Design of Seven Level Dynamic Voltage Restorer for Voltage Sag and Harmonics Mitigation

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Abstract

The power quality disturbance in a power distribution network was voltage sag and swell and voltage harmonic. New ideas, methods and techniques had been introduced by researchers to improve the quality of supply particularly at the sensitive load end. Many of these methods have their own drawbacks such as complexity, slow response and sensitivity to parameter variations. In this research, an improved Dynamic Voltage Restorer (DVR) topology has been designed and modeled to be used on a 415 Volts distribution network. A seven level cascaded multilevel inverter using multicarrier SPWM technique controller was proposed to handle the voltage imperfections. An innovative controller based on the Synchronous Rotating Reference Frame (SRRF) to overcome the disadvantages of the existing controller schemes by reducing the complexity, number of signal measurements and computing time has been developed. The controller was able to control the zero sequence voltage during unbalance fault period. The switching frequency of the phase shift SPWM was low and hence, the switching loss was low. The Total Harmonic Distortion (THD) with the proposed DVR was significantly reduced to 1.64 % as compared to other traditional models and was within the IEEE Standards 519-2014. The proposed controller algorithm provides excellent voltage compensation.

Keywords: Dynamic Voltage Restorer, Voltage sag, Voltage harmonics, Phase shifted 7-level SPWM inverter

1.0 Background of the study

Power quality has gained tremendous attention since the late 1980s. Three parties are most concerned about power quality (PQ). They are utility companies, equipment manufacturers, and the end consumers (Wilson E. Kazibwe 1993). The end customer wants to know how the power disturbances will affect sensitive loads and the correct mitigation techniques required. The manufacturers need to know the practical electrical environment so that they can design equipment with reasonable tolerances or the ride through capability. The utility wants to know the user generated disturbances, which can affect the neighboring customers. There are two terms known in power systems about the quality of power: good power quality and poor power quality. Good power quality means the power supply is always available, within the voltage and frequency tolerances and has a pure sinusoidal wave shape to all equipment, because most electrical equipment was designed on that basis (IEC 61000-4-30 2003). Unfortunately, most of the equipment that is manufactured also distorts the supply voltage, (R.C. Sermon 2005) which is known as poor power quality. This will affect other equipment that was designed with the expectation of consistent undistorted voltage, and are thus sensitive to power disturbances resulting in reduced performance and will cause equipment mal-operation or premature failure (A. Rash 1998). In general, power quality disturbances comprise of a wide range of problems such as voltage sag, voltage swell, transients, over voltage, unbalance, harmonics, flicker, interruptions and notches. The most serious of all the disturbances are voltage sag, voltage swell and harmonics. A voltage sag condition implies that the voltage on one or more phase drops below the specified tolerance for a short period of time. Due to the insufficient energy availability, the equipment may mal-operate or trip. These activities cause production loss and heavy financial losses (Bhim Singh and Ambrish 2015). A voltage swell condition occurs when the voltage of one or more phase rises above the specified tolerance for a short period of time. Harmonic distortion in a power network is developed by devices with nonlinear operating characteristics. The cost of power quality problems can be very high and includes the cost of downtimes, loss of customer confidence and, in some cases, equipment damage. Power quality issues have become apparent since the late 1980s when engineers discovered that almost 95 % of the total equipment interruptions were due to power quality disturbances. The problem that needs to be addressed is the voltage imperfections. These problems will affect the quality of supply which also affects the performance of the equipment.

1.1 Problem Statement

Until 1970s, the main concern of consumers of electricity was the reliability of the electric supply. Today, however, a customer in an industry needs quality power supply with minimum voltage disturbances, minimum interruptions to processes, and minimum outages of the plant. Also, the end users in hospitals, manufacturing industries and financial institutions require reliable and high quality electrical supply at the sensitive loads. Poor power quality can affect the operation of electrical equipment that will lead to mal-operation or interruption. This will cause process and production losses and ultimately financial losses. Voltage sag, swell and voltage harmonics are the three major problems encountered in an electrical distribution network. Voltage sag is the most severe.

