Performance of Flexible D-STATCOM as a Flexible Distributed Generation in Mitigating Faults

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ABSTRACT

This paper proposes a flexible D-STATCOM (Distribution Static Compensator) and its new controller system, that be able to both mitigate all types of faults and operate as a Distributed Generation (DG), when it supplies power to sensitive loads while the main utility source is disconnected (i.e. it is under islanded operating condition). Thus D-STATCOM operates same as a flexible DG (FDG) and consequently, it is called Flexible DSTATCOM (FD-STATCOM). This paper introduces the performance of FD-STATCOM system to mitigate power quality problems and improve distribution system performance under all types of system related disturbances and system unbalanced faults, such as Line-to-Line (LL) and Double Line to Ground (DLG) faults and supplies power to sensitive loads under islanding condition. The 12-pulse D-STATCOM configuration with IGBT is designed and the graphic based models of the D-STATCOM are developed using the MATLAB simulation program. The reliability and robustness of the control schemes in the system response to the voltage disturbances caused by LL and DLG faults and islanded operating condition are obviously proved in the simulation results.

Keywords-component; FD-STATCOM; Voltage Sags; Energy Storage Systems; Islanding Condition

1. INTRODUCTION

Power quality is certainly a major concern in the present era. It becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage sags, and harmonics. Voltage dips are considered one of the most severe disturbances to the industrial equipment. A voltage dip of 75% (of the nominal voltage) with duration shorter than 100ms can result in material loss in a large range for the semiconductors industry. Swells and over voltages can cause over heating tripping or even destruction of industrial equipment such as motor drives.

This section analyzes the key issues in the Power Quality problems, specially keeping in mind the present trend towards more localized generations or distributed generations and restructuring of power transmission and distribution networks. This study describes the techniques of correcting the supply voltage sag in a distribution system. DG provides many potential benefits, such as peak shaving, fuel switching, improved power quality and reliability, increased efficiency, and improved environmental performance. There is a high demand for utility DG installations due to their advantages of deferment or upgrading the distribution infrastructure. Most DG units are connected to the distribution system through a shunt nonlinear link such as a VSI or a Current Source Inverter (CSI) [1]. There are many types of DG. Among them are wind, biogas, fuel cells and solar cells. Generally, these sources are connected to grid through inverters and their main function is to deliver active power into the grid. The DGs are designed to supply active power or both active and reactive power. Flexible DG systems would indeed be possible to implement integrated functions like harmonic mitigation, unbalance mitigation, zero sequence component suppression schemes, and etc. The new trends in power Electronics converters make the implementation of such multiple functions feasible. A DG is islanded when it supplies power to some loads while the main utility source is disconnected. Islanding detection of DGs is considered as one of the most important aspects when interconnecting DGs to the distribution system. With the increasing penetration and reliance of the distribution systems on DGs, the new interface control strategies are being proposed [2]. This paper proposes a flexible D-STATCOM system designed to operate in two different modes. Initially, it can mitigate voltage sags caused by LL and DLG faults. Secondly, it can mitigate voltage sags caused by three-phase open-circuit fault by opening the three phases of a circuit-breaker and disconnecting the main power source (islanding condition). Reactive power compensation is an important issue in the control of distribution systems. Reactive current increases the distribution system losses, reduces the system power factor, shrink the active power capability and can cause large-amplitude variations in the load-side voltage [3-4]. Various methods have been applied to mitigate voltage sags. The conventional methods use capacitor banks, new parallel feeders, and uninterruptible power supplies (UPS). However, the power quality roblems are not completely solved due to uncontrollable reactive power compensation and high costs of new feeders and UPS. The D-STATCOM has emerged as a promising device to provide not only for voltage sag mitigation but also for a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction, and harmonic control [5]. In this paper, the proportional gain of the PI controller is fixed at a same value, for all types of faults, by tuning the transformer reactance in a suitable amount. Then the robustness and reliability of the proposed method is more than the mentioned methods. In this method, the dc side topology of the D-STATCOM is modified for mitigating voltage distortions and the effects of system faults on the sensitive loads are investigated and the control of voltage sags are analyzed and simulated.

2. CONSEQUENCES DUE TO VOLTAGE DIPS

Voltage dips are today one of the most occurring power quality problems. Off course, for an industry an outage is worse, than a voltage dip, but voltage dips occur more often and cause severe problems and economical losses. During the last years equipment has become more and more technically advanced, in many cases followed by increased voltage dip susceptibility. As a result, there are more interruptions in the production with an increased power quality related cost. The understanding and opinion about the importance of voltage dips are also very different depending on whom you are talking to. Utilities often focus on disturbances from end-user equipment as the main power quality problems. This is correct for many disturbances, flicker, harmonics, etc., but voltage dips mainly have their origin in the higher voltage levels. Faults due to lightning, is one of the most common causes to voltage dips on overhead lines. The customers on the other hand often experience their problems due to disturbances from the feeding grid as the main priority, despite the fact that some disturbance has its origin by the customer himself. Customers often explain tripping of equipment due to voltage dips in the supply voltage as a result of bad power quality from the utilities. The utilities, on the other hand claim disturbances from the end customer as a main power quality problem. The fact is that a lot of modern power electronic equipment is sensitive to voltage disturbances and it has been confirmed that this equipment causes disturbances for other customers as well as to themselves. Unfortunately, equipment susceptibility has become worse compared to its counterparts 10 or 20 years ago. The increased use of converter-driven equipment, non-linear consumer electronics and computers, has led to a large growth of voltage disturbances in the systems. A balanced three-phase voltage dip will result in a *type A*. Since the voltage dip is balanced, the zero-sequence is zero, and a transformer will not affect the appearance of the voltage dip. This holds both for the phase-ground voltage and phase-to-phase-voltage. A phase-to-ground-fault will result in a *type B*. If there is a transformer that removes the zero-sequence between the fault location and the load, the voltage dip will be of *type D*. A phase-to-phase-fault results in a *type C*. The resulting voltage dip types caused by different fault are listed in Table 1.

