# AN ADAPTIVE FAULT IDENTIFICATION SCHEME FOR DC MICROGRID USING EVENT BASED CLASSIFICATION

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**Abstract-***The recent high penetration of stationary renewable energy sources yielding DC output coupled with the increased interest in storage systems, electronic loads, machine drives and other components operating with DC input, require the development of new techniques for control and link integration. Faults in power distribution systems have high impact on continuous supply and quality service. If a contingency occurs in a system, instability and cascading failures blackout would be possible. Protection against such severe faults increases the transfer capabilities of the existing transmission systems. The literature survey shows various methods available for the fault identification and fault location. In the existing system each protection unit is able to autonomously identify the type of fault using the current derivative fault identification method. Then the event judgment is sent to other interconnected protection units through high level data communication. But in the existing system there is a limitation that it is possible to limit the load voltage drop up to 2.88%.A novel protective method is proposed to identify the fault, isolate the faulted area and restore the system quickly. The fault identification is based on voltage derivative method. In the voltage derivative protection method, the derivatives ∂V/∂t and ∂I/∂t are calculated from the dc voltages and currents measured locally at the relaying point to detect, locate and isolate the fault. The local voltage and current measurements are taken for each instance of time. It requires less data and doesn't require high speed communication and synchronization. The advantage of this method is that the first incident/reflected wave from the fault is used in the detection and, therefore, the response time is very fast, providing fault detection within 2-3ms than current derivative method. The expected results of the proposed system are to identify the fault, isolated the faulted area and restore the system quickly. The results of the proposed system are verified using MATLAB Simulink.*

***Key Words:*** *Event-based classification, Artificial Inductive Line Impedance (AILI), Super capacitor*

## 1. INTRODUCTION

DC microgrid is an effective architecture to achieve a more reliable power with higher efficiency through the implementation of the power electronic converters and the storage energy devices. In various applications, such as telecommunication systems, shipboard and spacecraft, and distribution systems involving a large number of electronic loads and data centers, dc architectures provide a more effective solution for electric power distribution. A dc shipboard power system is an example of advanced dc microgrid concept where the system is capable of self-diagnosing, self-healing, and self-reconfiguring. In the case of heavy pulse loads or loads with large startup current, energy management and power control of these systems are a fundamental concern. Such a high short-time current behavior not only requires higher rating of the power components but also can potentially cause the system voltage and frequency to drop in the entire microgrid.

Recent developments in basic technology have made super capacitors an interesting option for short-term energy storage in low-voltage power electronic systems. Usually, super capacitors are modeled using simple RCcircuits. However, these models cannot accurately describe the voltage behavior and the energy efficiency of these devices during dynamic current profiles. This shortcoming is important because many applications, e.g., the 42-V Power net of future automobiles, will use super capacitors just under these operation conditions. The operation and control strategy is evolving from centralized control to decentralized, multilevel, and hierarchical structure of control. Control centers at each level in the hierarchy have predefined roles mandated by the orders under the regulatory framework. Accordingly, the scope and nature of the information processed varies at different levels from specifics at lower levels to generalized information at higher levels of control centers. Data and events are aggregated, summarized, and reported up the hierarchy as laid out in the operational procedures for efficient operation and control of interconnected power grids.

Supervisory Control And Data Acquisition systems and Energy Management Systems (SCADA/EMS) deployed in each control center carry out their functions on the data received from respective control areas. If a contingency occurs in a system, instability and partial or even nationwide blackout would be possible. Restoring the network to the normal condition after the occurrence of a blackout requires complex restoration operations that may result in relatively long power outages. Therefore, to prevent instability and outages, special protection and advanced control schemes are used.

## 2. DC MICROGRID

Microgrid is a small-scale grid that is designed to provide power for local communities. It is an aggregation of multiple Distributed Generators (DGs) such as renewable energy sources, conventional generators, in association with energy storage units which work together as a power supply network. It consists of interconnected distributed energy resources capable of providing sufficient and continuous energy to a significant portion of internal load demand. The main components of a microgrid are:

- Distributed generation sources such as photovoltaic panels, small wind turbines, fuel cells, diesel and gas micro-turbines etc.
- Distributed energy storage devices such as batteries, super capacitors, flywheels etc.
- Critical and non-critical loads
- Energy storage devices are employed to compensate for the power shortage or surplus within the microgrid

Microgrids can be intended as back-up power or to bolster the main power grid during periods of heavy demand. Often, microgrids involve multiple energy sources as a way of incorporating renewable power. Other purposes include reducing costs and enhancing reliability.

