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Identifying Characteristics of Fault in Distributed Solar Generation System

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Abstract: The fault current in inverter-based distributed energy resources (DERs) is very low, and there are almost no negative or zero sequence currents. For fault analysis and putting up protective relays, it's important to know how DER faults behave. Even though a lot of work has been done on modelling DER, not much has been done to look at how DER behaves during real problem events. This suggested system looks at recorded fault events that Dominion Energy has kept track of. The size, angle, and order of the fault components are looked at to show that the real DER fault reaction may be different from what was thought before. Radial lines are what most distribution feeders are, and the utility is the only source of fault current. Most of the time, overcurrent methods are used to find faults. An overcurrent device works in overcurrent schemes when the measured current goes over a certain number, either for a short time or after a delay in time. The primary and backup protective devices work together to make sure that a fault is safely fixed before the backup device starts a delay. With the rise of Distributed Energy Resources (DERs) on distribution lines, there is now another source of fault current. The fault current from DERs can partly cancel out the fault current contribution from the utility, which causes relay operations to be delayed. Because DER affects fault current, it is very important to have a good picture of how a DER fault looks for fault analysis and setting the protection relay.

Keywords: *Distributed, Fault, Energy, Resources, Analysis*

I. Introduction

The fault characteristics revealed in this proposed system have implications on short circuit modelling and protective device setting. By modelling the inverters at Site P with features including low fault current, close to unity power factor, and power curtailment, it is found that there can be a 10% reduction in fault current seen by distribution feeder relays, compared to inverters in the fault ride-through mode. The discernible reduction in fault current can impair feeder relays' sensitivity to downline faults and therefore deserves relay setting reviews. The solar sites under study are utility scale inverter-based DERs that are interconnected at 34.5 kV distribution circuits (19.92 kV phase to neutral). As shown in Table I, the electrical distance from the solar sites to corresponding substations is approximately 3 miles. Each solar site consists of multiple three phase solar inverters and step-up transformers. The solar generation capacity ranges from 22.0 to 22.5 MVA. Each inverter is rated between 2.0 to 2.5 MVA. All step-up transformers are Wye-ground/Delta connected with the Wye side facing the utility. This type of transformer connection provides a zero sequence source. Neutral grounding resistors (NGRs) are installed between the Wye neutral and the ground to limit ground fault current being injected from solar sites. In the electric power business, distributed energy resources (DER) are a relatively recent phenomenon. The modularity of DERs has led to the concept's rise in popularity. With their modest capacity, they may be seen as more adaptable power sources than centralised energy units. Derived Energy Resources (DERs) are power generating or storage devices that are either directly or indirectly linked to a utility distribution network. Fuel cells, wind power, solar power and a variety of energy storage options are all examples of these energy sources.

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II. Literature Survey

You and M. E. Baran, H. [4] A distribution feeder with PV is not the same as a standard feeder when it comes to the fault current profile. This study comes up with a new way to improve the ability of the standard short-circuit analysis method to figure out the fault current profile on this kind of feeder. This paper shows that overcurrent switches and other similar devices make it harder to guess how long a fault current will keep flowing. Based on IEEE standard node system and power system analysis theory, Alsfasfeh et al. [6] give a way to solve capacity maximization problems for PV power sources that are affected by changes in voltage. A simulator made in MATLAB R2017B is used to look at and rate the performance of the suggested work. We look at the range of PV power integration capacities and find the highest PV power integration capacity at each node by modeling the IEEE 33-node system.

[7] Mohamed-M-H et al. Wind power facilities are becoming more and more popular for utilities to add renewable energy to their distribution networks. And a DFIG (Doubly Fed Induction Generator) is used to get power from the wind. Problems with both short and long transmission lines are looked at in this study. Faults and the Static Synchronous Compensator (STATCOM) are also looked at. The main goal of this study is to find ways to control the amount of voltage and current in electrical systems. A Distribution Static Synchronous Compensator (DSTATCOM) is suggested in this work. We connect DSTATCOM to the power grid through a DFIG-based wind farm, which also provides power.

D. Kim, N. Cho, et al. [8] The purpose of this study is to come up with a way to look at steady-state short-circuits in power networks that use local energy sources (DERs). So, we suggest a way to look for faults that takes into account the effect of DERs that are currently handled. It is important to pay attention to two things about a current-controlled DER: its big filter inductance and the effects of its output current and voltage limits. For the fault analysis, we should also think about the features of loads that need power all the time in the network. To fix these problems, we offer a fault analysis way based on power flow.