In order to improve the power quality disturbances, many methods of solving power quality problems have been suggested. The development and improvement of power semi-conductor switching devices capable of carrying large current with high voltage enable power electronics technologies to be applied to this area. Many voltage mitigation schemes are based on inverter systems consisting of energy storage and power switches. Large energy storage is required when it is necessary to supply real power, which makes these systems expensive. Many researchers have proposed voltage sag mitigation and voltage harmonics compensation methods independently by using series active power filter and tuned shunt passive LC filters as a hybrid integrated model (Fang Zheng Peng 1993) (Kannan Kartik and J.E. Quaicoe 2000) (Hideaki Fujita and Hirofumi 1991). The controller is not tested for different types of faults such as balanced and unbalanced faults, balanced and unbalanced faults with harmonics generating loads, as well as harmonics alone. The simulation results in various faults that are not presented or discussed. Three prominent problems need to be addressed. Firstly, mitigation of balanced and unbalanced voltage sags; secondly, suppression of voltage harmonics and thirdly, mitigation of balanced and unbalanced voltage sags combined with voltage harmonics.

The primary goal of this research is design and development of a voltage sag mitigation scheme with high reliability at low cost. This research proposes an improved Hybrid DVR incorporated with an innovative control scheme and a seven level phase shifted SPWM inverter. The proposed scheme is able to quickly recognize the voltage imperfections in the supply system. It corrects the voltage by either boosting the input voltage during voltage sag events or reducing the input voltage during voltage swell events. The innovative control scheme is implemented with minimum components and fast response than the traditional models. The system becomes more reliable and less expensive. The model will be able to correct voltage disturbances such as voltage sag, swell and voltage harmonics. The percentage voltage THDs in the three phase load voltages are considerably less with the new DVR topology. The total dc supply voltage is 300 V per pole which is only 55.4 % compared with the traditional DVR of 542 Volts.

1.2 Scope of Work

Non-linear loads cause distortion of sinusoidal waveform. This will adversely affect the power quality performances. Switching heavy loads, capacitance, transformer and faults on the power network are some of the source that contributes to voltage sag. The voltage sag can affect the performance of the electrical equipment. This research is directed towards further developments on the improvements to the voltage imperfection on a distribution network. The scope of the research work is limited to the low voltage 415 Volts distribution network. In order to quickly and precisely control the output voltage or mitigate the input voltage sag, this research includes several design issues such as the design of the voltage controller, the voltage sag detector, and the Filter circuitry. The thesis contributes to this field in four different ways: the first category is to identify and determine the connected nonlinear load to the distribution network for voltage sag detection. The second category is to identify and determine the harmonics extraction methods. The third category is to combine the sag detection and the harmonics extraction as a hybrid unit. The fourth approach is to design and model the three-phase Hybrid DVR with an innovative control scheme to detect and mitigate the voltage sag, swell and voltage harmonics. The specially design seven level phase shifted H-Bridge inverter and the RLC interface filter will provide an improved performance. The new improved controller will provide excellent voltage compensation with a low THD that is within the IEEE Std. 519-2014.

1.3 Significant Contribution of the Research

a) Improvement in system voltage transient is achieved by using the seven level cascade multilevel converter based DVR.
b) Seven level cascade multilevel converter based DVR for power quality improvement of the distribution systems has been successfully developed and simulated in PSCAD/EMTDC.
c) Mathematically developed an innovative controller based on new improved SRRF for better performance in terms of estimating the reference voltage signals quickly, the accuracy of injection voltage, and obtaining the source phase information quickly and accurately. The dq0 transformation was selected for the harmonic detection because of the fast calculation time which is suitable for the real time application. This controller is simple in terms of component assembly and costs.
d) Mathematically developed and evaluated an improved RLC interface filter connected between the IGBT based (VSI) and the injection transformer to eliminate the voltage harmonics and switching harmonics from the VSI by producing a PWM controlled harmonic voltage. The sizing of the RLC values has an impact on the price, dimension, weight, and capacity of the Voltage Source Inverter.
e) Evaluate and summarize the DVR ability to compensate the various voltage imperfections such as voltage sag/swell and voltage harmonic under different operation conditions and improvement in system voltage transient. Improved simulation results obtained, presented and compared to the discussion in the literature.
f) The proposed DVR can be integrated with the distribution generation sources, such as solar cells, and supply high quality power to the consumers concerning sensitive loads, ranging from shopping malls and hospitals to semiconductor manufacturing.

