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Mitigation of Voltage Sag with Multi-Type Custom Power Devices Using MATLAB-SIMULINK

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Abstract*— Power quality of gains its importance with the introduction of sophisticated electrical gadgets. The performances of these devices are sensitive to the quality of input power supply. Various power quality problems results in failure or mal-operation of end user equipments. One of the major problems is voltage sag. To solve this problem, capacitors and voltage regulators are conventionally used. These techniques involve inherent drawbacks. With the advancement of power electronic devices these drawbacks can be overcome easily. The invention of various custom power devices such as Distribution Static Compensator (D-STATCOM), Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioner (UPQC) can be used to mitigate voltage sag. In this work, it is proposed to mitigate voltage sag and to improve the reactive power support at the end user level by using, multi-type custom power devices like DVR and D-STATCOM. Custom power devices are the most efficient and effective modern devices used in power distribution network. These devices have added advantages like lower cost, smaller size, and fast dynamic response to disturbances. The proposed work presents the analysis of simulating multi-type custom power devices namely DVR and D-STATCOM for voltage sag reduction problem using in MATLAB-SIMULINK.

***Index Terms*— Voltage Sag, Multi-Type Custom Power Devices, DVR, D-STATCOM, MATLAB-SIMULINK.**

I. INTRODUCTION

The term "Power Quality" is associated with electrical distribution and utilization systems. The deviation of the electrical parameters like voltage, current, frequency etc… from its rated value may cause power quality problems like interruption, voltage sag, voltage swell, waveform distortion and harmonics. Research related to power quality issues are focused only during the last decade. Voltage sag is one of the major power quality problems at the end user level. It refers to long duration voltage reduction. Remote location of load from power source, Switching of heavy loads, capacitors, and transformers and unbalanced load on a three phase system are some of the sources that contribute voltage sag. If this problem is not encountered at the right time it may lead to interruption and mal-operation end user facilities. Transformer with a tap changer, Constant voltage (CVT/ Ferro-resonant) transformer, Switch Mode Power Supply (SMPS), saturable reactor and custom power devices are some of the means that can combat with voltage sag problem. While Flexible AC Transmission Systems (FACTS) deal with transmission issues, the custom power devices are applied to the distribution sector to deal with power quality issues. The power electronic devices applied at the customer location for load and voltage compensation and regulation is termed as custom power device which can be of shunt and series type. The strength and benefits of these devices become manifold, when they are combined and this concept leads to the evolution of multi-type custom power devices. In this work it is proposed to reduce voltage sag by using the combination of two different custom power devices namely DVR (series type) and D-STATCOM (shunt type). The devices are designed using MATLAB SIMULINK. In order to justify their functionality the devices are connected to the proposed 14 bus system [21] and the simulated results are analyzed both numerically and graphically.

II. LITERATURE SURVEY

A power system is a complex interconnected structure with generation, transmission and distribution sectors as its components. The power from generation system is connected to the distribution system through long transmitting lines. The quality of power has a direct economic and financial impact on both utilities and industrial customers. Various power quality problems occur when a nonstandard voltage, current or frequency results in failure or mal-operation of end user equipments. One of the major problem is voltage sag [1, 2]. To solve this problem, capacitors, reactive power compensators and voltage regulators were conventionally used. These techniques involve inherent drawbacks. With the advancement of power electronic devices these drawbacks can be overcome easily. To reduce a severity of power quality problems, mitigation devices can be placed in the transmission and distribution systems. The concept of Flexible AC Transmission Systems (FACTS) was introduced by N.G. Hingorani to combat with the power quality issues that originates from transmission systems [3, 4]. The invention of various custom power devices [5, 6] such as Distribution Static Compensator (D-STATCOM), Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioner (UPQC) can be used to solve the power quality problem in economical way than by using FACTS devices. The custom power devices are broadly classified into two categories namely series and shunt devices. DVR is connected in series with the system which is operates in voltage control mode and it is used to protect sensitive loads from sag/swell or disturbances in the supply voltage [7-9]. D-SATCOM is

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connected in shunt and operated in current control mode that eliminated harmonics and/or unbalance [10-12]. A better solution can be obtained by using both series and shunt devices together in the system. This thought results in the usage of multi-type custom power devices in the system for the improvement of power quality [13-15].

