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Short Circuit Fault Detection and Protection of DC Microgrid

Nidhi Patel[1], Swatantra Singh Verma[2]
Department of Electrical Engineering VEC Ambikapur

ABSTRACT
This paper presents a fault simulation on DC microgrid based on direct current was designed using solar PV, battery and fuel cell as a source in MATLAB/Simulink. The power produced by different sources is combined on the same DC bus and given to a DC load. The system takes some precautions against some undesired situations. In case of a fault, the failed section of microgrid has been separated rapidly using circuit breaker and restore using protective devices. The short circuit is the one of the faults which affect the stability of system. we need to make sure to this type of faults don't affect the stability and reliability of system. Thus, we make the short circuit protection circuit, this circuit don't affect the stability and reliability of system.In this circuit, over current relays for detection and circuit breakers for protection and for extra protection, FCL i.e., fault current limiter in PV array side is used.

1. Also fuel cell and PV array are taken at the source side and for backup lithium-ion battery is taken. For battery, bi-direction
converter is designed. Initially battery is charged up to 70% and at this time bidirectional converter work as a boost converter and when battery discharges till 30 %, battery starts charging and then bi-directional converter act as buck converter and battery remain charging mode.

Keywords— Short-circuit fault; FCL; MPPT; Circuit Breaker; bidirectional converter

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I. INTRODUCTION

A microgrid is a local electrical grid containing sources and loads. The definition of a microgrid is a cluster of distributed resources which have the ability to operate autonomously. Microgrids are being used to bring electricity into areas where transmission lines cannot reach. A traditional system with generation in one place and then distribution at high voltages is designed for high energy density fossil fuels. Distributed generation can be used to increase the reliability of a system and allow for the integration of renewables. Distributed generation is a much more suitable method of electricity distribution for renewables due to their lower energy density as compared to fossil fuels and since the power generation is on site losses due to transmitting electricity are proportionally eliminated. Energy storage can be used in microgrids to improve the power quality and smooth out the fluctuations of renewable energy generation. The recent trend in renewables is to use distributed power sources and energy storage to form a microgrid. DC microgrids are not very widespread but have the potential to present many advantages in terms of facilitating renewable energy integration and improving power quality. DC microgrids usually contain distributed energy resources (DER), loads and energy storage. Renewable energy sources such as photovoltaic modules and wind turbines are typically connected to the DC bus via power electronic converters. These converters have the ability to control the output voltage of DER in order to stabilize the bus voltage and extract maximum power. There are power electronic converters that have the ability to increase or decrease the output voltage. DC loads can be directly connected to the DC bus and if an AC load is required an inverter would be needed in order to invert the DC bus voltage into a usable AC voltage. Batteries are typically used in DC microgrids due to their relatively cheap price and longer backup times. A longer backup time and low losses are desirable for energy storage technologies for microgrids which contain renewable energy generation in order for the load to be met. The problem with batteries is that their service life is relatively short and therefore they need to be changed out more often. Charge controllers are used in order to control the flow of power in the microgrid. Devices are needed to control when power is sent to the batteries or sent to power the load. These controllers also help to improve the power quality in the microgrid. Why fault occur in

DC microgrid? Due to the low impedance nature of DC microgrid system, the capacitive filters associated with converters will rapidly discharge into a fault, resulting a large current surge within very short duration.