Dip type	***Fault type***
Type A	Three-phase
Type B	Single-phase-to-ground
Type C	Phase-to-phase
Type D	Phase-to-phase fault (experienced by a delta connected load), single-phase-to-ground (zero sequence-component removed)

Table.1 Overview of different types of voltage dips due to three-phase, two-phase or single-phase-to-ground-fault.

The voltage dips of *type E*, *F* and *G* are due to a two-phase-to-ground-fault. An overview of the different types of voltage dips due to a two-phase-to-ground fault is shown in Table 2.

Dip type	***Fault type***
Type E	Two-phase-to-phase fault (experienced by a Wye connected load)
Type F	Two-phase-to-phase fault (experienced by a delta connected load)
Type G	Two-phase-to-phase fault (experienced by a load connected via a non- grounded transformer removing the zero-sequence the component)

Table.2 Overview of different types of voltage dips due to two-phase- to-ground-fault.

3. DISTRIBUTION STATIC COMPENSATOR

3.1. Introduction:

In power distribution networks, reactive power is the
main cause of increasing distribution system losses and various power problems. Conventionally, Static Var Compensators (SVCs) have been used in conjunction with passive filters at the distribution level for reactive power compensation and mitigation of power quality problems. Though SVCs are very effective system controllers used to provide reactive power compensation at the transmission level, their limited bandwidth, higher passive element count that increases size and losses, and slower response make them inapt for the modern day distribution requirement. Another compensating system has been proposed by , employing a combination of SVC and active power filter, which can compensate three phase loads in a minimum of two cycles. Thus, a controller which continuously monitors the load voltages and currents to determine the right amount of compensation required by the system and the less response time should be a viable alternative. Distribution Static Compensator (DSTATCOM) has the capacity to overcome the above mentioned drawbacks by providing precise control and fast response during transient and steady state, with reduced foot print and weight. A DSTATCOM is basically a converter based distribution flexible AC transmission controller, sharing many similar concepts with that of a Static Compensator (STATCOM) used at the transmission level. At the transmission level, STATCOM handles only fundamental reactive power and provides voltage support, while a DSTATCOM is employed at the distribution level or at the load end for dynamic compensation .

3.2. Basic Principle of DSTATCOM:

A DSTATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator. The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Fig. 3.1

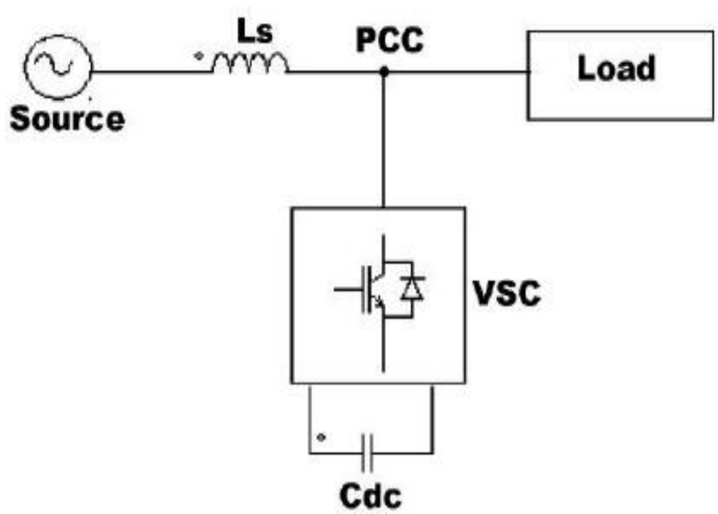

Fig.3.1. Block diagram of D-STATCOM

The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be precharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. The voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages; where as, for power factor correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a DSTATCOM for power factor correction and harmonic mitigation.

3.3. Operating Principles of the D-STATCOM:

The STATCOM is the solid-state-based power converter version of the SVC. The concept of the STATCOM was proposed by Gyugyi in 1976. Operating as a shunt-connected SVC, its capacitive or inductive output currents can be controlled independently from its connected AC bus voltage. Because of the fast-switching characteristic of power converters, the STATCOM provides much faster response as compared to the SVC. In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously; therefore, the STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for the STATCOM to inject capacitive power to support the dipped voltages .Theoretically, the power converter employed in the STATCOM can be either a VSC or a current-source converter (CSC).

In practice, however, the VSC is preferred because of the bi directional voltage-blocking capability required by the power semiconductor devices used in CSCs. To achieve this kind switch characteristic, an additional diode must be connected in series with a conventional semiconductor switch, or else the physical structure of the semiconductor must be modified. Both of these alternatives increase the conduction losses and total system cost In general, a CSC derives its terminal power from a current source, i.e., a reactor. In comparison, a charged reactor is much lossier than a charged capacitor. Moreover, the VSC requires a current-source filter at its AC terminals, which is naturally provided by the coupling transformer leakage inductance, while additional capacitor banks are needed at the AC terminals of the CSC. In conclusion, the VSCs can operate with higher efficiency than the CSCs do in high-power applications. A suitable VSC is selected based on the following considerations: the voltage rating of the power network, the current harmonic requirement, the control system complexity, etc. Basically, the STATCOM system is comprised of three main parts: a VSC, a set of coupling reactors or a step-up transformer, and a controller. In a very-high-voltage system, the leakage inductances of the step-up power transformers can function as coupling reactors.

The main purpose of the coupling inductors is to filter out the current harmonic components that are generated mainly by the pulsating output voltage of the power converters. The STATCOM is connected to the power networks at a PCC, where the voltage-quality problem is a concern. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches of the power converter accordingly. In general, the VSC is represented by an ideal voltage source associated with internal loss connected to the AC power via coupling reactors. In principle, the exchange of real power and reactive power between the STATCOM and the power system can be controlled by adjusting the amplitude and phase of the converter output voltage. In the case of an ideal lossless power converter, the output voltage of the converter is controlled to be in phase with that of the power system. In this case, there is no real power circulated in the STATCOM; therefore, a real power source is not needed. To operate the STATCOM in capacitive mode or var generation, +Q, the magnitude of the converter output voltage is controlled to be greater than the voltage at the PCC. In contrast, the magnitude of the output voltage of the converter is controlled to be less than that of the power system at the PCC on order to absorb reactive power or to operate the STATCOM in inductive mode, -Q. However, in practice, the converter is associated with internal losses caused by non-ideal power semiconductor devices and passive components.

