Applying D-STATCOM Based on New Control Method Under Shunt, Series and Simultaneous Fault Conditions

[1]Amin Nazarloo, Student Member,IEEE, [2]Seyed Hossein Hosseini, Member, IEEE and [3]Mohammad Bagher Bannae Sharifian

[1]Department of Electrical Engineering, Khoy Branch, Islamic Azad University, Khoy, Iran.
[2]Islamic Azad University, Tabriz branch, Tabriz, Iran.
[3]Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran.

Abstract: This paper proposes a new control method for D-STATCOM (Distribution STATIC Compensator) control system. Operating this proposed control method enables D-STATCOM to mitigate all types of fault. This paper validates the performance of D-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 series (open-circuit or open conductor faults) and simultaneous faults. Finally, mitigation of three line to ground fault by new control method and pole placement method is compared. In this paper, the 12-pulse D-STATCOM configuration with IGBT is designed and the graphic based models of the D-STATCOM are developed using the PSCAD/EMTDC electromagnetic transient simulation program. The reliability and robustness of the control schemes in the system response to the voltage disturbances caused by series and simultaneous faults are obviously proved in the simulation results.

Key words: D-STATCOM, Voltage Sags, Energy Storage Systems, Series and Simultaneous Faults.

INTRODUCTION

Abnormal system conditions cause phase unbalance. Phase to ground, phase to phase and open conductor faults are typical examples. These faults cause voltage dips in one or more of the phases involved and may even indirectly cause over voltages on the other phases. The system behavior is then unbalanced by definition, but such phenomena are usually classified under voltage disturbances (B. R. Lakshmikantha *et al*., 2008). There are three types of unbalanced/unsymmetrical faults in power networks, such as shunt, series and simultaneous faults. Unsymmetrical fault types involving one or two phases and ground are:
. A single line to ground fault
. A double line to ground fault
. A line to line fault
These are called shunt faults. The unsymmetrical series type faults are:
. One conductor opens
. Two conductors open
These faults are in series with the line and are called series faults. One or two conductors may be opened, due to mechanical damage or by operation of fuses on unsymmetrical faults (J. C. Das, 2002). Simultaneous faults are a combination of two or more faults that occur at the same time. They may be of the same or different types and may occur at the same or at different locations.

A broken overhead line conductor that falls to earth is a simultaneous one-phase open-circuit and one-phase short-circuit fault at one location (N. D. Tleis, 2008).

Voltage sags are the most important power quality (PQ) problems that many industries and utilities face it. It contributes more than 80% of power quality problems that exist in power systems. Voltage sags are not tolerated by sensitive equipment used in modern industrial plants such as process controllers; programmable logic controllers (PLC), adjustable speed drive (ASD) and robotics (R. C. Dugan *et al*., 1996). Various methods have been applied to reduce or mitigate voltage sags. The conventional methods are by using capacitor banks, introduction of new parallel feeders and by installing uninterruptible power supplies (UPS). However, the PQ problems are not solved completely 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 (S. H. Hosseini *et al*., 2011). D-STATCOM is a shunt device that generates a balanced three-phase voltage or current with ability to control the magnitude and the phase angle (S. Aizam *et al*., 2006). Generally, the D-STATCOM configuration consists of a typical 12-pulse inverter arrangement, a dc energy storage device; a coupling transformer connected in shunt with ac system and associated control circuits, as shown in Fig. 1. The configurations that are more sophisticated use multi-pulse

---

Corresponding Author: Amin Nazarloo, Department of Electrical Engineering, Khoy Branch, Islamic Azad University, Khoy, Iran.
E-mail: nazarloo@ieee.org,

and/or multi-level configurations. The voltage source converter (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. Nazarloo *et al.*, 2011). A control method based on RMS voltage measurement has been presented in (O. Anaya-Lara and E. Acha, 2002) and (H. Hatami *et al.*, 2007) where they have been presented a PWM-based control scheme that requires RMS voltage measurements and no reactive power measurements are required. Also 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 and using the same proportional gain for all types of voltage distortions while no 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 this method, both dc side topology of the D-STATCOM is modified and the performance of control system is improved by leaving a feedback in out of PI controller and then the proportional gain of the PI controller is selected intelligently (based on the proposed Lookup Table in feedback) for mitigating voltage distortions. The robustness and reliability of proposed method is more than mentioned methods. In this method, dc side topology of the D-STATCOM is modified for mitigating voltage distortions. In addition, effects of system faults on the sensitive loads are investigated and the control of voltage sags are analyzed and simulated.

Configuration of D-STATCOM:

Fig. 1 shows the schematic representation of the D-STATCOM. The basic electronic block of the D-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 D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system.