III. Components Of DER Technologies

A DER technology is mostly made up of energy-generating and storage systems that are put at or near the point of use. These systems usually include fuel cells, reciprocating engines, micro turbines, load reduction techniques, and ways to manage energy. Power electrical interfaces, communications, and control devices are also used in DER to improve efficiency and run single generators, multiple system packages, and collective power blocks[3].

- Distributed Generation: technology like fuel cells, micro turbines, and PV cells that make electricity away from the power grid
- Distributed Power: technology that charges batteries and flywheels to make electricity or store it.
- Distributed Energy Resources: a mix of technology from DG and DP, as well as steps to lower demand. Power can be sent back to the grid in this case.

IV. Characteristics And Application Of Der

DER is mostly used for:

- Premium power: less frequency changes, voltage transients, and other disturbances
- Back-up power: used as a backup in case of an outage
- Peak shaving: used when electricity use and demand charges are high
- Low-cost energy: a primary power source that is available locally and doesn't cost much Combining heat and power, or cogeneration, is a way to make power generation more efficient by using waste heat for other thermal processes.
- DER basically makes the power grid more reliable, helps keep transmission lines from getting too busy, ensures good power quality, controls price changes, increases energy security, and makes the grid more stable.

V. Fault Characteristics

Distributed solar generation, also known as rooftop solar or distributed photovoltaics (PV), brings several benefits such as reduced grid congestion, lower transmission losses, and environmental advantages. However, like any power generation system, distributed solar also presents its own set of fault characteristics. Here are some common fault characteristics associated with distributed solar generation:

• **Partial shading**: Partial shading of solar panels can significantly reduce their output. This could occur due to nearby buildings, trees, or even clouds passing over part of the array. Partial shading can cause hotspots, which can damage solar cells over time and decrease overall system efficiency.

• **Module failures**: Individual solar panels within an array may fail due to manufacturing defects, physical damage, or degradation over time. These failures can reduce the overall output of the system and may require maintenance or replacement.

• **Inverter faults**: Inverters are crucial components of solar PV systems, converting DC power generated by the solar panels into AC power suitable for use in homes or the grid. Inverter faults such as short circuits, overloads, or failures can disrupt power generation and may require replacement or repair.

• **Intermittent generation**: Solar power generation is inherently intermittent due to variations in weather conditions, time of day, and seasonal changes. Cloud cover, rain, and nighttime all affect solar output. While this is not a "fault" in the traditional sense, it poses challenges for grid integration and reliability.

• **Voltage fluctuations**: Rapid changes in solar output, such as those caused by passing clouds, can lead to voltage fluctuations in the distribution grid. These fluctuations can impact the stability and performance of other connected loads and may require voltage regulation measures.

• **Islanding**: In some cases, distributed solar PV systems may continue to generate power even during grid outages. This can create safety hazards for utility workers attempting to restore power and may also damage grid infrastructure if not properly managed.

• **Reverse power flow**: Distributed solar systems can feed excess power back into the grid, particularly during periods of high solar generation and low local demand. While this can help reduce reliance on conventional power plants, it can also cause operational challenges for grid operators in managing bidirectional power flows.

• **Communication failures**: Many modern distributed solar PV systems incorporate monitoring and communication capabilities to allow for remote monitoring and control. Communication failures or malfunctions can hinder the ability to diagnose and address issues promptly.

