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Protection of Dc-Micro grid From Multiple Line and Ground Faults

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Abstract: In this paper, a protection scheme for the microgrid system on low voltage side is proposed as a dc system's protection techniques are relatively unexplored as compared to the ac systems, whereas the ac systems face numerous problems like frequency matching, reactive power violation and instability. The core objective of the project is to eliminate the faulty section (in the event of occurrence of a fault) promptly while keeping the healthy sections functioning unaltered. In this work, a segment controller exists in the loop type. This has master and slave controllers continually monitoring the segments of grid comprising of semiconductor bidirectional switches and snubber circuits. A master controller is used for all the three segments that monitors the difference between the input and output currents and in the event of the difference being greater than the acceptable limit, instructs the slave controllers to take the required action and eliminate the section under fault. Both line as well as ground faults have been tested on all the sections separately as well as together and perspicuous analysis has been done. It is inferred that the protection scheme is able to isolate the faulty section in a short time and after the faulty section has been eliminated other sections regain their stable voltage and current limits. The protection scheme can identify faults of the grid irrespective of the fault current's amplitude or the power supply's feeding capacity. The simulations are designed and verified using MATLAB Simulink 2015a software.

Index Terms: Bidirectional switches, fault, Low Voltage DC Systems, Microgrid.

I. INTRODUCTION

Planning of distributed generation is very important for the system to be more reliable. More comprehensive simulations of cost of customer damage and capacity constraints are in need instead of rigid capacity planning rules. The utilities are at high risk at present that past [1]. Stimulation of contingencies, load variations, control action and dispatch are vital for calculating limits of the capacity and costs that are related. Besides it is necessary to estimate the economic risk because of uncertainties. As the demands for energy has doubled in the last few years and the overall concern for global warming and pollution has shifted the focus towards using renewable energy as a more clean source of energy – – Renewable energy sources like solar, hydro, wind are more reliable than the conventional sources like oil and coal [2] . As a result of this Distributed Power Generation Systems (DPGS) are being developed globally including Japan, USA, Denmark and Germany which leads the market. A more rigid protocol needs to be applied in terms of protection systems (quicker islanding), better power quality and safe running. Respectively, distributed generation control needs to be advanced for better networking of the grid. In the past few years microgrids have gained more popularity as application of individual distributed generators can cause a lot of problems. To optimize the capability of distributed generators and to reduce the shortcomings, a new approach of using them as a group subsystem or microgrids is apt. Microgrid [3] is a system consisting of renewable sources and loads of different types connected closely. If a fault appears in microgrid, the faulty section can be isolated from the healthy system so that damage to the system will be at very less level. Also a microgrid can operate in grid-connected and isolated mode as per the need which makes microgrid more reliable and safe. A power electronic interface is presented in [4] with an inverter and a surge source to couple microgrid with micro-sources. The interface controls the power flow based on the dynamic changes in the system. It also maintains the power that is exchanged between the energy modules based on the load demand and the quantity of power that is readily available. The world being more exposure to the Distributed Energy Resources [5] and the advancement in technology has attracted the power industry. This has made the research to concentrate more on integration of renewable energy sources with the present grid and control the microgrid in an optimal manner both in grid connected and isolated mode. As microgrids are small local system of traditional power systems, their operation in past was limited compared to traditional system. With the increase in acceptance for DERs, focus has also been shifted to microgrid and for novel approaches to improve the operational and control of it. The dc microgrid has more advantages than ac microgrid but there are no proper standards and guidelines for feasible implementation of dc microgrid [6].The immense potential dc microgrids promise requires more research about their protection systems and architecture. The microgrid system can make use of power converter elements for its fmi protection. Solutions need to be provided for low cost downstream dc circuit breakers for overcoming the difficulties faced in circuit breaker coordination produced by capacitor discharge effects.

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We also need high intelligence system interruption, proper isolation of the fault and rapid recovery of the system rather than completely relying upon external protective systems. Nowadays, use of renewable energy resources and low voltage dc microgrid systems is attaining tremendous popularity [7].