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 D-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 D-STATCOM. The D-STATCOM is connected in shunt to the system (E. Babaei *et al.*, 2010; S. H. Hosseini *et al.*, 2010; N. Mariun *et al.*, 2004).
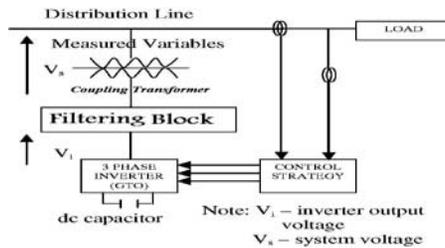

Fig. 1: Schematic representation of the D-STATCOM as a custom power controller.
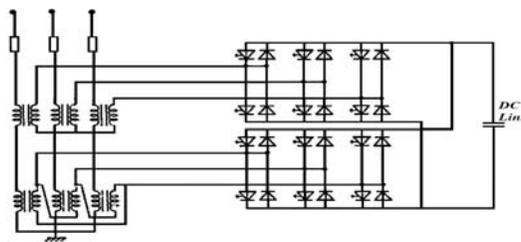

Fig. 2: The 12-pulse D-STATCOM arrangement.

Proposed Control Method:

In this paper, in order to mitigate voltage sags caused by series and simultaneous faults, a new method is proposed in which firstly, the D-STATCOM and super capacitor energy storage system (ESS) are integrated and secondly, a feedback in out of PI controller is used to improve the control system performance under different types of operational conditions.

Considering this fact that all types of faults may occur in distribution system, controller system must be able to mitigate any types of voltage sags. The integration and control of ESSs, such as super capacitor or Ultra

Capacitor (UC) into a D-STATCOM is developed to mitigate such problems, enhance power quality and improve distribution system reliability. The UC is explained as following:

The UC system is known as double layer capacitor. Its pole boards are made of activated carbon, which have huge effective surface so the capacitance could attain several farad even thousands farad. When the UC is charged, the electrons at the cathode attract positive ions and on the anode the vacancies of electrons attract negative ions in order to locally obtain a charged balance. This attraction of ions leads to a capacitance being formed between the ions and the surface of the electrode. The name dual layer comes from the two layers of ions at each electrode. The layer closest to the electrode acts as a dielectric and the layer outside the first layer holds the charges. This occurs at both electrodes in the UC and the total capacitance consists of these two capacitances connected in series. When charges attract ions, they are gathered at the electrode surface. This is shown in Fig. 3 which is an ideal case. In the picture that describes the charged state, all the ions are at the respective electrodes. In reality the diffusion causes some ions to be located at varying distances around the electrodes. The intensity of the electric field determines the concentration of ions at the electrodes, which means that an increased voltage results in an increased capacitance. The UC doesn't have electrochemical reaction and only have electric charges adsorption and desorption when it is charged and discharged therefore its charge/discharge operation is very fast. It has many merits such as high charge/discharge current, less maintenance, long life and some other perfect performance (P. Johansson and B. Andersson, 2008; A. Nazarloo *et al.*, 2011).
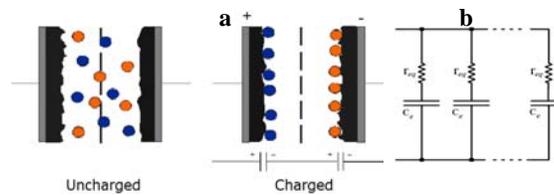

Fig. 3: a UC structure, yellow circles describe positive ions and blue describes negative ions b) DC model of a UC.

The block diagram of the control scheme designed for the D-STATCOM is shown in Fig. 4. The RMS voltage (V_{RMS}) at the Load point is measured instantaneously and compared with the reference value of RMS voltage (V_{RMS_Ref}), that is set to 1p.u., when the fault occurs the V_{RMS} is decreased to less than 1p.u. and the error signal is appeared, thus, the voltage sag is detected. A PI controller processes the difference between these two signals in order to obtain the phase angle delta that is required to drive the error to zero. The angle delta 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 f_{sw}=1450 HZ and the modulation index is $M_a \approx 1$ (E. Acha *et al.*, 2002).

The modulating angle delta is applied to the PWM generators in phase A. The angles of phases B and C are shifted 120 and 240 degrees, respectively.

The new method develops the control concepts of charging and discharging the UC by D-STATCOM and validates the performance of an integrated D-STATCOM/UC system for improving distribution system performance under all types of system related disturbances and system faults, such as series and simultaneous faults. A UC is integrated with dc capacitor. The UC capacitance is determined by applying a constant-current discharge with $C = I \times dt/dv$. Since dv/di is almost constant, UC capacitance can be modeled as a constant. The equivalent series resistance (ESR) is calculated by measuring the output voltage drop from no load to steady-state load and then dividing by the load current. Since the open-circuit voltage has no significant effect on the ESR, the ESR can be modeled as a constant (Z. Xi *et al.*, 2008).

Determining the number of energy storage module can save UC and further reducing volume, quality and cost of the energy storage unit. It is assumed that each UC is represented as an equivalent resistance r_{eq} and equivalent ideal capacitor ce in series, R and C of UC bank respectively are R=$n_s.r_{eq}/n_p$; C= $n_p.c_e/n_s$; that n_s and n_p are the number of monolithic UC connected in series and parallel for constituting storage energy module. In this paper, UC is made of 10 arrays in parallel with c_e=3 mF and r_{eq}=1 Ω for every array.

