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FAULT MITIGATION USING FD-STATCOM

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***Abstract*—This paper proposes a FD-STATCOM(Flexible Distribution Static Compensator) and its newcontroller system,that be able to both mitigate all types of faults and operate as aDistributed Generation (DG), hen it supplies power to sensitiveloads while the main utility source is disconnected (i.e. it is underislanded operating condition). Thus D-STATCOM operates sameas a flexible DG (FDG) and consequently, it is called Flexible DSTATCOM(FD-STATCOM). This paper validates theperformance of FD-STATCOM system to mitigate power qualityproblems and improve distribution system performance under alltypes of system related disturbances and system unbalancedfaults, such as Line-to-Line (LL) and Double Line to Ground(DLG) faults and supplies power to sensitive loads underislanding condition. In this paper, the 12-pulse D-STATCOMconfiguration with IGBT is designed and the graphic basedmodels of the D-STATCOM are developed using the MATLAB/SIMULINK software.**

The reliability and robustness of the control schemes in thesystem response to the voltage disturbances caused by faults and islanded operating condition are obviouslyproved in the simulation results.
Keywords-component; FD-STATCOM; Voltage Sags; EnergyStorage Systems; Islanding Condition.

I. INTRODUCTION

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 various faults. Secondly,it can mitigate voltage sags caused by three-phase open-circuitfault by opening the three phases of a circuit-breaker anddisconnecting the main power source (islanding condition).Reactive power compensation is an important issue in thecontrol of distribution systems.

Reactive current increases thedistribution system losses, reduces the system power factor,shrink the active power capability and can cause large-amplitudevariations in the load-side voltage [3-4]. Various methods havebeen applied to mitigate voltage sags. The conventionalmethods use capacitor banks, new parallel feeders, anduninterruptible power supplies (UPS). However, the powerquality problems are not completely solved due touncontrollable reactive power compensation and high costs ofnew feeders and UPS. The D-STATCOM has emerged as apromising device to provide not only for voltage sagmitigation but also for a host of other power quality solutionssuch as voltage stabilization, flicker suppression, power factorcorrection, and harmonic control [5]. D-STATCOM is a shuntdevice that generates a balanced three-phase voltage or currentwith ability to control the magnitude and the phase angle [6].

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Generally, the D-STATCOM configuration consists of atypical 12-pulse inverter arrangement, a dc energy storagedevice; a coupling transformer connected in shunt with acsystem, and associated control circuits, as shown in Fig. 1.The configurations that are more sophisticated use multi-pulseand/or multilevel configurations. The VSC converts the dcvoltage across the storage device into a set of three-phase acoutput voltages. These voltages are in phase and coupled withthe ac system of network through the reactance of the couplingtransformer [7]. A control method based on RMS voltagemeasurement has been presented in [8] and [9] where theyhave been presented a PWM-based control scheme thatrequires RMS voltage measurements and no reactive powermeasurements are required. In addition, in this given method,Clark and Park transformations are not required. However,they have been investigated voltage sag/swell mitigation dueto 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. In [10] and [11], a Lookup Table is used to detect the proportional gain of PI controller, which is based only on Trial and Error. 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. Previous simulations carried out using PSCAD/EMTDC [17]. Here MATLAB Software is taken for simulations.

II. THE 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.

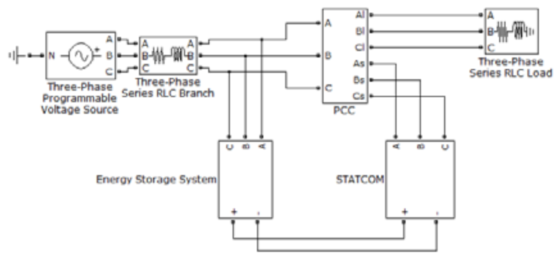

Figure.1. Schematic representation of the FD-STATCOM

Fig. 2 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 [12]. 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.