### 2.1 Structure of DC Microgrid

DC microgrid is an efficient method to combine a system of high reliability and the possibility to reduce the losses in the system. It can eliminate DC/AC or AC/DC power conversion stage and thus has advantages in the stand of efficiency, cost and system size. DC microgrid is inspired by the absence of reactive power, possibility of an efficient integration of small distributed generation units and the fact that, internally, all the loads operate using a DC voltage.

grid is suitable for home loads which are mainly of DC loads. This method eliminates the ac/dc interface. DC microgrid, also by one or more inverters is connected to the utility grid and industrial loads (AC loads). A DC grid within a building (or serving several buildings) can minimize or eliminates entirely these conversion losses.

The structure of DC grid is shown in Figure-1. DC micro-In the DC microgrid system, AC power converts to DC when entering the DC grid using a high efficiency rectifier, which then distributes the power directly to DC equipment served by the DC grid.

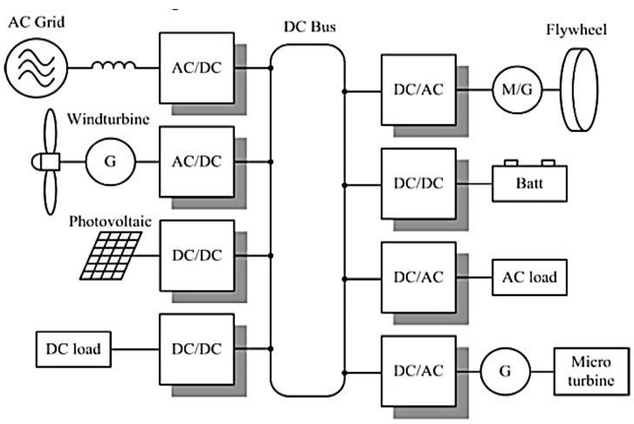


**Fig-1:** Structure of DC Grid

On average, this system reduces AC to DC conversion losses from an average loss of about 32% down to 10%.

### 2.2 Grid Support During Transient Time using Capacitor Controller

One of the advantages of the direct connection of the supercapacitor to a redundant dc microgrid is its capability to support the grid during the transient time when it is highly loaded. In order to evaluate the performance of the AEC and the EMS, the load 2 is emulated as a load with high starting power, based on where PNis the steady state power of load, $k$ is the transient load coefficient and $\tau$ is its time constant.

The dynamic behavior of a supercapacitor is strongly relatedto the ion mobility of the electrolyte used and the porosity effects of the porous electrodes. The real part of the supercapacitor impedance decreases with frequency; its value is reduced by half from dcto very high frequencies (some kilohertz). This reduction in the capacitance with an increase in the charge/discharge frequency is mainly the result of ion inertia. Thus, it is impossible touse the full capacitance of the device at high frequencies in practice. Instead, the reduced resistance can be explained bya reduction in friction losses as ion migration slows in the electrolyte solution.

In order to regulate the injection of power to the grid, the uncontrolled rectifiers are connected to the dc buses through boost converters. Controller of the converter is shown in Figure-2, which has voltage and current control modes set by the EMS. In each mode, a Proportional-Integral (PI) controller with anti-wind up is employed to further improve control loop responses by preventing the controller output saturation during transients. The controller adjusts the duty ratio of the insulated-gate bipolar transistor switching at 5 kHz fixed frequency. In order to protect the system from dangerous overvoltage, the dc–dc converters are equipped with hysteresis voltage protection.

