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Analysis on Performance of DC Microgrid under Fault Condition

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Abstract

DC Microgrid is the high quality electric power by using DC distribution focused on the development of renewable energy resources such as photovoltaic cells, wind turbines, fuel cells and etc. In this system, DC grid is connected to the AC utility grid through AC/DC rectifier and several distributed generations are connected to DC line through converters in order to improve the reliability of the power system. Most of the faults cause on overhead lines of power system. When a fault occur on a power system, it is very important to check quickly, to detect it, to find its definite location and to restore power system as soon as possible. In this paper, the configurations of DC microgrid system and control methods of distributed generation are expressed. Moreover, fault on source side, fault on load side and fault on DC transmission line are analyzed. Faults are shown single line to ground fault for generation side and load side and line to line fault for DC transmission side. In order to identify the various faults characteristics of DC Microgrid, simulation results are performed with Matlab/ Simulink Software.

Keywords: DC Microgrid; Distributed Generation; High Quality Power; Converters; Faults.

1. Introduction

Nowadays, the ever increasing demand of power causes the imbalance between supply and demand. A large gap between supply and demand of power is increasing and also there is large scarcity of non-renewable sources.

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Because of the power gap there is load shedding in many sections and numbers of people in isolated area are live without electricity. The electrified area also faces problem of power outage. To fulfill this increasing demand, there is a need to increase the generation from renewable energy resources like wind energy systems, solar energy systems and etc. Also distributed generations with renewable energy systems are likely to become wide spread in the future and it has more advantages. Power generated from distributed generation is transferred through AC or DC grid. When this power is supplied to the isolated area, there is large scope for DC microgrid instead of ac system [1].

The development of distributed generation has lead to a more recent concept called microgrid, which is a systematic organization of distributed generation systems. Compared to a single distributed generation, microgrid has more capacity and control flexibilities to fulfill system reliability and power quality requirements. Microgrid has two operation modes. They are standalone mode and grid connected mode. The microgrid can be divided into AC bus and DC bus systems. The dc distribution system faces problems regarding protection because of no current zero crossing. But there is a large development in ac distribution and transmission system protection technology because it is simple and easy to control. While most of the microgrids adopt AC system as a main distribution, DC microgrids are researched for the good connection with DC output type sources such as photovoltaic (PV), fuel cell, and secondary battery. Moreover, if loads in the system are supplied with DC power, the conversion losses from sources to loads are reduced compared with AC microgrid. And then, it is easier than AC microgrid to disconnect from the power system without any fault. In this case, DC output type sources such as photovoltaic (PV) system, wind generation system, fuel cell and energy storages (secondary battery and ultra capacitor) need inverters. In addition, some gas engine cogenerations and wind turbines also need inverters because the output voltages and the frequencies are different from those of the utility grids.

In this research, the configurations of DC microgrid system and control methods of distributed generation are expressed. Moreover, fault on source side, fault on load side and fault on DC transmission line are analyzed. Simulation to the proposed system is carried out by MATLAB/ SIMULINK.

The first section gives the introduction and importance about the paper. The second section is about DC microgrid. The third section of the paper discusses about the control strategies of the DC microgrid. Faults in DC microgrid are discussed in the fourth section of the paper. The fifth section deal with the simulation carried through MATLAB environment and about the results and discussions. The final section present in this paper is the conclusions.

2. DC Microgrid

DC microgrid is a super high quality electric power system with using dc distribution. The main components of a microgrid are: (i) distributed generation sources such as photovoltaic panels, wind turbines, fuel cells, diesel and gas micro turbines etc., (ii) distributed energy storage devices such as batteries, ultra capacitors, etc., and (iii) critical and non-critical loads. A typical DC microgrid configuration is shown in Figure 1. The utility grid voltage is converted into dc line by a rectifier. In addition, several distributed generations are also connected to DC line in the system through ac/dc inverter and DC/DC converter. At the load side, DC distributed power is converted into required AC or DC voltage by each converter. These load side converters do not need transformers by choosing proper DC distribution voltage.

For the high quality power supplying, the dc distribution voltage is quite effective. On the other hand, high quality power is essential for some customers such as bank, hospital and semiconductor factory because the downtime related to voltage sag or blackout become a great concern. Besides, high quality power is also requested in our dependable society. Security of electric power is becoming more important in our daily life [2].