2.0 Simulated component modules of DVR

Figure 2.1 shows the different simulated component modules of DVR. Power module M1 represents the three-phase 0.415 kV supply connected to M2 which is the sensitive load. Module M3 will simulate the faults like SLGF, DLGF, LLF and 3 LGF and swell. Module M4 will simulate the voltage harmonics at junction J1. Module M5 system which measures and processes the voltage imperfections sensed at junction J2 and then feeds into the control scheme module M6. Module M7 generates the injection voltage and feeds into the junction J3 to correct the voltage imperfections.

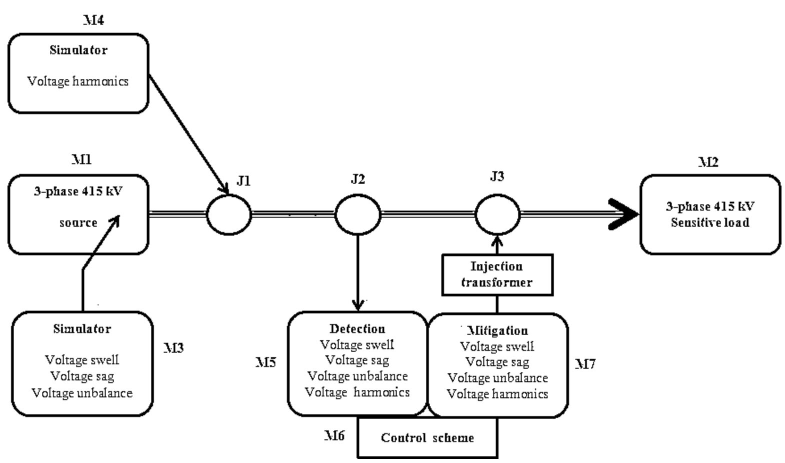


Figure 2.1: Different simulated component modules of DVR

3.0 Synchronous Frame Theory

The control system sense the voltage imperfections, the DVR will compute and acknowledge immediately injecting an ac voltage in series with the main supply system. The voltage at the load end is restored to its rated value and sinusoidal waveform. The sag detection method will be implemented using the synchronous reference frame (SRF) technique based on the instantaneous values of the supply voltage. The supply three phase voltages are converted from the abc reference frame to the dqo reference by the Park's transformation. The dqo method gives the sag depth and phase shift information from the start to the end times (H.G. Sarmiento and E. Estrada 1994). The quantities are expressed as the instantaneous space vectors. The error signal is the difference between the main supply voltage and the reference value. The reference signal is set at the rated peak voltage. The error signal is the modulation signal that allows generating a commutation pattern for the power switches (IGBT's) of the voltage source inverter. The forward and inverse transformation of abc / dqo signal are as follows (Wongsong Hong 2014) (Dmitry Baimel 2017):

$$Vd = 2/3\ [Va \sin(\omega t) + Vb \sin(\omega t - 2\pi/3) + Vc \sin(\omega t + 2\pi/3)] \quad \text{(Equation 3.1)}$$
$$Vq = 2/3\ [Va \cos(\omega t) + Vb \cos(\omega t - 2\pi/3) + Vc \cos(\omega t + 2\pi/3)] \quad \text{(Equation 3.2)}$$
$$V_0 = 1/3\ (Va + Vb + Vc) \quad \text{(Equation 3.3)}$$
$$Va = [Vd \sin(\omega t) + Vq \cos(\omega t) + V_0] \quad \text{(Equation 3.4)}$$
$$Vb = [Vd \sin(\omega t - 2\pi/3) + Vq \cos(\omega t - 2\pi/3) + V_0] \quad \text{(Equation 3.5)}$$
$$Vc = [Vd \sin(\omega t + 2\pi/3) + Vq \cos(\omega t + 2\pi/3) + V_0] \quad \text{(Equation 3.6)}$$