Regarding that every PI controller has a proportional gain that is playing an important role in D-STATCOM correct performance, it is necessary to use a separated proportional gain for each type of operational conditions. The second part of this method uses a feedback in out of PI controller to improve control system performance. Considering this fact that the PI controller needs different proportional gains for special conditions, such as no fault and fault conditions, therefore this paper proposes a Lookup Table to present separated proportional gains for each special operational conditions. Therefore, the presented Lookup Table operates as a feedback for adjusting the proportional gain of the PI controller in D-STATCOM for mitigating of the voltage distortions, intelligently. As shown in Fig.5, angle delta of PI controller is exerted to Lookup Table, a suitable proportional

gain is selected and eventually, the suitable proportional gain is exerted to PI controller for creating an improved angle delta. The Lookup Table arrangement in feedback that is based on qualitative testing by individual parameter alterations is shown in Table 1. From Table 1, it is observed that the angles between -10 and 10 degree are usually involved in no fault conditions, then a low proportional gain is needed, while the angles from -50 to -10 degree are usually involved in voltage sags caused by fault conditions and hence the high proportional gain is needed and the angles between 10 and 20 degree are usually involved in transient states caused by condition changes from fault state to ordinary (no fault) state and hence a higher proportional gain is needed for mitigating the transient states. The proposed feedback improves the speed of dynamic response of controller system and mitigates the transient states rapidly.

The speed of response and robustness of the control scheme are clearly shown in the simulation results.
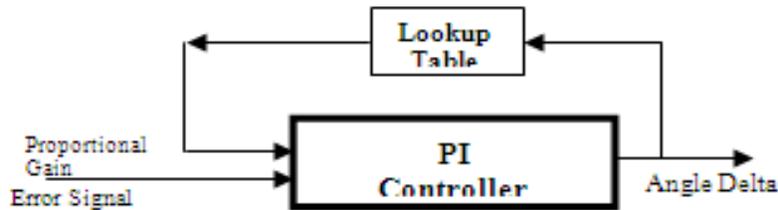
Fig. 4: Application of Lookup Table as a feedback.

Table 1: Lookup Table Arrangement.

Angle Delta	-50	-10	10	20	
Proportional Gains	370		319		386

Simulation Results:

Fig. 6 shows the test system implemented in PSCAD/EMTDC to carry out simulations for the D-STATCOM. 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 period of operation of the D-STATCOM. A 12-pulse D-STATCOM is connected to the tertiary winding by closing Brk. 1 at 0.2 s, for maintaining load RMS voltage at 1pu. An UC on the dc side, instead of capacitor, provide the D-STATCOM energy storage capabilities. Simulations are carried out for both cases where the D-STATCOM is connected to or disconnected from the system. The simulations of the D-STATCOM in fault condition are done using series and simultaneous faults. In series faults, one or two conductors open by Brk. 2.

In simultaneous faults, one phase (phase A) of the 230 kV line has been interrupted (by Brk. 2) and the transformer side or the source side conductor and/or both side conductors has/have fallen on the ground, thus creating a combined phase-to-earth and open-circuit fault. The duration of the series and simultaneous faults are set for about 0.1 s and 0.3 s, respectively. The faults are exerted at 0.4 s. The total simulation time is 1.6 s. In this paper, the D-STATCOM by using proposed control method mitigates load point voltage sags due to all types of faults. The simulations are done for all types of faults as follows:

Simulation Results For Series Faults:

Two situations are analyzed in series faults, such as:

A1. One-phase open-circuit fault:

Fig. 7 shows the representation of an unbalanced one-phase open-circuit fault occurring on phase A.
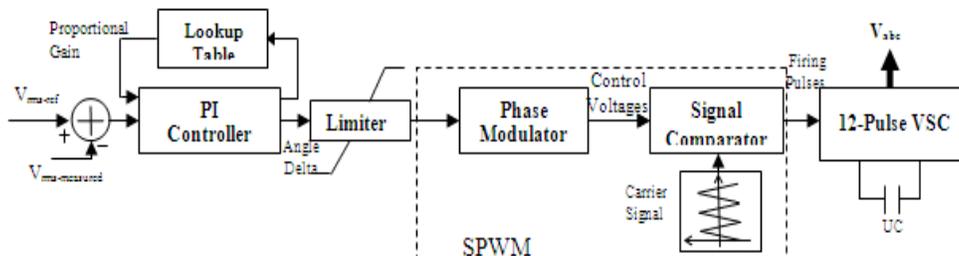
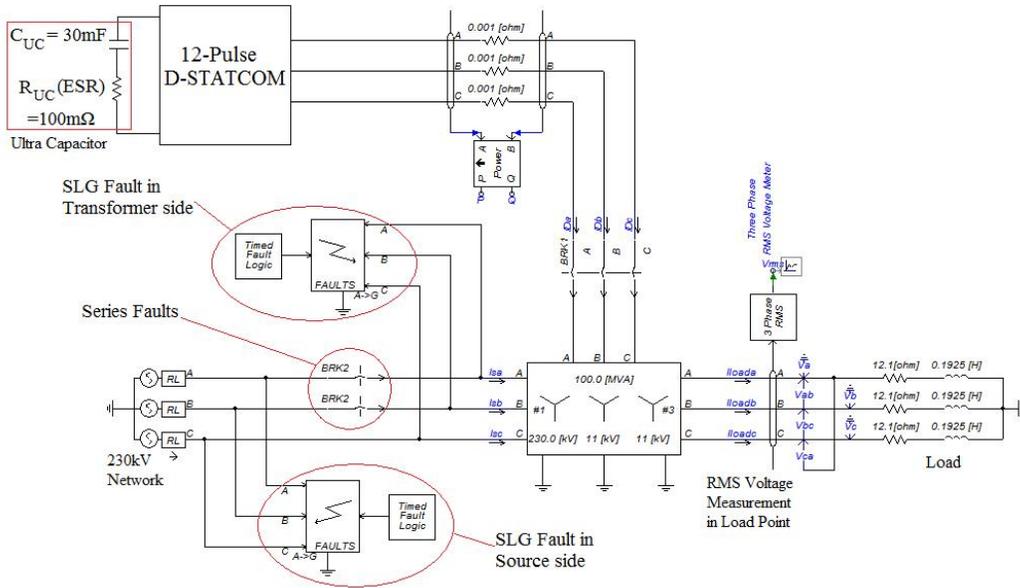**Fig. 5:** Control scheme designed for the D-STATCOM.