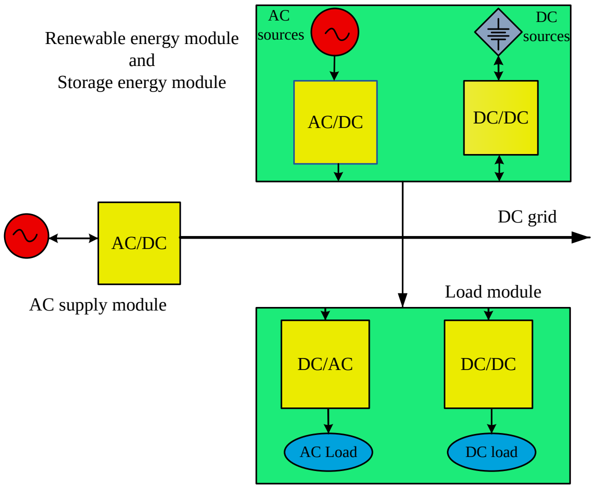


Figure 1: Configuration of DC Microgrid System

Characteristics of DC microgrid can be summarized as follows:

(i) DC microgrids are more efficient than ac microgrids.

(ii) The system efficiency becomes higher because of the reduction of conversion losses of inverters between DC output sources and loads.

(iii) There is no need to consider about synchronization with the utility grid and reactive power.

(iv) Distributed scheme of load side converters contributes to provide a super high quality power supplying. For instance, even if a short circuit occurs at one load side, it does not affect other loads.

(v) If power consumption becomes more than a power production during long term isolation, distributed generation microgrid can stop supplying power for some loads intentionality by load side converters in order to continue supplying power for high quality loads.

(vi) Electric power can be shared by using additional electric power lines between load side converters when a temporary overload occurs at one load.

(vii) The loads are not impacted by harmonics, voltage sag or swell, non symmetry of phase voltages.

(viii) When a blackout or voltage sag occurs in the utility grid, it does not affect dc bus voltage of DC microgrid directly due to the stored energy of the DC capacitor and the voltage control of AC/DC converter. Therefore, distribution generations in DC system are not easy to trip against these disturbances.

It is also possible to form DC loop configuration at DC distribution part [4] and share power between other DC microgrid systems.

3. Control Strategies of the DC Microgrid

The schematic diagram of DC microgrid is shown in Figure 2. This system incorporates three modules together, namely AC supply module, renewable energy module and load module. The utility grid voltage is converted into DC grid through IGBT rectifier. It is characteristic of the system to adopt 3wire DC distribution which consists of +200V, neutral and -200V lines. Figure 3 shows the block diagram of control structure of grid rectifier.

