International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol. 3, Issue. 4, Jul. - Aug. 2013 pp-2367-2373 ISSN: 2249-6645

Mitigation of Fault in the Distribution System by using Flexible Distributed Static Compensator (FD-STATCOM)

B. Giri Prasad Reddy[1], V. Obul Reddy[2]
M. Tech (power electronics), Aurora Engineering College, JNTU Hyderabad, AP, India[1]
Assistant professor, Aurora's Engineering College, JNTU Hyderabad, Andhra Pradesh, India[2]

ABSTRACT: *This paper proposes a flexible D-STATCOM (Distribution Static Compensator) and its new controller system, that be able to mitigate all types of faults (LG, DLG, LL, LLL and LLLG), and improve the distribution system performance. This paper validates the performance of D-STATCOM system to mitigate the power quality problems such as voltage flickers, voltage sags/swells harmonics and improve the distribution system performance under all types of system related disturbances and system unbalanced faults (LG, LL, DLG), balanced faults (LLL and LLLG). A 12-Pulse converter based STATCOM was used to mitigate the voltage flicker with respect to the harmonic problem. A multilevel converter has several advantages over a conventional 12-pulse converter such a Staircase waveform quality, Common-mode (CM) voltage, Input current and harmonic control. Multi level based D-STATCOM configuration with IGBT is designed and the graphic models of the D-STATCOM is developed using the MATLAB/SIMULINK*

KEYWORDS: *Distribution System, D-STATCOM, Voltage Sags, Faults.*

I. INTRODUCTION

The modern power distribution network is constantly being faced with an ever-growing load demand. Distribution networks experience distinct change from a low to high load level every day. Electric load growth and higher regional power transfers in a largely interconnected network becoming more complex and less secure power system operation. Power generation and transmission facilities are unable to meet these new demands. Many loads at various distribution ends like domestic utilities, computers, process industries, adjustable speed drives, printers, and microprocessor based equipment etc. have become intolerant to voltage fluctuations, harmonic content and interruptions[1]. Electrical power losses in distribution systems correspond to about 70% of total losses in electric power systems. One of the most severe problems faced by distribution networks operators is voltage drop along distribution feeders, which is caused by real and reactive power flow. Voltage control is a difficult task because voltages are strongly influenced by random load fluctuations. Voltage profile can be improved and power losses can be considerably reduced by installing Custom Power Devices or Controllers at suitable location.

These controllers which are also named Distribution formally defined as the employment of power electronic or static controllers in distribution systems rated up to 38 kV for the purpose of supplying a level of reliability or PQ Flexible AC Transmission System (D- FACTS) are a New generation of power electronics-based equipment flows in low-voltage distribution networks. Custom power that is needed by electric power customers who are sensitive to power variations. Custom power devices or controllers include static switches, inverters, converters, injection transformers, master-control modules and energy-storage modules that have the ability to perform current-interruption and voltage-regulation functions within a distribution system [2].

The STATCOM is applied in distribution system is called D-STACOM (Distribution STACOM) and its configuration is the same, or with small modifications, oriented to a possible future amplification of its possibilities in the distribution network at low and medium voltage implementing the function so that we can describe as flicker damping, harmonic, filtering and short interruption compensation. D-STATCOM exhibits high speed control of reactive power to provide voltage stabilization, flicker suppression, and other types of system control. The D-STATCOM utilizes a design consisting of a GTO- or IGBT-based voltage sourced converter connected to the power system via a multi-stage converter transformer. This paper proposes a flexible D-STATCOM system designed to mitigate the voltage sags caused by LG, LL, DLG, 3-Phase and 3-Phase to ground faults. And improve the power quality of the distribution system. Reactive power compensation is an important issue in the control of distribution systems. The main reason for reactive power compensation in a system is the voltage regulation increased system stability, better utilization of machines connected to the system, reducing losses associated with the system and to prevent voltage collapse as well as voltage sag. 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]. Various methods have been applied to mitigate voltage sags. The conventional methods use capacitor banks, new parallel feeders, and uninterruptible power supplies (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. By a similar argument, the D-STATCOM is also suitable for reducing the impact of voltage transients The DSTATCOM configuration consists of a typical Three-level voltage source converter arrangement, a dc energy storage device; a coupling transformer connected in shunt with ac system, and associated control circuits. The configurations that are more sophisticated use multi pulse and/or multilevel configurations [4]. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system of network through the reactance of the coupling transformer.