III. METHODOLOGY

A. The concept of Dynamic Voltage Restorer

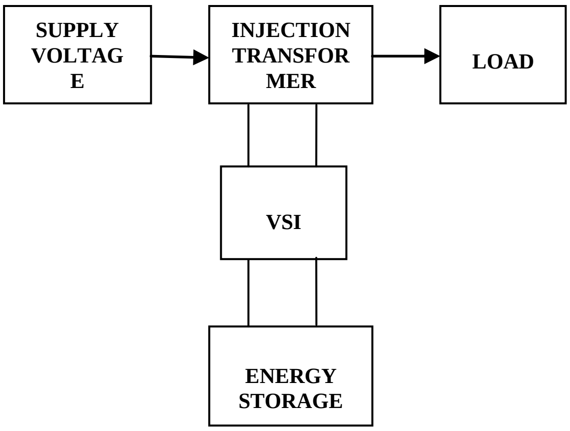

Fig 1: Block Diagram of DVR

The block diagram of Dynamic Voltage Restorer (DVR) is shown in Fig 1. A DVR is a custom power device used to eliminate the supply side voltage disturbances. The magnitude and phase of load voltage is maintained at nominal value by compensating the voltage sag/swell [7]. The dynamic voltage restorer is connected in series between the source voltage and sensitive load through injection transformer. The DVR is typically installed in a distribution system and the function of the restorer is to rapidly boost up the load-side voltage in the event of a disturbance in order to avoid any power disruption to that load. The DVR is used to inject only the missing part ie.sag or swell voltages. The injection (booster) transformer, a harmonic filter, a Voltage Source Inverter (VSI), DC charging circuit, control system and protection system are the major components of DVR. In most sag correction techniques, the DVR is required to inject active power into the distribution line during the period of compensation [8]. The injection transformer is connected series between the supply side and load side voltages. The series Voltage Source Inverter (VSI) can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. The energy storage consists of a capacitor which gives dc input to the inverter. The inverter is responsible for converting DC to AC. It also ensures that only the swell or sag voltage is injected to the injection transformer. During voltage sag, the DVR injects a voltage to restore the load supply voltages [9].

B. Protecting sensitive loads using DVR

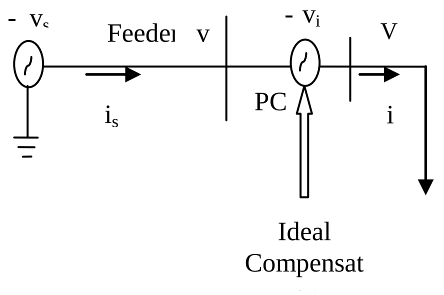

Fig 2: Load Compensation Using DVR

DVR is used to protect sensitive loads from sag/swell or disturbances in the supply voltage. The Fig 2. shows the schematic diagram of a sensitive load protected by an ideal series compensator. The DVR is represented by the ideal voltage source that injects a voltage v_f in the direction shown. The resulting load voltage is equal to the sum of supply voltage and injected voltage. $v_l = v_t + v_f$, Where v_l is the load bus voltage. The DVR can regulate the bus voltage to any arbitrary value by measuring the terminal voltage v_t and the supplying the balance through v_f.

C. The concept of Distribution Static Compensator

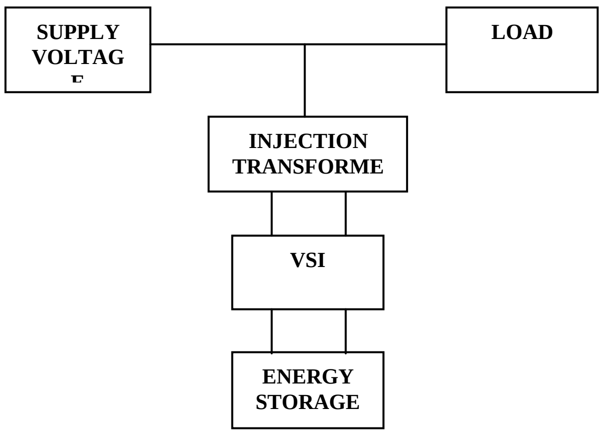

Fig 3: Block Diagram of D-STATCOM

A Distribution Static Compensator (D-STATCOM) is one of the custom power devices which are used to eliminate the harmonics from the source current [10]. It will also provide reactive power compensation to improve the power factor. It operates in voltage control mode in which it is required to follow a set of reference voltages [11]. The Fig 3. Shows the block diagram of D-STATCOM. It employs the same block as DVR but the only difference is the injection transformer is connected in shunt. The D-STATCOM provides not only for voltage sags mitigation but also provides other power quality solutions such as voltage Stabilization, flicker suppression, power factor correction and harmonic control [12].

