Available online at www.ijsrnsc.org
IJSRNSC
Volume-6, Issue-6, December 2018
Research Paper
Int. J. Sc. Res. in Network Security and Communication
E-ISSN:2321-3256
www.ijsrnsc.org

Sensing of Ground Fault in Bipolar LVDC Grid

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Received: 04/Dec./2018, Accepted:22/Dec./2018, Published: 31/Dec/2018

Abstract— The new demand for distributed energy systems (D.E.S) has emerged due to depleting natural energy reserves and for successful implementation of D.E.S, the micro-grid development with low voltage D.C (LVDC) is essential. The Best LVDC topology is bipolar. For practical application of the LVDC system, therefore, it is necessary to perform any simulation in advance by considering various conditions that can occur in an LVDC system. There are different problems in LVDC grid such as cost, security, complexity. The conventional protection schemes will not give best results in developing a secure and reliable network of LVDC. The main difficulty here is identification of ground fault and protecting the front end converter. So, in this paper a bipolar LVDC grid is modelled and ground fault is created and its impact on front end converter is observed. Finally, the ground fault is sensed by the modelled devices and front end converter is isolated on occurrence of fault in Simulink environment.

Keywords— LVDC , Distributed Energy Systems, Ground Fault, Bipolar(key words)

I. Introduction

The demand for undisturbed electricity is growing while society relies more and more on electricity. The occurring outages have more effects to the customers and outage costs increases. At the same time the challenges in network security are also increasing in severity and number .These challenges have raised demand for more reliable network solutions compared to traditional 20/0.4 KV 3-phase AC distribution systems. The LVDC distribution system concept responds to these challenges in the field of electricity distribution.

In the early days the first electricity distribution systems were based on DC technology but were rapidly replaced with AC systems due to its benefits compared to DC. Today's utilization of DC technology concentrates mainly to HVDC transmission systems, industrial distribution and electric drives. The technical and economical developments during last decades have established opportunity to create a new competitive distribution system based on modern power electronic technology. There are different topologies of LVDC such as unipolar and bipolar. The need for grounding and there are difficulties in protecting the LVDC especially the power electronic converter [5].So, in this paper the implementation of grid with Voltage source inverter**(VSI)** with extra balancing technique is proposed. Impact of ground fault on V.S.I i.e., Front End Converter is shown and a directional protection scheme is designed to current sensing of ground fault on fault occurrence

II. LVDC

Low Voltage in DC is not (yet) strictly defined, but regarded to be up to 1.5 kV [3]. It refers to applications regarding distribution level systems, and has several benefits in comparison to the 400 V AC distribution, including higher transmission capacity and higher thermal limits for current [7]. However, due to the very recent interest in the field of LVDC, there are no definite standards so far, which is a challenge in itself. Previous experience with DC systems in the telecom and transportation sector is valuable in this new field. Some elements of the HVDC technology can be used here with some alterations.

While the AC load converter may indeed only work as a rectifier, the component between the DC micro grid and the AC grid will definitely need to have bidirectional power flow capability, due to production from the DC level. The same goes for the converters connecting wind turbines or AC storage devices, such as flywheels. For this level of flexibility, VS converters are the most appropriate, as mentioned in [8]. One of the main advantages of DC micro grids becomes apparent in this figure. The latest technological developments suggest that DC loads will soon command a significant percentage of power consumption [4].