If the voltage of the dc bus exceeds its high limit, the converter will be turned off until the super capacitor is discharged to the low voltage limit. During the charging process, the converter is in buck mode and the duty ratio of the switching output

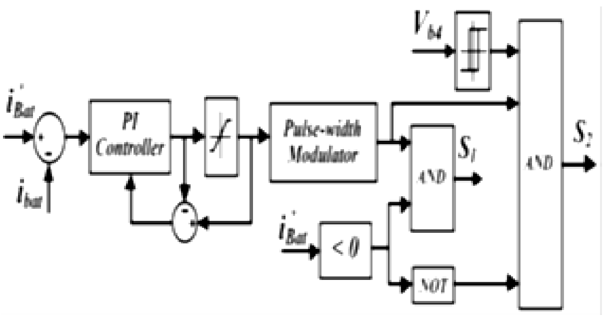


**Fig-2:** Converter Controller

S1 is controlled by the PI controller at a fixed frequency of 5 kHz and the output S2 is turned off. Similarly, during grid support, the converter is in boost mode and the output S1 is turned off and S2 is switched on while the voltage limit of the grid is verified.

## 3. ENERGY MANAGEMENT SYSTEM

In order to regulate the injected power to the grid, the rectifiers are connected to the dc buses through boost converters. Also, the battery bank is connected to the grid through a bidirectional buck-boost converter. Each converter has voltage and current control modes which are set by the Energy Management System (EMS). For each control mode, a proportional-integral controller is employed. The controllers are equipped with an anti-windup to further improve the control loop responses by preventing the controller output saturation during transients. Moreover, in order to protect the supercapacitor bank from dangerous overvoltage, all the converters are equipped with hysteresis voltage protection.

### 3.1 Errors and their Effect on Energy Management

For the real time energy management of a redundant hybrid dc microgrid, one should ensure that the injected energy to the grid and the consumed energy are equal. However, the EMS that employs only current control is associated with three major sources of error, which are explained below.

- **Converter Controller Error** - Any controller, depending on the application and whether it is optimized or not suffers from the steady-state and transient errors. The errors, especially the steady state error, highly affect the EMS performance.
- **Measurement Uncertainty -** Measurements in the hybrid dc microgrid are incorporated with biased and nonbiased noise. Erroneous data in the current measurements for energy estimation can be removed by applying a low pass filter. More sophisticated techniques using statistical methods and random-fuzzy approaches are also applicable. However, it is often times problematic and may even be impossible to filter out all data corrupted with noise and bias errors.

The main objective of the EMS unit is to set the current or the voltage reference of each converter based on the required power of the grid, availability of the converters, and the battery's state of charge. The EMS is composed of two parts: control mode selection and current reference assignment. If the supercapacitor bank is connected to the grid, the EMS sets all the converters to the current control mode. Otherwise, the EMS will set one of the converters to voltage control. In this case, the priority is given to the first converter. It should be noted that during the dc grid fault period, since the voltage of the dc bus drops, the feed-forward diode of the converters will be biased. As the result, the insulated-gate bipolar transistor switches could not to be turned on regardless of the control scheme of the converter.

### 3.2 System Efficiency

Electrical efficiency has traditionally been defined as how efficiently the power within the building is being used. As a society, this creates a skewed result when measuring how efficient electrical systems are. For many purposes this is still an accurate measure when comparing AC buildings vs. other AC buildings. However, this type of comparison does not take into account the transmission and conversion losses that occur in the system, the losses are simply held constant between structures.

### 3.3 Conversion Losses

The load profile has shifted from AC to more and more DC loads over the past several decades and is continuing down that path. The driving factor in efficiency for many of today's devices is the conversion from AC power to DC power. It is not possible to get a 100% efficient conversion from one form to the other. The energy is lost to either heat, magnetism, or shunted to ground depending on the conversion technique. As loads go more and more to DC the amount of these losses is increasing at the same rate. These conversions are happening all over buildings and they are often not considered when designing a system. By the same standard, many of these losses are amplified in conditioned spaces.

## 4. EVENT BASED FAULT IDENTIFICATION TECHNIQUES

An electrical power system is expected to deliver undistorted sinusoidal rated voltage and current continuously at rated frequency to the end users.Each power unit should be able to autonomously classify the type of fault whether it is bus fault, interconnected feeder fault, or adjacent bus or feeder fault. Then fault identification will be made based on the data received through high-level data communication from other interconnected units.

