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Voltage Sag Compensation Scheme Based on Power Quality Using Dynamic Voltage Restorer

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ABSTRACT

This paper details about the various issues in voltage sag and its ruthless impact on non linear loads in a power system. Voltage sag is the utmost significant power quality issues that the utility industry facing today. Now a day ample range of highly flexible controller which capitalizes on recently accessible power electronic equipment is rising for custom power usages in various fields. Under this situation the Dynamic Voltage Restorer (DVR) offers novel advancing with economically sustained solution to voltage sag issues. The DVR control is based on park transformation method and PI controller along with Hysteresis voltage control.

Index Terms- Dynamic Voltage Restorer (DVR), Power Quality, Voltage sag, Voltage Source Converter (VSC), and Energy storage.

1. INTRODUCTION

The prominence of Power Quality (PQ) has been rising very significantly past two decades due to a noticeable increase in the number of sensitive equipment which adverse to PQ environments, where the turbulences caused by non-linear load, and the rise of renewable energy sources , among others. At slenderest 50% of all Power Quality instabilities are mainly caused due to the voltage quality type. The most known power quality issue related to voltage are the voltage sag and swells, harmonic and inter harmonic voltages, and, for three phase systems voltage imbalances.

Voltage sag defined as a momentary decrease in the rms voltage between 0.1 to 0.9 per unit at power frequency, for a duration ranging from 0.5 cycle up to 1 minute. It is clearly described as a sudden drop in supply voltage down to 90% to 10% of so called voltage. It is usually due to faults in system and differentiated by by its amplitude and time duration. Dip in magnitude of the voltage called Voltage sag is the net rms voltage during voltage sag, which is usually defined in pu of the usual voltage range. The different factors where voltage sag depends on the faulty type, location of the fault and the fault impedance value. The time duration of voltage sag mainly related to how fast the fault is completely mitigated by the suitable shielding device.

Generally many custom power devices are in use which includes Parallel Active Power Filters(APF), Distribution Static Synchronous Compensator(DSSC), Dynamic voltage restorer (DVR), Battery energy storage systems(BESS), and Uninterruptible Power Supply [1] [2] .All above mentioned Custom Power devices are having their own restrictions. The most promising devices among this the Dynamic Voltage Restorer (DVR) is selected for making compensation effectively.

There are several causes for preferring DVR over the other custom power devices like the ability to controlling active power flow with SVC is highly predominant one[3].In addition DVR is less cost than Uninterrupted Power Supply [4],[5] . UPS (Uninterrupted Power Supply) is costly due to maintenance factors which cause due to battery leak and it should replace for every five year [5]. In addition DVR has higher range of energy capacity with less cost compared with SMES devices [3] also low cost with smaller in size than DSTATCOM [3]. Due to these reasons DVR is widely used as suitable custom power scheme during the mitigation of voltage sag problems [6].Power factor correction and Harmonics reduction also can be done in addition with the along with voltage dip (Voltage Sag) and Rise (Voltage Swell) issues in power system. This paper explains in details about the principle operation of the Dynamic Voltage Restorer (DVR). It is illustrated and explained after simulated using MATLAB/SIMULINK where DVR connected series with flexible.

2. DYNAMIC VOLTAGE RESTORER

A Dynamic Voltage Restorer (DVR) is newly projected with chain linked called series connection with power electronic device which shoots up the voltage into the power system to normalize voltage in customer side. This series mitigating device DVR was first established and fit in 1996 [6] for voltage issues compensation in power systems. It is usually fitted in a distribution side in-between the source and the perilous load feeder [7]. Its most important purpose is to quickly increasing the load-side voltage along with disturbance in order to eliminate all kinds of power disruption at the load [5, 14]. Now days many circuit topologies with recent control schemes are put into practice in a power quality mitigation using DVR. Voltage sag and swell can additionally compensated with the following features like, decreasing of sudden rise in voltage for small duration called Transients in voltage and fault current restrictions along with line voltage harmonics reimbursement.