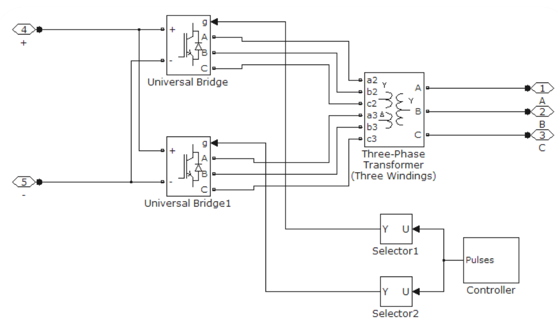

Figure. 2. The 12-pulse FD-STATCOM arrangement

III. CONTROL STRATEGY

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

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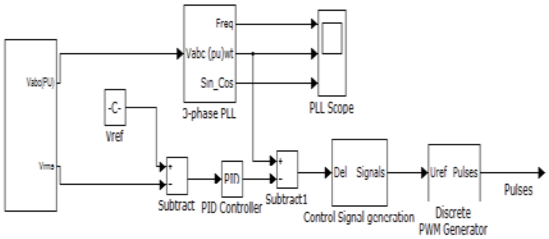

Figure. 3. Control scheme designed for the FD-STATCOM

The voltage error signal is obtained by comparing the measured VRMS voltage with a reference voltage, VRMS_Ref. 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 fsw=1450 Hz and the modulation index is Ma ≈ 1 [13]. 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.

IV. PROPOSED CONTROL METHOD

In this paper, 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. The SCESS is explained as following:

Super capacitor is a new energy device emerged in recentyears. It is also known as double-layer capacitor. Theelectrical double-layer capacitor is a novel energy storagecomponent developed in 1970s. Its pole boards are made ofactivated carbon, which have huge effective surface so thecapacitance could attain several farad even thousands farad.When it is charged, the electric charges are spontaneouslydistributed negative and positive ion layers on the interfacebetween pole boards and electrolyte, so the super capacitordoes not have electrochemical reaction and only have electriccharges adsorption and desorption when it is charged anddischarged. It has many merits such as high charge/dischargecurrent, less maintenance, long life and some other perfectperformance. At the same time, its small leakage currentenables it has long time of energy storage and the efficiencycould exceed 95% [15].

The structure of SCESS is shown in Fig. 4. Its circuit ismainly composed of three parts: rectifier unit, energy storageunit, and inverter unit. Rectifier unit adopts three phase fullbridge rectifier to charge super capacitor and supply dc powerenergy to inverter unit. Inverter unit adopts three phasevoltage inverter composed of IGBTs, it connects to power gridvia transformer. When SCESS works normally, voltage at dcside is converted into ac voltage with the same frequency aspower grid through IGBT inverter. When only consideringfundamental frequency, SCESS can be equivalent to acsynchronizing voltage source with controllable magnitude andphase.

Energy storage unit i.e. super capacitor energy storagearrays are composed of many monolithic super capacitors. If alarge number of super capacitors be in parallel, at the sametime improving capacity of power electronics devices inpower conversion system can be easily composed of morelarge capacity SCESS, but operational reliability and controlflexibility will not be affected. Super capacitor is very easilymodularized, when required, and it is very convenient incapacity expansion.

SCESS based on DG connected to power grid can bedivided into three function blocks: super capacitor arrays components stored energy, power energy conversion system inenergy transformation and transmission, and an integratedcontrol system.

SCESS stores energy in the form of electric field energyusing super capacitor arrays. At the lack of energy emergencyor when energy needed, the stored energy is released throughcontrol system, rapidly and accurately compensating systemactive and reactive power, so as to achieve the balance ofpower energy and stability control.

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Determining the number of energy storage module cansave super capacitors, and further reducing volume, qualityand cost of the energy storage unit.

It is assumed that each super capacitor is represented as anequivalent resistance req and equivalent ideal capacitor ce inseries. R and C of super capacitor bank are R=ns.req/np and C=np.ce/ns, respectively; that ns and np are the number ofmonolithic super capacitors connected in series and parallelfor constituting storage energy module [16].

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. 4.

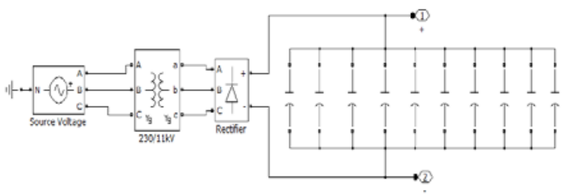

Figure. 4. Structure of SCESS

Fig. 5 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.

