MultiCraft

International Journal of Engineering, Science and Technology
Vol. 2, No. 10, 2010, pp. 44-55

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY
www.ijest-ng.com

Mitigation of voltage sag using DVR under feedback and feedforward control scheme

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Abstract

The paper deals with Dynamic Voltage Restorer (DVR) that aims at the integration of series active filter with minimum VA handling. The DVR not only regulates the voltage at load end but also acts as series active filter. The scheme of DVR is modeled and simulated with MATLAB/Simulink under feedback and feedforward controller. It is also thoroughly analyzed, both from the point of view of the choice of the components and their ratings. The proposed scheme provides stability under varying gains thus eliminating the problem of tuning of conventional proportional and integral controller and improves the speed of response of the device. The results of simulation for the proposed scheme are presented.

Keywords: DVR, Minimum VA loading, PWM Technique, Feedback and Feedforward Controller, Matlab/Simulink

1. Introduction

In a power distribution system, the power quality problems (Bolen, 1999) such as the voltage sags and momentary interruptions are probably the most common and important problems affecting low and medium voltage customers. Voltage sags are usually associated with faults in the power grid but can also be caused by switching of heavy loads, starting of large motors, and by transformer energizing. According to the EN50160 standard (Giroux *et al.* IECON,2001), the term "voltage dip" is defined as a sudden reduction of supply voltage to a value between 90% and 1% of the rated voltage, followed by a voltage recovery after a short period of time, ranging from half a cycle up to 1 min. In the same standard, the depth of a voltage dip is defined as the difference between the minimum rms voltage during the voltage dip and the rated voltage. In the IEEE Standard 1159-1995, the term "sag" is used instead of "dip" and defined as the decrease in rms voltage or current to values between 0.1 to 0.9 p.u. for durations of 0.5 cycles to 1 min. Anyhow the voltage sag which is one of the important parameters of power quality, has been great concern for both suppliers and customers.

The value power quality is strictly related to the economic consequences associated with the equipment and should therefore be evaluated considering the customers point of view. For example, the voltage sags despite their very short duration, are issues of reliability, as they can disrupt an industrial process and require several hours to get back into production. So the need for solutions dedicated to single customers with highly sensitive loads is great and since a fast response of voltage regulation is required. The STATCOM which is modeled by Giroux *et al.* (2001) is the vital component of the devices used in power quality. It has several applications such as power factor corrector, harmonic compensator and voltage mitigator etc. Sun *et al*. (2002) and Ding *et al.* (2002) have used STATCOM with space vector PWM as voltage injector in line (i.e, so called DVR) for unbalanced condition. Now the DVR which has been utilized in optimized way by Vilathgamuwa *et.al.* (2003) has been put under new technique of sag detection by Fitzer *et al*. (2004). The performance of DVR has been studied and improved with elimination of selective predominant harmonics by Newman *et al.* (2005). Various control strategies have been developed by Choi *et al.* (2005), Delfino. *et al*.(2005), and Kim *et al*. (2005) to mitigate the voltage sag/swell. The DVR acting as series active filter has been focused by Riberio *et al*. (2006). The researcher Kolhatkar *et al.* (2007) have developed a technique to inject voltage so as to result minimum volt-ampere loading, The problem of voltage swell and over voltage has been overcome by Lam *et al.* (2008) using unidirectional power flow controlled DVR.

Singh *et al.*(2008) have developed a new technique of current decomposition for improvement of power quality using selective compensating power quality problem, whereas the power quality of an unbalanced system has been investigated by Morsi *et al.* (2008). Routimo *et al.* (2008) and Kim *et al.* (2009) have analysed the problem of voltage flicker using a hybrid controller and power factor angle respectively. Roncero-Sanchez *et al.* (2009) have developed a versatile control technique for improvement of power quality. Space vector method for minimizing switching loss in inverter has been incorporated by Ignatova *et al.* (2009). The problem voltage flicker mitigation in an arc furnace has been overcome using a non-linear control operation of STATCOM by Yazdani *et al.* (2009). Salmeron *et al.* (2010) have used used hybrid comination of series and shunt STATCOM for improvement of power quality. Bae *et al*. (2010) have developed a novel technique for detection of voltage sag for DVR.

In the following paper, the DVR has been used for injecting voltage in the line and it has been analysed under the influence of hybrid controller that comprises a PI, feedback and feedforward controller. The use of feedback and feedforward control, which exhibits a faster response with minimum oscillation and provides stability to the system, has been investigated and the relevant results presented.

2. Basic Structure of STATCOM as DVR

The basic structure of DVR is shown in Figure 1. The basic elements of a DVR are dc side energy source, voltage source converter, injection series transformer and harmonic filter. The details about these components are described as follows.