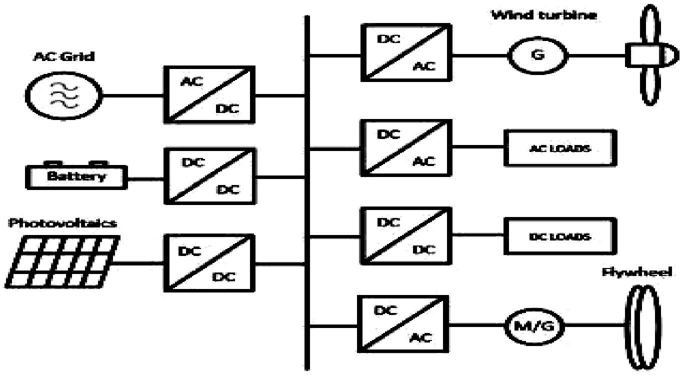

Figure 1. LVDC system block diagram

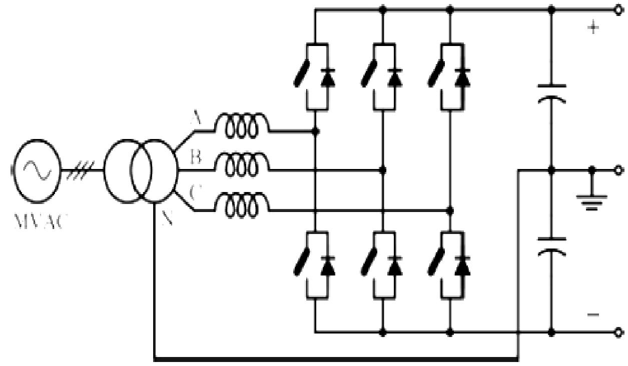

Figure 3 VSC with neutral line connected to DC mid-point

III. LVDC DISTRIBUTION SYSTEM TOPOLOGY:

An LVDC distribution system constructs of power electronic converters and DC link between the converters. The topology of LVDC distribution system can have different kind of variations. Common to these different topologies are that AC/DC conversion is always located near MV line. The DC/AC conversion can instead be located at different locations. Depending on the location the LVDC system can be either a HVDC link type solution or a wide LVDC distribution district where the DC/AC conversion is made at the customer-ends.

The wide LVDC distribution district can be compared to existing LVAC network topology with multiple branches. In this case there is no need for separate 3-phase AC network because the AC lines have been replaced with DC lines.

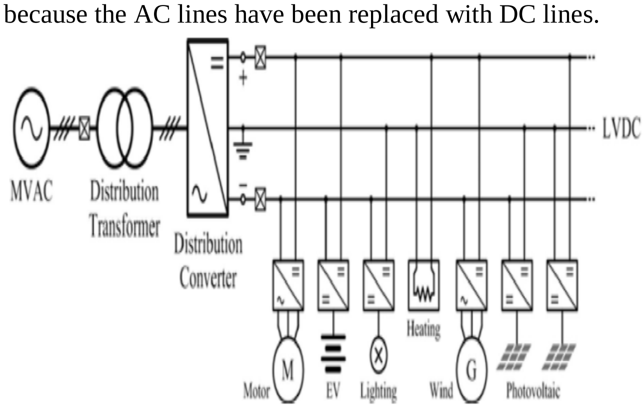

Figure 2 Example of a wide LVDC distribution district

A.EXISTING SYSTEM:

Bipolar DC voltage can also be acquired by a single voltage source converter (VSC) which is shown in above figure. In this we are connecting a neutral line of the transformer to the mid-point of the DC output capacitors. The current in the neutral line can be regulated to balance the DC side voltage [8]

Unfortunately, the neutral line current may contain significant DC component, so this should be strictly limited to prevent transformer saturation.

B.PROPOSED SYSTEM

In order to prevent the neutral line DC current, an extra half bridge is employed as shown in below figure which is dedicated to voltage balancing by actively redistributing the currents.

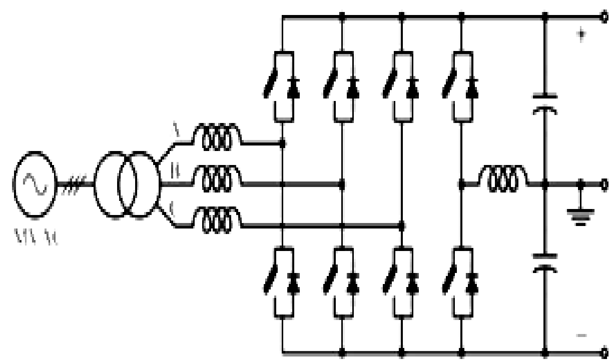

Figure 4 VSC with extra voltage balancing half-bridge

C.WORKING:

Initially the 3 phase supply is given to transformer for stepping down and that stepped down voltage is given to DC converter to convert
stepped down ac voltage to dc voltage. The controlling strategy used here is space vector PWM .Whenever the ground current flows in reverse direction, it affects the entire system. Hence, to overcome this problem a circuit breaker is connected between transformer and to the mid-point of output dc capacitor. When the fault takes place, the circuit breaker trips and prevents the entire system from damage.

The control strategy is explained as: Pulse width Modulation (PWM) is a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. Space vector modulation (SVM) is an algorithm for the control of pulse width modulation. It is used for the creation of alternating current (AC) waveforms most commonly to drive 3 phase ac powered motors at varying speeds from DC using multiple class-D amplifiers. One active area of reduction of Total harmonic distortion (THD) created by the rapid switching inherent to these algorithms.

The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred o the load, there is almost no voltage drop across the switch .the switches must be controlled so that at no time are both switches in the same leg turned on or else the DC supply would be shorted. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which because of their on/off nature, can easily set the needed duty cycle. The duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is Duty cycle is expressed in percent, 100% being fully on [9].

IV. LVDC NETWORK GROUNDING ARRANGEMENT:

At distribution network faults the LV standardization defines maximum contact voltage limit to be 120 VDC in DC systems. Occurring contact voltage at fault point is always only a part of earth voltage. Therefore earth voltage limit is defined to be twice as contact voltage limit. The earth voltage limit is thereby 240 VDC.

It is studied that grounded TN system can introduce high earth and contact voltages over allowed limits already at small earth resistances values in a 750 VDC system. The example network used in ground fault analysis is shown in figure 3. The fault location is 3.5 km apart from MV line. Figure 5 shows the example LVDC with grounded TN. In this paper a model of TN is developed with 760 V between T and N .Extra voltage balance with 380V between T and ground,-380V between N and ground and it is shown in results section figure 8. Occurring contact voltage at fault point is always only a part of earth voltage. Therefore earth voltage limit is defined to be twice as contact voltage limit. The earth voltage limit is thereby 380 V DC

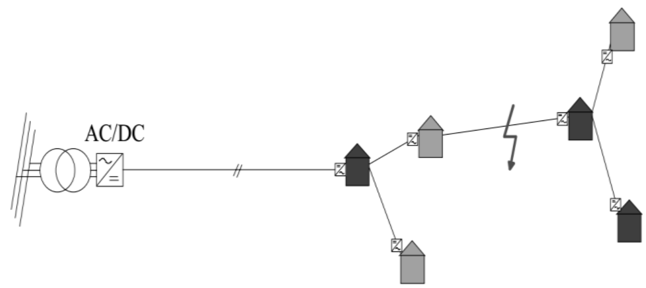

Figure 5 Example network for ground fault in TN system

V. PURPOSE OF GROUNDING:

The primary purpose of grounding electrical systems is to provide protection against electrical faults. Electrical faults can be broken down into two categories: phase-to-phase faults and ground faults. Studies have shown that 98% of all electrical faults are ground faults Where fuses can protect against phase-to-phase faults, additional protection, such as protection relays, are typically required to protect against ground faults. There are other advantages for a grounded system, such as reduction of shock hazards and protection against lightning.

VI. PROTECTION CHALLENGES:

The protection of a DC micro grid constitutes one of the greatest challenges for its proper function. Despite the undoubted benefits of LVDC, the implementation of this innovative and beneficial technology arguably makes the task of designing a protection system much more complex.

Therefore, it becomes clear that the existing protection devices are not ideal for DC systems [6]. The first solution to that was to shut down the whole system at the converter level in case of a fault, but then there is absolutely no selectivity achieved, as all loads are disconnected. Another reason that makes the use of AC breakers in a DC system impractical is the fact that they operate very slowly compared to the rising slope of a DC fault current. By the time the breaker's contacts separate, the current will have reached high values, rendering the resulting arc very hard to stop. It should be stressed that power electronic components are the most troublesome regarding protection.