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D. Load compensation using DSTATCOM

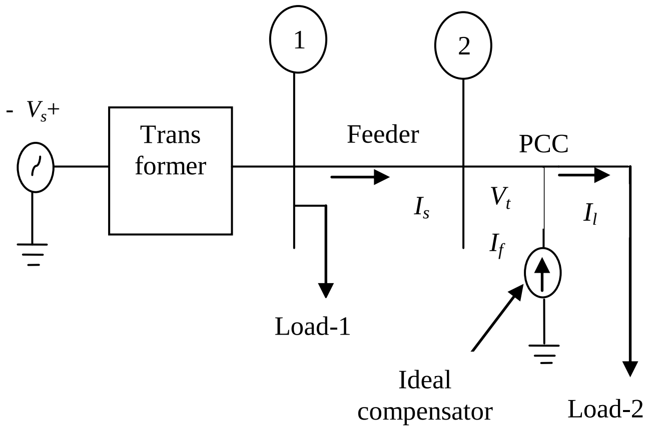

Fig 4: Load Compensation Using D-STATCOM

The Fig 4. Shows a 3-phase, 4-wire distribution system compensated by an ideal shunt compensator (DSTATCOM). Load-2 is assumed as reactive, nonlinear, and unbalanced. In the absence of the compensator, the current I_s flowing through the feeder will be unbalanced and distorted and hence the Bus-1 voltage will also be distorted. To alleviate this problem, the compensator must inject the current such that the current I_s becomes fundamental and positive sequence. In addition, the compensator can also force the current I_s to be in phase with the Bus-2 voltage. The point at which the compensator is connected is called the utility-customer Point of Common Coupling (PCC). Denoting the load current by I_l the KCL at the PCC yields $I_s + I_f = I_l$ and $I_s = I_l - I_f$. The desired operation of the compensator is that generate a current I_f such that it cancels the reactive component. The ideal compensator will inject current (I_f) that cancel from the load current, balance the load and forces the current drawn from the source to be unity power factor.

E. Voltage regulation using DSTATCOM

The Fig 5 (a). shows an ideal shunt compensator acting as a voltage regulator. This ideal compensator is represented by a voltage source and it is connected to the PCC.

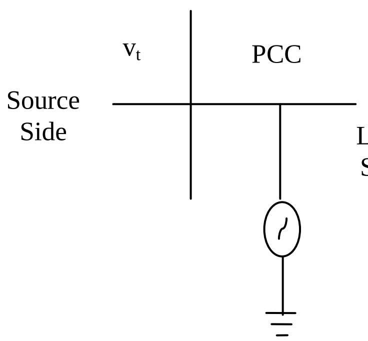

Fig 5(a): Ideal voltage controller

However it is rather difficult to realize this circuit and alternate structure is shown in Fig 5 (b). It has the advantage that the harmonics can be bypassed by the filter capacitor C.

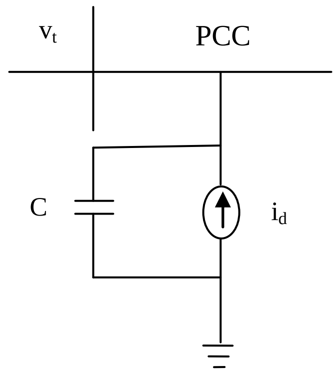

Fig 5(b): Practical realization of D-STATCOM

The basic idea is to inject the current i_d in such a way that the voltage v_t follows a specific reference. The compensator must be operated such that it does not inject or absorb any real power in the steady state.