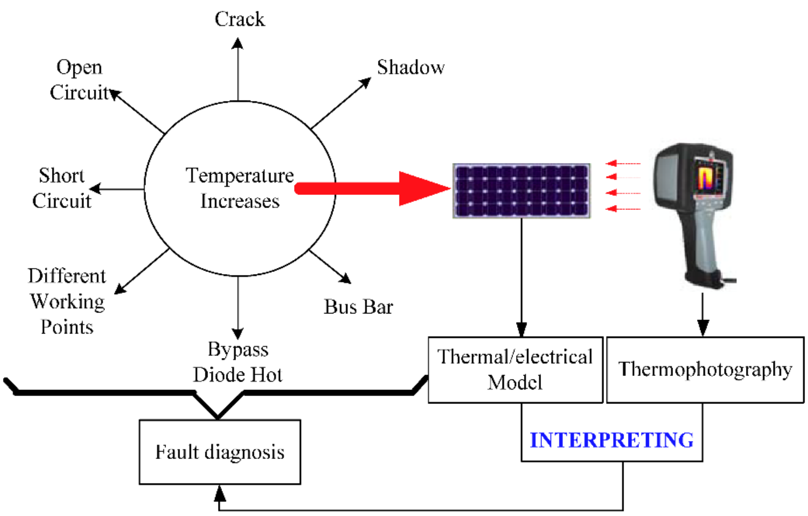

Fig. 1 Overview of Fault and interpreting in distributed system

VI. Distributed Solar Generation

Disconnections in distribution grids can happen in big areas, affecting millions of people and businesses, especially when severe weather events cause damage. When DER are added to some parts of the grid, those parts can still serve other loads on the same distribution network, meeting local needs with power generated nearby. The word for this is "islanding." People often use the term "microgrids" to refer to electrical systems that can intentionally cut themselves off from the main grid. Each microgrid is different in size, from a small one with just one customer to a full substation microgrid with hundreds of sources and power users. Small electrical devices that don't connect to the main power grid aren't new. Ships, military bases, outposts in the middle of nowhere, and towns all over the world have long relied on local power production and management to meet their energy needs. DER have made microgrids more popular because the equipment needed to make energy is now easier to find and can be put in neighborhoods. Microgrids on a community level may offer backup power and resilience during and after crises like hurricanes.

VII. Proposed System

There are limits to all numerical models, such as mathematical computer models. It is possible to get accurate simulation results for the type of phenomenon that you want to watch or study by including the right model components, such as controls, protections, and abilities. That is why power system engineers in both academia and business need to make sure that the right mathematical simulation model is chosen. The right choice of mathematical modeling model, on the other hand, is not simple. Spread out production will likely become more important in making electricity in the next few decades, especially near the low voltage consumer side. Power users are becoming more and more interested in putting their own generators so that they can use flexible DG technologies to make power during good times, improve the quality and reliability of power, or meet their heating and cooling needs. Because DG technologies come in a variety of sizes, work better or worse, and can be used for different things, they could be used to provide power in a wide range of industrial, commercial, and residential settings. In this way, DG is helping to make the electricity source more reliable. If DG does get a big piece of the generation market, distribution utilities will play a much bigger part than they do now. To make room for DG, the rules for designing distribution systems will need to be changed. More research should be done to find out what technical skills, operating strategies, and skill levels distribution network operators need in order to get the energy markets ready for a less centralized power system.