VII. Design of Proposed System and ground fault in Simulink

The proposed system which contains basically six blocks namely three phase A.C source, circuit breaker, VSI , extra voltage balancing switches, sinusoidal PWM converter

and the output dc terminals i.e., positive and negative terminals with neutral grounded, source impedance, transformer, low voltage dc circuit breaker,
space vector PWM controller, switching devices (i.e., MOSFET) half bridge known as voltage balancer, storage devices, load and if required a battery for backup purpose. The proposed system is modelled in Simulink is shown in figure 6

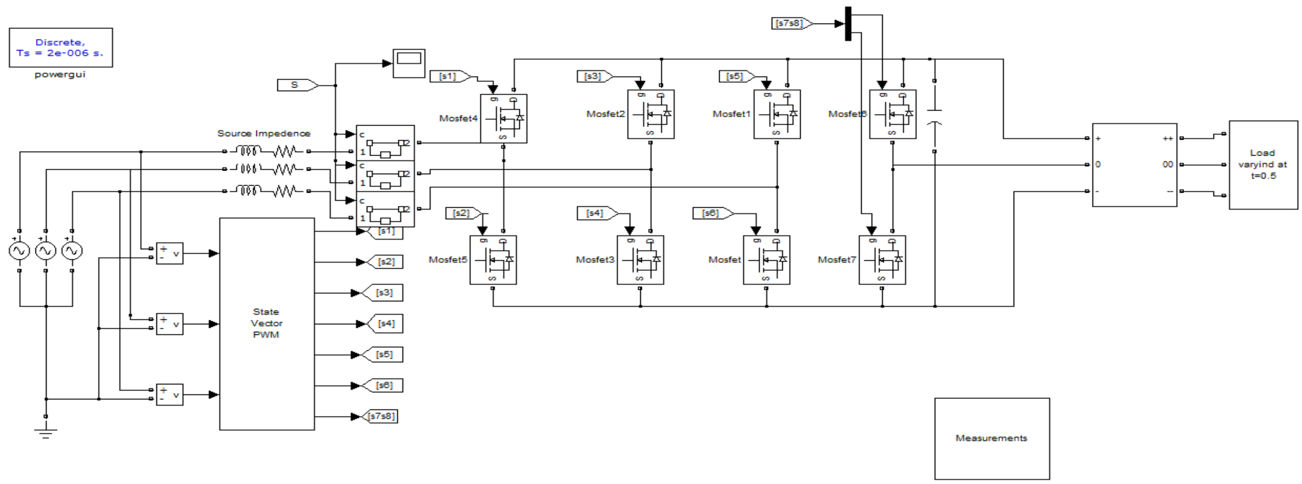

Figure 6 Modelled proposed LVDC with extra voltage balancing in Simulink

A. GROUND FAULT CREATION

A ground fault is created by placing a switch at the load end. One end of the switch is connected to the phase and other end is connected to the ground [9]. The switch is made to operate in a specified duration of time assume 0.4 to 0.6 and when the switch is in on position, a short circuited path is created i.e., phase to ground fault. The voltage and current in the system are varied whenever a fault occur and variation in the parameters is completely based on the value of Rg i.e., ground fault resistance. When the fault occurs, the energy source E0 is discharged and current direction is reversed and feeds the fault thereby increasing the fault current.