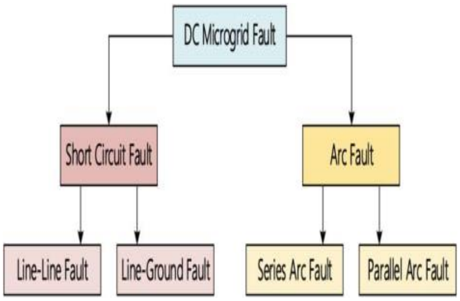

Fig 1 Types of faults

DC microgrid protection is an important part of the power system studies. One of the major objectives of DC microgrids is improving the overall reliability of the system. This is a complex challenge in DC Microgrid, but to overcome this complex challenge, and protection to it, requires various circuits with complicated designs to be added to the grid. The basic thing which is required for protection is to get to know are where it should be provided, which component to be used, what parameter shouldn't be altered while designing the circuit so that the DC Microgrid works as per the expectation. DC Microgrid has numerous advantages compared to AC Microgrid, so designing an appropriate protection circuit for the DC microgrids remains to be a significant challenge. So, to address the challenges of DC microgrid protection, accurate fault detection strategy, fault current limiting method, proper grounding design and a DC circuit breaker are required. In this model, we have used a normal Circuit Breakers which are available in MATLAB Simulink, and by using the Power electronic devices like MOSFET and IGBT as, control switch in the converters. When designing an appropriate fault detection strategy, the parameter which should be evaluated effectively are cost, computation, and performance. MATLAB/Simulink was used to design and simulate he individual components of the microgrid.

Power electronic converters were designed and simulated for the use with photovoltaic (PV) modules and maximum power point tracker (MPPT) in order to extract maximum power from the solar resource. The perturb and observe (P&O) algorithm was designed in MATLAB environment for the MPPT. A bidirectional converter was also designed to allow power to flow/to battery which was controlled by converter by PI technique. A traditional buck-boost converter could not be use of bidirectional converter due to presence of diodes in their design. The charge controller successfuly controlled the bidirectional converter allowing power to flow from/to the battery to achieve voltage stabilization. A lead-acid battery was found to be most cost-effective option for integration into the microgrid. A boost converter was also designed for solar PV and fuel cell to boost up the voltage as per the requirement. A protection model against short circuit fault for direct current (DC) microgrid using MATLAB/Simulink is designed.

II. BLOCK DIAGRAM

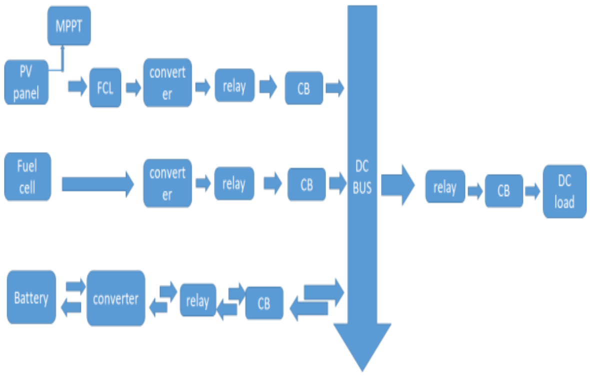

Fig.2 Microgrid system block diagram

Fig.2 represents the block diagram of DC microgrid system for short circuit fault detection and protection where two generating sources are taken which are solar PV& fuel cell and battery is connected in parallel.

As we know solar PV has many advantages but it has very low energy conversion efficiency. To overcome this problem, PV is connected to MPPT (Maximum Power Point Tracker) in order to extract maximum power from solar array during unfavourable condition. Solar PV is also connected with FCL (Fault current limiter) to limit the fault current without complete disconnection. Solar PV and fuel cell connected to boost converter in order to maintain the DC bus voltage and battery is connected with bidirectional converter which allows power to flow from battery or to battery to achieve voltage stabilization. Solar PV, fuel cell and battery is connected with relay and Circuit breaker. Whenever, fault occurs in the system, relay gives signal to the Circuit Breaker. As soon as the Circuit Breaker receives the signal it trips and separates the faulty section from DC bus so that fault does not proceed further or damage any equipment.