These power systems have separate ac and dc sections separated via converter, like in the case of a solar power plant or full-converter power plant of wind resources. This leads to a lot of confusion as different schemes are available for both ac and dc systems, and each scheme results in different after-effects on the functioning of the microgrid, and the characteristics and behavior of the fault. This paper discussed two grounding techniques for dc systems, that is, single-pole and middle point grounding. The operation of such grounding schemes for normal modes and during a ground fault were tested and resulting advantages and disadvantages were noted. DC traction power system grounding by D. Paul in [8] explains the real-time methods applied in North America. Proper analysis has been done in terms of grounding of power system and equipment separately and an interrelation between the both has been derived for developing safety of personnel as well as that of the equipment. The stray currents obtained due to the rail leakage and its effect on the personal safety was discussed. Keeping in mind the scope of dc microgrids and the need for better protection systems, a loop type dc microgrid is proposed in this work equipped with differential current limiters and segment controllers for fast detection and isolation of faults. Both line as well as ground faults have been tested on all the sections separately as well as together and perspicuous analysis has been done.

II. PROTECTION OF LVDC SYSTEMS

The LVDC microgrids are a relatively novel concept as compared to the HVDC systems. For small and localised systems these has many advantages over conventional systems (ac systems). Power electronic converters are a must for both types of microgrids whether ac or dc. However, for dc microgrids, less number of conversion stages are required which puts down the usage of power electronics compared to ac microgrids. Even though the cables in both ac and dc power systems are based on peak voltage, dc systems transfer more amount of power as the power delivered in ac cables is based on RMS value [9]. As there is no skin effect in dc lines, the dc systems results in more amount of power transfer and fewer losses. The dc systems face problems regarding reliable and versatile protection. The dc arc created due to the interruption of fault currents requires the components in dc systems to be very robust. Fuses and circuit breakers (CBs) [10] are used as protection devices in low voltage DC microgrid systems. Conventional ac protection devices working on the principle of natural current zero crossing to isolate the circuit, are not able to detect dc fault currents because no zero crossing occurs in this case. It result in more persistence of fault as it increases the operating time of CB and allows fault current to persist which can be fatal to the microgrid and result in damage of equipments. The microgrids make use of multi terminal VSC (Voltage Source Converters) for interfacing different subsystems to the bus. The problem in protecting VSC systems is the fault current should be located and removed as fast as possible because they can withstand fault parameters only up to two times the full load capacity. VSCs may also face internal switch faults that can lead to line-to-line short circuit faults. This kind of fault mostly occurs on the terminal and is difficult to be cleared which results in unnecessary replacement of the device. In ac systems ac side circuit breakers will trip to eliminate the fault. In dc systems dc fuses will be apt for protection against such faults. VSC-HVDC (Voltage Source Converter- High Voltage DC) [11] needs improved protective devices to compete with classical HVDC. The supreme form of protection will involve a combination of controllers and dc devices. Although, these are not very economical and increase system complexity they do improve the present system and are thus vitally useful [12]. DC devices provide best form of non-active protection and they perform faster than ac devices [13]..

III. FAULTS IN DC SYSTEMS

The two types of faults in dc system are Line to line and line to ground faults. A line fault is created when there is creation of path between negative and positive lines which shorts them both together. Similarly, a line to ground fault takes place when a path between any of the line (positive or negative) and ground is created, which shorts them [14]. VSCs face internal faults themselves and thus have a possibility for creating line to line type faults. In most cases such types of faults tend to result in terminal damage and device needs to be repaired [15]. Natural conditions such as trees falling on the line can also be the cause of a ground fault. However, in such cases, mostly the source causing the fault falls away from the line and thus, restores its normal functioning [16]. Whenever a fault exists in a system, the line current carries load current and fault current [17].

$$I_{Line} = I_{Fault} + I_{Load} \quad (1)$$

It depends upon two factors, that is, where the fault is located and the fault resistance in the path. DC fault current's time constant is very small because of very small line resistance in dc systems compared to ac systems which have high reactance [18][19]. During the event of occurrence of a fault, the bus voltage can even drop completely to zero or decrease tremendously based on power flow capacity and energy storage devices present in the system as well as the ground impedance [20].

