

VII. Faults And Related Causes

The magnitude of the cause will influence the consequences of the originating fault. If a minor cause occurs, it will result in a minor fault that will only affect a few residential houses and will be simple to repair, possibly being resolved in a matter of hours. On the other hand, if the cause is large-scale, such as a hurricane or a terrorist attack, it can cause a large-scale fault, such as a blackout or a cascading failure, affecting a large geographical area and possibly taking days or weeks to recover from. Large-scale outages have serious economic and social ramifications for consumers. In the event of a large-scale outage, a robust system is expected to recover faster than a non-robust system and to be capable of restoring to its original state.
Natural Causes: different types of natural disasters that could lead to a fault in the EPG, such as hurricanes, storms, flooding, earthquakes, tornados, heat waves or solar flares.

- Errors: causes related to human faults or equipment technical malfunction;
- Attacks: cyber-attacks such as denial of service (most common), or human attacks such as terrorism

When these causes occur, they can result in a wide range of EPG faults. Table 1 displays various EPG faults, which are divided into three clusters for each cause of the faults. First, there are natural causes, which include extreme events such as hurricanes, storms, and flooding. Second, there are errors, which can be caused by human or equipment failure, and third, there are attacks, which can be either cyber or physical in nature.

VIII. Conclusion

In a nutshell, It is critical that power networks can maintain stability and provide a consistent supply of electricity to customers in the event of a disruption. Because the electricity system is dispersed across a large geographic area, it is likely to encounter a variety of problems and breakdowns. Unfortunately, unanticipated errors and chain reactions frequently result in blackouts that disrupt modern life. As a result, this paper provides a broad overview of power system issues and their causes. We also discussed various fault types and how they affect the power distribution system.

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