### 4.1 Event Classificaton

- **Events or Disturbances**

Disturbances are measured by triggering on an abnormality in the voltage or the current. Transient voltages may be detected when the peak magnitude exceeds a specified threshold. RMS voltage variations (e.g., sags or interruptions) may be detected when it exceeds a specified level.

- **Steady-State Variations**

Steady state variation is basically a measure of the magnitude by which the voltage or current may vary from the nominal value, plus distortion and the degree of unbalance between the three phases. These include normal rms voltage variations, and harmonic and distortion. The classification of various fault events are shown in Table-1.

- Industrial equipment such as high-efficiency, adjustable speed motor drives and shunt capacitors are now extensively used. The complexity of industrial processes, which results in huge economic losses if equipment fails or malfunctions
- The complex interconnection of systems, resulting in more severe consequences if any one component fails

**Table-1:** Classification of Various Fault Events

| S. No. | Categories | | Duration | Voltage Magnitude |
|---|---|---|---|---|
| I | *Short Duration Variation* | | | |
| (a) | Sag | Instantaneous | 0.5-30 cycle. | 0.1-0.9 pu. |
| | | Momentary | 30 cycles-3 sec. | 0.1-0.9 pu. |
| | | Temporary | 3sec-1min. | 0.1-0.9 pu. |
| (b) | Swell | Instantaneous | 0.5-30 cycle. | 1.1-1.8 pu. |
| | | Momentary | 30 cycles-3 sec. | 1.1-1.4 pu. |
| | | Temporary | 3sec-1min. | 1.1-1.2 pu. |
| (c) | Interruption | Momentary | 0.5cycles-3sec. | <0.1 pu. |
| | | Temporary | 3sec-1min. | <0.1 pu. |
| II | *Long Duration Variation* | | | |
| (a) | Interruption, Sustained | | >1min | 0.0 pu. |
| (b) | Under-voltage | | >1min | 0.8-0.9 pu. |
| (c) | Overvoltage | | >1min | 1.1-1.2 pu. |
| III | *Transients* | | | |
| (a) | Impulsive | Nanosecond | <50nsec. | |
| | | Microsecond | 50-1msec. | |
| | | Millisecond | >1msec. | |
| (b) | Oscillatory | Low frequency | 0.3-50msec. | 0-4 pu. |
| | | Medium freq. | 20μsec. | 0-8 pu. |
| | | High freq. | 5μsec. | 0-4 pu. |
| IV | *Voltage Imbalance* | | Steady state | 0.5-2% |
| V | *Waveform Distortion* | | | |
| (a) | Harmonics | | Steady state | |
| (b) | Notching | | Steady state | |
| (c) | Noise | | Steady state | |

### 4.2 Fault in DC System

DC grid may be unipolar with ground as return path or bipolar with positive and negative terminal. Figure-3(a) and 3(b) depicts unipolar and bipolar grid respectively.

- **Single line to ground fault**

A single-line to ground fault is shown in Figure 4.2. This is most common type of fault. This fault reduces the reliability and continuity of supply. When lightning strikes on transmission line one of the conductor may break either positive or negative and fall on the earth. This causes the line to ground fault. And the line is out of operation till fault is unclear. It may also occur when objects falling on line and providing ground path for current.

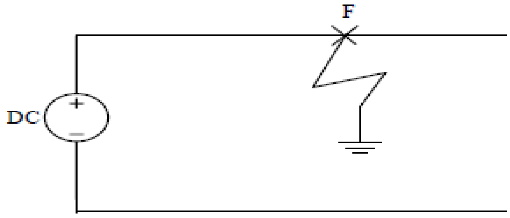


**Fig-3:** Single Line to Ground Fault

- **Line to line fault**

This is most harmful fault for the system than single line to ground fault. This fault rarely occurs in the system.

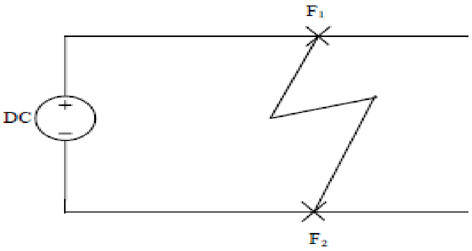


**Fig-4:** Line to Line Fault

In overhead transmission a double line fault occurs when objects falling across the positive and negative line and shorted them. In underground cables this fault causes because of insulation failure. Line to line fault between positive and negative line is shown in Figure 5.