As a result, without any proper controls, the capacitor voltage will be discharged to compensate these losses, and will continuously decrease in magnitude. To regulate the capacitor voltage, a small phase shift d is introduced between the converter voltage and the power system voltage. A small lag of the converter voltage with respect to the voltage at the PCC causes real power to flow from the power system to the STATCOM [13], while the real power is transferred from the STATCOM to the power system by controlling the converter voltage so that it leads the voltage at the PCC. Figure 2 illustrates phasor diagrams of the voltage at the PCC, converter output current and voltage in all four quadrants of the PQ plane.

3.4 Proposed FD-STATCOM Structure:

Unlike the Unified Power Flow Controller (UPFC) which consist from two parts, series and shunt, to manage the flow of active power from one part to the other, FDG consist of one part only, because it has a supply of the active power from DG system. Fig. 1 shows the schematic representation of the FDSTATCOM. The basic electronic block of the FD-STATCOM is the voltage source inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the FD-STATCOM output voltages allows effective control of active and reactive power exchanges between the FD-STATCOM and the ac system. Fig shows a typical 12-pulse inverter arrangement utilizing two transformers with their primaries connected in series. The first transformer is in Y-Y connection and the second transformer is in Y-Δ connection. Each inverter operates as a 6-pulse inverter, with the Y-Δ inverter being delayed by 30 degrees with respect to the Y-Y inverter. The IGBTs of the proposed 12-pulse FD-STATCOM are connected anti parallel with diodes for commutation purposes and charging of the DC capacitor. This is to give a 30 degrees phase shift between the pulses and to reduce harmonics generated from the FD-STATCOM. The FDSTATCOM is connected in shunt to the system.

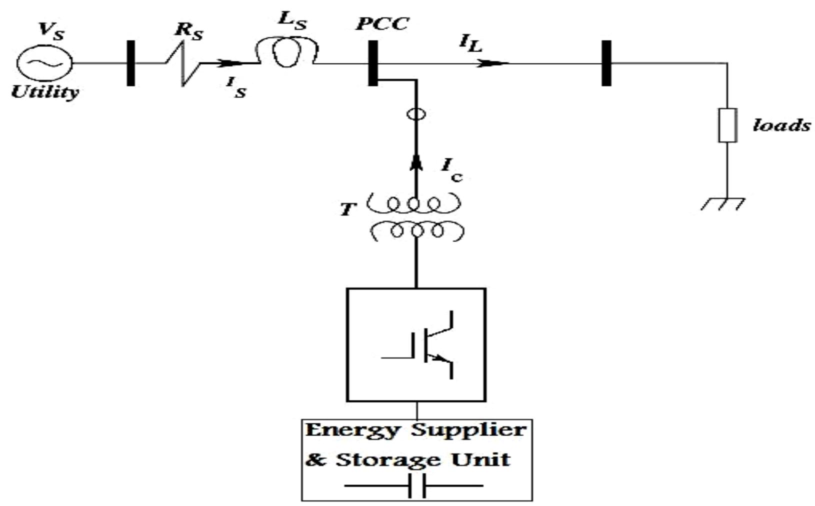

Fig3.2. Schematic representation of the FD-STATCOM

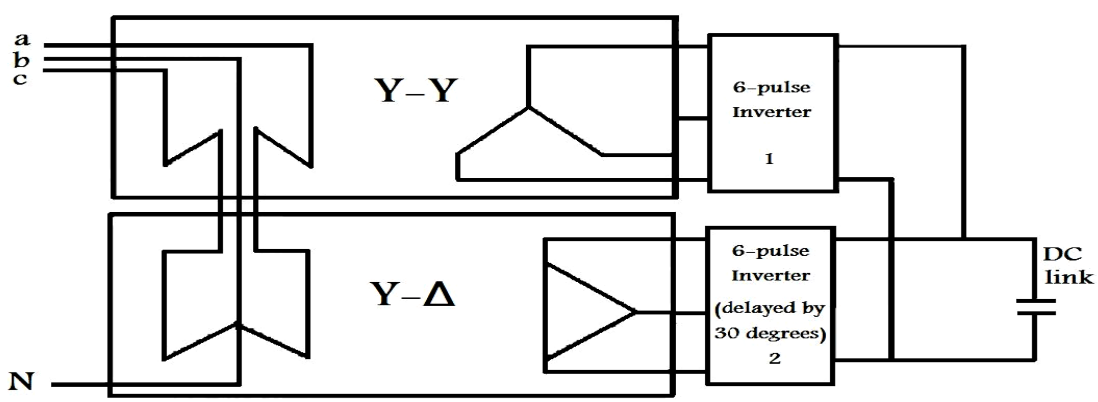

Fig. 3.3. The 12-pulse FD-STATCOM arrangement

3.4. Control Strategies:

Satisfactory performance, fast response, flexible and easy implementation are the main objectives of any compensation strategy. The control strategies of a DSTATCOM are mainly implemented in the following steps: 1. Measurements of system variables and signal conditioning. 2. Extraction of reference compensating signals. 3. Generation of firing angles for switching devices