V. SIMULATION RESULTS

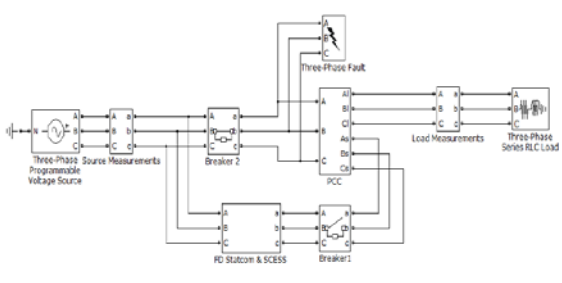

Figure. 5 shows the test system implemented in MATLAB/SIMULINK to carry out simulations for the FDSTATCOM.

The test system comprises a 230 kV transmissionsystem. A balanced load is connected to the 11 kV, secondaryside of the transformer. Brk. 1 is used to control the operationperiod of the FD-STATCOM. A 12-pulse FD-STATCOM isconnected to the tertiary winding by closing Brk. 1 at 0.2 s, formaintaining load RMS voltage at 1pu. A SCESS on the dcside provide the FD-STATCOM energy storage capabilities.The simulations are carried out for both cases where the FDSTATCOMis connected to or disconnected from the system.

The simulations of the FD-STATCOM in fault conditionare done using LL and DLG faults and under islandedoperating condition. In LL and DLG faults the faulted phasesare phases A and B while in islanded operating condition,three conductors open by Brk. 2 in 0.4 – 0.5 s. The duration ofthe islanding condition are considered for about 0.1 s and theLL and DLG faults are considered for about 0.3 s. The faultsare exerted at 0.4 s. The total simulation time is 1.6 s.

In this paper, the FD-STATCOM uses the proposedcontrol method to mitigate the load voltage sags due to alltypes of faults. The simulations are done for all types of faultsintroduced in the 11 kV distribution systems as follows:

A. Simulation results for Line-to-Line fault

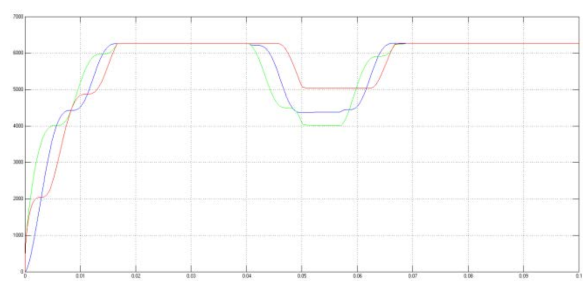

Figure. 6. RMS voltages without FD Statcom under LL Fault

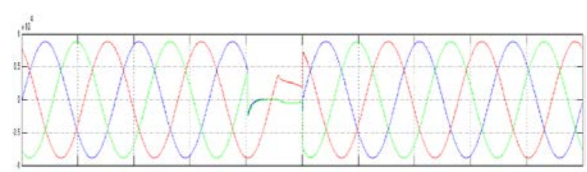

Figure. 7. Load Voltages without FD Statcom under LL Fault

Figs. 6 and 7 show the RMS voltage and phase voltages at the load point, respectively, for the case when thesystem operates without FD-STATCOM and under LL fault.

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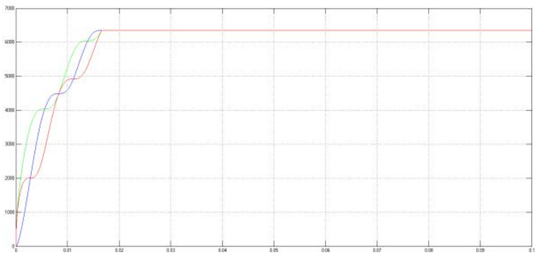

Figure. 8. RMS voltages with FD Statcom under LL Fault

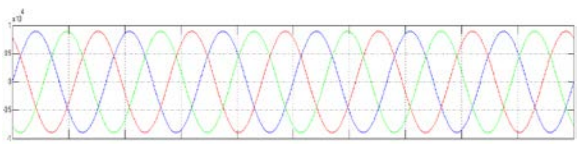

Figure.9. Load voltages with FD Statcom under LL Fault

In t = 0.2 s, the FD-STATCOM is connected to thedistribution system. The voltage drop of the sensitive loadpoint is mitigated using the proposed control method. Fig. 8shows the mitigated RMS voltage using this new methodwhere a very effective voltage regulation is provided. Fig. 9 shows the compensated Load voltages at the load point.