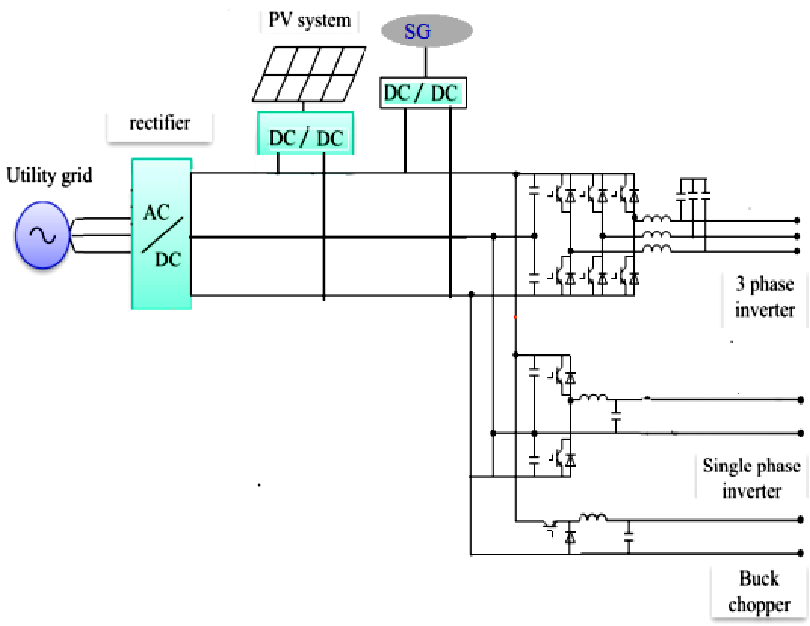


Figure 2: Schematic Diagram of DC Microgrid

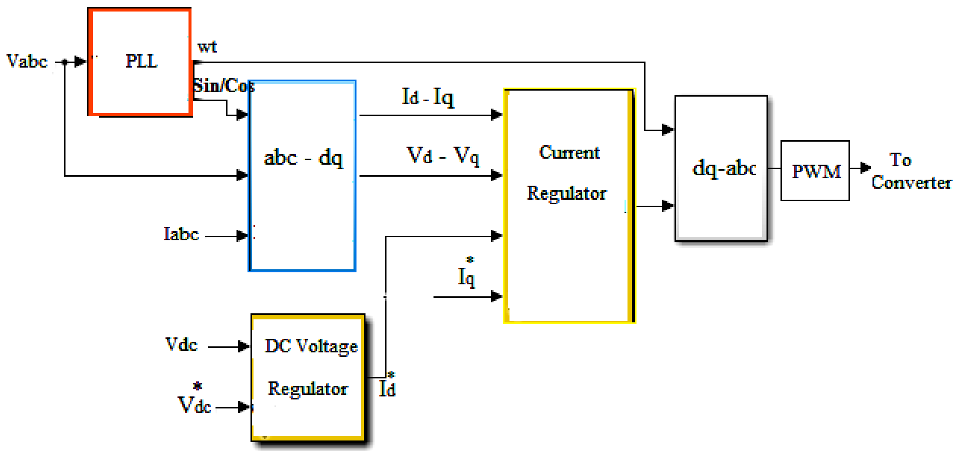


Figure 3: Control Structure of Grid Rectifier

Most of the converter choose voltage source converter (VSC). In this system, voltage source converter (VSC) control uses two control loops. They are outer control loop and inner control loop. The outer control loop which regulates V_{dc} and $V_{dc\text{-}ref}$ and the inner control loop which regulates I_d and I_q. Direct axis current component is used to control the DC link voltage and quadrature axis current component is used to regulate the reactive power. I_d current reference is the output of the DC voltage external controller. I_q current reference is set to zero. Voltage output converted from V_d and V_q in the current control loop are supplied to the Pulse Width Modulation (PWM) generator. PWM uses to control gate of the rectifier to output stable. It gives to reduce harmonics and to smooth the output of the rectifier. One of the methods to synchronize the reference current and voltage of the rectifier with the grid voltage and current is an algorithm called Phase Locked Loop (PLL). PLL determines a signal to track another so that the output signal is synchronized with the input one both in frequency and phase. The current control loop diagram of the DC micogrid is shown in Figure 4.

Photovoltaic system (PV) is connected to DC grid via DC-DC boost converter. The DC voltage is fixed 400V. The boost converter is controlled by Maximum Power Point Tracking (MPPT) to keep its efficiency high. MPPT technique is used to improve the efficiency of the solar panel. MPPT controller is based on the "incremental conductance" technique. And then, simplified synchronous generator (SG) is connected to DC distribution line through DC/DC converter.

DC microgrid distributes DC power and AC power that transmit various load side. Loads may be classified into three connections to the utility distribution system in DC microgrid. They are three phase load, single phase load and DC load. These loads are connected to the DC grid through power electronic interfaces such as inverters and buck converter. The rating of the rectifiers and converters will be dependent on the requirements of the customers.

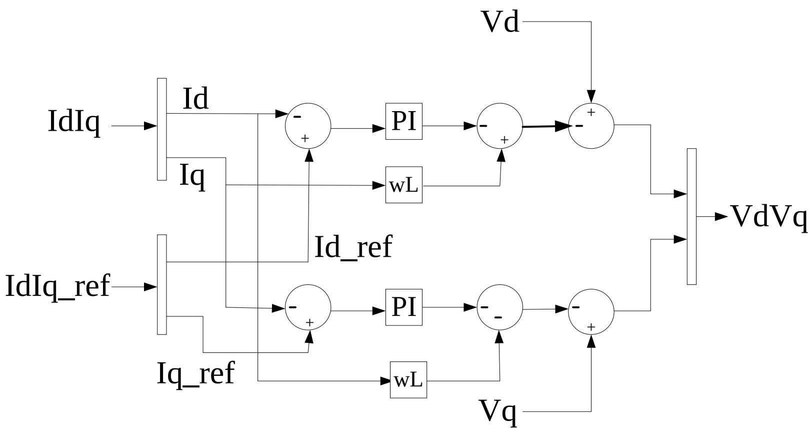


Figure 4: Current Control Loop

4. Faults in DC Microgrid

Most of the faults that occur on power system of overhead lines are unsymmetrical faults which may consist of single line to ground fault. In this paper, single line to ground fault and line to line fault are analyzed.