III. DESIGN AND SIMULATION:

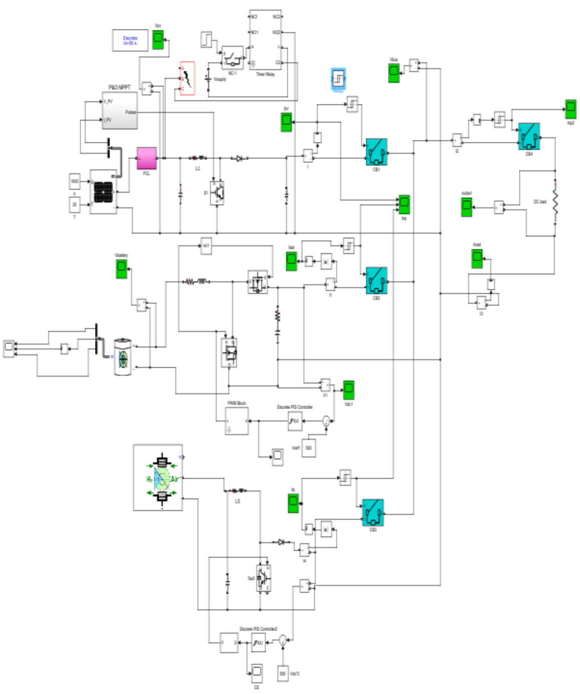

Fig.3 Distributed Generation system Simulink model

The above is the test system of the proposed topology with one PVA source, one battery source and fuel connected in parallel feeding the DC load. The PVA is operated by MPPT technique connected to booster converter for voltage stability.

Battery is connected with bidirectional DC-DC converter controlled by voltage-oriented control. Fuel is operated by PWM technique connected to a booster converter. The rated DC voltage is set at 500V. In this research, grid connected system is used. At the source side, photovoltaic source (PV) and fuel cell are demonstrated and the battery for back up is taken and DC loads is connected at the load side.

The PV source is connected with fault current limiter (FCL). FCL is a fault current limiter also known as a fault current controller is a device which limits the prospective fault current when a fault occurs in photovoltaic source. PV source is also connected to a P&O MPPT in order to extract maximum power from PV. Fuel Cell and PV both the sources are connected with the converters which will boost up the voltage and will supply it to the DC load through the DC bus.

A. Maximum Power Point Tracker

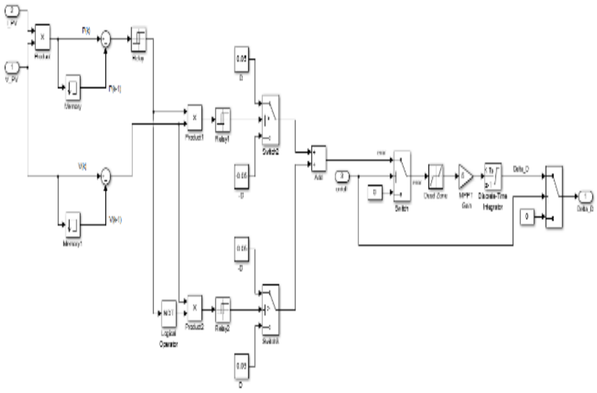

Fig.4 Simulation diagram of Maximum Power Point Tracker

The photovoltaic system has a non-linear current- voltage and power-voltage characteristics that continuously varies with irradiation and temperature. In order to track the continuously varying maximum power point of the solar array the MPPT (maximum power point tracking) control technique plays an important role in the PV systems. The task of a maximum power point tracking (MPPT) network in a photovoltaic (PV) system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). In a MPPT method and its implementation and performance are presented. Two existing drawbacks encountered while generating power from PV systems are: the first one that the efficiency of electric power generation is very low, especially under low radiation states, and the other drawback is the amount of electric power generated by solar arrays is always changing with weather conditions, i.e., irradiation and temperature. it can be observed that the output power characteristics of the PV system as function of irradiance and temperature is nonlinear and is crucially influenced by solar irradiation and temperature. The Maximum Power Point (MPP) of the PV array changes continuously; consequently, the PV system's operating point must change to maximize the energy produced. Therefore, a Maximum Power Point Tracking (MPPT) is an essential part of the PV system to ensure that system operates at the maximum power of the PV array.

According to the theory of maximum power transfer, the power delivered to the load is maximum when the source internal impedance matches the load impedance (ZS=ZL). Thus, the impedance seen from the converter side needs to match the internal impedance of the solar array.

The operation of MPPT cannot be achieved unless a tuneable matching network is used to interface the load to the PV array. The main constituent components of a PV system are power stage and controller as shown in fig.1 the power stage is realized using switch mode DC-DC converters (boost, buck-boost), employing PWM control. The control parameter is duty ratio δ which is used for the tuning of the network for maximum extraction of power. The P&O algorithm is also called "hill- climbing", while both names refer to the same algorithm depending on how it is implemented. Hill-climbing consist of a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturb the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique.