## 5. BLOCK DIAGRAM FOR FAULT DETECTION

### 5.1 Disturbance signal

The block diagram for fault detection is shown in Figure 6. In which disturbance signal divides the data sequence into stationary and non-stationary parts i.e. data is divided into a large number of transition segments (corresponding to large and sudden change in signal, and event segments). Events are the segments in between transition segments. The features are extracted from the event segments because the signal is stationary in this segment and normally contains the information that is unique enough to distinguish between different types of disturbances.

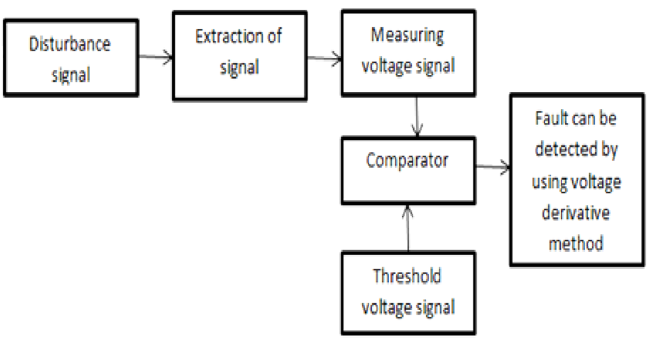


**Fig-5:** Block Diagram for Fault Detection

### 5.2 Signal extraction

The selection of suitable signal is extremely important for classification of any problem. The signal extracted by signal processing techniques is used as input to measuring block. Signal extraction can be defined as transformation of the raw signal from its original form to a new form, from which suitable information can be extracted. An appropriately chosen signal set reduces the burden over the classifiers. Signal may directly be extracted from the original measurements (e.g., RMS values), or from some transformed domain (e.g., Fourier, wavelet, STFT, and S-transform) or from the parameters of signal models (e.g., sinusoid KF and AR models). According to the voltage contents of the signal, fault can be detected.

### 5.3 Artificial Inductive Line Impedance

If the voltage variation with respect to time in the steady state operation of the DC power microgrid is low, the Artificial Inductive Line Impedance (AILI) do not create considerable voltage drop in normal operation. However, in transient conditions, the AILIs have a significant impact on *dv/dt* characteristics of fault voltage which can be utilized for fault identification.

### 5.4 Detection

Fault detection is important, especially on multi terminal systems, in order to isolate the fault in a short time and restore the system as soon as possible. The main issues of fault location are: fault resistance and grounding. The fault resistance can change from zero to dozens of ohms, which has influence over the location of the fault. Besides, regarding the type of neutral grounding, MTDC systems can be divided into two categories: grounding (including high-resistance grounding) and non-grounding system. The non-grounding systems can be used for a better reliability of power supply in pole-to-ground faults. Just like in AC systems, those issues have different fault responses. Fault detection plays two important roles in power system. On the one hand, the identification of fault section should be quick to initiate the relay protection system in a short time and thus, avoid the loss caused by over current. On the other hand, the identification of the specific fault point should be remarkably accurate. Finally, fault detection with sensitivity and selectivity in HVDC grids is an important. The flowchart for fault identification is shown in Figure 7.