4.1 Single Line to Ground Fault

A single line to ground fault is shown in Figure 5. This is most common type of fault occurred in power system. The reliability and continuity of supply in microgrid system is reduced by this fault. When lightning stroke strikes on the distribution line of microgrid, then one of 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. When objects falling on line, it may also occur and providing line to ground path for current [5]. The single line to ground fault are the most common types of faults in industrial distribution systems.

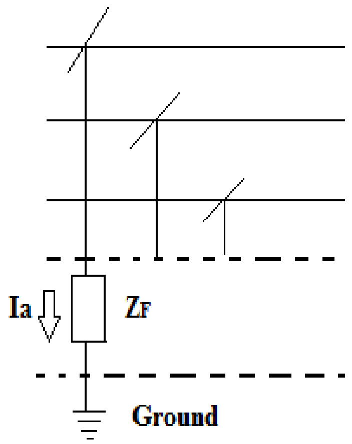


Figure 5: Single Line to Ground Fault

4.2 Line to Line Fault

This is most harmful fault for the system than above fault single line to ground fault. This fault is rarely occurs in the system. In overhead distribution lines, a double line fault occurs when objects falling across the positive and negative line and shorted them. In underground cables, this fault occurs because of insulation failure [5]. Line to line fault between positive and negative line is shown in Figure 6.