IV. RESULTS AND DISCUSSION

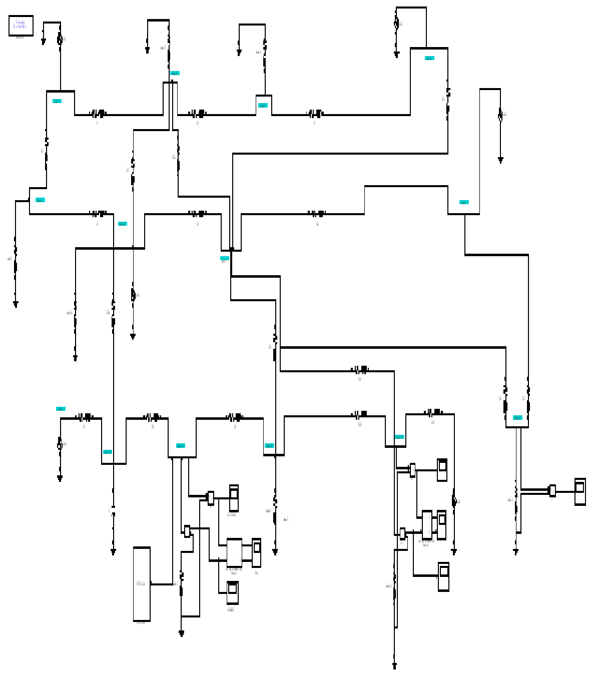

Fig 6: 14 Bus Systems with DVR & D-STATCOM

The proposed 14 bus system [21] is designed, simulated and analyzed for double line to ground fault (LLG) with multi-type custom power devices namely DVR and D-STATCOM connected at bus 11 and bus 14. Fig 6. shows the MATLAB-SIMULINK model with DVR and D-STATCOM at bus 11. Similarly analysis is carried out by connecting the devices at bus 14 and suitable parameters are calculated.

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F. Numerical Analysis

Table 1. DVR and D-STATCOM at bus-11

Measuring parameter	Without device	With DVR & DSTATCOM
Real Power (KW)	48.1	49.75
Reactive Power (KVar)	0.4008	0.4146
Bus Voltage (V)	69.3	69.8
Bus Current (A)	0.694	0.7125

Table 1. Shows the comparative analysis of various parameters of the 14 bus system without and with DVR and D-STATCOM connected at bus 11. It is inferred that the real power (P), reactive power (Q), bus voltage (V), bus current (I) are improved with the presence of the proposed multi-type custom power devices DVR and D-STATCOM.

Table 2. DVR and D-STATCOM at bus-14

Measuring parameter	Without device	With DVR & DSTATCOM
Real Power (KW)	39.32	39.75
Reactive Power (KVar)	0.3277	0.3313
Bus Voltage (V)	88.63	89.5
Bus Current (A)	0.885	0.895

Table 2. shows the comparative analysis of various parameters of the 14 bus system without and with DVR and D-STATCOM connected at bus 14. It is inferred that the real power (P), reactive power (Q), bus voltage (V), bus current (I) are improved with the presence of the proposed multi-type custom power devices DVR and D-STATCOM.

G. Graphical Analysis

The Fig 7 (a-c) shows the real power graphical analysis of the proposed 14 bus system simulated for double line to ground fault (LLG) without and with multi-type custom power devices connected at bus 11 and bus 14 using MATLAB SIMULINK V7.12.0, Internal Core Processor 2.2GHz.

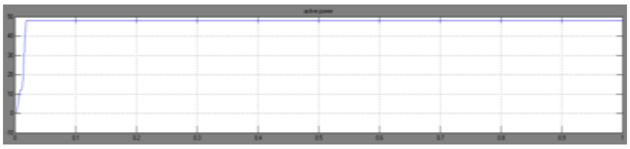

Fig 7 (a): Real power (P) without custom power devices

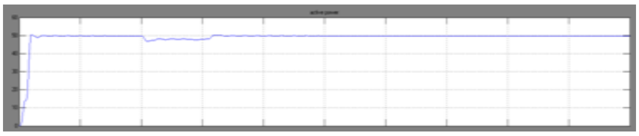

Fig 7 (b): Real power with DVR & D-STATCOM at bus11

Fig 7 (c): Real power with DVR & D-STATCOM at bus 14

The real power output without any device is 48.1 KW. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the real power output for the later is more than the former case by a value of 1.65 KW. The real power output with device placed at bus 14 is 39.32 KW. It is observed that the real power output for the later is greater than the former case by a value of 0.43 KW.

