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Voltage Sag Compensation Using Synchronously Reference Frame Theory Based Dynamic Voltage Restorer

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***Abstract* —This paper showcases one of the custom power device which is used to recover the voltage sag mostly occur at distribution system is Dynamic Voltage Restorer. The method applied to control this device is based on Synchronously Reference Frame theory to generate switching pulses for three phase inverter with the help of hysteresis voltage controller to maintain voltage profile sinusoidal at linear load terminal against voltage sag. The simulation of DVR model is performed in MATLAB software.**

***Index Terms*— Dynamic Voltage Restorer, inverter, switching pulses**

I. INTRODUCTION

Power quality problems in the distribution systems are interruption, voltage sag and voltage swell due to the increased use of sensitive and critical equipments in the system. Some examples are equipments of communication system, process industries, precise manufacturing processes etc.

Power quality problems such as transients, sags, swells and other distortions to the sinusoidal waveform of the supply voltage affect the performance of these equipments. The technologies like custom power devices are emerged to provide protection against power quality problems.

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Custom power devices are mainly of three categories such as series-connected compensator like dynamic voltage restorer (DVR), shunt connected compensator such as distribution static compensator (DSTATCOM), and a combination of series and shuntconnected compensators known as unified power quality conditioner (UPQC) [2, 4-6]. The series connected compensator can regulate the load voltage from the power quality problems such as sag, swell etc. in the supply voltage. Hence it can protect the critical consumer loads from tripping and consequent loss of production.The custom power devices are developed and installed at the consumer point to meet the power quality standards such as IEEE-519 .

A DVR is used to compensate the supply voltage disturbances such as sag and swell. The DVR is connected between the supply and sensitive loads, so that it can inject a voltage of required magnitude and frequency in the distribution feeder. The DVR is operated such that the load voltage magnitude is regulated to a constant magnitude, while the average real power absorbed/ supplied by it is zero in the steady state. The capacitor supported DVR is widely addressed in the literature [8-13]. The instantaneous

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reactive power theory (IRPT) [6], sliding mode controller [9], instantaneous symmetrical components [2,13] etc., are discussed in the literature for the control of DVR. In this project a new control algorithm is proposed based on the current mode control and proportional-integral (PI) controllers for the control of DVR. The extensive simulation is performed todemonstrate its capability, using the MATLAB with its Simulink and Power System Blockset (PSB) tool boxes.

II. POWER QUALITY PROBLEMS

A. Power Quality Problems

- **Voltage dip**: A voltage dip is used to refer to short-term reduction in voltage of less than half a second.
- **Voltage sag**: Voltage sags can occur at any instant of time, with amplitudes ranging from 10% to 90% and duration lasting for half a cycle to one minute.
- **Voltage swell**: Voltage swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min.
- **Voltage 'spikes', 'impulses' or 'surges'**: These are terms used to describe abrupt, very brief increases in voltage value.
- **Voltage transients**: They are temporary, undesirable voltages that appear on the power Supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time.
- **Harmonics**: The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.
- **Flickers**: Visual irritation and introduction of many harmonic components in the supply power and their associated ill effects.

B. Causes of Dips, Sags and Surges:

1. Rural location remote from power source.
2. Unbalanced load on a three phase system.
3. Switching of heavy loads.
4. Long distance from a distribution transformer with Interposed loads.
5. Unreliable grid systems.
6. Equipments not suitable for local supply.

C. *Causes of Transients and Spikes:*

1. Lightening.
2. Arc welding.
3. Switching on heavy or reactive equipments such as motors, Transformers, motor drives.
4. Electric grade switching.

D. Solutions To Power Quality Problems:

There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side or from utility side First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. However, with the restructuring of power sector and with shifting trend towards distributed and dispersed generation, the line conditioning systems or utility side solutions will play a major role in improving the inherent supply quality; some of the effective and economic measures can be identified as following:

- Lightening and Surge Arresters:

Arresters are designed for lightening protection of transformers, but are not sufficiently voltage limiting for protecting sensitive electronic control circuits from voltage surges.