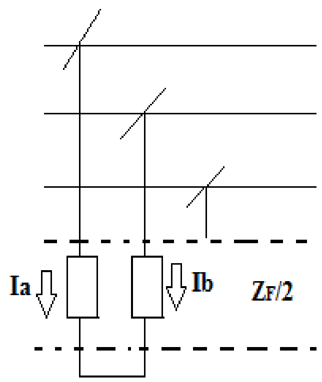


Figure 6: Line to Line Fault

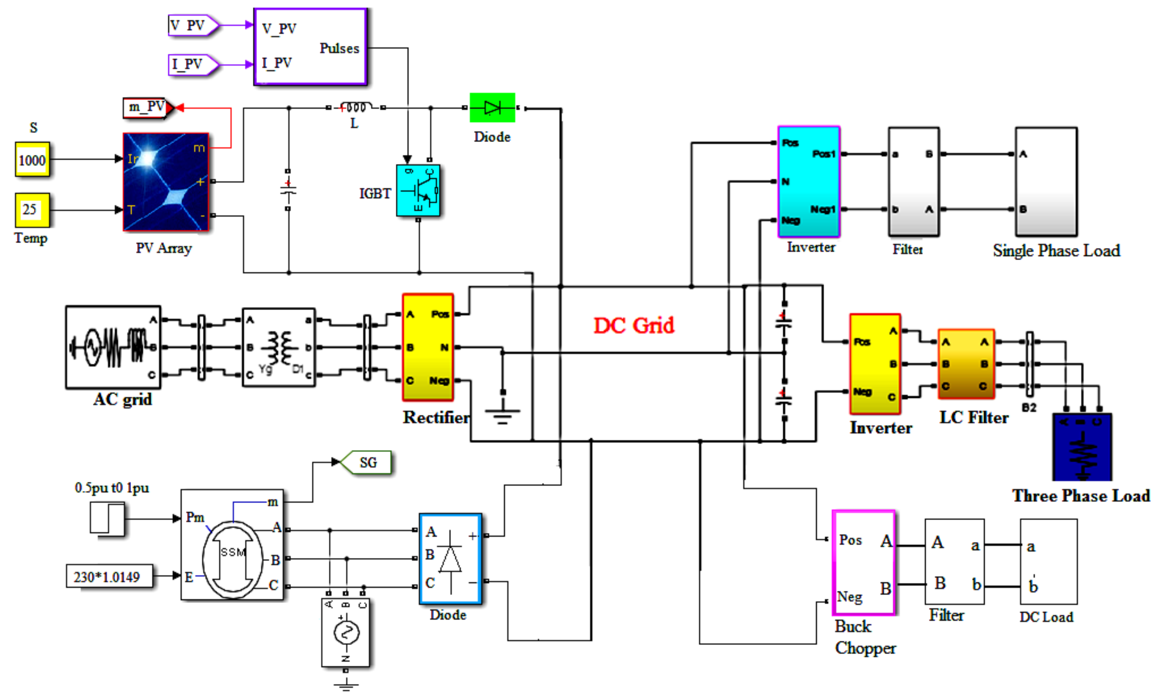


Figure 7: Simulation Diagram of DC Microgrid

Table I: Main Parameters of the System

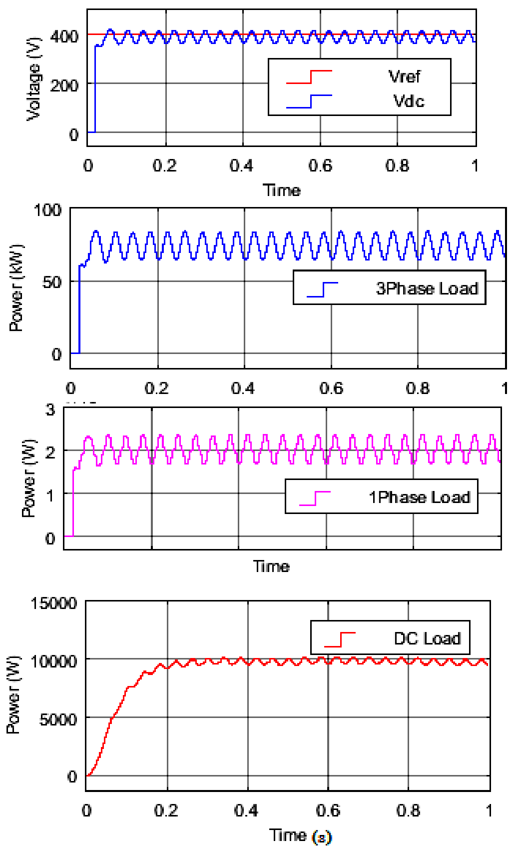
PV	19.8kW, 273.5V, 50Hz
Synchronous Generator	17kVA, 230V, 3000rpm, H=0.6s
Switching frequency	5kHz
DC Voltage	400V
AC Grid	20MVA, 11kV
Step Down Transformer	11kV/230V
Loads	
Three Phase load	70kW
Single Phase Load	20kW, 2Ω
DC Load	10kW, 1Ω

5. Simulation Results of DC System

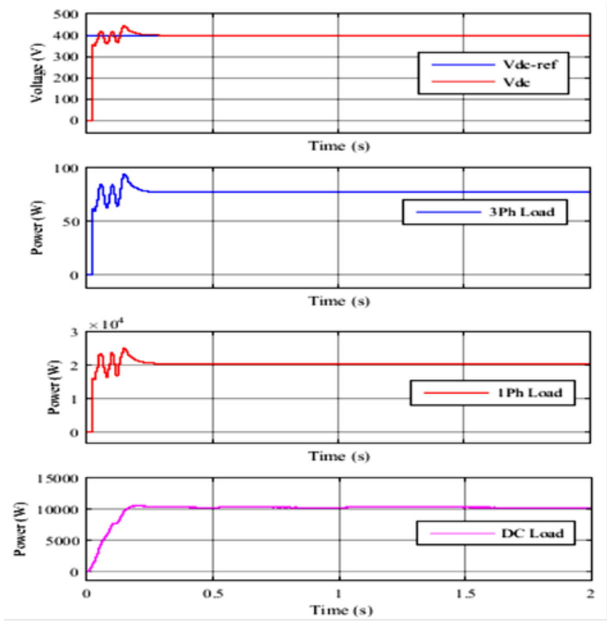
In order to confirm the control strategies of the DC microgrid, computer simulations were carried out by using MATLAB/SIMULIMK. The main parameters of this system show in Table 1 and the simulation circuit is shown in Figure 7. In this research, grid connected system is used. At the source side, photovoltaic source and synchronous generator are demonstrated and AC loads (both single phase and three phase load) and DC load are connected at the load side. In this paper, (A) faults on source side, (B) faults on load side and (C) faults on DC transmission line are considered. Faults are shown single line to ground fault for generation side and load side and line to line fault for DC transmission side.