The Fig 8 (a-c) shows the reactive power graphical analysis of the proposed 14 bus system simulated for double line to ground fault (LLG) without and with multi-type custom power devices connected at bus 11 and bus 14.

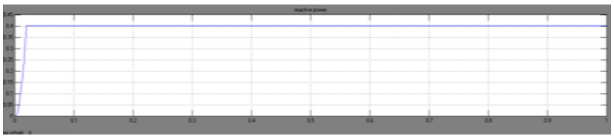

Fig 8 (a): Reactive power without custom power devices

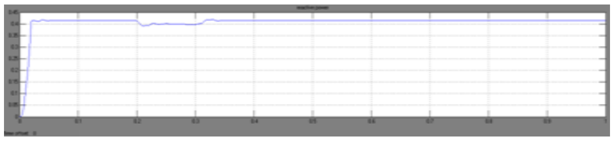

Fig 8 (b): Reactive power with DVR & D-STATCOM at bus 11

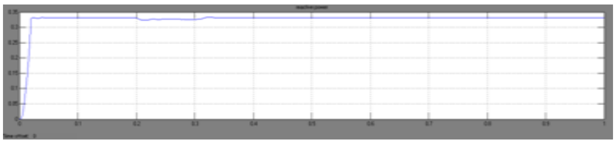

Fig 8 (c): Reactive power with DVR & D-STATCOM at bus 14

The reactive power output without any device is 0.4008 KVar. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the real power output for the later is more than the former case by a value of 0.0138 KVar. The real power output with device placed at bus 14 is 0.3277 KVar. It is observed that the real power output for the later is greater than the former case by a value of 0.0036 KVar.

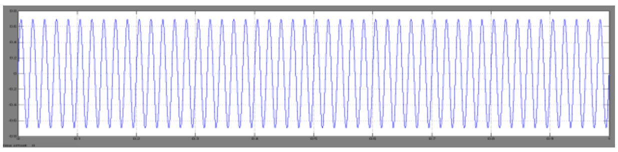

Fig 9 (A): Bus Voltage without Custom Power Devices

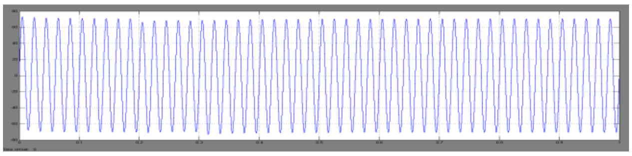

Fig 9 (b): Bus voltage with DVR & D-STATCOM at bus 11

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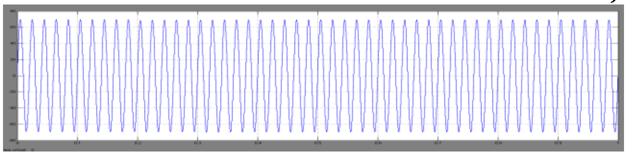

Fig 9 (c): Bus voltage with DVR & D-STATCOM at bus 14

The Fig 9 (a-c) shows the graphical analysis of voltage simulated for double line to ground fault (LLG) without and with multi-type custom power devices connected at bus 11 and bus 14. The output voltage without any device is 69.3 V. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the reactive power output for the later is more than the former case by a value of 0.5 V. The reactive power output with device placed at bus 14 is 88.63 V. It is observed that the reactive power output for the later is greater than the former case by a value of 0.87 V.