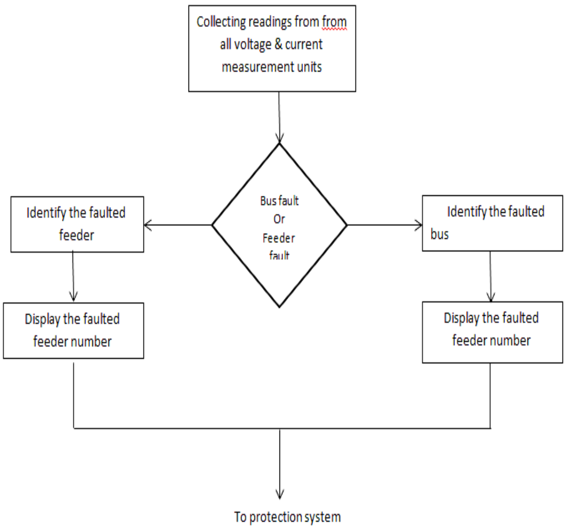


**Fig-6:** Flowchart for Fault Identification

### 5.4 Control Strategies

The control method should govern the basic functions of each converter and coordinate all the converters of the grid with a proper control strategy in consonance with the different operating modes. It must also take care of the various disturbances that can affect the system. Additionally, the power flow through a HVDC line needs to be controlled to avoid exceeding the power rating of its components. There are different control strategies available. In order to choose the most effective strategy, the grid topology is a major consideration. For instance, in the case of parallel MTDC systems, the basis of the control goal is to maintain a constant DC voltage and power balance.in the flowchart, if the feeder fault occur, then it displays faulted feeder number and if the bus fault occur then it display the faulted bus number. Whereas in radial HVDC grid systems, the power flow through each line can be controlled by the DC voltages of the individual converter stations.. In these systems, the flow through parallel paths depends on the DC voltage at the converter stations and on the line impedances. Thus, such systems may need additional DC Line Power Flow Controllers to achieve a required power flow. DC Line Power Flow Controllers will insert a certain DC voltage in series with the line, in order to control the current.

## 6. SIMULATION STUDY

The generated power supply of 25KV, 50 Hz and then step down to 415V in the distribution side. The boost converter is used to boost the voltage up to 500V and then connected to DC microgrid.

The test system parameters are given in Table 2. employed to take out the simulations regarding the islanding detection. The system composed of 3-phase,

**Table-2:** System Parameters

| S.No | SYSTEM QUANTITY | SPECIFICATION |
|---|---|---|
| 1 | Source | 3-phase, 25KV, 50 Hz |
| 2 | Inverter specifications | MOSFET Based, 3 Arms, 6 Pulse,<br>Carrier Frequency=1080Hz,<br>Sampling time=5μs |
| 3 | DC Grid | 500V |
| 4 | Load | 100 Ohm Resistive load |
| 6 | Transformer | 25KV/415V |

25KV, 50 Hz generating system, feeding power to the load by using above system parameters.The proposed fault identification method is carried out using simulation. The three phase voltage is applied to the system and the corresponding waveform is shown in figure 8. The normal three phase sine waveform is obtained. Under normal conditions, the voltage is not varied and corresponding waveform is shown in Figure 8.

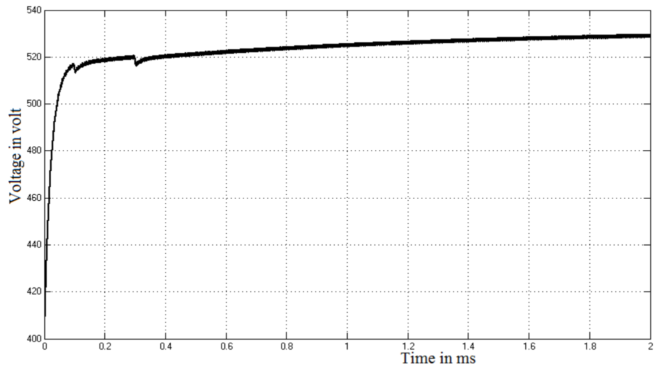


**Fig-7:** Voltage under Normal Condition

In the six bus system, bus 2 voltage is boosted from 400V to 530V under normal condition is shown in Figure 8. The voltage is increased from the time period 0.2s to 2s. If the bus fault or feeder fault is occurred in the system, then the voltage is varied and by measuring the voltage variations and compare with threshold voltage the fault can be identified.

The voltage under fault condition is varying and the corresponding waveform is shown in figure 9. The fault occur in the bus 2, then the voltage magnitude is reduced to 350V, whereas the time period is from 0.3 to 2s is shown in Figure 8.