3.1 Control algorithm

In the d-q based controller algorithms, the measured system incoming voltage is transferred into Stationary Reference Frame using Clarke transformation, and then transferred into Synchronous Rotating Frame (SRF) using Park transformation. Based on Clarke transformation, the three-phase instantaneous voltages are transformed into stationary coordinates α-β-0 using Equation 3.7.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \mathrm{C} * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{(Equation 3.7)}$$

Based on Park transformation, the instantaneous voltages of the stationary coordinates α-β-0 as shown in Equation 3.7 is transformed into synchronous reference coordinates using Equation 3.8.

$$\begin{bmatrix} v_0 \\ v_d \\ v_q \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\omega t) & \sin(\omega t) \\ 0 & -\sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \mathrm{S} * \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \quad \text{(Equation 3.8)}$$

Similarly, by substituting Equation 3.7 in Equation 3.8 the transformation from
a-b-c coordinates to synchronous rotating frame d-q coordinates is obtained as in Equation 3.9.

$$\begin{bmatrix} v_0 \\ v_d \\ v_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\omega t) & \sin(\omega t) \\ 0 & -sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$
$$= S\,(\omega t) * C * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = P\,(\omega t)\ * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{(Equation 3.9)}$$

Equation 3.9 can be rewritten as in Equation 3.10

$$\begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} = P\,(\omega t) \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{(Equation 3.10)}$$

The inverse of the park transformation, d-q coordinates to the a-b-c coordinates is obtained as in Equation 3.11.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\omega t) & -\sin(\omega t) \\ 0 & \sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_0 \\ v_d \\ v_q \end{bmatrix} \quad \text{(Equation 3.11)}$$

When the three-phase supply voltage is distorted, both the positive and negative sequence components exist in the distribution system which can be expressed as shown in Equation 3.12.

$$\begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} = \begin{bmatrix} v_{dp} \\ v_{qp} \end{bmatrix} + P\,(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix} \quad \text{(Equation 3.12)}$$

where,

$P(-2\omega t) = e^{-j2\omega t}$

In Equation 3.12 the subscripts *p* and *n* represents respectively, the positive and negative sequence components of in Synchronous Rotating Frame Theory (SRFT) or d-q theory. For the fault detection purpose it is not crucial to extract the original positive and negative sequence component of SRFT (M. Emin Meral 2009). Using the positive sequence *q* component is adequate for the fault detection since *q* component has a DC value for the balanced faults condition (M. Emin Meral 2009). For effective voltage sag/swell detection, the Equation 3.12 is differentiated in time domain as shown in Equation 3.13.

$$\begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix} = -2\omega P\left(\frac{\pi}{2}\right) P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix} \qquad \text{(Equation 3.13)}$$

$P(-2\omega t) = e^{-j2\omega t}$

$\frac{dP(-2\omega t)}{dt} = -j2\omega e^{-j2\omega t}$

$= -2\omega\, j\, e^{-j2\omega t}$

$= -2\omega\, e^{j\pi/2}\, e^{-j2\omega t}$

$= -2\omega\, P\left(\frac{\pi}{2}\right) P(-2\omega t)$

Multiply Equation 3.13 by $e\, j^{\frac{\pi}{2}} = P\left(\frac{\pi}{2}\right)$

$$e\, j^{\frac{\pi}{2}} \begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix} = -2\omega\, e\, j^{\frac{\pi}{2}} P\left(\frac{\pi}{2}\right) P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$P\left(\frac{\pi}{2}\right) \begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix} = -2\omega\, e\, j^{\frac{\pi}{2}}\, e\, j^{\frac{\pi}{2}} P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$= -2\omega\, e\, j^{\frac{\pi}{2}}\ P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$P\left(\frac{\pi}{2}\right) \begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix} = -2\omega\, e\, j^{\pi}\ P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

Divide by -2*ω* the result is shown in Equation 3.14.