IV. PROPOSED SCHEME FOR PROTECTION

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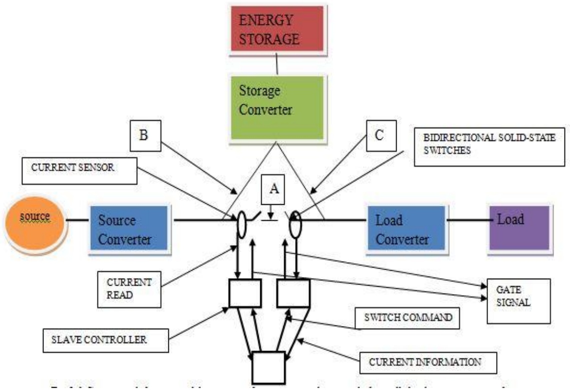

Fig.1. Conceptual diagram of the proposed protection scheme including all the three sections and protection controllers shown in only segment A.

A. Segment Control

This is a unique protection scheme for dc microgrids on low voltage side as shown in Fig.1. It uses solid state circuit breakers. This control will not shut down the whole system or limit the bus current and will isolate the faulty section from healthy one up on identifying the fault without disrupting the entire system. Therefore, no de-energization takes place. A loop type dc-bus is used to make the system resilient under faulty conditions. We have created several (three) zones of protections in the system. We have simulated three segments that are posed to faults and analysis has been done on the results received. The loop type dc-bus has better efficiency for short distribution lines than the long ones; therefore the scheme is more applicable to short microgrid systems. The entire loop (or the whole of the system) is subdivided in a series of segments between the subsystems. Each segment consists of some part of the bus (positive and ground lines or positive line or negative) and a control called segment controller. Although, we have applied the protection scheme for all the three segments, For ease of understanding only a conceptual diagram of the protection scheme is shown.

The protection scheme consists of two slave controllers, one master controller and freewheeling branches for each line to ground. The slave controller observes the current of each bus segment at its end point used for interfacing the components and supplies the information to the master controller; these controllers also operate freewheeling branches and bidirectional solid state switches on the bus segment according to the commands of the master controller. The slave control can also operate the freewheeling path and two-way switches on the bus segment based on the commands from master control. During normal operation mode, the current remains same at the input and output ends of bus segment and hence the switches will be in normal working mode. In case of fault mode, the slave control operates to open the circuit breakers for isolating the faulty section of system from healthy section. If the faulted bus segment do not de-energize fully, the slave control of the bus will send the signals to its adjacent control till the complete de-energization happens. If the de-energization completes in the first step, the bus controller closes the circuit breakers to restore the fault segment/zone. In the case that any fault is again detected in the segment the circuit breakers trip and it is cut-off.

B. Detection of the Fault and Isolation of the Faulty Section.

As mentioned above the difference of the two current readings from the slave controllers is monitored by the master controller.

$$I_{diff} = I_{in} - I_{out} \qquad (2)$$

Iin and Iout are input and output line currents of bus segment and when the difference of these two i.e. Idiff exceeds the prescribed value, the slave controller immediately sends the signal to the master controller which isolates the faulty section from system. Thus, from (1), the differential principle is used by the protection system for tracking the difference of input and output current of each segment and detect the fault. After the isolation of the faulty section, the healthy section recovers the bus voltage and comes back to normal operation mode as the microgrid is in loop connection. Even if the fault exists on more than one segment, the system can still operate if the segments connecting the power sources to loads are operating normally. The controllers should be installed close to the connection point to reduce the occurrence of fault in the vicinity of device connection. When the fault is detected, the segments are separated using semiconductor based diodes and bidirectional switches. In normal course of operations the diodes are open and switches are closed. In the event of the occurrence of a fault, the master control accesses it using information of the current received and gives the command to the slave controllers to open the switches and remove the faulty segment from the rest of the healthy system. In the meantime, a freewheeling path is created through the diodes for the fault current opening the switches and diminishes the fault current through resistors. The faults of line to line nature or line to ground nature can be accessed by the segment controller. In this project we have demonstrated and analyzed both. A turnoff snubber circuit shown in Fig.2 has been used to reduce the overshoot in voltage source due to line inductance.

When a shunt or ground fault takes place between two line or with respect to line in the grid, the voltage of the bus comes down to low value .The input current to the load during this time will not be sufficient as the current is limited from the source because of capacity being insufficient. VSC-interfaced microgrid systems face the same problems. Moreover, the fault current has to be terminated as fast as possible irrespective of the fact that the system has the required current feeding capacity. Therefore, the time for the isolation of the faulted section is critical in keeping the healthy segments unaffected. For achieving this controller should be capable of fast bus switch control and differential current detection.