Case 1- Faults on the Generation Side of the DC Grid - Single line to Ground Fault

The simulation results are shown in Figure 8. The comparison of Figure 8 (a) and (b), voltage fluctuation and ripples significantly cause on DC bus voltage and consumer side because of fault. This condition can never get back to stable. Therefore, protection devices should be installed. In Figure 8 (b), voltage across the load is falls down and three phase load, single phase load and DC load are slightly changed when fault occurs at 0.02 second. And then, these power and voltage are immediately restored and faulty section is isolated because other generation sources (Photovoltaic system and Synchronous generator) and protective device (circuit breaker) supports to DC microgrid. Therefore, the system gets back to its stable condition after reaching the fault clearing time (0.12 second).



(a)

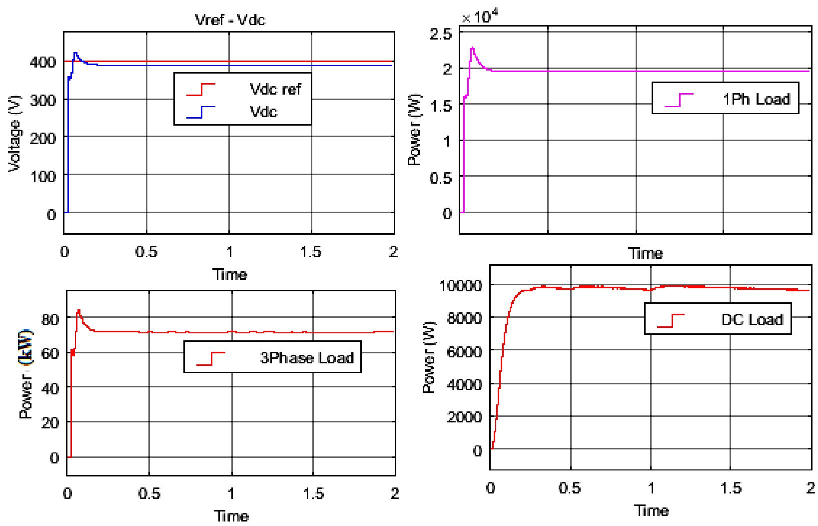


(b)

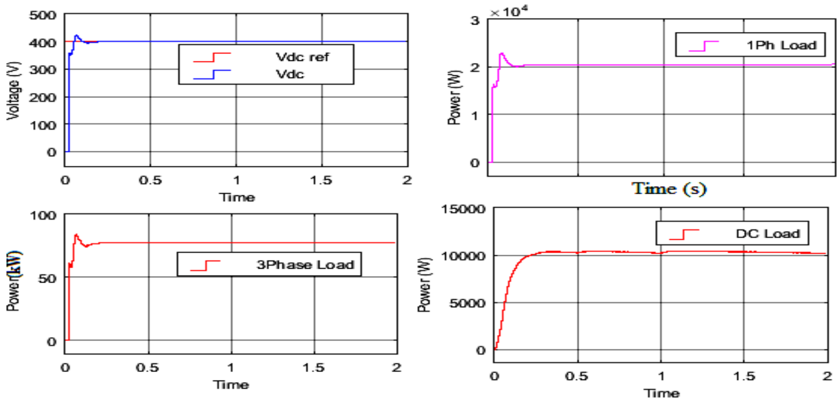
Figure 8: DC Grid Voltage, three phase load, single phase load and dc load (a) without protection (b) with protection

Case 2- Faults on Three Phase Load Side of the DC Grid -Single line to Ground Fault

The simulation results of single line to ground with and without protection system are shown in Figure 9 (a) and (b). DC bus voltage drops significantly when the compare of Figure 9 (a) and (b). In three phase load and DC load, ripple effects are significantly seen throughout. When the protection is used the voltage is restore quickly after the clearance of fault. It is seen that fault is cleared within 0.12 second in Figure 9 (b). This provides the system stability and reliability.



(a)



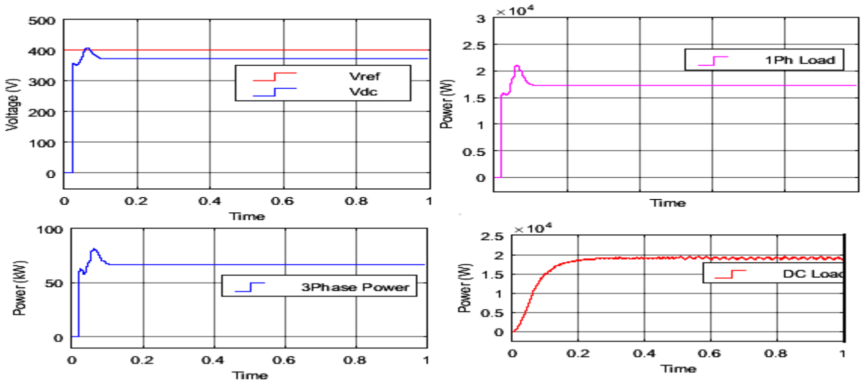
(b)