- Thyristor Based Static Switches:

The static switch is a versatile device for switching a new element into the circuit when the voltage support is needed. It has a dynamic response time of about one cycle. To correct quickly for voltage spikes, sags or interruptions, the static switch can used to switch one or more of devices such as capacitor, filter, alternate power line, energy storage systems etc. The static switch can be used in the alternate power line applications.

- Energy Storage Systems:

Storage systems can be used to protect sensitive production equipments from shutdowns caused by voltage sags or momentary interruptions. These are usually DC storage systems such as UPS, batteries, superconducting magnet energy storage (SMES), storage capacitors or even fly wheels driving DC generators .The output of these devices can be supplied to the system through an inverter on a momentary basis by a fast acting electronic switch. Enough energy is fed to the system to compensate for the energy that would be lost by the voltage sag or interruption.

Though there are many different methods to mitigate voltage sags and swells, but the use of a custom Power device is considered to be the most efficient method. For example, Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers in a distribution system, specially, to deal with various power quality problems. Just as FACTS improves the power transfer capabilities and stability margins, custom power makes sure customers get pre-specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, low harmonic distortion in load voltage, magnitude and duration of overvoltage and under voltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage There are many types of Custom Power devices.

Some of these devices include: Active Power Filters (APF), Battery Energy Storage Systems (BESS), Distribution STATic synchronous COMpensators (DSTATCOM), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Surge Arresters (SA), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid-State Transfer

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Switches (SSTS), Solid State Fault Current Limiter (SSFCL), Static Var Compensator (SVC), Thyristor Switched Capacitors (TSC), and Uninterruptible Power Supplies (UPS).

E. Voltage SAG

Voltage sags and momentary power interruptions are probably the most important PQ problem affecting industrial and large commercial customers. These events are usually associated with a fault at some location in the supplying power system. Interruptions occur when the fault is on the circuit supplying the customer. But voltage sags occur even if the faults happen to be far away from the customer's site.

Voltage sags lasting only 4-5 cycles can cause a wide range of sensitive customer equipment to drop out. To industrial customers, voltage sag and a momentary interruption are equivalent if both shut their process down. A typical example of voltage sag is shown in fig 2.2 The susceptibility of utilization equipment to voltage sag is dependent upon duration and magnitude of voltage sags and can be define

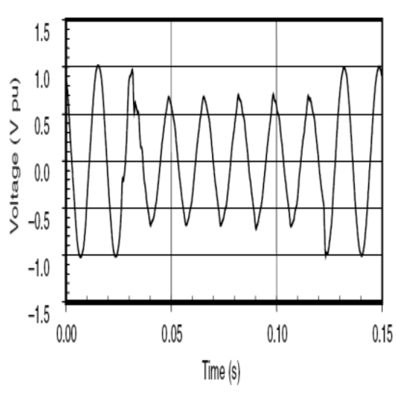

Figure 1.Typical Voltage Sag

F. Voltage swell

A swell is the reverse form of a Sag, having an increase in AC Voltage for a duration of 0.5 cycles to 1 minute's time. For swells, high-impedance neutral connections, sudden large load reductions, and a single-phase fault on a three phase system are common sources. Swells can cause data errors, light flickering, electrical contact degradation, and semiconductor damage in electronics causing hard server failures. Our power conditioners and UPS Solutions are common solutions for swells.

It is important to note that, much like sags, swells may not be apparent until results are seen. Having your power quality devices monitoring and logging your incoming power will help measure these events.

III. DYNAMIC VOLTAGE RESTORER

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

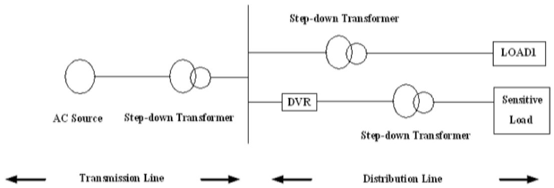

Figure 2.Location of DVR

A. Basic Configuration Of Dvr:

The general configuration of the DVR consists of:

- An Injection/ Booster transformer.
- A Harmonic filter.
- Storage Devices.
- A Voltage Source Converter (VSC).
- DC charging circuit.
- A Control and Protection system.