The general outline of DVR with booster / injection transformer, energy storage unit, inverter circuit, active filter unit with control system, shown in Figure1.

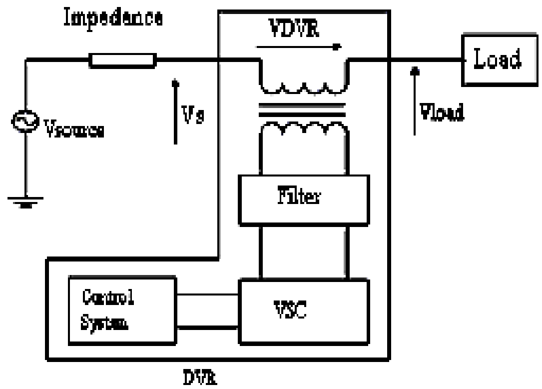

Figure.1 Schematic Diagram of DVR

A. Injection Transformer /Booster Transformer

An exclusively constructed Injection/Booster transformer is used to limits the link of transient energy with noise from the supply side to the load side [15]. The main functions of Injection/Booster Transformer are: connect the DVR to the distribution network through the High Voltage (HV) windings of the transformer and mitigate the voltages from VSC to voltage source. Additionally, the Injection / Booster transformer connects the initiative of separating the system from the load (VSC with regulating instrument). The electrical parameter of the transformer must be chosen properly to make sure the utmost consistency and efficiency [4]. To incorporate the injection transformer appropriately into the DVR, the MVA ratings, the turn's ratio with impedance short circuit value of transformer are essential.

B. Harmonic Filter

The output of the inverter is associated with Harmonics due to the nonlinear characteristics devices used in it and it results distorted waveforms. To prevail over this issue and to endow with extraordinary quality energy supply, filter is normally adopted. The Line and inverter side filtering are basic types of filtering methods [8], [9], [10]. The filter connected in the inverter side is nearer to the low voltage side and harmonic source as a result it keep away from the harmonic currents to infiltrate into the sequentially injecting transformers [10]. This consequence the phase shift of fundamental component of inverter output and voltage drop at the output of the inverter. Similarly, the filter connected in supply side is closer to great voltage side and it is subsequently higher rating on transformer is needed [9]. In both the filtering methods, inverter rating is increased by filter capacitor. Also it provides superior value of harmonic attenuation but the inverter rating is interconnected with the value of capacitor. In this study inverter side filtering method is chosen for compensation.

C. Inverter circuit

The adjustable voltage received in the inverter is attained by voltage source converter (VSC). Inverter circuit has a power electronic device which has turn off capability. The unidirectional direct current supply voltage having a low impedance value at the input is used to energize inverter circuit. The output voltage of filter is self-regulating of load current. In VSCs, output voltage depends upon capacitor which would be relatively low. By modulation of output voltage waveform voltage control in inverter is attained.

D. Energy storage Unit

The reason to feed the required energy into the VSC through a DC link for the purpose of generating the injection voltage. Superconductive magnetic energy storage (SMES), batteries, and capacitors are some of energy storage devices. Actually, the stored energy directly determines the time period of dip in voltage (sag) could be compensated by the DVR. For high voltage battery configuration batteries were universal choices which are accommodated largely. The maximum voltage string of batteries could be located through the controlled dc bus having a slight or no supplementary integrated circuit. But, in general the batteries are having short lifetime and frequently need a various kind of battery organization system, which can be fairly costly. Recently the alternate to the batteries are Ultra-capacitors, which is having extensive voltage range than batteries and can be straightly connected across the input bus. Ultra capacitors are having less precise energy density than the battery, but have a precise power larger than a battery, creating them in ideal for short pulses (more than a few seconds) of power. Some Ultra-capacitors (asymmetrical electrochemical) can keep the charge over an extensive periods of time, in order to perform like a battery. On the other hand, not like batteries, these ultra-capacitors have a small charging period and extensive lifespan.