Fig. 6: Distribution system with D-STATCOM integrated with UCAP and controller.
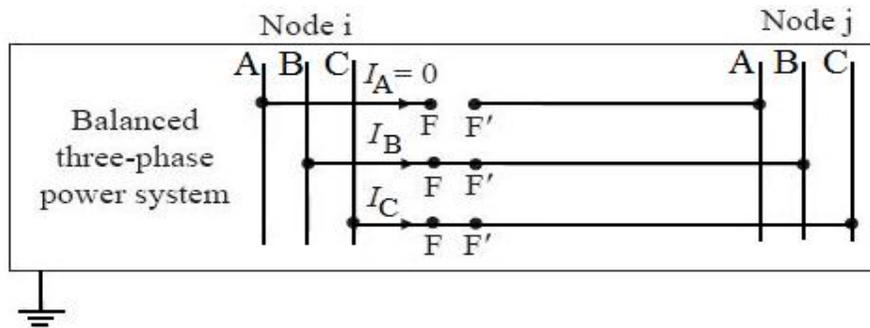

Fig. 7: Unbalanced one-phase open-circuit fault.

Figs. 8 and 9 show the RMS voltage and line voltages at the load point, respectively, for the case when the system operates without D-STATCOM and under one-phase open-circuit fault. In this case, the voltage drops by almost 30% with respect to the reference value. In t = 0.2 s, D-STATCOM is connected to the distribution system. The voltage drop of the sensitive load point is mitigated using the proposed control method. Fig. 10 shows the mitigated RMS voltage using this new method where a very effective voltage regulation is provided. Fig. 11 shows the compensated line voltages at the load point in interval 0.4 - 0.5 s, (when the voltage drops by almost 30% because of the unbalanced one-phase open-circuit fault by opening Brk. 2). In addition, from Figs.10 and 11, it is observed that the detection time of voltage sag is very small because the D-STATCOM should be very fast to answer the transient states and in this method, the UC is used in dc link that has very fast charge/discharge performance.
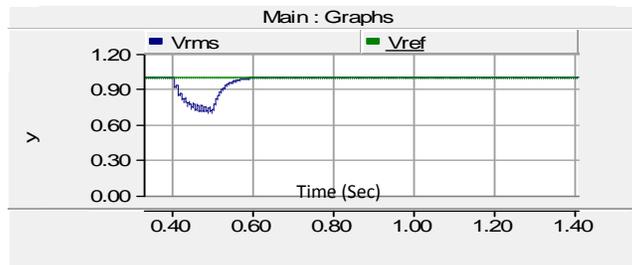
Fig. 8: The V_{RMS} at the load point without D-STATCOM.
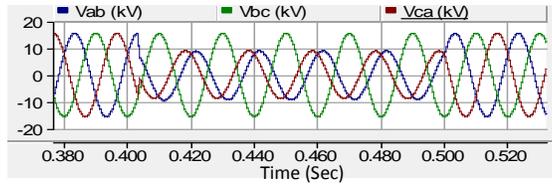
Fig. 9: Line voltages without D-STATCOM.
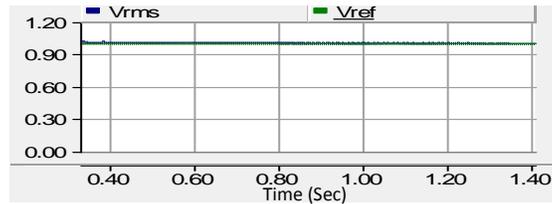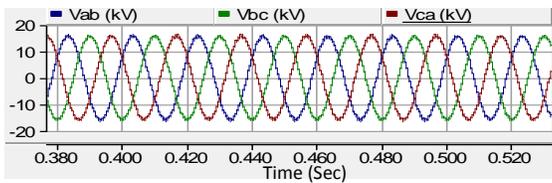

Fig. 10: Compensated RMS voltage.