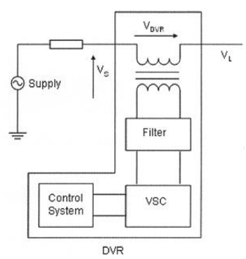

Figure 3.Schematic Diagram of DVR

- Injection/ Booster Transformer:

The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are:

1. It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the I incoming supply voltage.

2. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

- Harmonic Filter:

The main task of harmonic filter is to keep the harmonic voltage content generated by the VSC to the permissible level.

- Voltage Source Converter:

A VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing. There are four main types of switching devices:

- Metal Oxide Semiconductor Field Effect Transistors (MOSFET),
- Gate Turn-Off thyristors (GTO),
- Insulated Gate Bipolar Transistors(IGBT), and
- Integrated Gate Commutated Thyristors (IGCT).

Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices.

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The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

- DC Charging Circuit:

The dc charging circuit has two main tasks.

- The first task is to charge the energy source after a sag compensation event.
- The second task is to maintain dc link voltage at the nominal dc link voltage.

- Control and Protection:

The control technique to be adopted depends on the type of load as some loads are sensitive to only magnitude change whereas some other loads are sensitive to both magnitude and phase angle shift. Control techniques that utilize real and reactive power compensation are generally classified as pre- sag compensation, in-phase compensation and energy optimization technique. For our study, pre-sag compensation was used where the load voltage is restored to its pre-sag magnitude and phase. Therefore, this method is suitable for loads which are sensitive to magnitude and also phase angle shift. Differential current protection of the transformer, or short circuit current on the customer load side are only two examples of many protection functions possibility.

B. Operating Modes Of Dvr:

The basic function of the DVR is to inject a dynamically controlled voltage VDVR generated by a forced commutated converter in series to the bus voltage by means of a booster transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage VL. This means that any differential voltages caused by transient disturbances in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer.

The DVR has three modes of operation which are: protection mode, standby mode, injection/boost mode.

- Protection Mode:

If the over current on the load side exceeds a permissible limit due to short circuit on the load or large inrush current, the DVR will be isolated from the systems by using the bypass switches (S2 and S3 will open) and supplying another path for current (S1 will be closed).

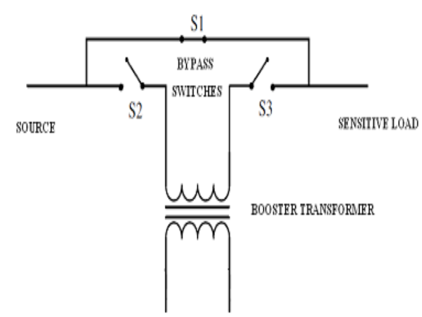

Figure 4.Protection Mode

- Standby Mode: (VDVR= 0)

In the standby mode the booster transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation and the full load current will pass through the primary.

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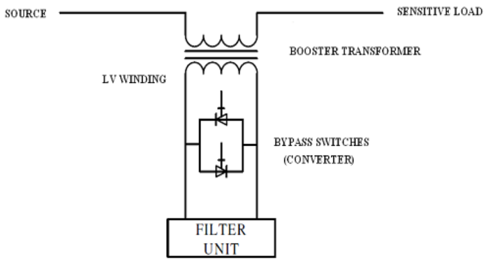

Figure 5.Standby Mode

- Injection/Boost Mode: (VDVR>0)

In the Injection/Boost mode the DVR is injecting a compensating voltage through the booster transformer due to the detection of a disturbance in the supply voltage.

C. Voltage Injection Methods Of Dvr:

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as: DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angel jump and some are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics.