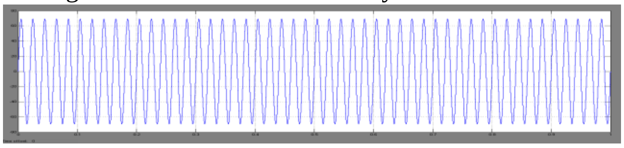

Fig 10 (a): Bus current without custom power devices

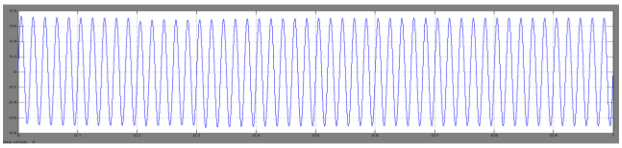

Fig 10 (b): Current with DVR & D-STATCOM at bus 11

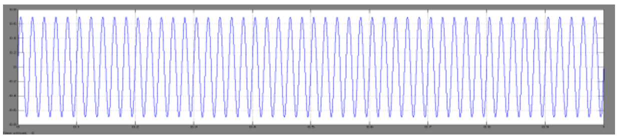

Fig 10 (c): Current with DVR & D-STATCOM at bus 14

The Fig 10 (a-c) shows the graphical analysis of current simulated for double line to ground fault (LLG) without and with multi-type custom power devices connected at bus 11 and bus 14. The output current without any device is 0.694 A. The system is then simulated with DVR/ D-STATCOM placed at bus 11. It is observed that the output current for the later is more than the former case by a value of 0.0185 A. The output voltage with device placed at bus 14 is 0.885 A. It is observed that the real power output for the later is greater than the former case by a value of 0.10 A.

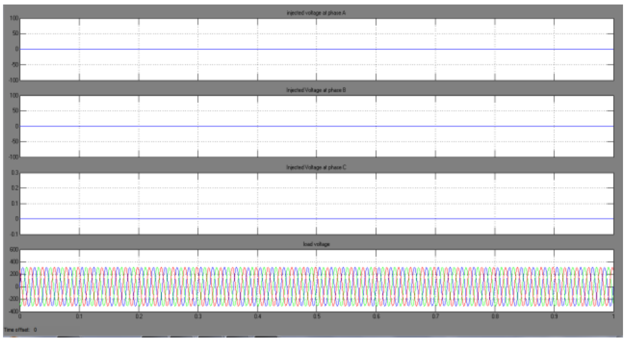

Fig 11: 3ϕ voltage waveform for without fault without device

Fig 11 shows the 3ϕ voltage waveform of without custom power device and without fault. The waveform is smooth without any voltage sag.

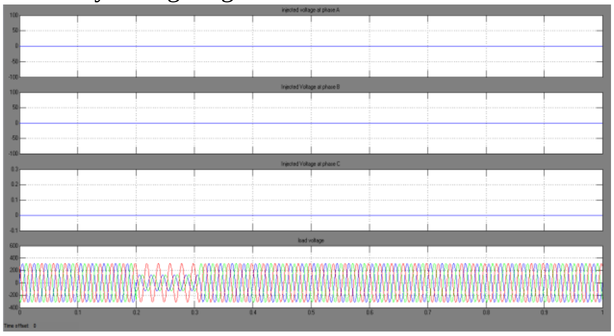

Fig 12 (a): 3ϕ voltage waveform for with fault without device

The 3ϕ voltage sag waveform of without custom power device and with LLG fault (fault on phase A and phase B) shown in Fig 12 (a).

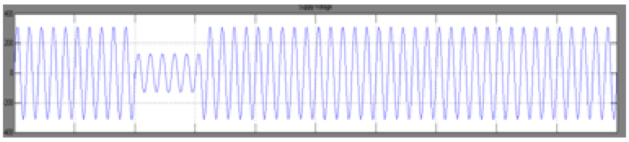

Fig 12 (b): Phase A Voltage sag wave form without device

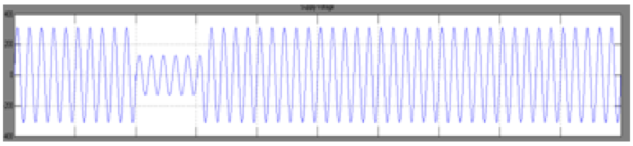

Fig 12 (c): Phase B Voltage sag waveform without device

The Fig 12 (b) and Fig 12 (c) shows the simulation result of voltage sag on system with LLG fault on phase A and phase B without placing any custom power device.