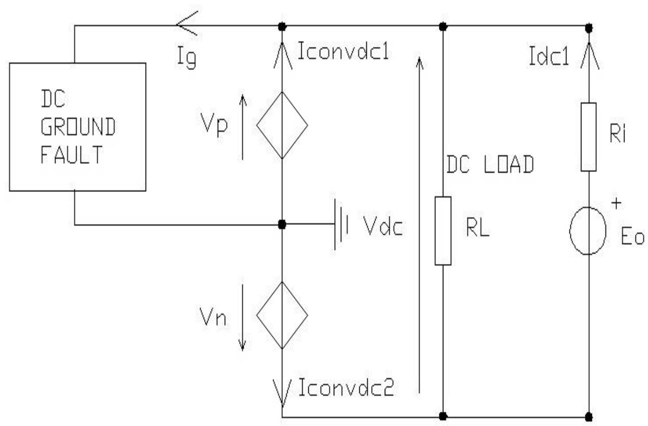

Figure 7 Equivalent model of proposed system during fault

B. FAULT CURRENT CALCULATIONS

The equivalent model of above LVDC grid during a DC ground fault with LV transformer neutral point grounded is developed as below [11]

E_0 is Energy storage element

RL is resistance across the load

V_{dc} is resultant voltage $= V_p - V_n$

V_p is voltage across the positive terminal

V_n is voltage across negative terminal

R_I is internal resistance

$I_{convdc1}$ is current through positive terminal

$I_{convdc2}$ is current through negative terminal

Application of Kirchhoff's laws provides the following system of equations

Where, $V_{dc} = V_p - V_n$

$$V_{dc} = E_o - R_i . I_{dc1} \quad \ldots\ldots (1)$$

$$I_{dc1} = I_{convdc2} + V_{dc}/R_L \quad \ldots\ldots (2)$$

Current flowing in the lower terminal of the FEC can be calculated as:

$I_{convdc2}$ = (E_0- (1+R_i/R_l)*V_{dc})/R_i ………...……..(3)

VIII RESULTS

The simulated results of the modeled proposed system with and without sensing devices are shown in this section

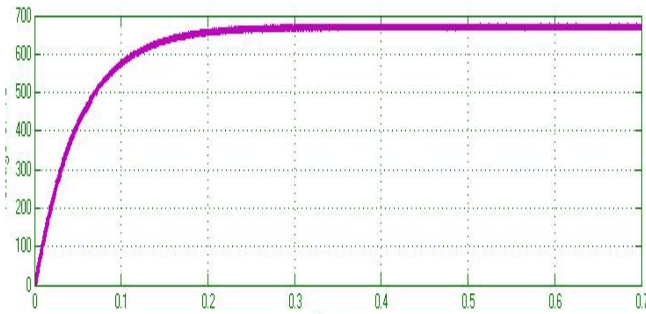

Figure 8 Waveform shows the voltage across the grid

A. *Voltage* & current *waveforms without sensing device*

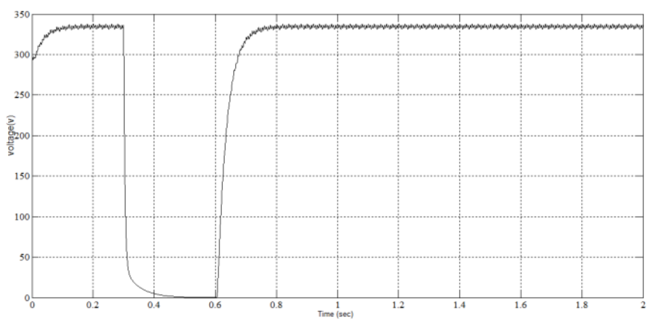

Figure 9 Voltage across the load

The figure 10 shows that the current changes its direction and rises when ground fault occurs to a value of -440 amperes when ground fault resistance is 50 milliohms