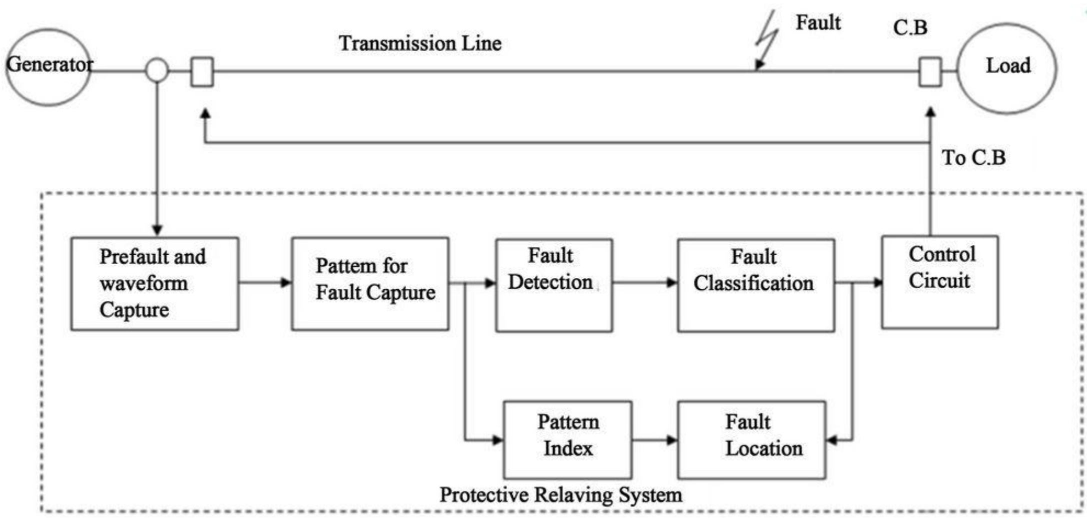

Fig. 2 Basic flow for identifying faults in the system

VIII. Methodology

This setup looks at what happens when an inverter-based solar DER fails and an SFCL is connected in series, recording several fault events. It looks at both transient and steady state fault reactions. During transient times, high phase and negative sequence fault currents are seen. How big the fault current is depends on how bad the fault is and how the output was before the problem. It is found that fault currents are always less than the maximum output current when the system is in steady state. Negative sequence currents and zero sequence currents are both very small. Power factor is controlled when there is a fault, which makes the positive sequence voltage and current closely aligned. When the sequence voltage is positive, the active power flow is proportionally cut off. The results of this study have an impact on fault analysis and relay setting in terms of distributed solar production. If the machine is hooked up to SFCL during the fault timing, the fault current will drop.

A. Matlab Simulink

Market-leading companies use Model-Based Design, which involves using models throughout the whole process, to change how complicated systems are built.

- Run your system through a virtual model and test it often and early on.
- Use physical models, Hardware-in-the-Loop testing, and rapid prototyping to make sure your design works;
- Write production-quality C, C++, CUDA, PLC, Verilog, and VHDL code and deploy it directly to your embedded system; • Keep a digital thread that can be tracked through requirements, system architecture, component design, code, and tests;
- Apply models to systems that are already running so that problem analysis and predictive maintenance can be done.

B. Simulink

Virtual system integration can help you rely less on prototype tools and give all of your engineers access to the system virtually at any point in the product development process. Simulink® lets you create, test, and study complicated virtual systems that are made up of hardware, software, algorithms, and the world in which the system works. With Simulink, you can:

- Use easy-to-understand architecture models to describe system design
- Use domain-specific tools and prebuilt blocks to model systems that span multiple fields.
- Develop large-scale models that are easy to keep and have parts that can be used again and again.
- It is easy and safe to add parts from different teams and tools to a single system-level example.
- Run simulations and analyses to learn about and confirm how systems work.
- Run very large simulation jobs at the same time on a multicore desktop or computer cluster, or in the cloud; • Make simulations available as stand-alone executables, web apps, and Functional Mockup Units (FMUs);
- Use System ComposerTM to define and look over the design of a system. Make models of the system design that describe it and connect them to models of how it will be implemented in Simulink. Things in the architecture and design processes stay in sync thanks to the connected environment.
- Use these design models to make a template for a virtual system. Set up a system simulation with structures that have already been defined, and the virtual system will be put together instantly.

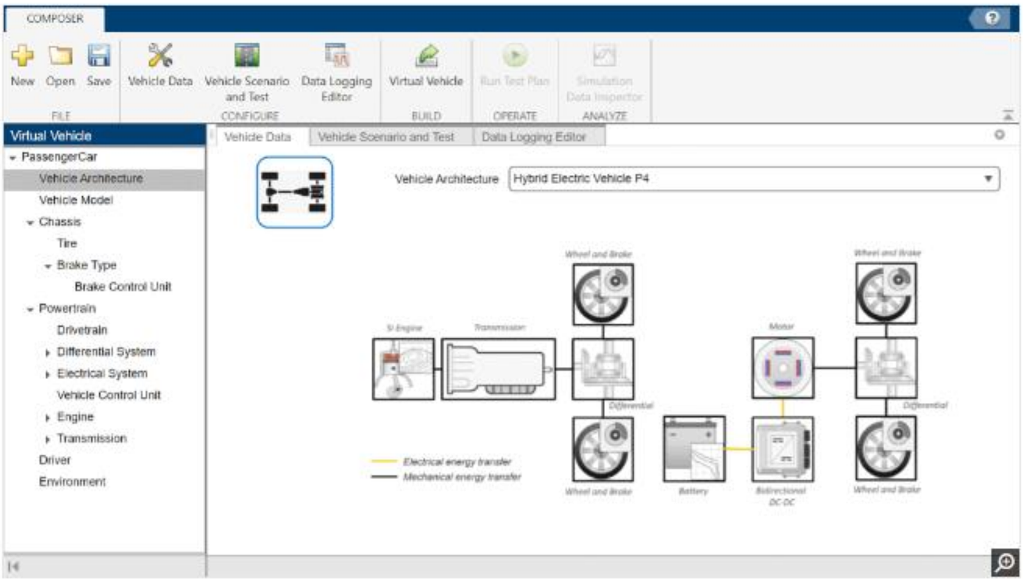

Fig. 3 Overview of Simulink platform

Complex virtual systems can contain multiple-domain components. In one model, build continuous-time, discrete-time, and hybrid simulation components using Simulink.