3. DVR MODES OF OPERATION

Normally, the DVR is classified into three different methods of operation like defense mode, backup mode (in steady state period) and vaccination mode (in dip condition). The figure 2 represents the equivalent circuit of the DVR. Under protection mode the Dynamic Voltage Restorer is protected from the over current in the customer side. It is due to the very high inrush currents or short circuit on the load. But, the DVR is typically operated in the injection mode or standby mode. In backup mode (V_{DVR}=0), converter short booster transformer in low voltage winding. Due to separate converter legs were triggered in order to launch a short-circuit path for the transformer connection in DVR were semiconductors do not need any switching in this mode of operation.

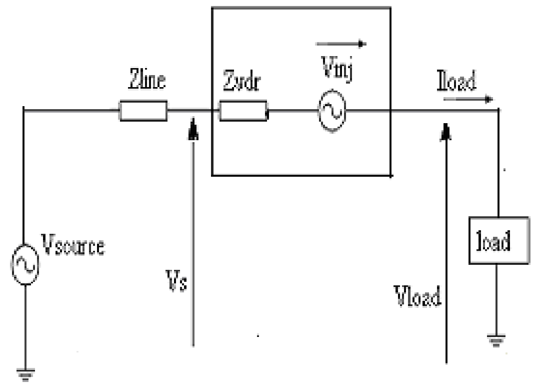

Figure.2 DVR-Equivalent circuit

DVR inject required mitigation voltage in boost mode of operation (V_{DVR}>0), through booster transformer when it detect source voltage disturbance [4].

Figure.2 shows the DVR equivalent circuit, as soon as the voltage source goes down or rise DVR add a series voltage V_{inject} through the injection transformer. By means load voltage magnitude V_L is retained. The injected series voltage of the DVR is written as,

$$V_{inject} = V_{load} + V_S \tag{1}$$

Where,

V_{load} is the magnitude of the load voltage

V_S is the source voltage under sag / swell condition.

The load current I_{load} is given by

$$I_{load} = \left[\frac{P_{load} \pm J * Q_{load}}{V_{load}} \right] \tag{2}$$

4. CONVENTIONAL METHODS OF VOLTAGE INJECTION

A. Pre – sag compensation method

Pre – sag compensation technique which inserts the voltage variance between small changing dip (called sag) and pre-fault voltages to the system. It is the eminent result to acquire the equivalent utility voltage as the pre-fault voltage but no control on vaccinated active power so high volume of energy storing is essential.

B. Phase advance method

In Dynamic Voltage Restorer, the real power spent is reduce by lessening the angle between the Load current and sag voltage. Phase of sag voltage can varied by predetermining the value of load voltage and current.

C. Minimum energy injection method with tolerance voltage

Usually the voltage scale between 90% to 110% of extraneous voltage and phase angle deviation between 5% to 10% of normal state do not perturb the load characteristics operation. This technique is able to preserve the utility voltage in the acceptance level with slight magnitude variation in voltage.

D. In phase voltage injection method

Phase voltage injection method is the forward and normally used technique where the added DVR voltage which super imposed exactly with the source side voltage despite of the pre fault voltage and utility current shown in Figure.3. This can be achieved by two different methods. The first method is by accepting a synchronized PLL with the post-fault voltage [15] and the latter is the well-adjusted and stable components method [16].Even though the post fault PLL is a fast governing practice, it cannot evade phase jumps on the load voltage at the fault incidence which can interrupt the phase-angle controlled converter loads. As a replacement for the symmetrical components technique has a delay time introduced by the Fortes cue transform calculation [17], and factors requisite of the filter sequence [18].Additionally, the symmetrical components technique can endure the effect of a phase jump by using the pre-fault phase angle [17]. This IPC technique is appropriate for bare slightest voltage or smallest energy operation schemes [13]. In addition, this technique needs huge amounts of real power to alleviate the voltage dip, which means a very bulky energy storage device.