There are four different methods of DVR voltage injection which are

- Pre-sag compensation method
- In-phase compensation method
- In-phase advanced compensation method
- Voltage tolerance method with minimum energy injection

IV. PRINCIPLE OF OPERTION OF DVR

The single line diagram of a system with the DVR connected in series with the supply is shown in Fig.4.1(a)

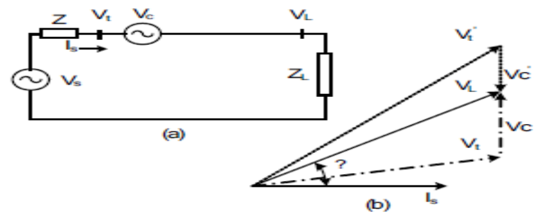

Figure 6. (a) Single line diagram of DVR and (b) Phasor diagram

The DVR injects a voltage (Vc) in series with the terminal voltage (Vt) so that the load voltage (VL) is always constant in magnitude. Fig.4.1(b) shows the phasor diagram of DVR when the terminal voltage is having sag (Vt) and swell (Vt') in the voltage. The schematic diagram of a three phase DVR connected to a three phase 3-wire system is shown in Fig.(a). The source impedances (Za, Zb, Zc) are between the source and the terminal.

The DVR uses three single-phase transformers (Tr) to inject voltages in series with the terminal voltage. A voltage source converter (VSC) along with a dc capacitor (Cdc) is used to realise a DVR. The inductor in series (Lr) and the parallel capacitor (Cr) with the VSC are used for reducing the ripple in the injected voltage. Fig.4.2(b) shows the phasor diagram for the injected voltage and the fundamental voltage drop to maintain the dc bus voltage of DVR. VL' and IL' are the load voltage and current before the sag occurred in the supply system. After the sag event, themagnitude of the load voltage (VL), the load current (IL) and the power factor angle (ϴ) are unchanged, but a phase jump is occurred from the pre-sag condition. The injected voltage (Vc) has two components. The voltage injected at quadrature

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(Vcq) with the current is to maintain the load voltage at constant magnitude and the in-phase voltage (Vcd) is to maintain the dc bus of VSC and also to meet the power loss in the DVR.

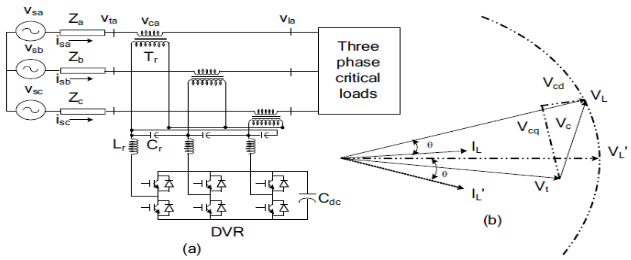


Figure7. (a) Three-phase DVR scheme and (b) Phasor diagram

The control strategy of the DVR is to achieve these two components of the injection voltage and this is achieved by controlling the supply current. The currents are sensed and the two components of currents, one is the component to maintain the dc bus voltage of DVR and the second one is to maintain the load terminal voltages, are added with the sensed load current to estimate the reference supply current.

A. Control Scheme:

The major objective of the control strategy is to ensure that the load bus voltages remain balanced and sinusoidal (positive sequence). Since the load is assumed to be balanced and linear, the load currents will also remain balanced (positive sequence) and sinusoidal. An additional objective is to ensure that the source current remains in phase with the fundamental frequency component of the PCC voltage. This requires that the reactive power of the load is met by the DVR. It is also possible to arrange that DVR sup- plies a specifed fraction of the reactive power required by the load

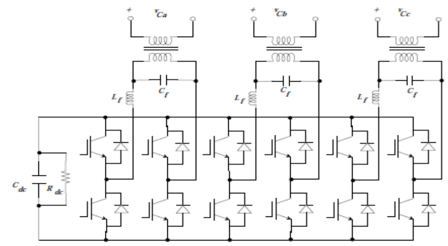


Figure 8.DVR Conifiguration

The DVR configuration chosen is shown in Fig:4.3. Here, three single phase full bridge converters are connected to a common DC bus. The sine PWM technique is used to control the DVR. The DC bus voltage is held by the capacitor Cdc. Since no energy source is connected, the net real power exchanged by the DVR is zero in steady state, if the losses are neglected.