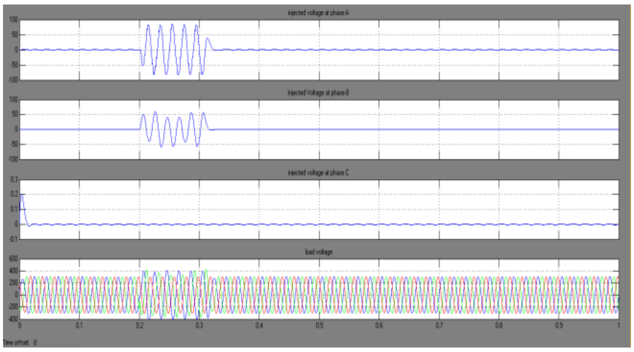

Fig 13: Phase A &B voltage sag waveform for with DVR

The Fig 13. shows the graphical result of three phase voltage waveform of dynamic voltage restorer with LLG fault occur in phase A and B.

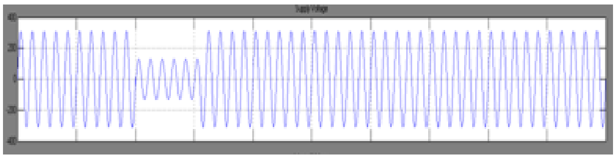

Fig 14 (a): Voltage sag waveform on phase A with fault

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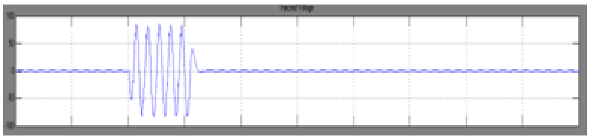

Fig 14 (b): Injected voltage at phase A

The Fig 14 (a). Shows the voltage sag in phase A. The duration of voltage sag ranges between 0.2 to 0.3 seconds. To overcome this problem the injection transformers are used to inject the phase A voltage in Fig 14 (b).

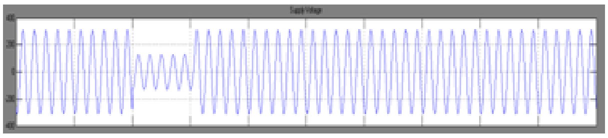

Fig 15 (a): Voltage sag waveform on phase B with fault

Fig 15 (b): Injected voltage at phase B

The Fig 15 (a). shows the voltage sag in phase B. The duration of voltage sag ranges between 0.2 to 0.3 seconds. To overcome this problem the injection transformers are used to inject the phase A voltage in Fig 15 (b).

From Fig 14 and Fig 15 it is evident that the injection of compensation voltage from the injection transformer neutralizes the voltage sag and produce a three phase clean and smooth waveform as shown in Fig 17.

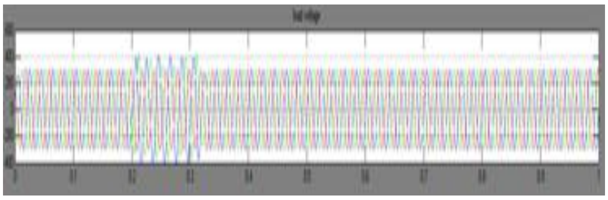

Fig 17: 3ϕ load waveform

V. CONCLUSION

The proposed 14 bus system has been modeled, simulated and analyzed using MATLAB [20]. It is found that the bus voltage with DVR and D-STATCOM are improved. The bus voltage increases with the increase in the magnitude of injected voltage and at the same time the reactive power compensation has been carried out successfully. Overall power quality can be improved by placing more DVR and D-STATCOM at various load buses. DVR is a most efficient device and it has a higher energy capacity compared to UPS device and also the DVR is smaller in size and cost is less. In future the work can be extended by connecting various custom power devices to the proposed 14 bus system. It is also planned to solve other power quality problems associated with voltage sag like interruption, harmonics, etc… The same multi-type custom power devices can be used to deal with other power quality issues like voltage swell, transients and waveform distortion.

REFERENCES

[1] Dugan, R. C., McGranaghan, M. F., Surye Santoso., and Wayne Beaty, H. 2008. Electrical Power System Quality. Tata McGraw-Hill Edition.

[2] Sankaran, C. 2002. Power Quality. CRC Press LLC.

[3] Hingorani, N. G. 2007. FACTS Technology – State of the Art, Current Challenges and the Future Prospects. Life Fellow, IEEE.

[4] Milanovic, J. V., Yan Zhang. 2010. Modeling of FACTS Devices for Voltage Sag Mitigation Studies in Large Power Systems. IEEE Transactions on Power Delivery, Vol. 25, No. 4, (Oct. 2010).