$$-\frac{1}{2\omega} P\left(\frac{\pi}{2}\right) \begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix} = P(\pi) P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix} \qquad \text{(Equation 3.14)}$$

where,

$\dot{v} = \frac{dv}{dt}$

Adding Equation 3.13 and Equation 3.14 leaves only the positive sequence component. Thus all the negative sequence components have been removed and the result is expressed as in Equation 3.15.

$$= \begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} - \frac{1}{2\omega} P\left(\frac{\pi}{2}\right) \begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix}$$

$$= \begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} + P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix} + P(\pi) P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$= \begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} + [1 + P(\pi)]\, P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$= \begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} + [1 + e\, j^{\pi}]\, P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$= \begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} + [1 + (-1)]\, P(-2\omega t) \begin{bmatrix} v_{dn} \\ v_{qn} \end{bmatrix}$$

$$= \begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix}$$

Thus,

$$\begin{bmatrix} v_{d(p)} \\ v_{q(p)} \end{bmatrix} - \frac{1}{2\omega} P\left(\frac{\pi}{2}\right) \begin{bmatrix} \dot{v}_{d(p)} \\ \dot{v}_{q(p)} \end{bmatrix} = \begin{bmatrix} v_{dp} \\ v_{qp} \end{bmatrix} \qquad \text{(Equation 3.15)}$$

Using Equation 3.15, the reference compensation voltage component can be obtained by the following equations:

$$v_{dp} = v_{d(p)} - \frac{1}{2\omega} P\left(\frac{\pi}{2}\right)\ \dot{v}_{d(p)} \qquad \text{(Equation 3.16)}$$

$$v_{qp} = v_{q(p)} - \frac{1}{2\omega} P\left(\frac{\pi}{2}\right)\ \dot{v}_{q(p)} \qquad \text{(Equation 3.17)}$$

For efficient voltage sag/swell detections, the references can be represented as follows:

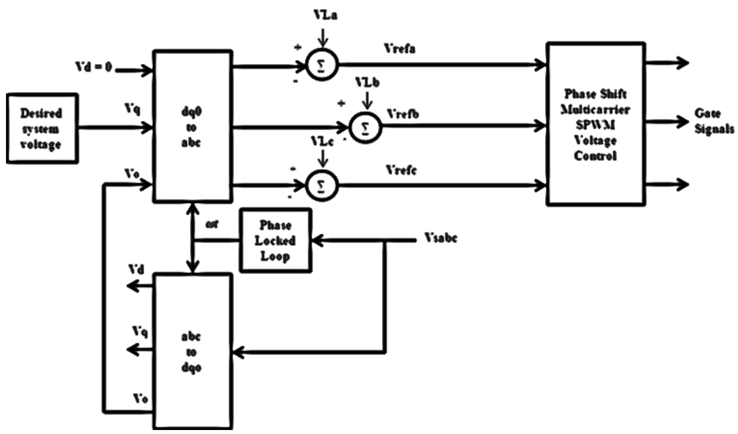
$$v_{qp} = v_{d(p)} - \frac{1}{2\omega}\, P\left(\frac{\pi}{2}\right) \dot{v}_{d(p)} \rightarrow v_{q(p)} = 1$$

$$\frac{1}{2\omega}\, P\left(\frac{\pi}{2}\right) \dot{v}_{q(p)} = v_0 \qquad \text{(Equation 3.18)}$$

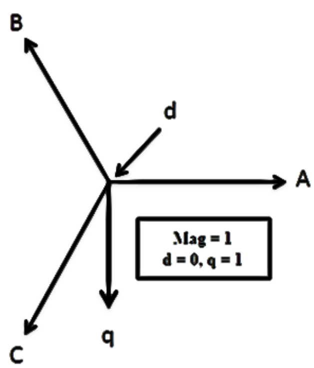
$$v_{dp} = v_{q(p)} - \frac{1}{2\omega}\, P\left(\frac{\pi}{2}\right)\dot{v}_{q(p)} \rightarrow \quad v_{d(p)} = 1$$
$$\frac{1}{2\omega} P\left(\frac{\pi}{2}\right)\, \dot{v}_{q(p)} = 0 \qquad \text{(Equation 3.19)}$$

With reference to Equation 3.18 and Equation 3.19, the estimation of the reference compensation voltage for the proposed DVR controller can be accomplished. The first method of calculation is based on *q* axis positive sequence component and zero-sequence value as shown in Equation 3.18. In the second method the calculation is accomplished under consideration of the *d* axis positive sequence component only as shown in Equation 3.19.