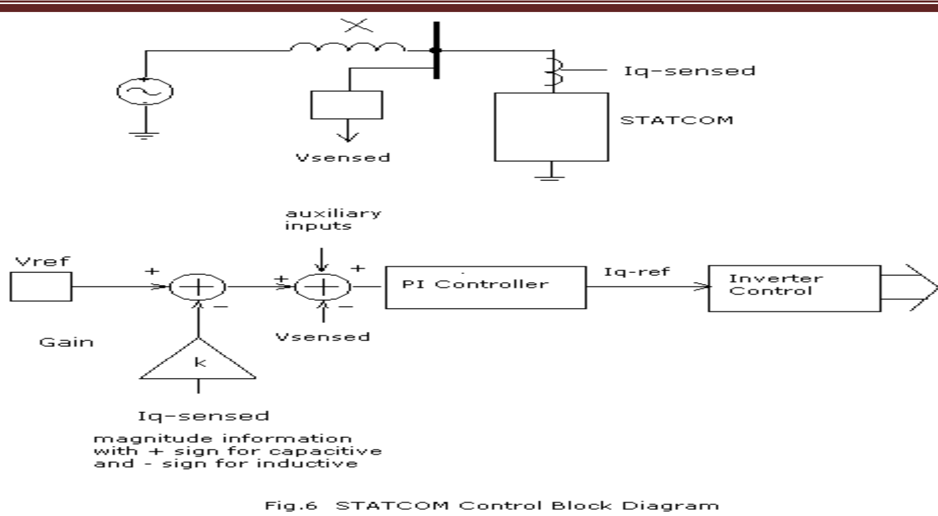

Fig. 3.4 Schematic diagram of DSTATCOM control

Fig. 3.4 shows the schematic diagram of DSTATCOM control, taking into consideration the above steps. The generation of proper pulse width modulation (PWM) firing is the most important part of DSTATCOM control and it has a great impact on its compensation objectives, transient as well as steady state performance. Since a DSTATCOM shares many concepts with that of a STATCOM at the transmission level, a few control techniques have been directly implemented to a DSTATCOM, incorporating PWM switching, rather than fundamental frequency switching (FFS) methods. A PWM based distribution static compensator offers faster response and capability for harmonic elimination. This paper is an attempt to compare the following schemes of a DSTATCOM for power factor correction and harmonic mitigation based on:1.Phase shift control2.Indirect decoupled current control3.Regulation of AC bus and DC link voltage.The performance of DSTATCOM with different control schemes have been studied through digital simulations for common system parameters, as given in the Appendix.

3.5 Control Strategy for FD-STATCOM**:**

The block diagram of the control scheme designed for the FD-STATCOM is shown in Fig. It is based only on measurements of the voltage VRMS at the load point.

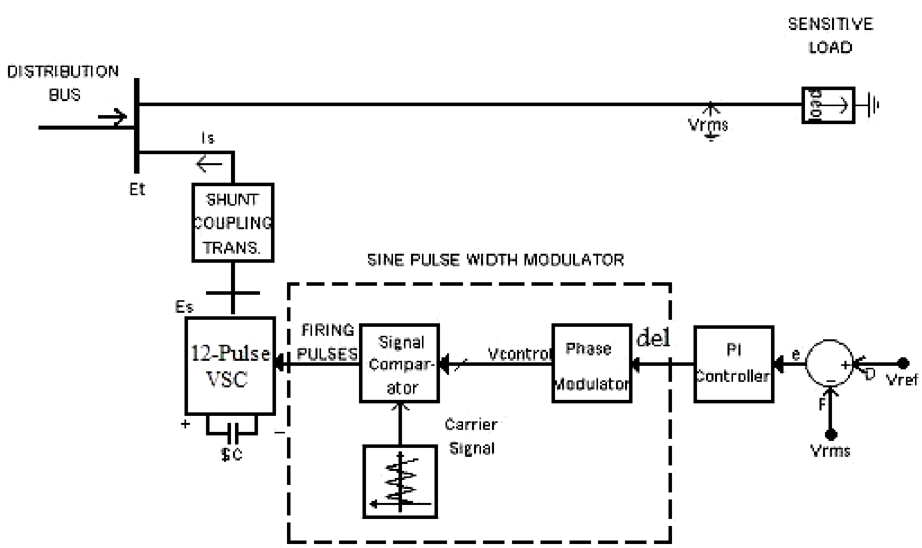

Fig3.5. Control scheme designed for the FD-STATCOM

3.5.1 Proposed Control Method:

In this project, in order to mitigate voltage sags caused by LL and DLG faults and to supply power to sensitive load, a new method is proposed in which the FD-STATCOM and Super Capacitor Energy Storage system (SCESS) are integrated. Considering this fact that all types of fault may occur in distribution system, controller system must be able to mitigate any types of voltage sags. The integration and control of SCESS into a FD-STATCOM is developed to mitigate such problems, enhance power quality and improve distribution system reliability [14]. The new method develops the control concepts of charging and discharging the SCESS by DSTATCOM, and validates the performance of an integrated DSTATCOM/ SCESS for improving distribution system performance under all types of system related disturbances and system faults, such as LL and DLG faults and under islanded operating condition.

Super capacitor is a new energy device emerged in recent years. It is also known as double-layer capacitor. The electrical double-layer capacitor is a novel energy storage component developed in 1970s. Its pole boards are made of activated carbon, which have huge effective surface so the capacitance could attain several farad even thousands farad. When it is charged, the electric charges are spontaneously distributed negative and positive ion layers on the interface between pole boards and electrolyte, so the super capacitor does not have electrochemical reaction and only have electric charges adsorption and desorption when it is charged and discharged. It has many merits such as high charge/discharge current, less maintenance, long life and some other perfect performance. At the same time, its small leakage current enables it has long time of energy storage and the efficiency could exceed 95% . The structure of SCESS is shown in Fig. Its circuit is mainly composed of three parts: rectifier unit, energy storage unit, and inverter unit. Rectifier unit adopts three phase full bridge rectifier to charge super capacitor and supply dc power energy to inverter unit. Inverter unit adopts three phase voltage inverter composed of IGBTs, it connects to power grid via transformer. When SCESS works normally, voltage at dc side is converted into ac voltage with the same frequency as power grid through IGBT inverter. When only considering fundamental frequency, SCESS can be equivalent to ac synchronizing voltage source with controllable magnitude and phase. Energy storage unit i.e. super capacitor energy storage arrays are composed of many monolithic super capacitors. If a large number of super capacitors be in parallel, at the same time improving capacity of power electronics devices in power conversion system can be easily composed of more large capacity SCESS, but operational reliability and control flexibility will not be affected. Super capacitor is very easily modularized, when required, and it is very convenient in capacity expansion. SCESS stores energy in the form of electric field energy using super capacitor arrays. At the lack of energy emergency or when energy needed, the stored energy is released through control system, rapidly and accurately compensating system active and reactive power, so as to achieve the balance of power energy and stability control. Determining the number of energy storage module can save super capacitors, and further reducing volume, quality and cost of the energy storage unit.