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C. Protection of Circuit Breakers

Snubber circuits are vital for the protection of the solid-state circuit breakers from the transients of voltage caused due to the presence of inductance in the bus cable. Unlike the point to point system it is more necessary to include circuit breakers in this application as the inductance of the line is present on both the sides. As we have analyzed that the fault current should be extinguished as quickly as possible, however the high di/dt can make the transient voltages calamitously high for the solid state switches. There are a few snubber circuit topologies to suppress the overvoltage at turn-off due to line inductance, like discharge-charge type RCD snubber; discharge restricted decoupling capacitor, decoupling capacitor; and discharge-suppressing-type RCD snubber. Charge-discharge-type RCD snubber is used for better suppression of voltage without use of freewheeling path of fault current but they are not as popular as they fail to operate on bidirectional currents.

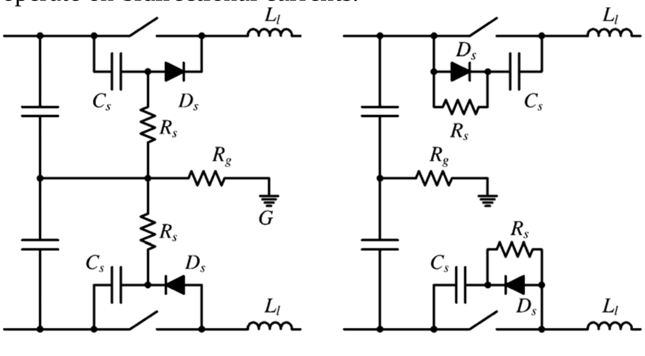

Fig.2. Snubber circuits of source . (a) Snubber- Charge-suppressing-type (b) Snubber- Charge-discharge-type

D. Grounding of the System and its Importance

Grounding is an important method of power system's protection and safety. There are a lot of advantages of grounding dc-bus systems such as – reducing voltage stress, better operating environment and more reliable detection of the location of fault. The low voltage dc systems contain power electronic devices that cannot withstand large fault currents and it reduces the fault current to low level for proper fault detection and extinction. Because of all these constraints, resistance grounding is an appropriate measure. However, protection devices still need to be included in the system to have 100% protection from fault current. There are four options that can be considered while grounding a dc system – solid grounding, low-resistance grounding, high resistance grounding and no grounding. Despite of some applications of no grounding in some application to avoid the effects of low resistance on pole to ground fault and stray currents, they are avoided because they can prove catastrophic under abnormal fault conditions.

V. SIMULATION

All the analysis and experiments for this protection scheme are done using MATLAB Simulink. The dc-bus microgrid system consists of three main parts, that is, the source, the load and the energy storage. It is made sure to have a constant fault current from the sources without any drop. A fault is created at the middle of 240 V dc-bus. Simulation parameters are as given in the Table 1 and 2.We will test the protection scheme for two conditions, one in which the protective devices exist only in segment A in the other in which it exists in all the three segments.

Table 1. Simulation Parameters

Bus Voltage	240V
Cable cross-section areas	241.9mm2
Resistance	121mΩ/km
Inductance	0.97mH/km
Capacitance	12.1nF/km
Segment length, l	200m
Fault location, d	100m
Ground resistance, Rg	0.5Ω
Freewheeling resistance, Rfw	1Ω

Table 2. RCD Snubber Unit Specifications

Resistance, Rs	10Ω
Capacitance, Cs	10micro farad

A. When the Protection Scheme is Applied only to segment A

Fig.3 shows the block diagram of when ground fault is applied on segment A at 1ms and the remaining two segments (B and C) have not been equipped with protective devices. The whole analysis on the system is produced for duration of 2.5ms. Fig. 4-6 shows the current from source and load side during line-to-ground fault and voltage of the system without protection, respectively. It can be seen that on the occurrence of a line-to-ground fault on segment A with no protection scheme being applied, the current on the source side increases drastically on contrast of all the current dropping nearly to zero on the load side. The voltage behaves on accordance with the load side current. This is due to the fact that the fault supplies current to the source and consumes all the load side current decreasing it to an almost zero value. Here, the load side current reduces to 32 A and source side current increases to 375 A.