Figure 9: DC Grid Voltage, three phase load, single phase load and dc load (a) without protection (b) with protection

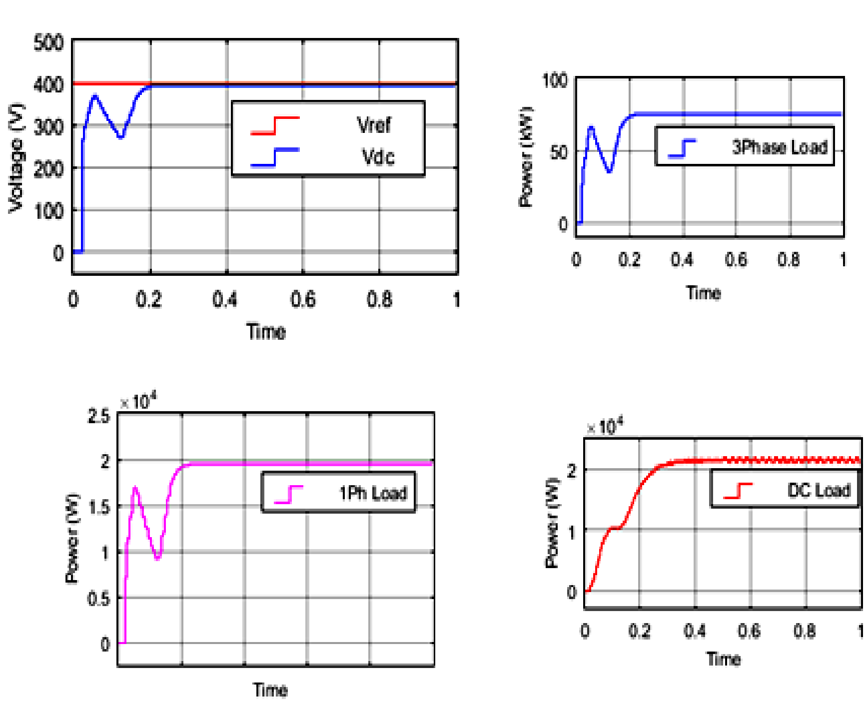
Case 3- Faults on DC Grid - Line to Line Fault

In this paper, the length is assumed to be 100m, rated voltage 600V and conductor size 250mm^2 is chosen. Then, the resistance is 0.01Ω and the inductance is set to 0.03mH.

The simulation results of bus voltage, AC loads and DC load without and with protection are shown in Figure 10 for line to line fault. Figure 10 (a) shows that without protection system. The DC bus voltage is fixed 400V. When line to line fault is occurred on DC line, the bus voltage is decreased about 371.16V. But, the system is stable after 0.1second. AC loads is also stable at 0.12second and DC load has ripple effects. To solve these problems, suitable protection devices must be installed. Fuses also used for protection, but it has limitations. But, moulded case circuit breaker (MCCB) can use in DC systems. Figure 10 (b) shows that the simulation results of DC microgrid with protection system. When the protective device is used in the DC microgrid, the voltage is quickly restored after fault clearing time. So, this increases the system stability, reliability and continuity of supply.



(a)



(b)

Figure 10: DC Bus Voltage, AC Loads and DC Loads (a) without protection (b) with protection

6. Conclusions

To satisfy high efficiency and quality power supply, "Analysis on performance of DC Microgrid under Fault Condition" is proposed. This paper is implemented the concept of DC microgrid, control methods for distributed energy resources, power converters and load side in dc microgrid. Moreover, faults are shown single line to ground fault for generation side and load side and line to line fault for DC transmission side. It is analyzed for system stability and reliability. When fault occurs on generation side, it was not affected on consumption side seriously because of electronic devices and distributed generation systems. When fault also causes in three phase load of consumer side, it could be seen that the other loads were not influenced by fault. Finally, stable conditions can be easily found in demand side of DC microgrid because of any no effects. This will maximize efficiency from all of the sources and improve stability in the DC grid. The demonstration of DC microgrid for high quality distribution system is carried out with MATLAB/ SIMULINK Software.

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