In this paper, SCESS is made of 10 arrays in parallel with ce=3 (mF) and req=1 (Ω) for every array, as shown in Fig .it shows a typical distribution system controlled by this method. Also, when Timed Fault Logic operates LL and DLG faults are exerted, therefore, the FD-STATCOM supplies reactive power to the system. In this method, the proportional gain is 300. The speed of response and robustness of the control scheme are clearly shown in the simulation results.

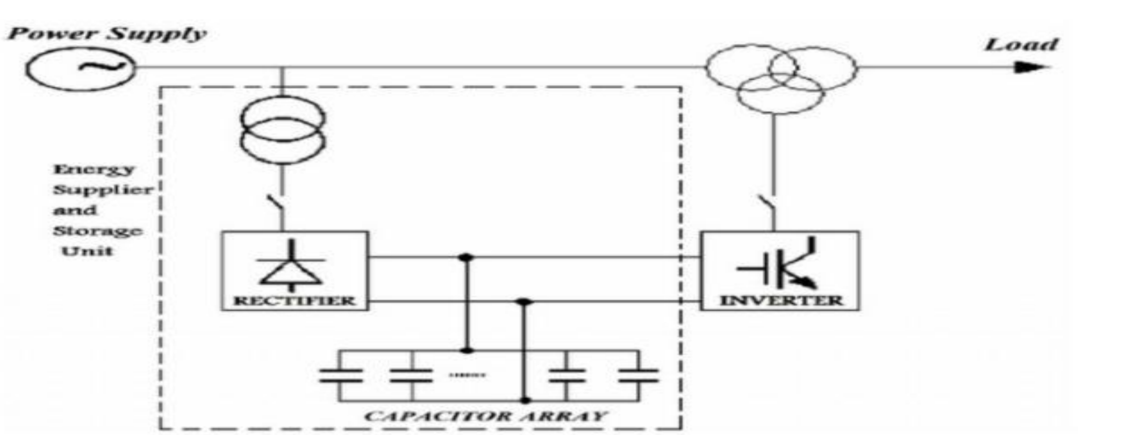

Fig. 4. Structure of SCESS

Fig 3.6 : Structure of SCESS

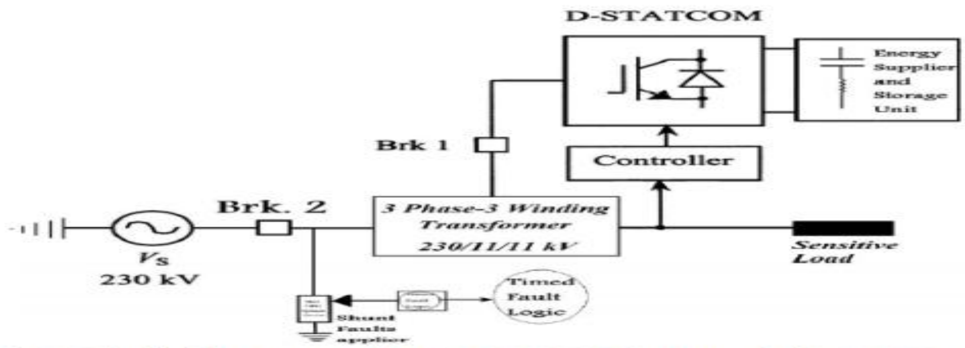

Fig. 5. Distribution system with FD-STATCOM integrated with SCESS and controller

Fig 3.7: Distribution system with FD-STATCOM with SCESS and controller

4. SIMULATIONS AND RESULTS

4.1 Sinusoidal Pwm-Based Control

This section describes the PWM-based control scheme with reference to the D-STATCOM. The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the r.m.s voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the fundamental frequency switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses. Fig shows the test system and D-STATCOM controller implemented in MATLAB SIMULINK.