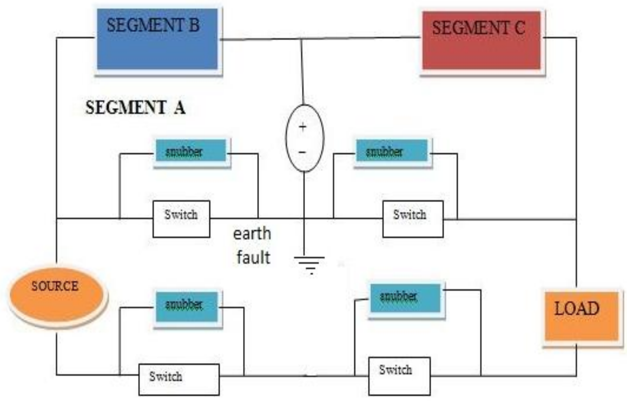

Fig.3. Simulation of earth fault in segment A.

When we apply protection scheme to the system, totally different results are observed as shown in Fig. 7-9.

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Since, the fault is stimulated at 1ms , the source side current remains constant at 24A till 1ms and when the fault occurs it rises for a short duration of around 0.2ms and then decreases to an almost zero value as the segment A is cut-off by the protection scheme. This happens because the master controller detects the fault by analyzing the difference in readings of current sent by the slave controllers and sends the signal back to the slave controllers to open the switches and isolate the faulty section, which in this case, is segment A. Similarly, at the load side, the current remains constant at 48A till the occurrence of the fault at 1ms and then decreases till the time the fault is being isolated from the system and after the isolation slowly rises to attain a constant value of around 46A. The effects of the ground fault on the voltage are also similar to its effect on the load side currents.

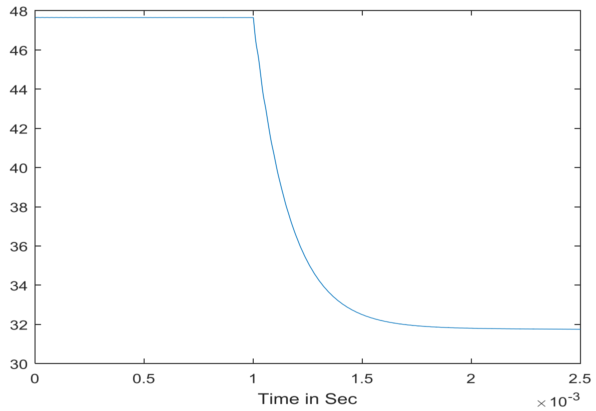

Fig.4. Load side current in the event of a line-to-ground fault on segment A, without protection.

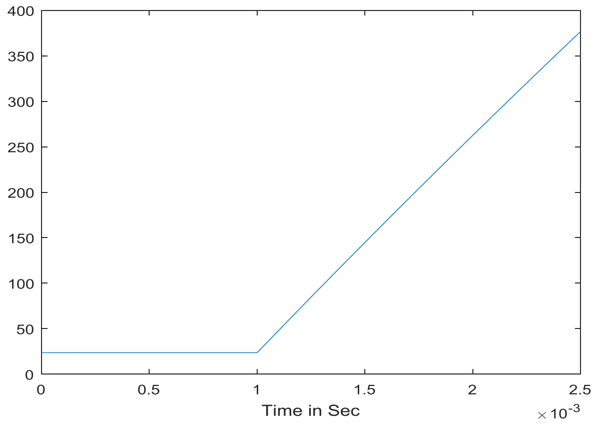

Fig.5. Source side current in the event of line-to-ground fault on segment A, without protection

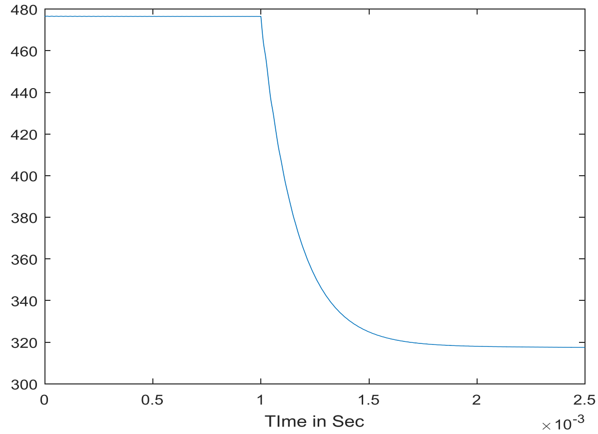

Fig.6. Load Voltage without protection during a line-to-ground fault on segment A.