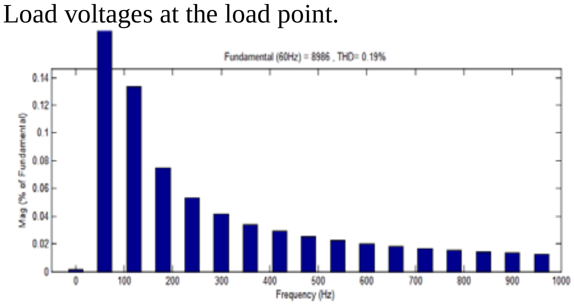

Figure. 10. Frequency Spectrum of load voltages under LL Fault

Fig. 10 shows the load voltages frequency spectrums duringmitigation of voltage sag that is presented in percent. TheTHD in percent for Vab in during mitigation of LL faultoccurrence is 0.19%. Because of a 12-pulse FD-STATCOMis used in this paper, then the THD is very small.

B. Simulation results for Double Line to Ground fault

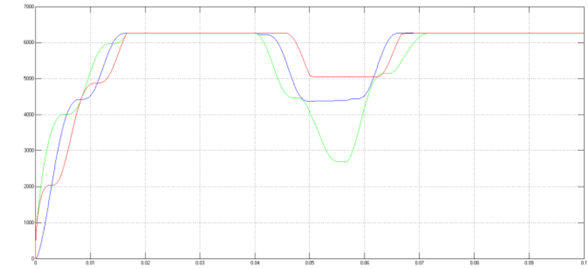

Figure. 11. RMS voltages without FD Statcom under DLG Fault

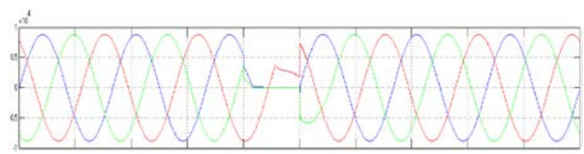

Figure. 12. Load voltages without FD Statcom under DLG Fault

Figs. 11 and 12 show the RMS voltage and line voltagesat the load point, respectively, for the case when thesystem operates without FD-STATCOM and unbalanced DLGfault is occurred.

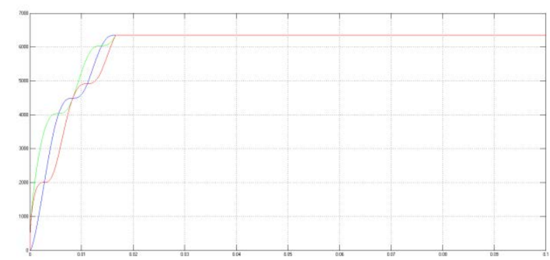

Figure. 13. RMS voltages with FD Statcom under DLG Fault

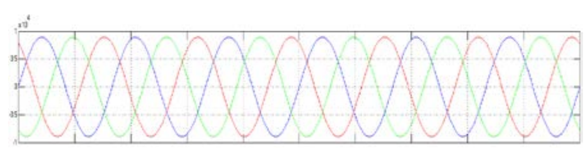

Figure. 14. Load voltages with FD Statcom under DLG Fault

Figs. 13 and 14 show the compensated RMS voltage andmitigated voltage of Vab at the load point, respectively, underDLG fault using proposed method. It is observed that theproposed method has correctly mitigated voltage sag.

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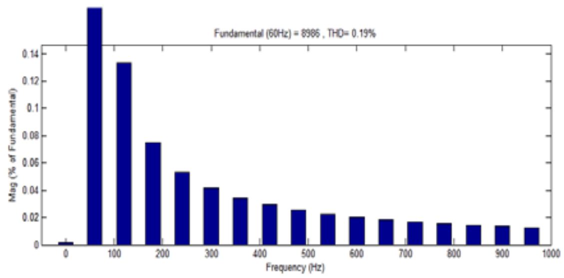


Figure. 15. Frequency Spectrum of load voltages under DLG fault

Fig. 15 shows the Load Voltages frequency spectrums duringmitigation of voltage sag. The THD of Vab in duringmitigation of DLG fault occurrence is very suitable and0.19%.