Figure 3.0(a) show the flow of proposed controller of DVR and the mathematical description of the first method. The position of the vector is shown in Figure 3.0(b).



(a)



(b)

Figure 3.0: (a) Proposed controller of DVR system multi-carrier
(b) Vector representation

The voltage sag, swell and unbalance voltage sag with zero sequence is compensated very effectively. As shown in Figure 3.0(a), the adapted control scheme is simple, has minimum component assembly and complexity in comparison with the existing ISRRF. The proposed control scheme is reliable and has fast signal tracking response for both in the steady state and dynamic operation conditions. This controller has the ability to compensate for different types of voltage variations. The voltage at the sensitive load is maintained sinusoidal at the desired value. The controller is robust and is able to operate under sudden load changes and system parameters. The controller is compact and much cheaper.
This modeling and analysis of the DVR systems are necessary for both the computer simulation and for satisfactory operation. A better and feasible control scheme for the DVR was proposed. The methodology and technology of

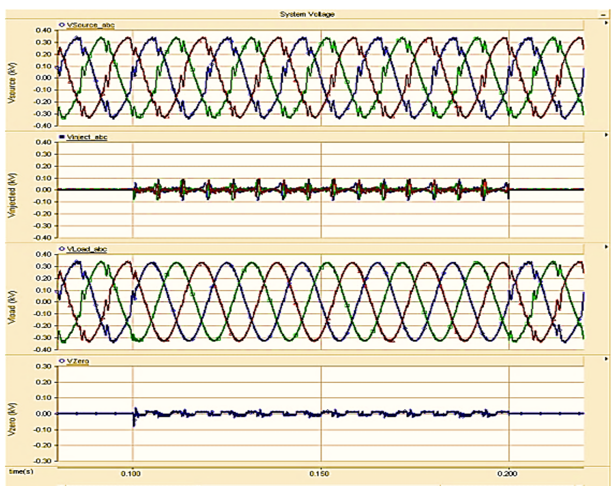
voltage sag / swell mitigation and voltage harmonic suppression have been discussed. The proposed DVR is able to mitigate voltage sag/swell and voltage harmonics and combination of both voltage sag with voltage harmonics. Compare to the traditional model, this model does not require any tuned harmonic passive filters at the sensitive load end. A new innovative control technique has been proposed, enabling the DVR to operate in balanced and distorted supply condition. The proposed control scheme for the DVR was able to perform the multi role function for sag / swell mitigation, voltage harmonic suppression and control both voltage sag and voltage harmonics. The main objective of the control scheme was to operate for any voltage imperfections so that voltage at the sensitive load end was sinusoidal at its rated value.

4.0 Verification through simulation

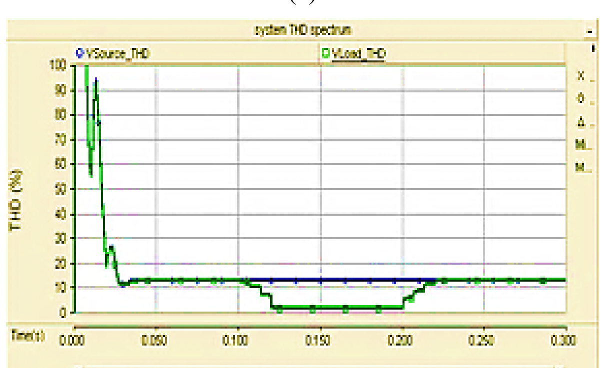
In this section, simulation results are presented to demonstrate the effectiveness of the proposed DVR control scheme in mitigating voltage harmonics, voltage swell and voltage sag. The simulations were exploited using PSCAD/EMTDC.