According to Figure 3, the apparent power of DVR is:

$$S_{DVR} = I_L . V_{DVR} = I_L (V_L - V_s) \tag{3}$$

And the DVR active power is

$$P_{DVR} = I_L V_{DVR} \cos\theta_s = I_L (V_l - V_s) \cos\theta_s \tag{4}$$

The DVR voltage magnitude and phase angle are:

$$V_{DVR} = V_L - V_s \tag{5}$$

$$\theta_{DVR} = \theta_S \tag{6}$$

DVR mostly operated in the injection mode or standby mode. Since the separate converter legs were triggered such as to form a short-circuit path for the transformer link, there is no switching of solid state devices happen in this mode of operation, In this technique the injected voltage and the phase angle are in phase due to phase loop lock (PLL). Thus the sag voltage reimbursement is also precise and in phase with the source voltage. This technique is more suitable in compensation methods as it takes less time in identifying the dip in voltage known as sag. In proposed method uses hysteresis voltage control and dqo transformation for sag compensation.

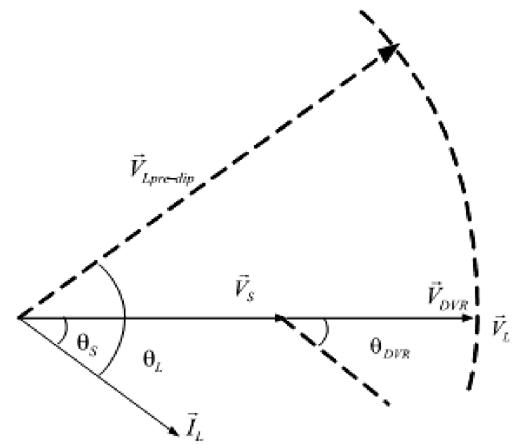

Figure.3 Phasor diagram of IPC Method

5. CONTROL ALGORITHM

Whenever a voltage imbalance arises, with the help of dq Transformation control arrangement, the DC–AC converter output voltage could directed exactly associated with the inward ac source at the same time as the load is constantly retained. According to the filtering technique of the anticipated technique output in the inverter is connected with passive filtering components like capacitors and inductors. The important functions of a DVR controller is to reveals the Dip in voltage (sag) and voltage rise (swell) in the system; determining trigger pulses at time of event, modification of irregularities in series injected voltage and trigger pulse generation for sinusoidal PWM based inverter. The controller also implemented to change the DC-AC inverter into rectifier mode to control the capacitors in the DC energy link in the nonexistence condition of voltage sags/swells.

The Park's transformation or dqo transformation [6-7] is adapted for DVR controlling. The dqo techniques furnish the depth of the sag and information about the phase shift with start and end times. The different quantities are uttered/ represented as the fast space vectors by initially change the voltage from a-b-c reference parameters to d-q-o reference parameter.

For the purpose of ease zero the phase sequence components is flouted. Figure.4 describes the feed forward dqo transformation flow chart for voltage sags/swells detection. The identification is carried out in all three phases. The proposed system control scheme is depends on the comparison of a reference voltage with the measured terminal Voltage (V_a,V_b,V_c).The Sag voltage is recognized when the source voltage dips below 90% of the reference signal, but the voltage swells is detected when source voltage rises up to 25% of the reference signal.