[5] Ghosh, A., Ledwich, G. 2002. Power Quality Enhancement Using Custom Power Devices. Kluwer Academic Publishers.

[6] Hingorani, N.G. 1995. Introducing Custom Power. IEEE Spectrum,32p, p. 4l-48.

[7] Boonchiam, P., Mithulananthan, N. 2006. Understanding of Dynamic Voltage Restorers through MATLAB Simulation. Thammasat Int. J. Sc. Tech., 11(3), pp. 1-6.

[8] Saleh, S. A., Moloney, C. R., and Azizur Rahman, M. 2008. Implementation of a Dynamic Voltage Restorer System Based on Discrete Wavelet Transforms. IEEE Transactions on Power Delivery, Vol. 23, No. 4, (Oct. 2008).

[9] Pedro Roncero-Sánchez., Enrique Acha. 2009. Dynamic Voltage Restorer Based on Flying Capacitor Multilevel Converters Operated by Repetitive Control. IEEE Transactions on Power Delivery, Vol. 24, No. 2, (Apr. 2009).

[10] Sao, C. K.., Lehn, P. W., Iravani, M. R., and Martinez, J. A. 2002. A Benchmark System for Digital Time- Domain Simulation of a Pulse-Width-Modulated D-STATCOM. IEEE Transactions on Power Delivery, Vol. 17, No.4, (Oct. 2002).

[11] Venkata Dinavahi., Reza Iravani., and Richard Bonert. 2004. Design of a Real-Time Digital Simulator for a D-STATCOM System. IEEE Transactions on Industrial Electronics, Vol. 51, No. 5, (October 2004).

[12] Bostjan Blazic., Igor Papic. 2006. Improved D-STATCOM Control for Operation With Unbalanced Currents and Voltages. IEEE Transactions on Power Delivery, Vol. 21, No. 1, (Jan. 2006).

[13] Anaya-Lara, O., Acha, E. 2002. Modelling and Analysis of Custom Power Systems by PSCAD/EMTD IEEE Transactions on Power Delivery, 17(1), pp. 266-272.

[14] Rambabu, Ch., Obulesu, Y. P., Saibabu, Ch. 2011. Improvement of Voltage Profile and Reduce Power System Losses by using Multi Type Facts Devices. International Journal of Computer Applications (0975 – 8887), Volume 13– No.2, (Jan 2011).

[15] Marouani Ismail1. Guesmi Tawfik. and Hadj Abdallah Hsen. 2012. Optimal Location of Multi Type FACTS Devices for Multiple Contingencies Using Genetic Algorithms. International Journal of Energy Engineering 2012, 2(2): 29-35.

[16] Eng Kian Kenneth Sng., Choi, S. S., and Mahinda Vilathgamuw, D. 2004. Analysis of Series Compensation and DC-Link Voltage Controls of a Transformer less

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ISO 9001:2008 Certified
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Self-Charging Dynamic Voltage Restorer. IEEE Transactions On Power Delivery, Vol. 19, No. 3, (July 2004).

[17] Carl Ngai-man Ho., Chung Henry S. H. and Au K. T. K. 2008. Design and Implementation of a Fast Dynamic Control Scheme for Capacitor-Supported Dynamic Voltage Restorers. IEEE Transactions on Power Electronics, Vol. 23, No. 1, (January 2008).

[18] Mohammad Mahdianpoor, F., Rahmat Allah Hooshmand. and Mohammad Ataei. 2011. A New Approach to Multifunctional Dynamic Voltage Restorer Implementation for Emergency Control in Distribution Systems. IEEE Transactions on Power Delivery, Vol. 26, No. 2, (April 2011).

[19] Rajani, B., Sangameswara Raju, P. 2012. Enhancement of Power Quality by Optimal Placement of Dstatcom For Voltage Sag Mitigation Using Ann Based Approach. International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-2, Issue-3, (Jul. 2012).

[20] David Houcque. 2005. Introduction To Matlab For Engineering Students. Version 1.2, (Aug 2005).

[21] Nirmalkumar, A. 2011. Modeling and Simulation Five Level Inverter Based UPFC System. International Journal of Computer Application (0975-8887), Vol 12-No. 11, (Jan 2011).

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