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented. The process is repeated until the MPP is reached. Then the operating point oscillates around the MPP.

However, P & O have certain limitations. In a situation where the irradiance changes rapidly, the MPP also moves on the right-hand side of the curve. The algorithm takes it as a change due to perturbation and in the next iteration it changes the direction of perturbation and hence goes away from the MPP.

However, in this algorithm we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing in both the directions. When this happens, the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm.

B. Fault Current Limiter (FCL)

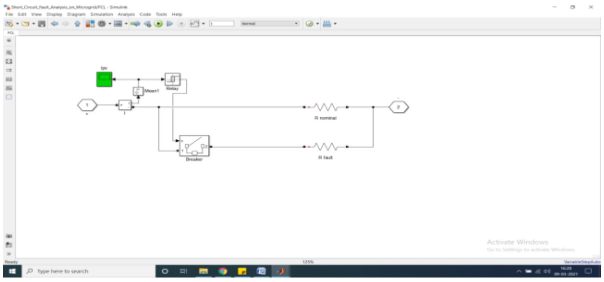

Fig 5 FCL internal modelling

The Fig.5 is the modelling of FCL connected at PVA controlled by relay trip signal depending on short circuit current.

Fault Current Limiters (FCLs) act as an additional high impedance to limit high fault currents to an acceptable level. In normal operation, FCLs have almost no impedance and are "invisible" to the system. Unlike fuses or disconnectors, FCLs do not completely disconnect in fault case. After the fault current disappears, they can return to normal operation. Due to their very short reaction time, FCLs can act and reduce the short circuit current so that the circuit breaker can act in their nominal performance range, if needed. Typically, FCLs are used in low and medium voltage levels.

Advantages & field application

By installing FCLs, system operators or commercial customers can optimize the system by application of standard solutions with specific (low) nominal short circuit currents. Major advantages include:

- Reduction of the short-circuit current of the system, allowing the circuit breakers to act in their nominal performance range
- Reduction of voltage sags and flicker due to the lower total source impedance
- Reduction of harmonics due to the lower total source impedance.

C. Battery

A lithium-ion battery or Li-ion battery is a type of rechargeable battery. In the batteries, lithium ions move from the negative electrode through an electrolyte to the positive electrode during discharge, and back when charging. Li-ion batteries use an intercalated lithium compound as the material at the positive electrode and typically graphite at the negative electrode. Lithium-ion batteries have become the most promising solutions for applications in microgrid networks due to their high energy density and high-power density. It is possible to realize fuel savings of 50 to 75 percent. Li-ion battery systems have emerged as the technology of choice for energy storage. Lithium-ion-based Battery Energy Storage System (BESS) play an important role in solving power supply problems in micro-grids due to their performance characteristics such as high power, high efficiency, low self-discharge, and long lifespan.

Benefits of Li-ion battery

- Maintenance: Unlike flooded lead-acid batteries with water levels that need to be monitored, lithium-ion batteries do not need to be watered. This reduces the maintenance needed to keep the batteries operational, which also eliminates training new team members on the procedure and monitoring machines to ensure that water levels are correct. Lithium-ion batteries also eliminate engine maintenance.
- Longevity**:** The average lithium-ion battery lifespan for a large-capacity battery pack can be as long as eight or more years. A long service life helps provide a return on your investment in lithium-ion battery technology.
- Easy & Fast Charging**:** Using fast-charging lithium-ion batteries mean less downtime for a machine while it's tethered to a charging station. In a busy facility, of course, the less time a machine has to sit idle, the better. Also reducing downtime for a machine, the lithium-ion battery can be opportunity charged. This means that cleaning procedures don't have to be designed around the need to allow a battery to fully charge in-between uses, and also simplifies training for team members.
- Safer Facilities: Improve indoor air quality and reduce the risk of accidents by eliminating exposure to flammable fuels and battery acid with lithium-ion technology. Also enjoy quiet operation with low dBa sound levels.

- Environmental Impact: Lithium-ion batteries provide significant environmental benefits over other fossil fuel alternatives. With the steady increase in electric vehicles, we are seeing an immediate impact in the reduction of carbon emissions.