The power electronics devices (IGBT's) having VSC (voltage source converter) requires generation of modulation signal with help of error signal. Sinusoidal Pulse Width (SPW) technique is used in generation of commutation signal and thereby controlling voltages through modulation. The Phase locked loop (PLL) is showed in Figure.4. The Phase Locked Loop (PLL) is used to create unit sinusoidal waves which in phase with supply voltage.

$$\begin{bmatrix} Vd \\ Vq \\ V0 \end{bmatrix} = \begin{pmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & 1 \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (7)$$

Equation (7) describes the conversion from three phase system a,b,c to dq0 symmetrical frame. This V_{abc} to V_{dq0} transformation, phase A is associated to the d-axis that is 90^0 departure with the q-axis. The theta (θ) is the angle between phase A to the d-axis. At the end of this variation, the three phase balanced voltage V_a , V_b and V_c becomes a persistent voltages V_d,V_q. They are controlled by PI controller simply as shown in Figure.5 [6]. In this paper, inverter gate signal and load voltage is perk up by one of digital control technique called Hysteresis voltage control. Error signal generation by Hysteresis Voltage control is based upon injected voltage by DVR and reference voltage.

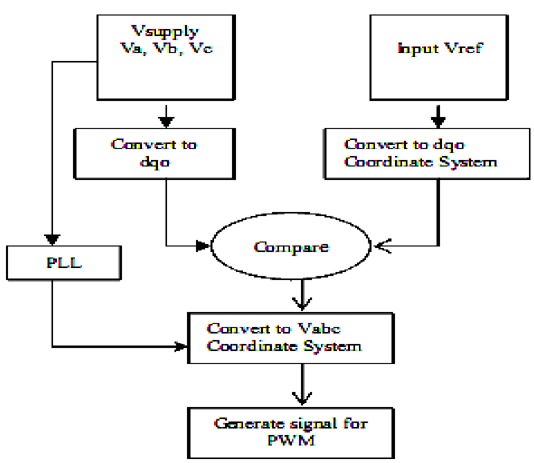

Figure.4 dqo transformation having feed forward control technique for DVR

This technique must not be exaggerated from the frequency variation, harmonics and unbalanced voltages since the exact finding of the phase of the source voltage is much

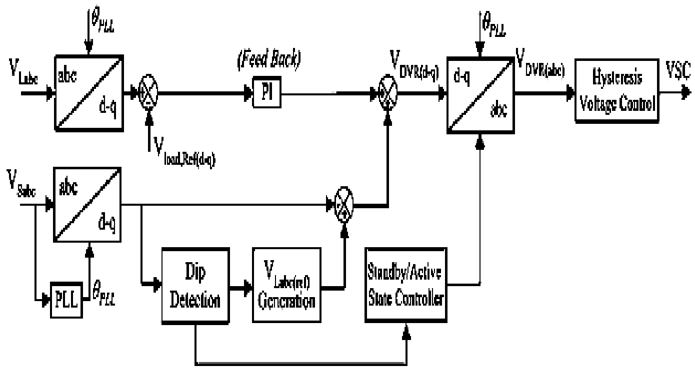

Figure.5 Control Structure of DVR

Important for DVR, This necessity can by satisfied by phase lock loop. Thus the pre-sag voltage will be in phase with the compensated voltage.

6. SIMULATION RESULT

Table I System Constraints And Constants Value

Main System supply voltage	230V
Transformation Ratio	1:1
Line frequency	50Hz
Filter Inductance	1mH
Filter Capacitance	1uF
Dc Bus voltage	185V
Load resistance	40Ω

Control strategy for efficiency is suggested by MATLAB/SIMULINK. The system constraints and constants values are listed in Table. I.

A. Voltage sags

Figure 6(a) gives an idea about of three phase voltage sag simulation. It starts with source voltage dip originated at 0.2s and it is held in reserve until 0.5s, with the total voltage dip time duration of 0.3s. Figure 6(b) shows the voltage added by the DVR and Figure 6(c) shows the resultant load voltage with its reimbursement.

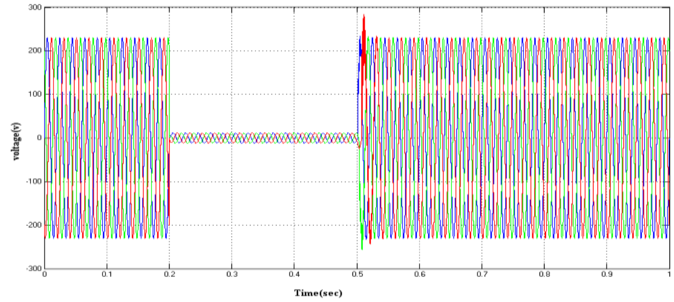

Figure.6 (a) Three phase voltage sag.