Till the occurrence of the ground fault the voltage stays constant at 480 V. When the fault occurs the voltage reduces to zero till the protection systems are acting to isolate the faulty section A for around 0.2 ms and afterwards gradually increases to attain a constant value of 460V.

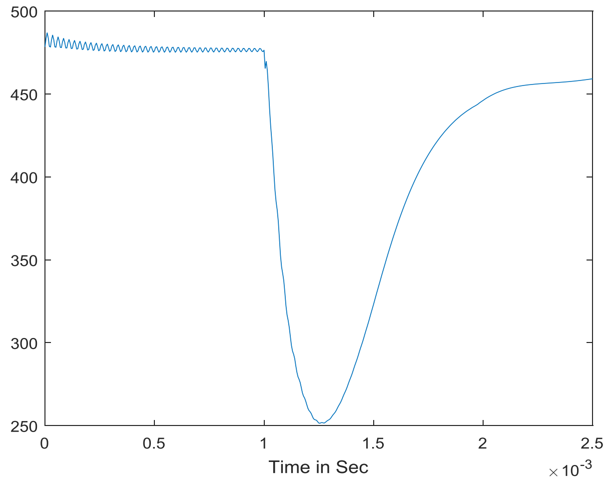

Fig.7. Load voltage with protection due to ground fault being generated at segment A

Now, consider the case when a line to line fault is applied on the segment A. Fig.11 shows the simulation of a line fault in segment A in the middle of the line segment. For the sake of convenience, we have omitted the protection circuits for segment B and C. Since, the fault is generated on segment A only this section needs to be isolated and after the isolation the operation of segment B and C needs to be restored immediately. Let us first consider the case when no protection scheme has been implied. Fig.12 and Fig.13 shows the load voltage and load current when a line fault occurs at 1ms without implementing any protection scheme. It can be seen that at the start the voltage remains constant at around 480 V till the line fault is applied. After 1ms the voltage drops significantly and almost reaches the zero line. Now, if we add protection devices and then simulate we observe completely different results. It can be noted that till 1ms the Voltage maintains its value at 480V. After 1ms the protection circuit comes into action and the circuit breakers are opened to eliminate the faulty

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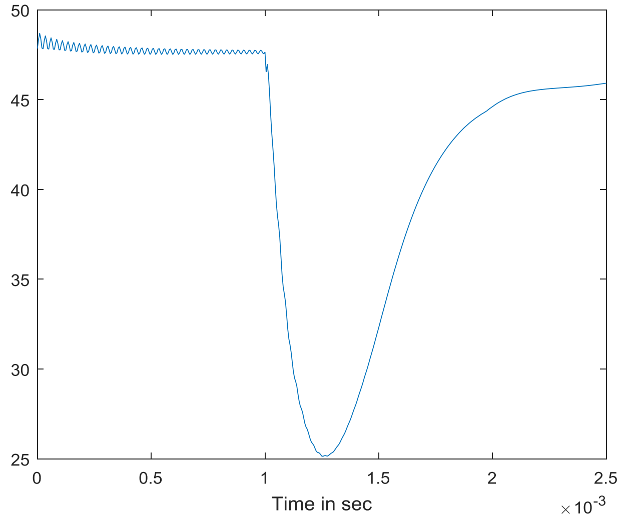

Fig.8. load side current with protection due to a ground fault being generated on segment A.