C. Simulation results under islanded operating condition

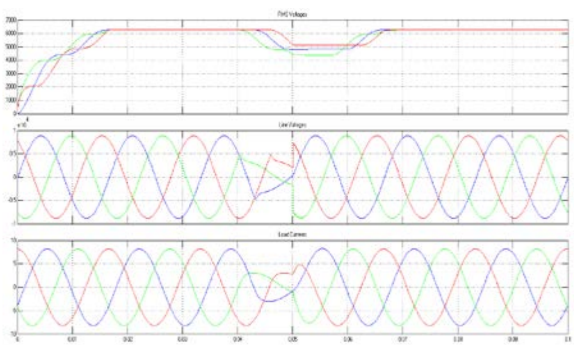
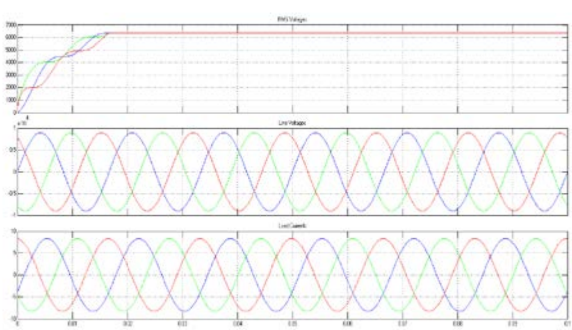


Figure. 16. PCC Measurements under islanded operated condition without FDStatcom

Fig. 16 show the RMS voltage, line voltagesand load currents (versus kA) at the PCC, for thecase when the system operates without FD-STATCOM andunder islanded operating condition.



. Figure. 17. PCC Measurements under islanded operated condition with FDStatcom

Fig. 17 show the mitigated RMS voltage, linevoltages at the load point and compensated load currents, using the proposed method.

It is observed that the RMS load voltage is very close tothe reference value, i.e., 1pu and FD-STATCOM is able tosupply power to sensitive loads, correctly.

Fig. 18 shows the load voltage 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 0.19%.

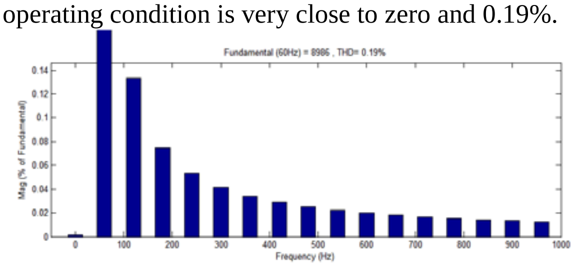


Figure. 18. Frequency Spectrum of load voltages under islanded condition

The proposed method merits with respect to the classicmethods are simplicity and control convenience and beingflexible, i.e. it can mitigate voltage distortions caused by bothLL/DLG faults and islanded operating condition only with thesame control system setting.

The presented results show that the proposed FDSTATCOMand its controller system not only could mitigatevoltage distortions caused by the faults but also have a suitableperformance under the islanded operating condition as a FDG.

VI. CONCLUSION

In this paper, a flexible D-STATCOM is proposed thatcould both mitigate unbalanced faults (such as LL and DLGfaults) and operate as a DG, when it supplies power tosensitive loads while the main utility source is disconnected.

As a result, D-STATCOM operates same as a FDG andconsequently, it is called FD-STATCOM. In addition, thispaper has proposed a new control method for mitigating thevoltage sags, caused by unbalanced faults and islandingcondition, at the PCC. The proposed method is based onintegrating FD-STATCOM and SCESS. This proposed controlscheme 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 inevery case. In addition, the regulated VRMS voltage showed areasonably smooth profile. It was observed that the loadvoltage is very close to the reference value, i.e., 1pu and thevoltage sags are completely minimized. Moreover, thesimulation results were shown that the charge/discharge of thecapacitor is rapid through this new method (due to usingSCESS) and hence the response of the FD-STATCOM is fast.

REFERENCES

[1] M. I. Marei, E. F. El-Saadany, and M. M. A. Salama, “A novel controlalgorithm for the DG interface to mitigate power quality problems,”*IEEE Trans. Power D*el., vol. 19, no. 3, pp. 1384-1392, July 2004.