Fig. 11: Compensated line voltages at the load point.

a2. Two-Phase Open-circuit Fault:

Fig. 12 shows the representation of an unbalanced two-phase open-circuit fault occurring on phases A and B.
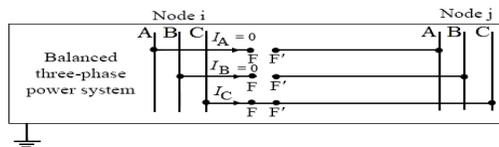

Fig. 12: Unbalanced two-phase open-circuit fault.

Figs. 13 and 14 show the RMS and line voltages at the load point, respectively, for the case when the system operates without D-STATCOM and unbalanced two-phase open-circuit fault is occurred. The RMS voltage faces with 60% decrease with respect to the reference voltage. Figs. 15 and 16 show the compensated RMS and line voltages at the load point, respectively, under two-phase open-circuit fault using proposed method. It is observed that the proposed method has detected voltage sag, rapidly and mitigated it, perfectly.

Moreover, the Total Harmonic Distortion (THD) for line voltage Vab during mitigation of voltage sags caused by series faults is presented in Table 2. It is observed that the THD for Vab in intervals of fault occurrence is very close to zero because a 12-pulse D-STATCOM is used in this paper.

Table 2: THD for Vab during mitigation of voltage sag caused by series faults.

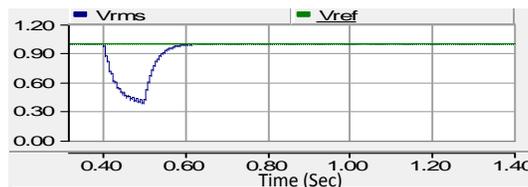| Fault Type	One-phase open-circuit fault	Two-phase open-circuit fault
THD	0.025%	0.030%

Fig. 13: Variation of V_{RMS} at the load point without D-STATCOM under two-phase open-circuit fault.
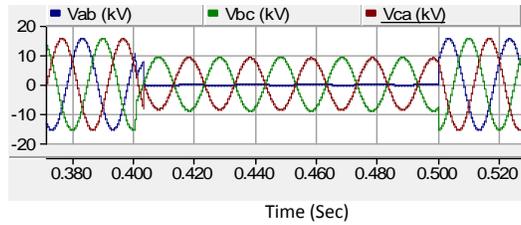
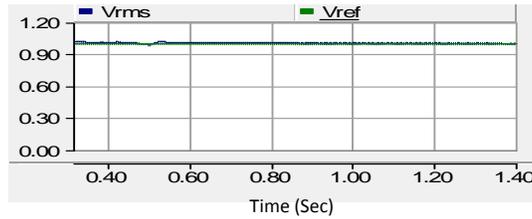**Fig. 14:** Line voltages at the load point without D-STATCOM.
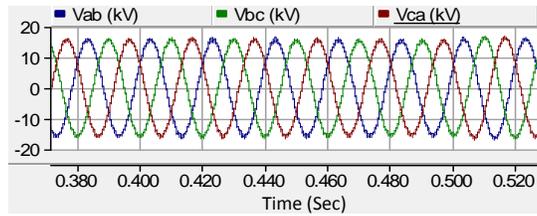

Fig. 15: Compensated RMS voltage.

Fig. 16: Compensated line voltages at the load point.

Simulation Results For Simultaneous Faults:
Fig. 17 shows the representation of a combination of unbalanced one-phase open-circuit fault and short-circuit (earth) fault occurring on phase A. Figs. 18 and 19 show the RMS voltage and line voltage (Vab) at the load point, respectively, for the case when the system operates without D-STATCOM and under simultaneous faults. In this case, the RMS voltage drops by almost 30% with respect to the reference value.
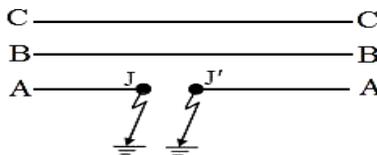

Fig. 17: Combination of unbalanced one-phase open-circuit fault and short-circuit fault.

Three situations are analyzed in simultaneous faults, such as:

B1. Combined Earth Fault on Transformer Side and Open-Circuit Situation:
Figs. 20 and 21 show the mitigated RMS and line voltages at the load point, respectively, using proposed method.
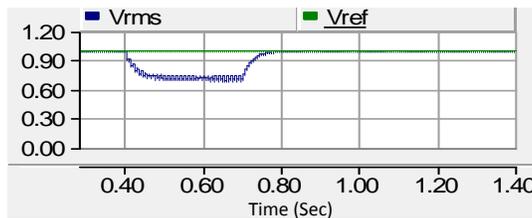It is observed that the RMS load voltage is very close to the reference value, i.e., 1pu.