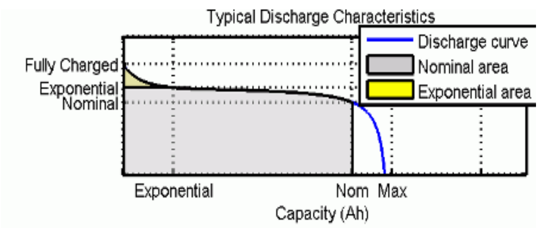

Fig 6 Discharge characteristics of battery

The first section represents the exponential voltage drop when the battery is charged. The width of the drop depends on the battery type. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly.

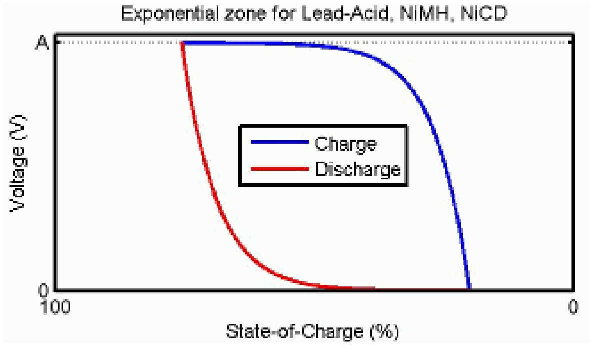

Fig.7 Battery's State of charge (SOC)

The state of charge (SOC) for a battery is a measure of battery's charge, expressed as a percent of the full charge. The depth of discharge (DOD) is the numerical compliment of the SOC, such that DOD = 100% - SOC.

For example, if the SOC is:

- 100% — The battery is fully charged and the DOD is 0%.
- 75% — The battery is 3/4 charged and the DOD is 25%.
- 50% — The battery is 1/2 charged and the DOD is 50%.
- 0% — The battery is having 0 charge and the DOD is 100%.

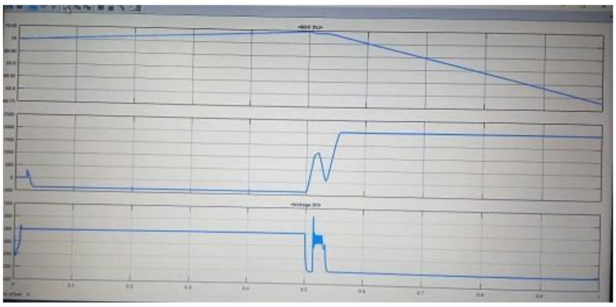

Fig.8 SOC during Simulation

Initially battery is charged up to 70% and slowly it starts discharging as it supplies power to DC bus and DC load.

IV. RESULT

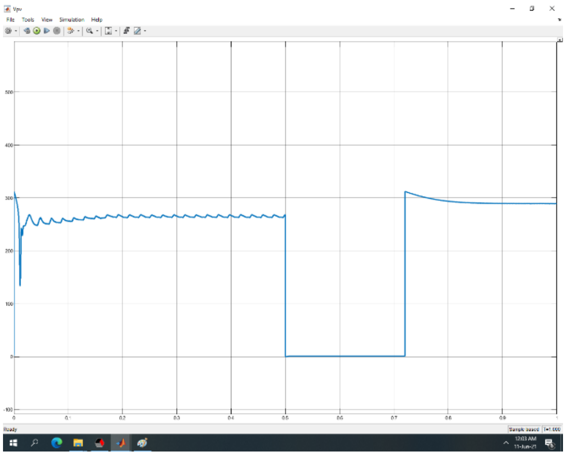

Fig.9 PV source voltage magnitude

The test system is introduced with fault on PV source at 0.5sec due to which voltage is reduced zero and using fault controller at 0.7 sec the voltage starts restoring and the results are observed. Due to FCL the current of the PVA is not increased and maintained at nominal value.