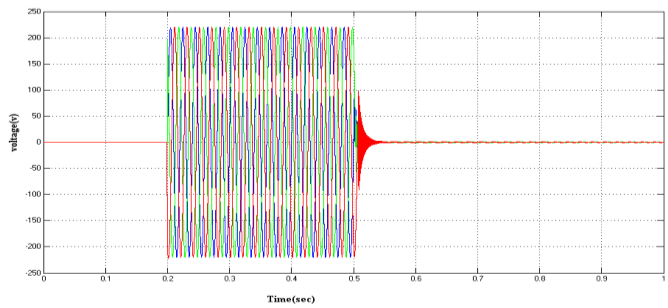

Figure. 6(b) Voltage injected by DVR.

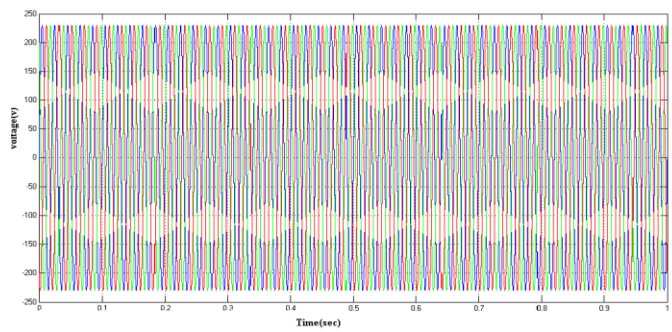

Figure.6(c) Load Voltage with compensation.

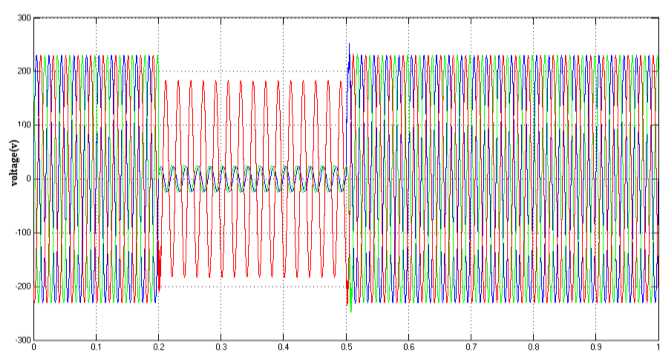

Figure.7 (a) Two phase voltage sag.

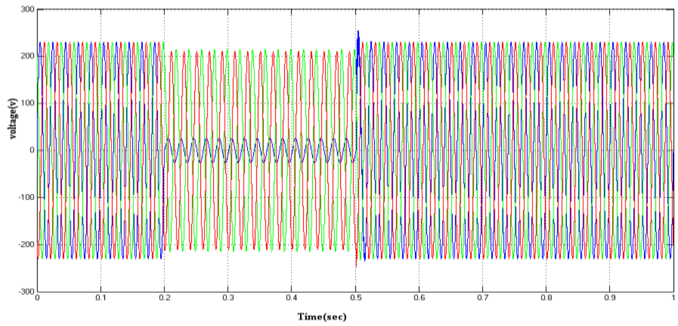

Figure.7(b) Single phase voltage sag.