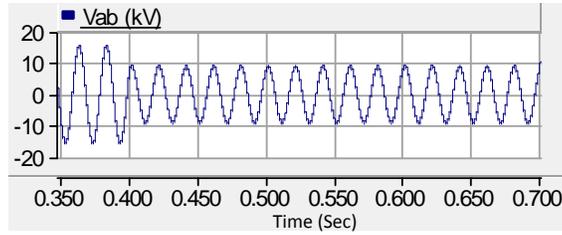**Fig. 18:** V_{RMS} at the load point without D-STATCOM under simultaneous faults.

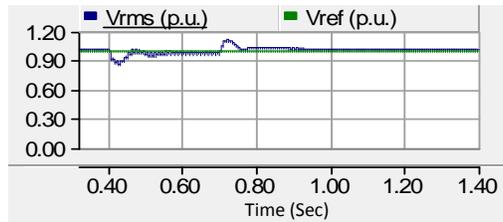**Fig. 19:** Line voltage (Vab) at the load point without D-STATCOM.

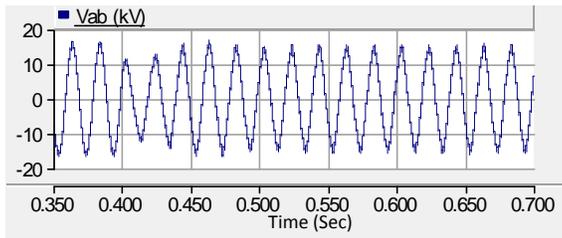**Fig. 20:** Compensated RMS voltage.

Fig. 21: Compensated line voltage (Vab) at the load point.

B2. Combined Earth Fault on Source Side and Open-Circuit Situation:

Figs. 22 and 23 show the mitigated RMS and line voltages at the load point, respectively, using proposed method. It is seen that this situation is very similar to the one-phase open-circuit fault situation, because short-circuit on source side (in one-phase open-circuit fault) does not affect the load point voltage.
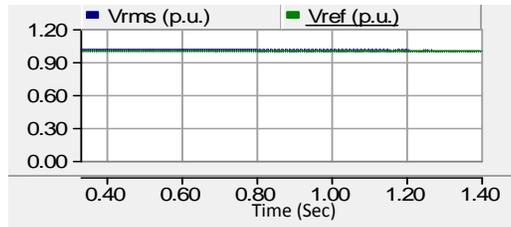

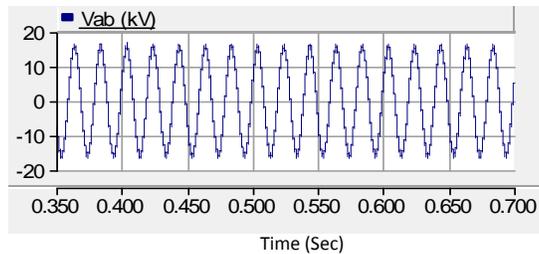**Fig. 22:** Compensated RMS voltage.

Fig. 23: Compensated line voltage (Vab) at the load point.

B3. Combined Earth Fault on Both Side and Open-Circuit Situation:

Figs. 24 and 25 show the mitigated RMS and line voltages at the load point, respectively, using proposed method.

It is observed that this situation is very similar to the combined earth fault on transformer side and open-circuit situation, because of the same mentioned reason in previous situation i.e. short-circuit on source side dose not affect the load point voltage.
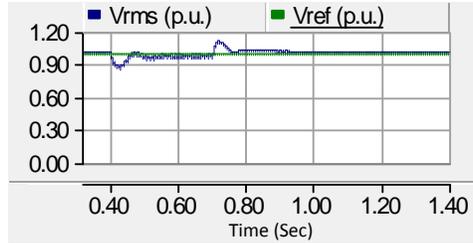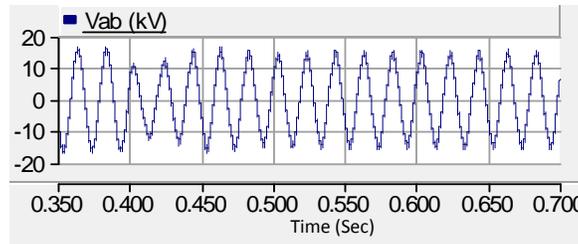
Fig. 24: Compensated RMS voltage.

Fig. 25: Compensated line voltage (Vab) at the load point.

The THD for line voltage Vab during mitigation of voltage sags caused by simultaneous faults is presented in Table 3. It is observed that the THD for Vab in intervals of fault occurrence is approximately zero.

Table 3: THD for Vab during mitigation of voltage sag caused by simultaneous faults.

Fault Type	Combined earth fault on transformer side and open-circuit situation	Combined earth fault on source side and open-circuit situation	Combined earth fault on both side and open-circuit situation
THD	0.060%	0.033%	0.060%

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 series and simultaneous faults only with the same control system setting.