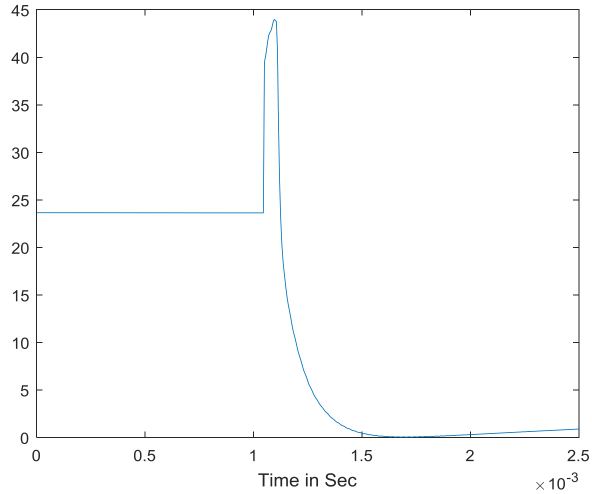

Fig.9. Surge side current with protection due to a ground fault being generated on segment A.

section from the rest of the system. For the time that the faulty section is being cut-off the voltage drops to zero and as the isolation takes places it starts rising gradually and reaches almost 460V and after that remains constant. The reason for the voltage drop is the same as seen in the case of the circuit without protection – the fault consumes most of the voltage itself. Thus, this protection scheme gives satisfactory results even with line faults, isolating the faulty section in just 0.1ms.

B. When protection scheme is applied in all the three segments

When no segment is at fault, it can be seen that the voltage and current remain constant at the values of 480V and 48A, respectively. It can be observed that when a ground fault occurs only on segment A at 1ms the load current drops to a value of 280 V till the diode is freewheeling and the circuit breaker opens to isolate the segment which takes around 0.1 ms. After the segment is isolated the rest of the power ystem resumes its operation with the voltage increasing to a value of 400V till 2.5ms and ultimately reaches its final value of 480V.

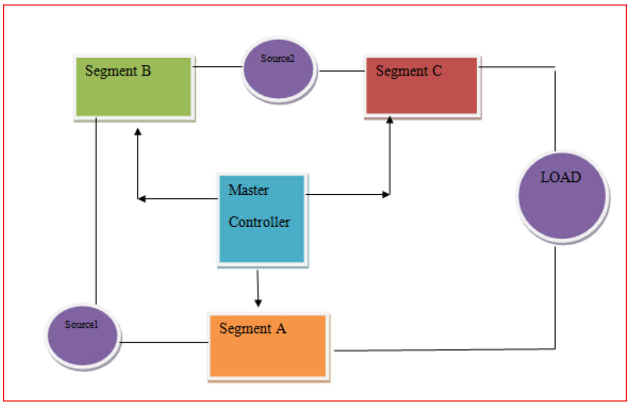

Fig.10. Simulation diagram of protection of all three buses

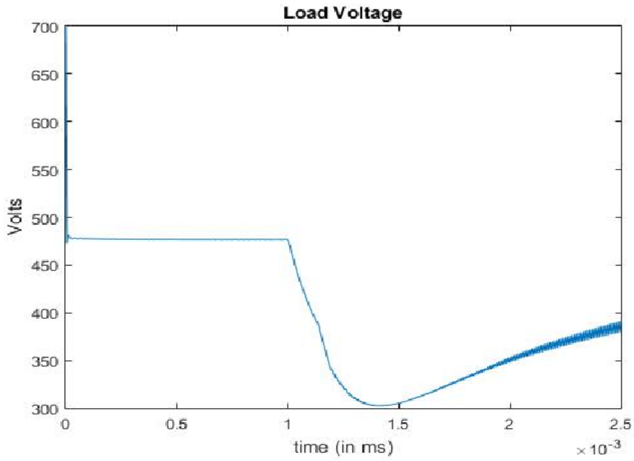

Fig.11. Load voltage when bus A is faulty.

The drop in the initial voltage in comparison to the final voltage is because of the decrease of a segment in the system. The load current goes through the same changes as experienced by the load voltage. It starts with the current being 48A, and after the fault is eliminated the system continues its operation at 40 A. In the case of two segments (B and C) suffering a fault, a major part of the system needs to be isolated and the rest of the operation needs to be carried out using only segment A. Similar operation takes place in this case only as seen in the earlier case, however it takes more time for the system to reach its initial voltage and current.