[2] H. H. Zeineldin, E. F. El-Saadany, and M. M. A. Salama, “Impact of DGinterface control on islanding detection and nondetection zones,” *IEEETrans. Power D*el., vol. 21, no. 3, pp. 1515-1523, July 2006.

[3] C. J. Gajanayake, D. M. Vilathgamuwa, P. C. Loh, F. Blaabjerg, and R.Teodorescu, “A z-source inverter based flexible DG system withP+resonance and repetitive controllers for power quality improvement ofa weak grid,” in *Proc. IEEE Power Electronics Specialists Conference*,2007, pp. 2457-2463.

[4] M. I. Marei, E. F. El-Saadany, and M. M. A. Salama, “Flexibledistributed generation: (FDG),” in *Proc. IEEE Power Engineering Soc.Summer Meeting*, 2002, vol. 1, pp. 49-53.

[5] G. F. Reed, M. Takeda, and I. Iyoda, “Improved power quality solutionsusing advanced solid-state switching and static compensationtechnologies,” in *Proc. IEEE Power Engineering Society WinterMeeting*, 1999, vol.2, pp. 1132-1137.

[6] S. Aizam, B. C. Kok, N. Mariun, H. Hizam, and N. I. AbdWahab,“Linear feedback controller for D-STATCOM in DPG faultapplication,” in *Proc. IEEE Universities Power Engineering Conference*, 2006, vol. 3, pp. 986-990.

[7] L. S. Patil and Ms. A. G. Thosar, “Application of D-STATCOM tomitigate voltage sag due to DOL starting of three phase inductionmotor,” in *Proc. IEEE International Conference on Control,Automation, Communication and Energy Conservation*, 2009, pp. 1-4.

[8] O. Anaya-Lara and E. Acha, “Modelling and analysis of custom powersystems by PSCAD/EMTDC,” *IEEE Trans. Power Del.*, vol. 17, no. 1,pp. 266- 272, Jan. 2002.

[9] H. Hatami, F. Shahnia, A. Pashaei, and S.H. Hosseini, “Investigation onD-STATCOM and DVR operation for voltage control in distributionnetworks with a new control strategy,” in *Proc. IEEE Power Tech.*,2007, pp. 2207-2212.

[10] E. Babaei, A. Nazarloo, and S. H. Hosseini, “Application of flexiblecontrol methods for D-STATCOM in mitigating voltage sags andswells,” in *Proc. IEEE International Power and Energy Conference(IPEC)*, Singapore, 2010, pp. 590-595.

[11] S. H. Hosseini, A. Nazarloo, and E. Babaei, “Application of DSTATCOMto improve distribution system performance with balancedand unbalanced fault conditions,” in *Proc. IEEE Electrical Power andEnergy Conference (EPEC)*, Canada, 2010.

[12] N. Mariun, H. Masdi, S. M. Bashi, A. Mohamed, and S. Yusuf, “Designof a prototype D-STATCOM using DSP controller for voltage sagmitigation,” in *Proc. IEEE International Power and Energy Conference*,2004.

[13] E. Acha, V.G. Agelidis, O. Anaya-Lara, and T.J.E. Miller, “Powerelectronic control in electrical systems,” Newness Power EngineeringSeries, 2002, pp. 330-336.

[14] Z. Xi, B. Parkhideh and S. Bhattacharya, “Improving distribution systemperformance with integrated STATCOM and super-capacitor energystorage system,” in *Proc. IEEE Power Electronics SpecialistsConference*, 2008, pp. 1390-1395.

[15] J. Zhang, “Research on super capacitor energy storage system for powernetwork,” in *Proc. IEEE International Conference on Power Electronicsand Drives Systems*, 2005, pp. 1366-1369.

[16] K. Honghai and W. Zhengqiu, “Research of Super Capacitor EnergyStorage System Based on DG Connected to Power Grid,” in *Proc. IEEEInternational Conference on Sustainable Power Generation and Supply*,2009, pp. 1-6.

[17] Amin Nazarloo, SeyedHosseinHosseini, EbrahimBabaei,“Flexible D-STATCOM Performance as a Flexible Distributed Generation in Mitigating Faults”, *Power Electronics, drive systems and Technologies Conference.*, July 2011.