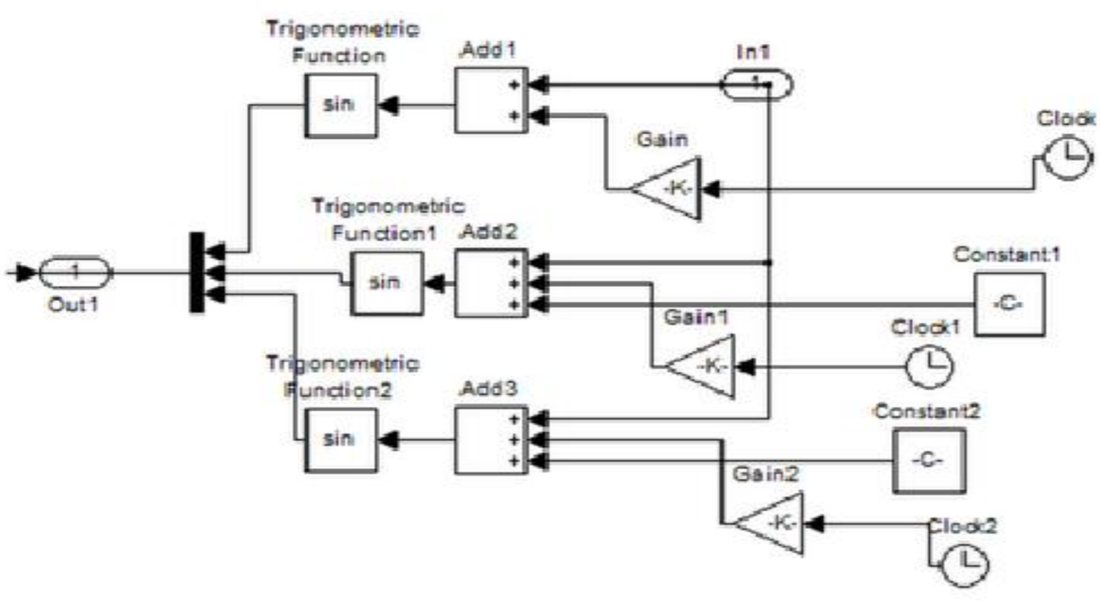

Fig 4.1: Control Mechanism

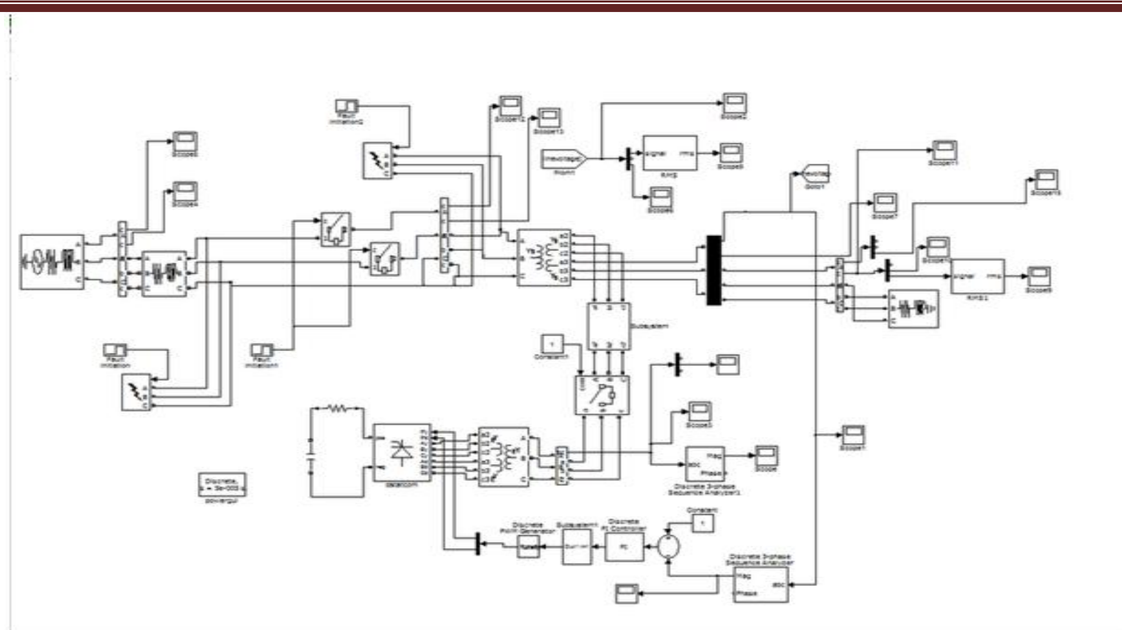

Fig 4.2: FD-STATCOM Simulink Circuit

Fig. shows the schematic diagram of DSTATCOM for providing voltage regulation. A three-phase alternator of 42.5 kVA, 50 Hz, 400V (L-L) rating feeds power to isolated distribution system. The alternator is coupled to the diesel engine with governor as prime mover. The load considered on the system represents an induction motor load. The synchronous machine output voltage and frequency are used as feedback inputs to a control system, which consists of the diesel engine with governor as well as an excitation system.Fig.lb shows the basic diagram of DSTATCOM connected as shunt compensator. It consists of a three-phase, current controlled voltage source converter (CC-VSC) and an electrolytic DC capacitor. The DC bus capacitor is used to provide a self supporting DC bus. AC output terminals of the DSTATCOM are connected through filter reactance or in practical case, by the reactance of the connecting transformer. The test system comprises a 230 kV transmission system. A balanced load is connected to the 11 kV, secondary side of the transformer. Brk. 1 is used to control the operation period of the FD-STATCOM. A 12-pulse FD-STATCOM is connected to the tertiary winding by closing Brk. 1 at 0.2 s, for maintaining load RMS voltage at 1pu. A SCESS on the dc side provide the FD STATCOM energy storage capabilities. The simulations are carried out for both cases where the FDSTATCOM is connected to or disconnected from the system.

4.2 Simulation results for Line-to-Line fault

When the system operates without FD-STATCOM and under LL fault. In this case, the voltage drops by almost 20% with respect to the reference value. In t = 0.2 s, the FD-STATCOM is connected to the distribution system. The voltage drop of the sensitive load point is mitigated using the proposed control method. Fig. 8 shows the mitigated RMS voltage using this new method where a very effective voltage regulation is provided.