4.1 Effectiveness on voltage harmonic mitigation

Figure 4.1 (a) represents supply voltage without DVR compensation and load voltage with DVR compensation. The voltage at the sensitive load is sinusoidal, no ripples and overshoot. With the DVR in service, the load voltage total harmonic distortion (THD) has been reduced to1.64% from 12.96 % which is below the permissible level of 5.0 % as shown in Figure 4.1(b).



(a)



(b)

Figure 4.1: DVR compensation (a) voltage at sensitive load
(b) Load voltage THD level

4.2 Effectiveness on sag mitigation

Single line-to-ground fault was created between time 0.1 sec and 0.2 sec for duration of 100 ms. For 100 ms, the DVR starts injecting the required compensating voltage. The voltages at the sensitive load was balanced, sinusoidal with no ripples and overshoot and was at its rated value, as shown in Figure 4.2.

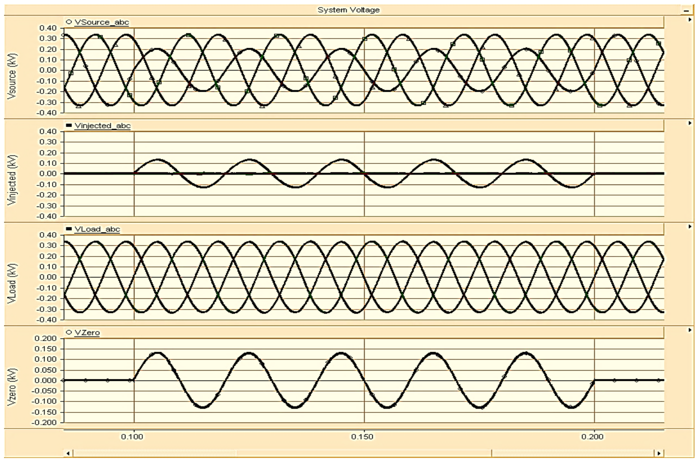


Figure 4.2: Single line to ground fault voltage sag

4.3 Effectiveness on swell mitigation

As observed from Figure 4.3, the amplitude of supply voltage was increased about 15% from its nominal voltage. The DVR reacted quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the load voltage. As can be seen from the results, the load voltage is kept at the nominal value 340 V by the DVR.

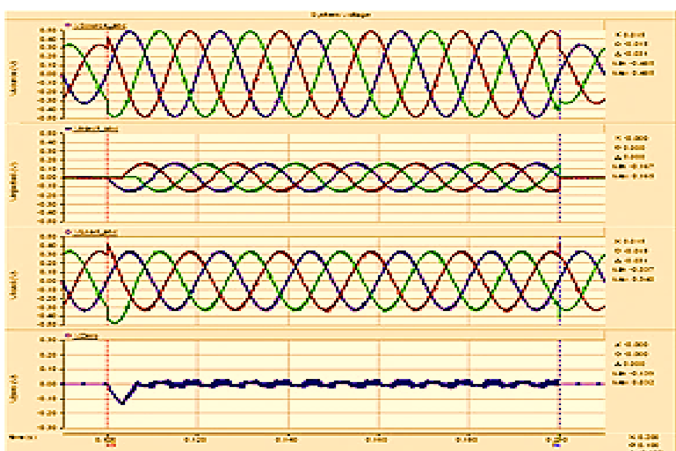


Figure 4.3. Swell mitigation by DVR

5.0 Conclusions

In this research the effectiveness of the proposed controller for DVR has been investigated. The innovative new control scheme was able to mitigate the voltage imperfections very efficiently. With the 7-level phase shifted multilevel inverter, there was a significant reduction in THD and a better performance. The 7-level inverter was a significant tradeoff between the number of hardware, control and performance requirement and the allowed THD. The DVR has improved the quality of voltage at the sensitive load end. This paper will be helpful to other researchers who are keen on power quality improvement in the power distribution network

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7.0 Biography

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