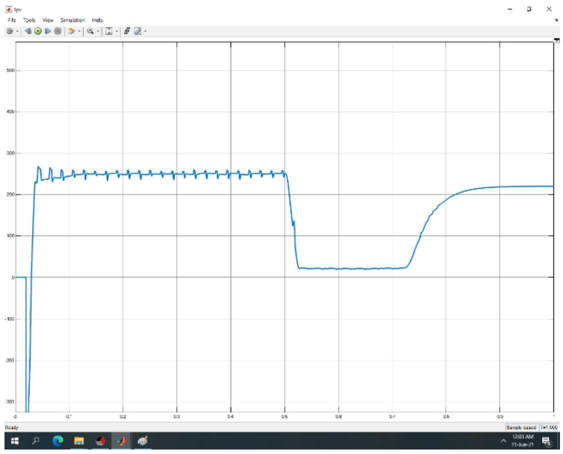

Fig.10 PV current magnitude

Similarly, PV source current is also reduced to zero during fault.

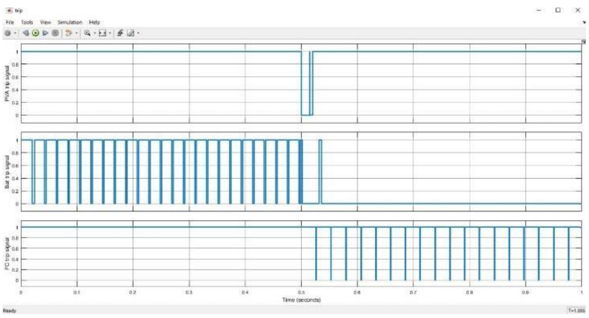

Fig.11 Trip signal of the PV, battery and fuel cell breaker

The trip signal of the PVA is recovered as FCL is present on the source side.

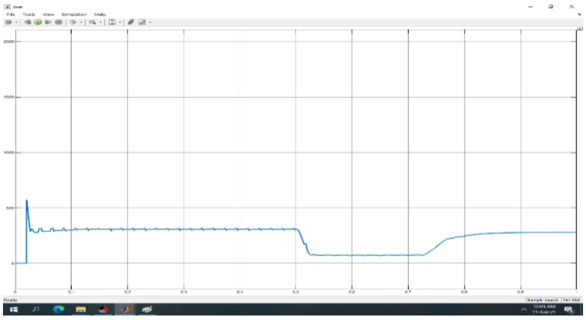

Fig.12 Battery current magnitude

Battery current is also reduced during fault as it is connected in parallel with PV source.

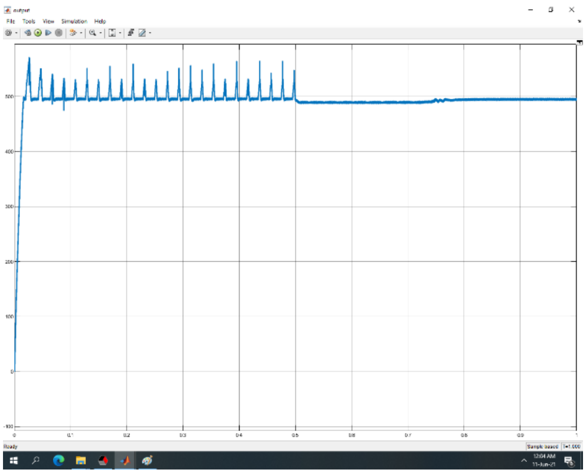

Fig.13 Output voltage

The failed section of microgrid has been separated from grid rapidly using breakers located at each energy sources and also at the output side to protect DC load and meanwhile the other two sources continue to fed the power to the load.

V. CONCLUSION

A DC microgrid model has been designed and simulated that comprises a protection model for multiple energy sources. At the time equal to 0.5 the system detects the fault at PV array and with help of circuit breaker and relay the PV array is separated from the system immediately and at the time equal to 0.7 the PV array starts restoring.

This model is used to protect the DC microgrid under short circuit fault. Whenever the fault occurs at any section of the DC microgrid then the system is protected against it rapidly using protective devices and also the system is restored quickly, maintaining the continuity of the power supply to the DC load. As a result of all these studies, its shown that the system has speed respond time against faults.

In DC microgrid time-based fault cannot be implemented directly in MATLAB, it must be developed in future. This model can be used for either industrial purpose or for any small-scale area.

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