The New Method Comparison With Pole Placement Method:

In this section the mitigation of three lines to ground (TLG) fault analyses by new control method and pole placement controller method (N. Mariun *et al*., 2005). The simulations are done for TLG fault introduced in the 11kV distribution system and are carried out for both cases where the D-STATCOM is connected to and disconnected from the system. Figs.26 and 27 show the RMS voltage and the phase currents at the load point, when the D-STATCOM is not applied to the distribution system, for the new method and pole placement method, respectively. Fault periods in the new method and pole placement method are 0.4 – 0.6 s and 0.1 – 0.3 s, respectively. From the graphs, the percentage of voltage sag during the TLG fault is about 16%, in both methods.

Figs. 28 and 29 show the outputs when the D-STATCOM was connected to the distribution system.

In Fig.28, it is shown that the voltage sag is mitigated and the voltage is maintain at 1.0 p.u. during the simulation and the load currents are increased to their nominal value because the D-STATCOM has injected the compensating currents (VSC currents) to the distribution system.

However, from Figs. 28 and 29, it is observed that in the pole placement method, the amount of injected current during no fault period is very higher than new method. In the other hand, in this new method the amount of injected current during no fault period is about 0 and the VSC inject compensating current to distribution system only during fault period, thus, it is just used to compensate the voltage sag. But in pole placement method, the VSC inject high current even during no fault period that it results in increase of equipment size and losses and decrease of equipment long life.
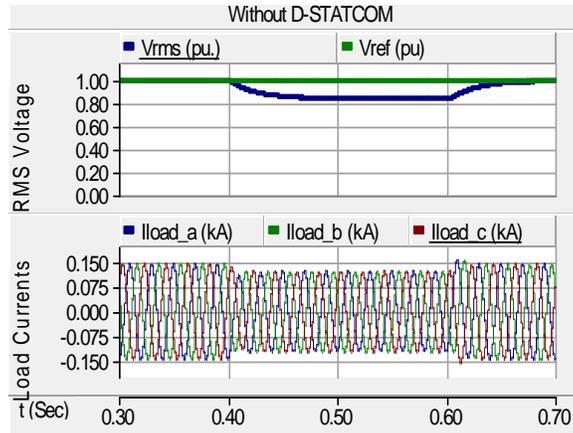
Fig. 26: V_{RMS} and phase currents at the load point for the new method.
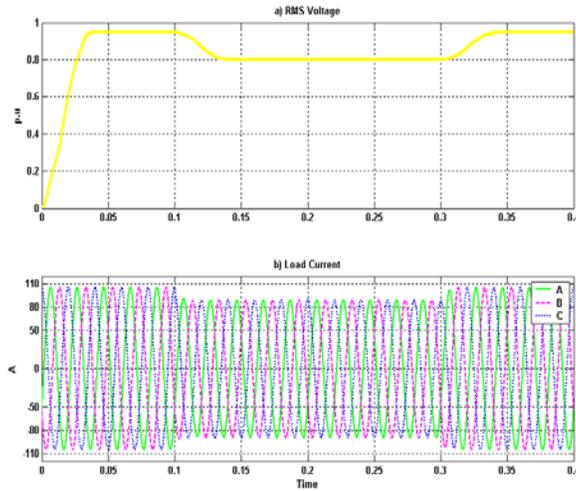

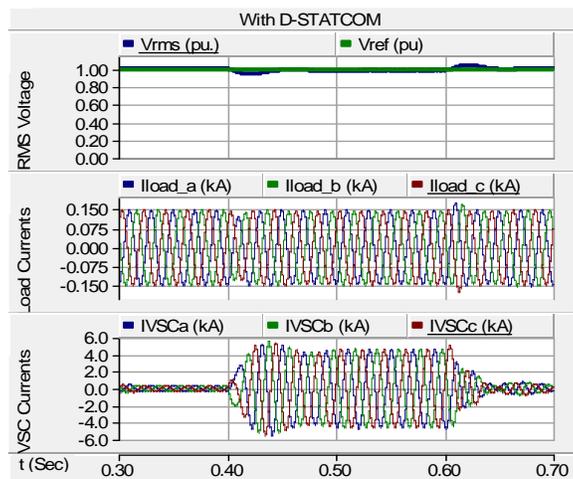**Fig. 27:** V_{RMS} and phase currents at the load point for the pole placement method.

Fig. 28: V_{RMS} and phase currents at the load point and injected currents to the distribution system for the new method.
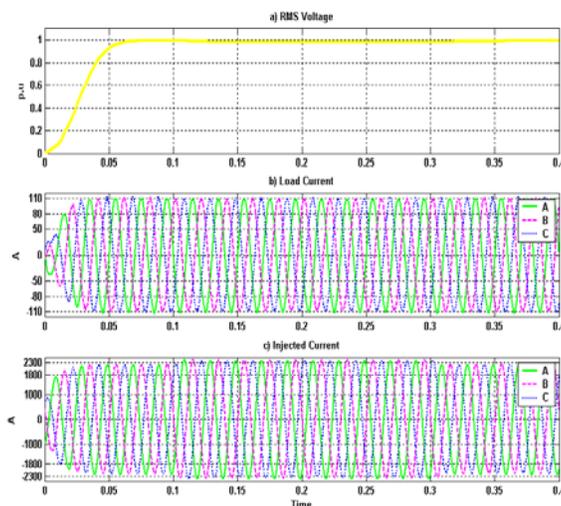
Fig. 29: V_{RMS} and phase currents at the load point and injected currents to the distribution system for the pole placement method.