However, to stabilize the operating point, a DC bus voltage control loop is necessary. The phasor diagram shows the current phasor is in phase with the voltage phasor VP (PCC voltage). The source and the load bus voltage phasor are also shown here. Á is the power factor angle of the load. The voltage injected by the DVR (VC) ensures that the current IS is in phase with VP. From the phasor diagram, the d-q components of the load bus voltage are given by

$$V_{Ld} = V_P + V_{Cd}$$

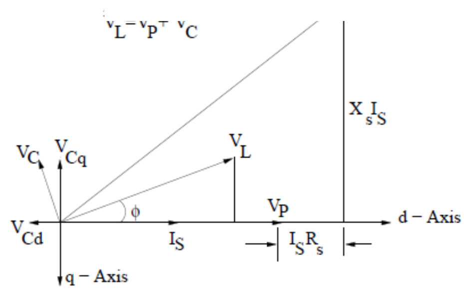


Figure 9.Phasor Diagram for the System

$$V_{Lq} = -V_{Ld} \tan \phi$$

The Synchronous Reference Frame (SRF) approach is used to generate the reference voltages for the DVR.

Fig. 4.4 shows the control scheme using SRF. The PCC voltage VPa, VPb and VPc are transformed into d-q components using the following equations.

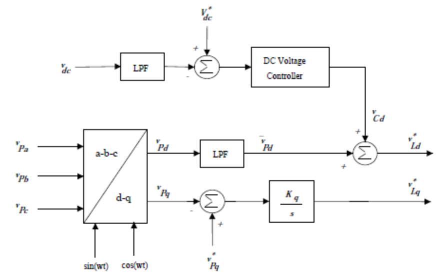
$$\begin{bmatrix} V_{P\alpha} \\ V_{P\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Pa} \\ V_{Pb} \\ V_{Pc} \end{bmatrix}$$

$$\begin{bmatrix} V_{Pd} \\ V_{Pq} \end{bmatrix} = \begin{bmatrix} \cos\omega_0 t & -\sin\omega_0 t \\ \sin\omega_0 t & \cos\omega_0 t \end{bmatrix} \begin{bmatrix} V_{P\alpha} \\ V_{P\beta} \end{bmatrix}$$

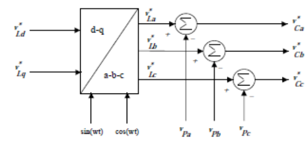
Where ω_0 is the operating system frequency. In the synchronously rotating reference frame, the positive sequence, fundamental frequency components are transformed into DC quantities. The negative sequence components and harmonic components (irrespective of the sequence) are transformed into oscillating quantities of frequency (fdq) given by

$$\begin{bmatrix} \bar{V}_{Pd} \\ \bar{V}_{Pq} \end{bmatrix} = G(s) \begin{bmatrix} V_{Pd} \\ V_{Pq} \end{bmatrix}$$

Where fabc is the frequency of the positive or negative sequence components in the phase coordinates. The sign associated with the second term in the R.H.S. of Equation is negative for positive sequence components and positive for negative sequence components. Note that zero sequence components in the phase coordinates do not contribute to d-q components.



(a) Computation of reference load voltages (d and q components)



(b) Generation of reference compensator voltages

Figure 10.Reference Voltages

The synchronously rotating reference frame is synchronized with the source current (IS) using a PLL. Therefore, the components Vpd and Vpq are the active and reactive components of the PCC voltage. The DC components in Vpd and Vpq are extracted by using a low pass filter Thus,

$$\begin{aligned} V_{Ca}^* &= V_{La}^* - V_{Pa} \\ V_{Cb}^* &= V_{Lb}^* - V_{Pb} \\ V_{Cc}^* &= V_{Lc}^* - V_{Pc} \end{aligned}$$

Where $\bar{V}_{Pd}$ and $\bar{V}_{Pq}$ are the DC components. From Equation we derive the reference for the active component of the load voltage (VLd) as

$$V_{Ld}^* = \bar{V}_{Pd} + V_{Cd}$$

Where, Vcd is obtained as the output of the DC voltage controller (with a proportional gain Kp). A second order Butterworth low pass filter is used in the feedback path of the DC voltage controller to

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filter out high frequency ripple in the DC voltage signal. In steady state, Vpq = 0 and $V_{Lq} = -V_{Ld} \tan \phi.$. These two conditions can be met by arranging

$$V_{Lq}^{*} = \frac{K_q}{s} \cdot V_{Pq}$$

Kq is chosen to optimize the controller response. From the reference values of Vld and Vlq we can obtain the desired load voltages in phase coordinates from the following equations.