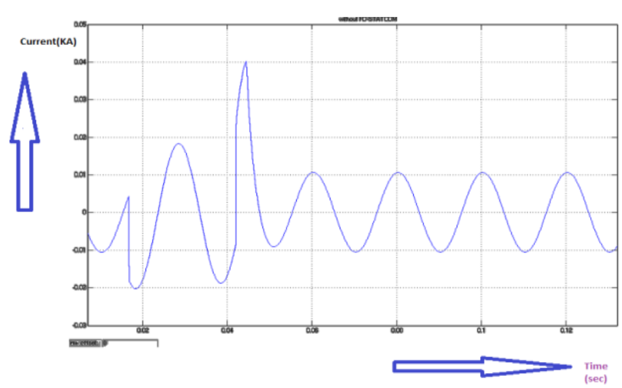

Fig 4.1: Current waveforms at PCC without FD-STATCOM

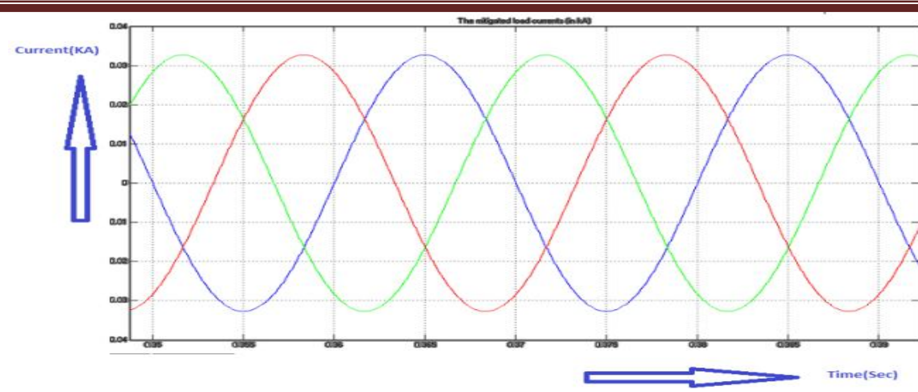

Fig 4.2:The mitigated load Current by using the FD- STATCOM

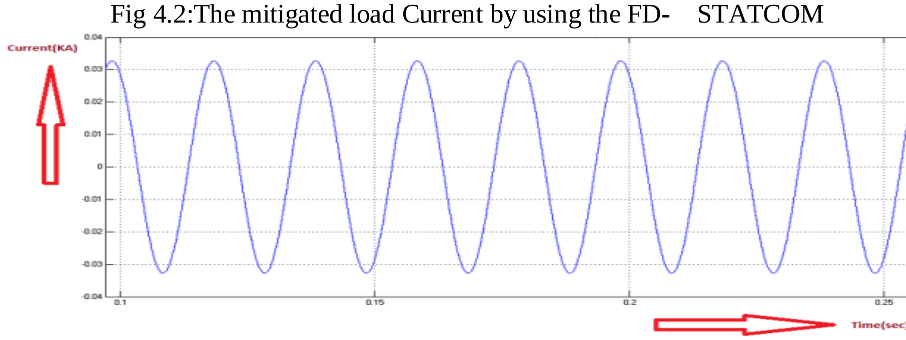

Fig 4.3:Compensated line voltage Vab at load point by using FD-STATCOM

4.3 Simulation results for Double Line to Ground fault

When the system operates without FD-STATCOM and unbalanced DLG fault is occurred. The RMS voltage faces with 20% decrease with respect to the reference voltage.It is observed that the proposed method has correctly mitigated voltage sag.

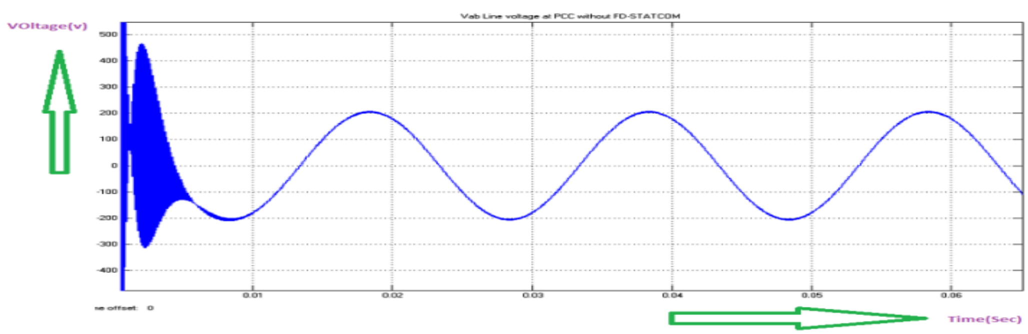

Fig 4.4:Vab line voltage without FD-STATCOM

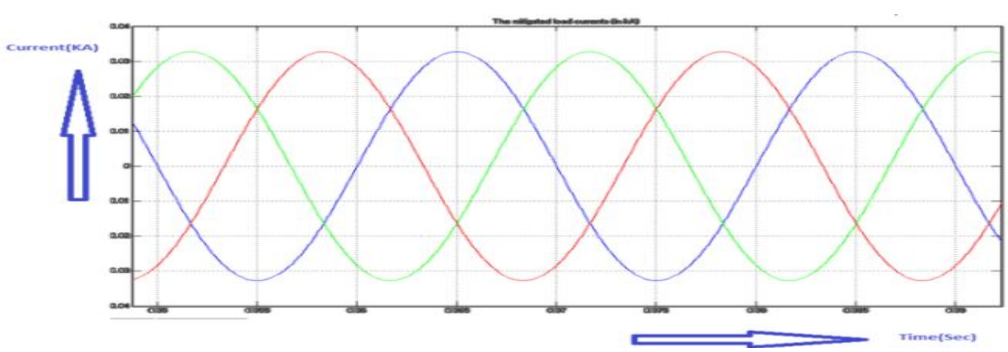

Fig 4.5:the mitigated load current(in KA)