Conclusion:

In this paper, a new control method for mitigating the voltage sags, caused by unbalanced faults including series and simultaneous faults, at the load point has been proposed. The proposed method is based on two factors; firstly, integrating D-STATCOM and ultra capacitor energy storage system and secondly, using feedback in controller system for determining proportional gain of PI controller, intelligently. This proposed control scheme was tested under a wide range of operating conditions (under all types of series and simultaneous faults) and compared with classic pole placement method and it was observed that the proposed method is very robust in every case. In addition, the regulated V_{RMS} 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 minimized completely. Moreover, the simulation results were shown that the charge/discharge of the capacitor is rapid through this new method (due to using UC) and the response of the D-STATCOM is fast due to using a feedback in controller system. This custom power controller may find application in automated industries with critical loads.

REFERENCES

Acha, E., V.G. Agelidis, O. Anaya-Lara, T.J.E. Miller, 2002. Power Electronic Control in Electrical Systems. Newness Power Engineering Series, pp: 330-336.

Aizam, S., B.C. Kok, N. Mariun, H. Hizam, N.I. Abd Wahab, 2006. Linear feedback controller for D-STATCOM in DPG fault application. In the Proceedings of the *IEEE Universities Power Engineering Conference*, 3: 986-990.

Anaya-Lara, O., E. Acha, 2002. Modelling and analysis of custom power systems by PSCAD/EMTDC. *IEEE Trans. Power Del.*, 17: 266-272.

Babaei, E., A. Nazarloo, S.H. Hosseini, 2010. Application of flexible control methods for D-STATCOM in mitigating voltage sags and swells. In the Proceedings of the *IEEE International Power and Energy Conference (IPEC)*, pp: 590-595.

Das, J.C., 2002. Power System Analysis: Short-Circuit Load Flow and Harmonics. *Amec, Inc.*, Copyright by Marcel Dekker.

Dugan, R.C., M.F. McGranaghan, H.W. Beaty, 1996. Electrical power systems quality. McGraw Hill Companies, Inc.

Hatami, H., F. Shahnia, A. Pashaei, S. H. Hosseini, 2007. Investigation on D-STATCOM and DVR operation for voltage control in distribution networks with a new control strategy. In the Proceedings of the *IEEE Power Tech.*, pp: 2207-2212.

Hosseini, S.H., A. Nazarloo, E. Babaei, 2010. Application of D-STATCOM to improve distribution system performance with Balanced and unbalanced fault conditions. In the Proceedings of the *IEEE Electrical Power and Energy Conference (EPEC)*, pp: 1-6.

Hosseini, S.H., A. Nazarloo, E. Babaei, 2011. Super-Capacitor based D-STATCOM applied in IEEE 13-Bus industrial distribution system. In the Proceedings of the *IEEE 8th International Conference on Electrical*

Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), pp: 715-718.

Johansson, P., B. Andersson, 2008. Comparison of Simulation Programs for Supercapacitor Modeling. Master of Science Thesis, Volvo Technology Corporation, Gothenburg, pp: 3-10.

Lakshmikantha, B.R., M. Mudaliar, K. Balaraman, R. Nagaraja, 2008. Mitigation of voltage unbalance in traction system. In the Proceedings of the WCECS, San Francisco, USA.

Mariun, N., H. Hizam, A.W.N. Izzri, S. Aizam, 2005. Design of the pole placement controller for D-STATCOM in mitigating three phases fault. In the Proceedings of the *IEEE PES Conference and Exposition*, pp: 349 - 355.

Mariun, N., H. Masdi, S.M. Bashi, A. Mohamed, S. Yusuf, 2004. Design of a prototype D-STATCOM using DSP controller for voltage sag mitigation. In the Proceedings of the *IEEE International Power and Energy Conference*.

Nazarloo, A., M. Sadeghi, S.H. Hosseini, E. Babaei, 2011. Mitigation of voltage sags in a sample distribution system using flexible D-STATCOM. In the Proceedings of the 19th Iranian Conference on Electrical Engineering (ICEE), pp: 1-6.

Nazarloo, A., S.H. Hosseini, E. Babaei, 2011. Flexible D-STATCOM performance as a flexible distributed generation in mitigating faults. In the Proceedings of the *IEEE 2nd Power Electronics, Drive Systems and Technology Conference (PEDSTC)*, pp: 568-573.

Tleis, N.D., 2008. Power Systems Modelling and Fault Analysis: Theory and Practice. Published by Elsevier Ltd.

Xi, Z., B. Parkhideh, S. Bhattacharya, 2008. Improving distribution system performance with integrated STATCOM and super-capacitor energy storage system. In the Proceedings of the *IEEE Power Electronics Specialists Conference*, pp: 1390-1395.