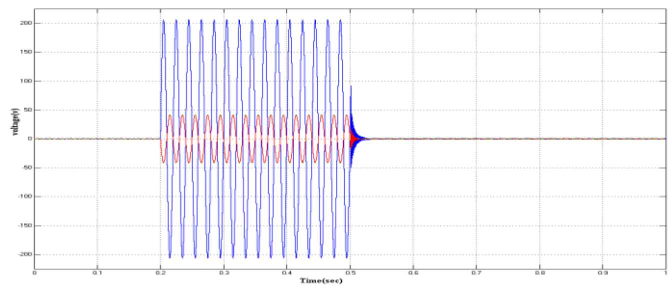

Figure.7(c) Two phase voltage injected by DVR

Under unbalanced conditions the effectiveness of DVR is shown in Figure.7(a) and 7(b) also shows the incidence of two phase and single phase voltage sags on utility grid. The voltage injected by the DVR is shown in Figure.7(c) and Figure.7(d) and the resultant load voltage with reimbursement is shown in Figure.7(e) and Figure.7(f).

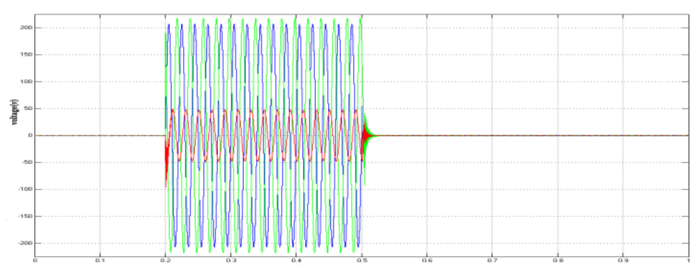

Figure.7 (d) Single phase voltage injected by DVR

Figure.7 (e) Load voltage with compensation (Single Phase Error)

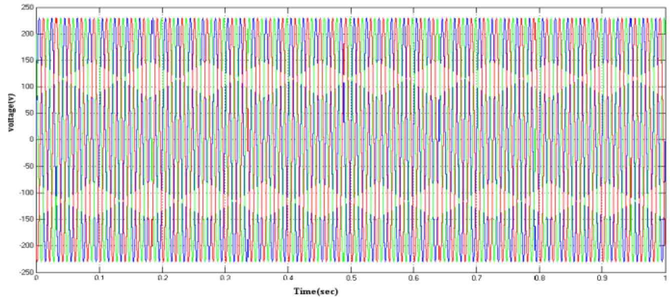

Figure. 7(f) Load voltage with compensation (Two Phase Error)

7. CONCLUSION

The DVR modeling and simulation using MATLAB SIMULINK has been presented. In DVR, scaled error between the supply side and its reference for sags has been presented based on dqo technique. The obtained simulation is acceptable in compensating voltage sags (dip) in DVR performance. Also from simulation results the DVR mitigates the Sag/Swell rapidly and provides tremendous voltage regulation.Under balanced and unbalanced states without any complications the DVR shoots up the suitable voltage component to proper and quickly in the source voltage to maintain the load voltage balanced and constant at the nominal value.The benefit of this DVR is simple control and low cost. It can compensate extensive duration of voltage sags/swells efficiently.

REFERENCES

[1] Chang S., HoY.S., and Loh P.C.: Voltage quality enhancement with power electronics based devices. In IEEE Power Engineering Society Winter Meeting, 2000, pp. 2937–2942.

[2] Kim H.: Minimal Energy Control for a Dynamic Voltage Restorer. In Proceedings of the Power Conversion Conference, Osaka, Japan, 2002, pp. 428–433.

[3] McHattie R.: Dynamic Voltage Restorer the Customer's Perspective. InIEE Colloquium on Dynamic Voltage Restorer—Replacing Those Missing Cycles, 1998, pp. 1/1–1/5.

[4] Chen S., Joos G., Lopes L., and Guo W.: A nonlinear control method of dynamic voltage restorers. In 2002 IEEE 33rd Annual Power Electronics Specialists Conference, 2002, pp. 88–93.

[5] Buxton.R. Protection from voltage dips with the dynamic voltage restorer. In IEE Half Day Colloquium on Dynamic Voltage Restorers —Replacing Those Missing Cycles, 1998, pp. 3/1–3/6.