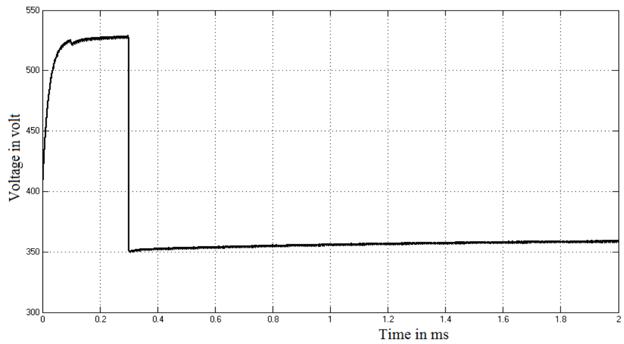


**Fig-8:** Voltage under Fault Condition

The fault condition displaying window in Matlab is shown in Figure 8. In which the condition of the system will be displayed. If any fault occur in the system i.e. bus fault or feeder fault, it will display the type of fault occur in the system. Finally we can identify the fault occur in the system.

## 6. CONCLUSION

This project deals with the new identification technique for DC grids using event based fault detection technique in a distribution system. By using event based technique the fault detection is very fast and it is reliable. This scheme has successfully identified the faulted line all over the interconnect system. The relay has a very fast detection time. The relay is based on sharing data from all areas. Fault detection is within less than a sec.

The DC voltage of the DC grid system has been identified to be an important parameter analogous to the frequency in AC systems. The variation of DC voltage indicates power unbalance in the DC grid. If the power is sustainably unbalanced, the DC voltage will either increase or decrease. The DC system dynamic, which is very fast, compared with AC system dynamic, demands fast actions; therefore, automatic measures must take place in order to keep the DC system stable. The control and protection of multi-terminal DC grid system are more complex, because the system must assure that when a fault appears in a zone the non-faulted converters and lines maintain secure operation with the coordinated strategy between stations. This way, coordinated control method among converters is particularly relevant in MTDC systems.. However, in all cases the power exchange between the AC system and the DC grid can be exactly controlled by the converter stations. This provides an additional degree of freedom for the operators of the combined AC and DC grid which can be used to influence the load flow conditions in the surrounding AC systems.

## REFERENCES

[1] Buller.S, E. Karden, D. Kok, R. W. De Doncker, (2002) "Modeling the Dynamic Behavior of Supercapacitors Using Impedance Spectroscopy," IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 38, NO. 6, NOVEMBER/DECEMBER 2002.

[2] Daniel Salomonsson, Lennart Söder, Ambra Sannino, (2009) "Protection of Low-Voltage DC Microgrids," IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 24, NO. 3, JULY 2009

[3] Flauzino.R.A, V. Ziolkowski, I. N. da Silv.,D. M. B. S de Souza, (2009) "Hybrid Intelligent Architecture for FaultIdentification in Power Distribution Systems," IEEE Transactions on power system, vol.4, no.2, pp.1113-1121.

[4] HUANG Yong, CHEN Minyou□ZHAI Jinqian, (2011) " High Impedance Fault Identification Method of The Distribution Network Based on Discrete Wavelet Transformation," IEEE Transactions on Power Delivery.

[5] Jae-Do ParkJared, Candelaria, Liuyan Ma, Kyle Dunn.,(2013) "DC Ring-Bus Microgrid Fault Protection and Identification of Fault Location," IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 28, NO. 4, OCTOBER 2013.

[6] Lianxiang Tang , Boon-Teck Ooi, (2007) "Locating and Isolating DC Faults in Multi-Terminal DC Systems," IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 22, NO. 3, JULY 2007

[7] Mustafa Farhadi,.; Mustafa Farhadi,.,(2014) "Adaptive Energy Management in Redundant Hybrid DC Microgrid for Pulse Load Mitigation," IEEE Transactions on Smart Gri.

[8] Pietro Cairoli, Igor Kondratiev, Roger A. Dougal, (2011) " Coordinated Control of the Bus Tie Switches and Power Supply Converters for Fault Protection in DC Microgrids," IEEE Transactions on Smart Grid.

[9] Vincenzo Musolino, Luigi Piegari, Enrico Tironi., (2013) "New Full-Frequency-Range Supercapacitor Model With Easy Identification Procedure," IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 60, NO. 1, JANUARY 2013.

[10] Yunjie Gu, Xin Xiang, Wuhua Li, Xiangning He, (2014) "Mode-Adaptive Decentralized Control for Renewable DC Microgrid With Enhanced Reliability and Flexibility," IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 29, NO. 9, SEPTEMBER 2014.