A control method based on RMS voltage measurement has been presented. Where they have been presented a PWM-based control scheme that requires RMS voltage measurements and no reactive power measurements are required. In addition, in this given method, Clark and Park transformations are not required. However, they have been investigated voltage sag/swell mitigation due to just load variation while no balanced and unbalanced faults have been investigated. In this paper, a new control method for mitigating the load voltage sags caused by all types of fault is proposed. A Lookup Table is used to detect the proportional gain of PI controller, which is based only on Trial and Error [5].

While 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.

II. THE PROPOSED D-STATCOM STRUCTURE

The basic electronic block of the DSTATCOM is the voltage source inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency.

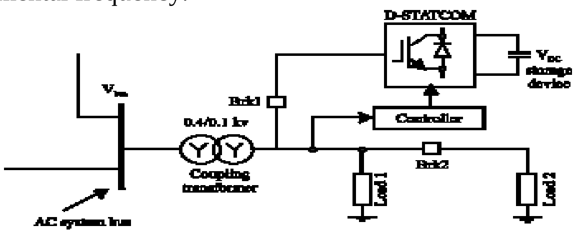

Fig.1 Block diagram of D-STATCOM

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 D-STATCOM output voltages allow effective control of active and reactive power exchanges between the D-STATCOM and the ac system

III. CONTROL STRATEGY

The block diagram of the control scheme designed for the FD-STATCOM is shown in Fig. 3 [6]. It is based only on measurements of the voltage VRMS at the load point.

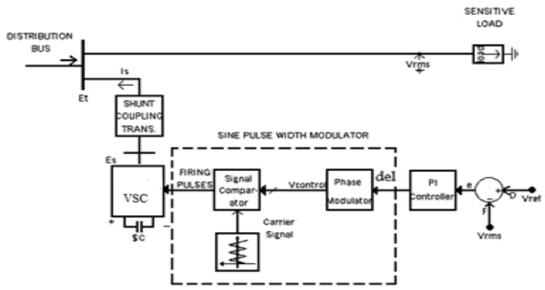

Fig.3. Control scheme designed.

D-STATCOM: The voltage error signal is obtained by comparing the measured VRMS voltage with a reference voltage, VRMSRef. A PI controller processes the difference between these two signals in order to obtain the phase angle δ that is required to drive the error to zero. The angle δ is used in the PWM generator as the phase angle of the sinusoidal control signal. The switching frequency used in the sinusoidal PWM generator is 1450 Hz and the modulation index is 1. The modulating angle δ is applied to the PWM generators in phase A. The angles of phases B and C are shifted 120 and 240 degrees, respectively [7].

IV. PROPOSED CONTROL METHOD

In this paper, in order to mitigate voltage sags caused by LG, LL, DLG, 3-Phase and 3-Phase to ground faults and improve the power quality improvement of the distribution system. 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 control of a D-STATCOM is developed to mitigate such problems and enhance power quality and improve distribution system reliability [8]. D-STATCOM is connected to the Y-Y and Y- Δ transformers for creating the 30 degrees phase shift. Harmonics mitigation will takes place by creating the 30 degrees phase shift.

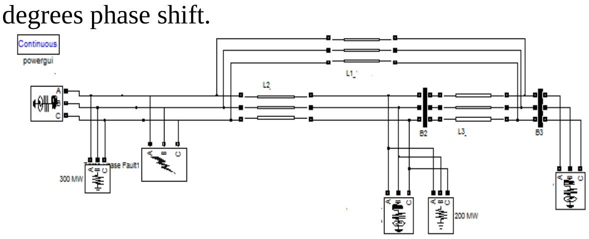

Fig 4: SIMULINK diagram WITHOUT D-STATCOM

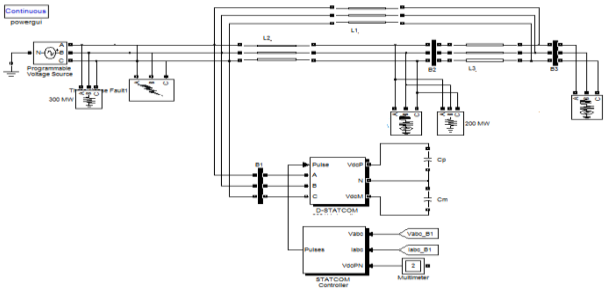

Fig 5: SIMULINK diagram WITH D-STATCOM

Table 1: Specifications of test system

Parameters	Values
Source 1	11KV
Source 2	11KV
Source 3	11KV
Load 1	300KW
Load 2	200KW
Length BW B1 to B2	25Km
Length BW B2 to B3	20Km