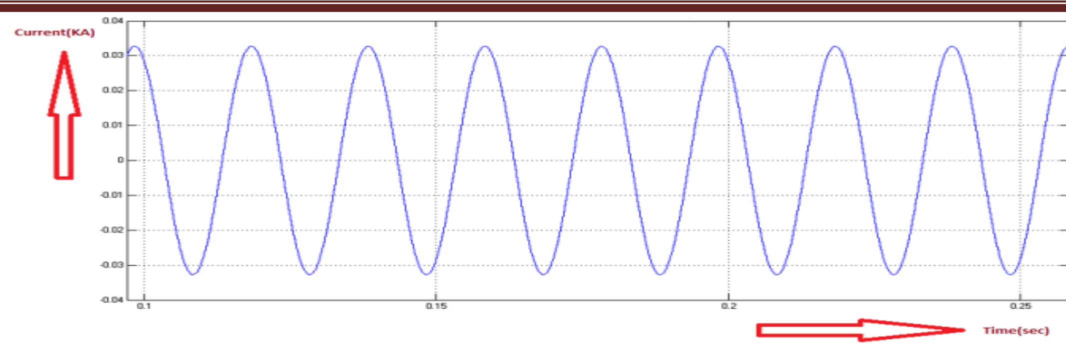

Fig 4.6: Compensated line Current(KA) at the load point

4.3 Simulation Results under islanding condition:

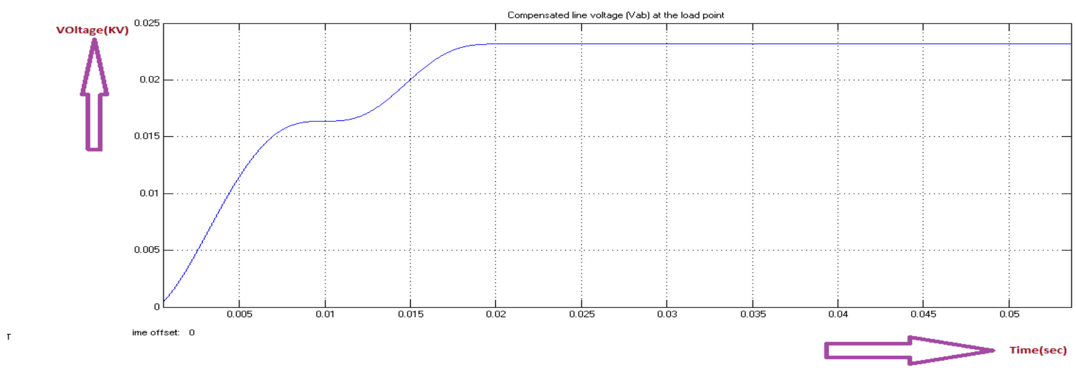

Fig 4.7: RMS voltage without using D-STATCOM

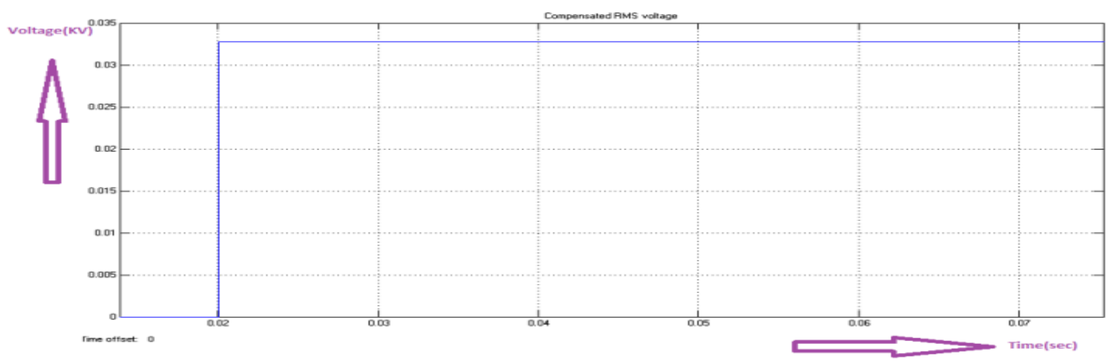

Fig 4.8: Compensated RMS Voltage by using D-STATCOM

5. CONCLUSION:

In this paper, a flexible D-STATCOM is proposed that could both mitigate unbalanced faults (such as LL and DLG faults) and operate as a DG, when it supplies power to sensitive loads while the main utility source is disconnected. As a result, D-STATCOM operates same as a FDG and consequently, it is called FD-STATCOM. In addition, this project has proposed a new control method for mitigating the voltage sags, caused by unbalanced faults and islanding condition, at the PCC. The proposed method is based on integrating FD-STATCOM and SCESS. This proposed control scheme was tested under a wide range of operating conditions (under unbalanced faults and islanded operating condition), and it was observed that the proposed method is very robust in every case. In addition, the regulated VRMS voltage showed a reasonably smooth profile. It was observed that the load voltage is very close to the reference value, i.e., 1pu and the voltage sags are completely minimized. Moreover, the simulation results were shown that the charge/discharge of the capacitor is rapid through this new method (due to using SCESS) and hence the response of the FD-STATCOM is fast.

REFERENCES:

[1]. Ghosh A., Ledwich G: *Power Quality Enhancement Using Custom Power Devices*. Kluwer Academic Publishers, Boston, 2002.

[2]. F. Peng, H. Akagi, H. Nabae: *Compensation characteristics of the combined system of shunt passive and series active filters*, IEEE Trans. on Industry Applications, 1993, Vol.29, No.1, pp.144-15.

[4]. R. Strzelecki, H. Supronowicz: *Power factor in AC supply systems and improvements methods*, Publishing house of the Technical University of Warszawa, Warszawa 2000.

[5]. R. Strzelecki, J. Rusiński, G. Benysek: *Voltage source power quality conditioner*, Electromagnetic phenomena in Nonlinear Circuits - EPNC 2002, XVII Symposium. Leuven, Belgia, 2002, pp. 179-182.

[6]. N. Mariun, H. Masdi, S. M. Bashi, A. Mohamed, and S. Yusuf, "Design of a prototype D-STATCOM using DSP controller for voltage sag mitigation," in *Proc. IEEE International Power and Energy Conference,*
2004.

[7] E. Acha, V.G. Agelidis, O. Anaya-Lara, and T.J.E. Miller, "Power electronic control in electrical systems," Newness Power Engineering Series, 2002, pp. 330-336.

[8] Z. Xi, B. Parkhideh and S. Bhattacharya, Improving distribution system performance with integrated STATCOM and super-capacitor energy storage system," in *Proc. IEEE Power Electronics Specialists Conference*, 2008, pp. 1390-1395.

[9] J. Zhang, "Research on super capacitor energy storage system for power network," in *Proc. IEEE International Conference on Power Electronics*
and Drives Systems, 2005, pp. 1366-1369.

[10] K. Honghai and W. Zhengqiu, "Research of Super Capacitor Energy Storage System Based on DG Connected to Power Grid," in *Proc. IEEE International Conference on Sustainable Power Generation and Supply,* 2009, pp. 1-6. Time (Sec) 573