[1] L i B.H., Choi S.S., and Vilathgamuwa D.M.: 12. Design considerations on the line-side filter used in the dynamic voltage restorer. IEE Proceedings — Generation, Transmission, and Distribution, vol. 148, pp. 1–7, Jan.2001.

[2] C h a n K. : Technical and Performance Aspects of a Dynamic Voltage Restorer. In IEE Half Day Colloquium on Dynamic Voltage Restorers —Replacing Those Missing Cycles, 1998, pp. 5/1–525.

[3] P. T.Nguyen.,Tapan.,and K.Saha,: "Dynamic Voltage Restorer Against Balanced and Unbalanced Voltage Sags: Modeling and Simulation IEEE 2004, pp.1-6

[4] V.K.Ramachandaramurthy, A.Arulampalam, C.Fitzer, C. Zhan, M. Barnes and N. Jenkins "Supervisory control of dynamic voltage restorers " IEE Proc.- Gener. Transm. Distrib. Vol. 151, No. 4, pp. 509-516, July 2004

[5] John Godsk Nielsen, Michael Newman, Hans Nielsen, Frede Blaahjergl, "Control and Testing of a Dynamic Voltage Restorer (DVR) at Medium Voltage Level" IEEE Transactions on Power Delivery, Vol. 19, No. 3, May 2004

[6] Sng E.K.K., Choi S.S., and Vilatgamuwa DM.: Analysis of Series Compensation and DC-Link Voltage Controls of a Transformerless Self- Charging Dynamic Voltage Restorer. IEEE Transactions on Power Delivery, vol. 19, pp. 1511–1518, July 2004.

[7] Bollen M.H.J.: Understanding Power Quality Problems. NewYork: IEEE Press, 2000.

[8] E -Otadui a , Viscarreti s U. ,Bacha S . , Caballero M., a n d Reyero R. : Evaluation of different strategies for series voltage sag cornpensation. In Proc. 2002 IEEE-PESC, vol. 4, pp. 1797–1802.

[9] ChungY. , Park S . -Y. , Moon S .- 1 . , a n d Hu r S . - 1 . :The control and analysis of zero sequence components in DVR system. In Proc. 2001 IEEE-PES Winter Meeting, Vol. 3, pp. 1021–1026.

[10] Haddad K. a n d Joos G. : Distribution system voltage regulation under fault conditions using static series regulators. In Proc. 1997 IEEE-IAS, Vol. 2, pp. 1383–1389.

[11] Joos Camp o s G. , Ziogas P, a n d Lindasy J .: Analysis and design of a series voltage compensator for three-phase unbalanced sources. IEEE Trans. on Industrial Electronics, Vol. 39, No. 2, pp. 159–167, April 1992.

[12] Tounsi R, Michalak P. ,Pouliquen H. , a n d Foch H.: Series compensator voltage dips: control strategy. In Proc. 1997 EPE Con., pp. 4.929–4.934.

[13] Sannino a n d Svensson J . : A series-connected voltage source converter for voltage sag rnitigation using vector control and a filter compensation algorithm. In Proc. 2000 IEEE-IAS, Vol. 4, pp. 2476–2481.

[14] Chang S., HoY.S., and Loh P.C.: Voltage quality enhancement with power electronics based devices. In IEEE Power Engineering Society Winter Meeting, 2000, pp. 2937–2942.

[15] Kim H.: Minimal Energy Control for a Dynamic Voltage Restorer. In Proceedings of the Power Conversion Conference, Osaka, Japan, 2002, pp. 428–433.

[16] McHattie R.: Dynamic Voltage Restorer the Customer's Perspective. In IEE Colloquium on Dynamic Voltage Restorer—Replacing Those Missing Cycles, 1998, pp. 1/1–1/5.

[17] Chen S., Joos G., Lopes L., and Guo W.: A nonlinear control method of dynamic voltage restorers. In 2002 IEEE 33rd Annual Power Electronics Specialists Conference, 2002, pp. 88–93.

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