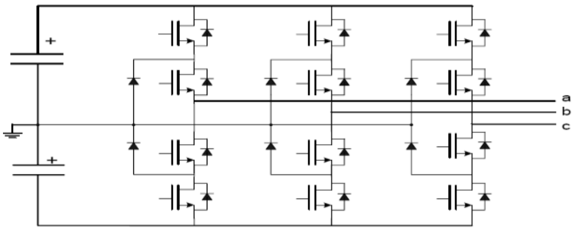

Fig 6: Simulink model for D-STATCOM

V. SIMULATION RESULTS

Fig. 3 shows the test system implemented in MATLAB/SIMULINK to carry out simulations for the FDSTATCOM. The test system comprises a 11 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 Three-level FD-STATCOM is connected to the tertiary winding by closing Brk. 1 at 0.2 s, for maintaining load RMS voltage at 1pu. The dc side provides the FD-STATCOM energy storage capabilities. The simulations are carried out for both cases where the FD-STATCOM is connected to or disconnected from the system.

The simulations of the FD-STATCOM in fault condition are done using LL and DLG faults and under islanded operating condition. In LL and DLG faults the faulted phases are phases A and B while in islanded operating condition, three conductors open by Brk. 2 in 0.4 – 0.5 s. The duration of the islanding condition are considered for about 0.1 s and the LL and DLG faults are considered for about 0.3 s. The faults are exerted at 0.4 s. The total simulation time is 1.6 s. In this paper, the FD-STATCOM uses the proposed control method to mitigate the load voltage sags due to all types of faults. The simulations are done for all types of faults introduced in the 11 kV distribution systems as follows:

A. Simulation results for Line-to-Line fault.

Fig. 7 and 8 show the RMS voltage and Vab (line Voltage) at the load point, respectively, for the case 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. At 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. 9 shows the mitigated RMS voltage using this new method where a very effective voltage regulation is provided.

Fig. 10 shows the compensated Vab at the load point in interval 0.4 - 0.7 s, (when the voltage drops by almost 20% because of the unbalanced LL fault by operating Timed Fault Logic). Fig. 11 shows the Vab frequency spectrums during mitigation of voltage sag that is presented in percent. The THD in percent for Vab in during mitigation of LL fault occurrence is 0.034%. Because of a 12-pulse FD-STATCOM is used in this paper, then the THD for Vab is very small.

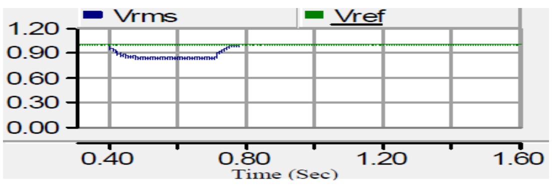

Fig 7: The RMS voltage (VRMS) at PCC without FD-STATCOM

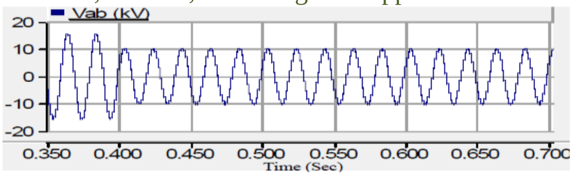

Fig 8: Vab at PCC without FD-STATCOM

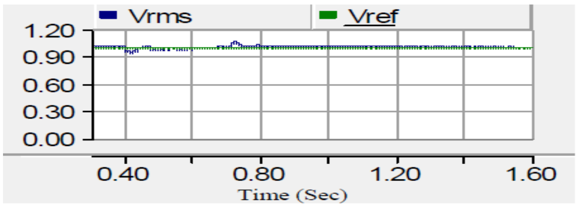

Fig 9: Compensated RMS voltage under LL fault

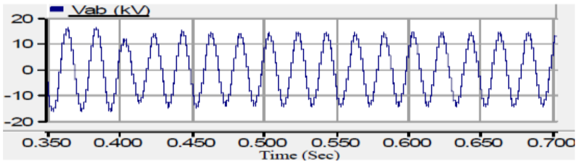

Fig 10: Compensated line voltage (Vab) at the load point

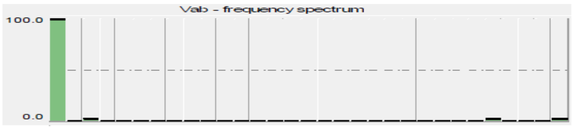

Fig 11: Frequency spectrum for Vab during mitigation of LL fault

B. Simulation results for Double Line to Ground fault

Figs. 12 and 13 show the RMS voltage and line voltage Vab at the load point, respectively, for the case 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.