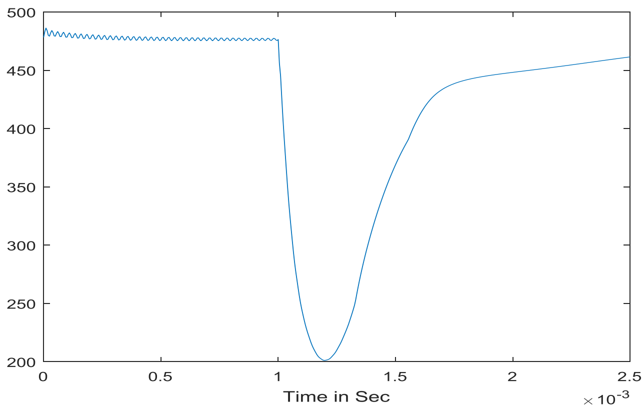

Fig.12. Load voltage when buses B and C are faulty.

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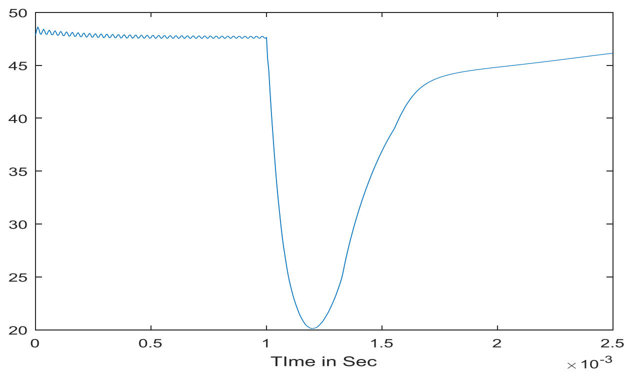

Fig.13. Load Current when buses B and C are faulty

If all the three segments are faulty, the slave controllers will send and acting upon their difference (greater than the threshold value), the master controller as shown in Fig.10 will command the slave controllers to isolate all three of them. This means that the entire system needs to be cut-off in this case. Therefore, the load voltage and current reduce to almost 110V and 12A, respectively, which is negligible as compared to their initial respective values of 480V and 48A as shown in Fig.14-15. Thus, this protection scheme proves useful for both line and ground faults, resulting in quick elimination of faulty section (about 0.1ms). Moreover, it efficiency remains the same regardless of the number of faulty sections making it a reliable form of protection. Therefore, the proposed protection scheme can be effectively used in the low-voltage dc microgrid systems.

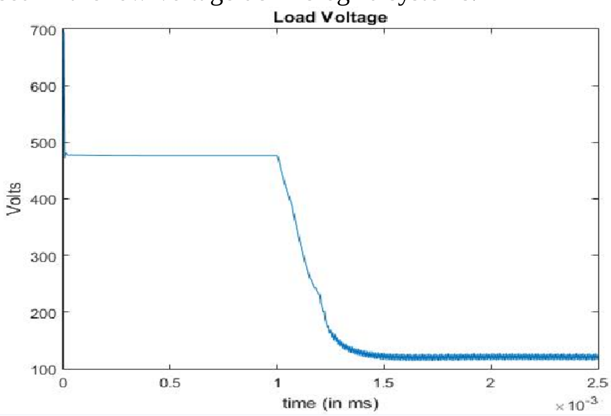

Fig.14. Load voltage when all the three buses are faulty.

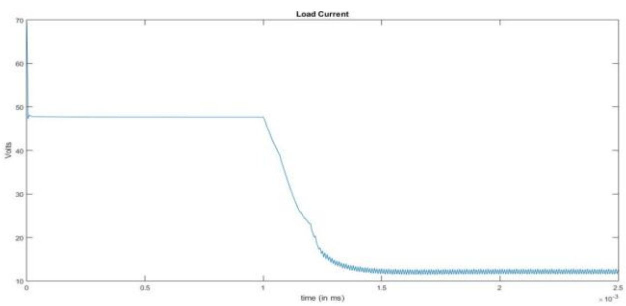

Fig.15. Load current when all the three buses are faulty.

VI. CONCLUSION

This project proposes a protection scheme for fast detection and isolation of faults in low-voltage dc microgrid system. DC bus systems are relatively unexplored as compared to the ac bus systems; as a result they lack standards and guidelines for their effective operation and protection. A loop-type dc-bus system is simulated using MATLAB Simulink 2015a. The system contains a segment controller (consisting of one master controller and two slave controllers) between connected components. Three segments, namely, segment A, segment B and segment C are used for testing of line to line and line to ground faults under different conditions, that is, when fault occurs in only one segment or two of the segments or all three segments

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