Finally, the reference voltages for the DVR are given by

$$\begin{bmatrix} V_{L\alpha}^{*} \\ V_{L\beta}^{*} \end{bmatrix} = \begin{bmatrix} \cos \omega_0 t & \sin \omega_0 t \\ -\sin \omega_0 t & \cos \omega_0 t \end{bmatrix} \begin{bmatrix} V_{Ld}^{*} \\ V_{Lq}^{*} \end{bmatrix}$$

$$\begin{bmatrix} V_{La}^{*} \\ V_{Lb}^{*} \\ V_{Lc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{L\alpha}^{*} \\ V_{L\beta}^{*} \end{bmatrix}$$

It is to be noted that the DVR will not be able to compensate for the harmonics in the load current produced by nonlinear loads. This would require shunt connected DSTATCOM. When both load compensation and harmonic isolation (from the source) are required, then Unified Power Quality Conditioner (UPQC), to be described in the next section, is the appropriate device for improvement of power quality. UPQC also helps in regulating the load bus voltage in the presence of large variations (sag or swell) in the supply voltages. The DVR with capacitor on the DC side has the limitations of having to inject only reactive voltage in steady state. This may not be able to compensate fully large variations in the PCC voltage.

B. Synchronous Reference Frame Based Extraction of Reference Currents

The block diagram of the control scheme to generate the reference values of the compensator currents is shown in Fig. 4.6. The desired source currents (in d-q components) are obtained as

$$i_{Sd}^{*} = \bar{i}_{Ld} + i_{Cd}$$

$$i_{Sq}^{*} = K_q \bar{i}_{Lq} + u i_{Cq}$$

where ILd and ILq are the average values of the d- and q- axis components of the load current, icd is the output of the DC voltage controller and icq is the output of the AC voltage controller (if the bus voltage (Vt) is to be regulated). u is a logical variable equal to (a) zero if PF is to be regulated and (b) one if bus voltage is to regulated. Kq = 1 in the latter case. When PF is to be controlled, Kq is determined by the required power factor as follows.

$$K_q = \frac{Q_S^{*}}{\bar{Q}_L}$$

where Q¤S is the reference reactive power supplied by the source (at PCC) and ¹QL is the average reactive power (at fundamental frequency) defined by

$$\bar{Q}_L = |V_t| \bar{i}_{Lq}$$

For unity power factor, Q¤S = 0 and Kq = 0. The average values of iLd and iLq are obtained as the outputs of two identical low pass filters and are defined as

$$\begin{bmatrix} \bar{i}_{Ld} \\ \bar{i}_{Lq} \end{bmatrix} = G(s) \begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix}$$

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where G(s) is chosen as the transfer function of a 2nd order Butterworth low pass filter (with a corner frequency of 30 Hz). The d-q components are computed from the following relations

where the $\alpha - \beta$ components are obtained as

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

The reference vector of source currents is given by

$$\begin{bmatrix} i^*_{Sa} \\ i^*_{Sb} \\ i^*_{Sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_{S\alpha} \\ i^*_{S\beta} \end{bmatrix}$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

$$\begin{bmatrix} i^*_{S\alpha} \\ i^*_{S\beta} \end{bmatrix} = \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} i^*_{Sd} \\ i^*_{Sq} \end{bmatrix}$$

where the currents are given by

Note that ! is the supply frequency expressed in radians/sec. The unit vectors sin !t and cos !t are obtained from Phase-Locked Loop (PLL) which is locked to the PCC voltage.