Figs. 14 and 15 show the compensated RMS voltage and mitigated voltage of Vab at the load point, respectively, under DLG fault using proposed method. It is observed that the proposed method has correctly mitigated voltage sag.

Fig. 16 shows the Vab frequency spectrums during mitigation of voltage sag. The THD of Vab in during mitigation of DLG fault occurrence is very suitable and 0.036%.

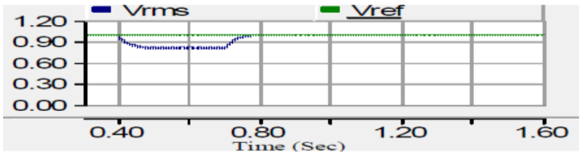

Fig 12: The RMS voltage (VRMS) at PCC without FD-STATCOM

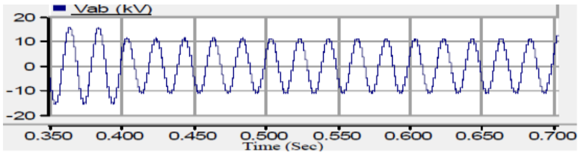

Fig 13: Vab Line voltage at PCC without FD-STATCOM

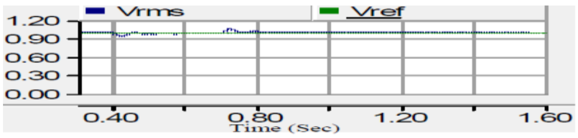

Fig 14: Compensated RMS voltage

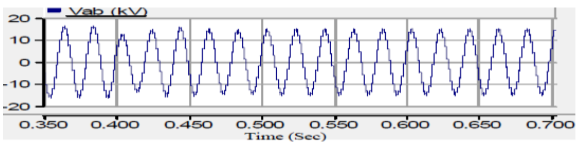

Fig 15: Mitigated line voltage Vab at the load point

The THD of Vab under islanded operating condition is very close to zero and 0.03%. The proposed method merits with respect to the classic methods are simplicity and control convenience and being flexible, i.e. it can mitigate voltage distortions caused by both LL/DLG faults and islanded operating condition only with the same control system setting.

The presented results show that the proposed FDSTATCOM and its controller system not only could mitigate voltage distortions caused by the faults but also have a suitable performance under the islanded operating condition as a FDG.

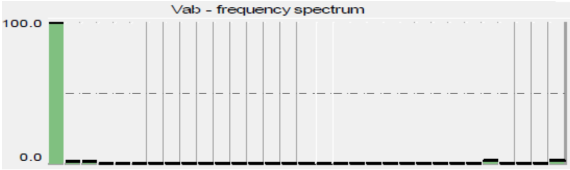

Fig 16: Frequency spectrum for Vab during mitigation of DLG fault

C. Simulation results under islanded operating condition

Figs. 17, 18 and 19 show the RMS voltage, line voltages and load currents (versus kA) at the PCC, respectively, for the case when the system operates without FD-STATCOM and under islanded operating condition.