IX. Conclusion And Future Scope

A. Conclusion

In this approach, the fault characteristics of solar distributed energy resources (DERs) that are based on inverters are investigated by means of a series of recorded fault events. In this research, both transient and steady-state fault responses are taken into consideration. The presence of fault currents with a high phase and a negative sequence is noticed during transient periods. The severity of the defect and the conditions that existed prior to the fault both have an impact on the amount of the fault current caused by the fault. In steady state, it has been found that fault currents are consistently lower than the rated output current. This was discovered through research. Neither negative sequence currents nor zero sequence currents are significant. A precise phasor alignment between the positive sequence voltage and current is achieved as a result of the regulation of the power factor that occurs during faults. The magnitude of the positive sequence voltage is directly proportional to the inverse of the active power output, which is accordingly lowered. Both relay configuration and fault analysis are connected to distributed solar generating, and the outcomes of this suggested system have an effect on both of these aspects. In conclusion, distributed solar production offers a multitude of benefits; yet, it also displays a number of flaw features that need to be fixed in order to guarantee that it will operate in a manner that is both safe and effective. Failure features include partial shading, inverter faults, intermittent generation, voltage fluctuations, islanding, reverse power flow, communication failures, and module failures. Other fault characteristics include islanding and reverse power flow. It is vital to coordinate with grid operators in order to handle these concerns, and it is also necessary to design, install, and maintain solar photovoltaic systems in a suitable manner while doing so. It is necessary to employ proactive management methods and constant technical advancements in order to eliminate these impediments and maximize the benefits of distributed solar generation while simultaneously ensuring grid stability and reliability. This can be accomplished by optimising the advantages of distributed solar generation.

B. Future Scope

The future scope for addressing the fault characteristics of distributed solar generation encompasses several avenues of research, innovation, and implementation. Here are some potential future directions:

- **Advanced Monitoring and Diagnostics:** Develop and deploy advanced monitoring systems equipped with sensors and data analytics to detect and diagnose faults in real-time. Machine learning and AI algorithms can be employed to predict and prevent faults before they occur, optimizing system performance and minimizing downtime.

- **Fault-Tolerant System Design**: Design distributed solar PV systems with built-in fault-tolerance mechanisms to withstand and mitigate common issues such as partial shading, module failures, and inverter faults. Redundant components, smart switching mechanisms, and decentralized control strategies can enhance system resilience.

- **Smart Inverter Technologies**: Further research and development of smart inverter technologies capable of rapid response to grid conditions, voltage regulation, and seamless integration with energy storage systems. These inverters can help mitigate voltage fluctuations, islanding, and reverse power flow issues, improving grid stability and reliability.

- **Predictive Maintenance Strategies**: Implement predictive maintenance strategies based on data-driven insights and condition monitoring to anticipate and address potential faults before they impact system performance. This approach can optimize maintenance schedules, reduce downtime, and prolong the lifespan of distributed solar PV systems.

- **Grid Integration Solutions**: Develop innovative grid integration solutions, such as advanced power electronics, energy management systems, and demand response mechanisms, to facilitate seamless integration of distributed solar generation with the electrical grid. These solutions can optimize power flow, manage voltage levels, and enhance grid stability in the presence of intermittent generation and fluctuating loads.

- **Standardization and Certification**: Establish industry standards and certification protocols for distributed solar PV systems to ensure compliance with safety, reliability, and performance requirements. Standardization can streamline deployment, improve interoperability, and build trust among stakeholders, fostering wider adoption of distributed solar generation.

- **Policy and Regulatory Support**: Advocate for policies and regulations that incentivize the adoption of fault-tolerant and grid-friendly distributed solar PV systems. This may include financial incentives, net metering policies, grid access agreements, and performance-based incentives to encourage investment in advanced technologies and practices.

By pursuing these future directions, stakeholders can enhance the reliability, efficiency, and grid integration of distributed solar generation, accelerating the transition towards a sustainable and resilient energy future.

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