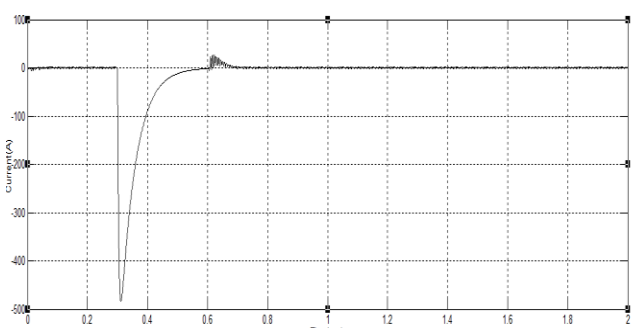

Figure 10 Current flowing in the load

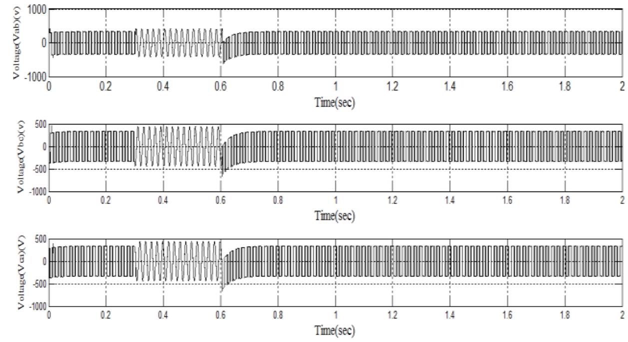

Figure 11 **Voltage** waveform across front end converter

B. *Voltage* & current *waveforms with sensing device*

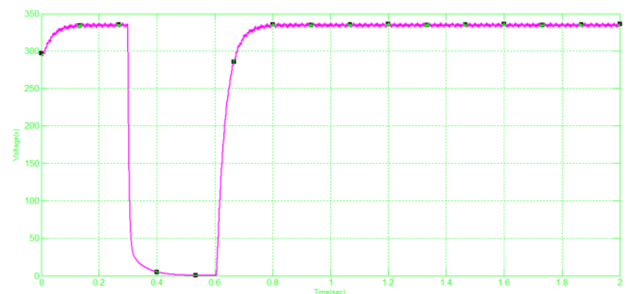

Figure 12 Voltage across the load

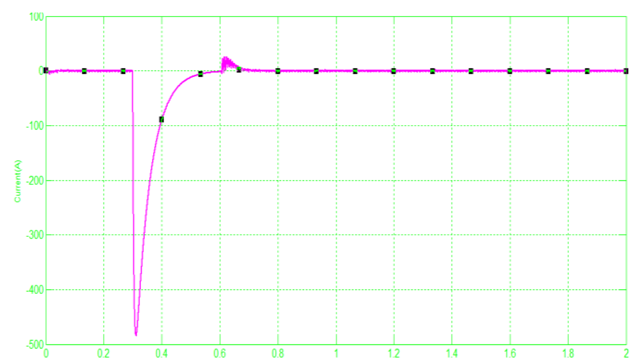

Figure 13 Current flowing in the load

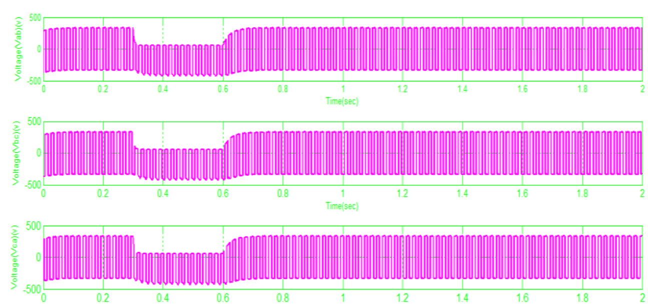

Figure 14 Voltage waveform across front end converter

IX. CONCLUSION

This paper presents a solution for ground fault sensing which is problem in LVDC. The ground fault is different from other faults in nature that there is no considerable increase at front end converter is observed but the stresses on the switches will be predominant and could considerable decrease in reliability and power quality and life time reduction of switches. Here, a sensing device is placed which measures the current and compares it with the reference value and if it is more than the reference value the circuit breaker trips and if it is less the system continues
to work as it is .The front end converter and LVDC are far from other so by using fast communication channel along with residual directional sensing relay will isolate the system from ground fault. From the characteristics of voltage and current, it is clear that during the faulty condition sensing device senses the fault current and circuit breaker trips as a result the system is protected from fault.

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