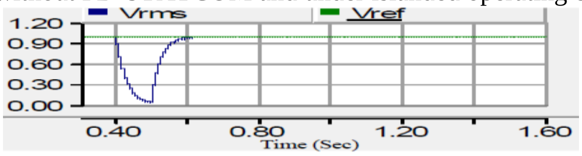

Fig 17: VRMS at PCC without FD-STATCOM under islanding condition

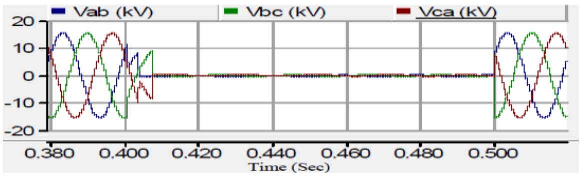

Fig 18: Line voltages at PCC without FD-STATCOM

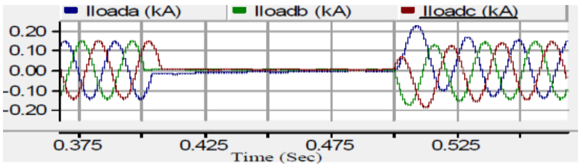

Fig 19: Load currents without FD-STATCOM in islanding condition

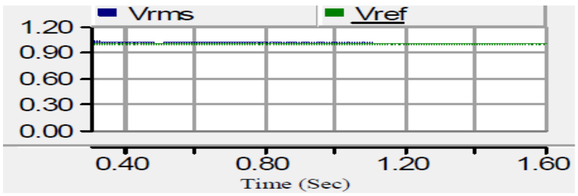

Fig 20: Compensated RMS voltage

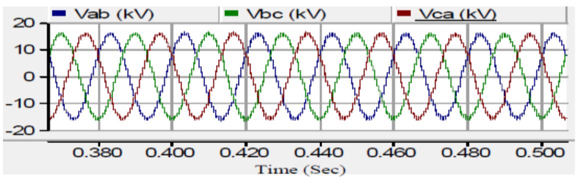

Fig 21: Compensated line voltages at the load point

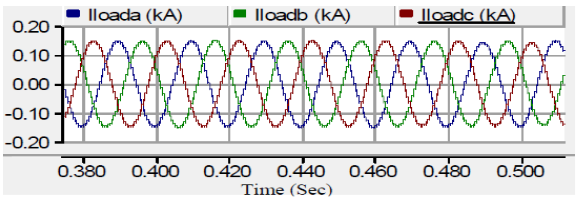

Fig 22: The mitigated load currents (in kA)

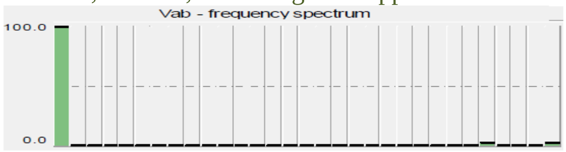

Fig 23: Frequency spectrum for Vab under islanded operating condition

Figs. 20, 21 and 22 shows the mitigated RMS voltage, line voltages at the load point and compensated load currents, respectively, using the proposed method.

It is observed that the RMS load voltage is very close to the reference value, i.e., 1pu and FD-STATCOM is able to supply power to sensitive loads, correctly. Fig. 23 shows the Vab frequency spectrums during mitigation of voltage sag caused by islanding condition. The THD of Vab under islanded operating condition is very close to zero and 0.03%.

The proposed method merits with respect to the classic methods are simplicity and control convenience and being flexible, i.e. it can mitigate voltage distortions caused by both LL/DLG faults and islanded operating condition only with the same control system setting. The presented results show that the proposed FDSTATCOM and its controller system not only could mitigate voltage distortions caused by the faults but also have a suitable performance under the islanded operating condition as a FDG.

Compression of different types of faults without D-STATCOM and with D-STATCON on distributed system

Type of Fault	Without D-STATCOM	With D-STATCOM	IMPROVEMENT IN VOLTAGE
L L Fault	✓ One phase voltage is reduced. ✓ Voltage drops by 20% w.r.t reference voltage. ✓ THD fault occurrence 0.034%	Voltage drop is reduced 10.571KV (voltage reference is 11kV)	96.1%
L L G Fault	✓ Two phase voltage are get affected. ✓ Voltage drops by 22.727% w.r.t reference voltage. ✓ THD fault occurrence 0.036%	Voltage drop is reduced 10.01KV (voltage reference is 11KV)	91%
Islanded Fault	✓ Supply disconnects. ✓ Voltage drops by 36.36% w.r.t reference voltage. ✓ THD fault occurrence 0.03%	Voltage drop is reduced 9.656KV (voltage reference is 11KV)	87.75%

VI. CONCLUSIONS

In this paper, the D-STATCOM and its control system proposed that could mitigate the voltage sags (such as LG, LL, DLG, 3-Phase and 3-Phase to Ground faults) and improved the power quality of the distribution system such as voltage flickers and power factor correction. The D-STATCOM is connected to the Y-Y and Y-Δ, the harmonics generated by a power electronic component is mitigated by providing the 30 degrees phase shift. The operation of the D-STATCOM and its control system are developed in MATLAB/SIMULINK for mitigating the voltage sags and improving the power quality of the distribution system.

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BIOGRAPHIES

V. OBUL REDDY was born in Andhra Pradesh, India, 1986. He received the B.Tech degree in Electrical and Electronics Engineering from JNTU Hyderabad, India, 2009, and the M.Tech. Degree in Power electronics from JNTU Hyderabad, India, 2011. He is presently working as a Asst. Professor in Aurora's Engineering College, AP, India. His main research areas are Switched Mode Converters, Renewable Energy Sources and Electric Drives.

B. Giri Prasad Reddy was born in Nemallagunta Palli,Chittoor at Andhra Pradesd received his B.tech degree from Sindhura College of Engineering and Technology, Ramagundam, Affiliated to JNTU Hyderabad. He is M.Tech degree from Aurora's Engineering College, Bhongir, Hyderabad Affiliated to JNTU Hyderabad. His area of interest is Application of FACTS devices in Power systems.