V. RESULTS AND DISCUSSION

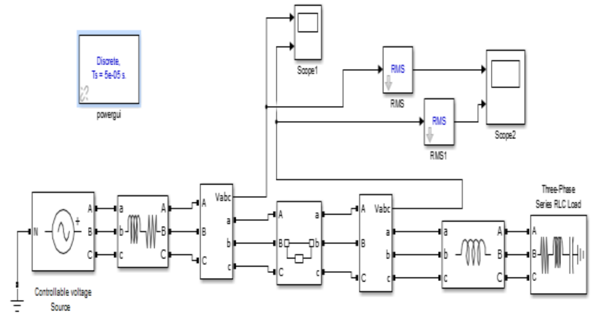

Figure 12.System MATLAB Model without DVR

(i) Source Voltage (ii) Load Voltage.

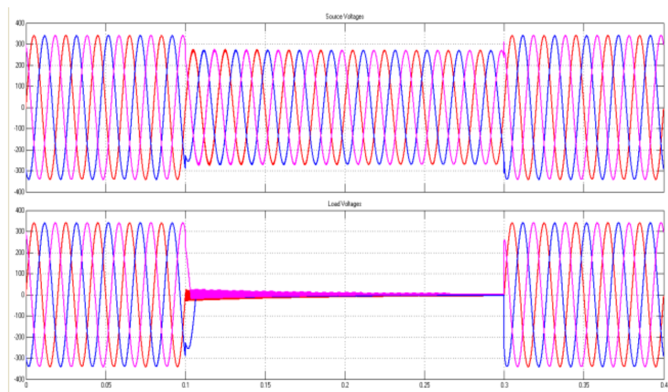

Figure 13.Voltages sag in three Phase (25%)

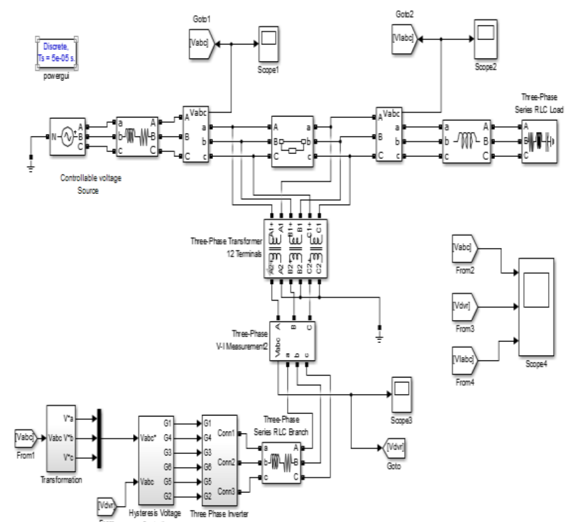

Figure 14.System MATLAB Model with DVR

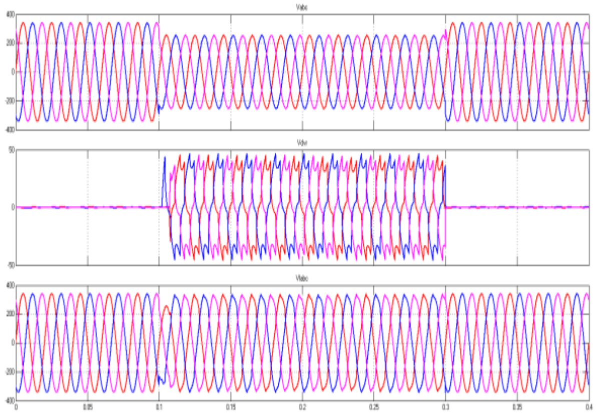

Figure 15.Voltages sag in three phase (25%) (i) Source Voltage (ii) Injected Voltage (DVR) (iii) Load Voltage.

VI. CONCLUSION

This showcases the modeling of Dynamic Voltage Restorer to compensate voltage sag in supply side voltage as well as linear load side voltage. Small size and efficient operation of this device is useful for generating a compensating voltage required to regulate load side voltage undisturbed. Control technique is based on hysteresis voltage controller and synchronously reference frame theory applied to DVR for better operation and fast response of DVR.

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