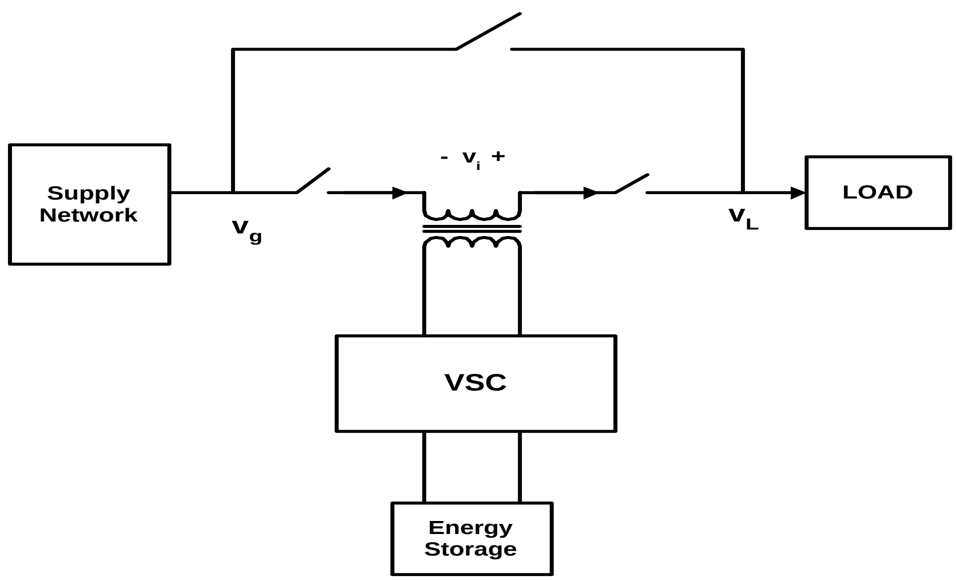


Figure 1. Basic Structure of DVR

2.1 DC side Energy Sour

The energy storage devices are dc capacitors, batteries, super conducting magnetic storage and flywheels. The present work employs dc capacitor banks. The rating of dc side capacitor has been chosen considering the voltage sag without phase angle jump. The size of capacitors should be chosen such that during sag of maximum expected magnitude and duration, the load voltage is kept at rated value and dc voltage does not decrease below a minimum allowable selected value. In case of voltage sag $V_{sag\,(pu)}$ with no phase angle jump, the DVR should inject an active power in order to restore the pre-sag rated voltage V_{lr} at the load terminals and this active power is given by

$$P_{DVR} = -v_{dc}\, i_{dc} = -C_{dc} v_{dc} \frac{dv_{dc}}{dt} = \sqrt{3}\, V_{lr}\, I_{lr} \cos\phi_{lr}\ (1 - V_{sag}) = P_{lr}\ (1 - V_{sag}) \tag{1}$$

where the load current I_{lr} and power factor cos Φ_r are assumed to be constant and equal to their rated value during sag compensation. P_{lr} is rated load power and v_{dc} is the dc voltage across the capacitor.

If t_{sag} is the voltage sag duration, the energy to be supplied by DVR is

$$W_{DVR} = \int_{t_0}^{t_0+t_{sag}} P_{DVR}\ dt = \int_{t_0}^{t_0+t_{sag}} (-C_{dc} v_{dc} \frac{dv_{dc}}{dt})\, dt = \int_{t_0}^{t_0+t_{sag}} P_{lr}(1 - V_{sag})\, dt \tag{2}$$

This simplifies to

$$-\frac{1}{2} C_{dc} \left[v_{dc}^{\,2}\,(t_0 + t_{sag}) - v_{dc}^{\,2}\,(t_0) \right] = P_{lr}\ (1 - V_{sag}) \tag{3}$$

If $v_{dc}(t_o) = V_{dcr}$ (i.e., the initial dc link voltage is assumed at its rated value, and $v_{dc}(t_o+t_{sag}) = k_d V_{dcr}$, where $k_d V_{dcr}$ is the minimum allowable dc-link voltage at the end of voltage sag ($0 < k_d < 1$) to compensate a maximum voltage sag magnitude $V_{sag,max}$ for a maximum expected sag duration $t_{sag.max}$, then value of capacitance should be

$$C_{dc} \geq \frac{2P_{lr}\, t_{sag.max}\, (1 - V_{sag.max})}{V_{dcr}^{2}(1 - k_d^{2})} \tag{4}$$

The size of dc capacitor will be reduced by increasing value of V_{dcr} and this voltage depends also on maximum voltage rating of the VSC power electronic devices. The voltage rating of capacitor also limits the maximum injection voltage.

2.2 Voltage- Source Converter (VSC)

The Voltage Source Converter (VSC) is controlled by a Pulse Width Modulation (PWM) technique. The magnitude of modulating signal is derived from control unit and this signal is then compared with fixed carrier signal to extract the signals of switching devices of converter. When the network is at its rated value, it is therefore possible to constrain the inverter to insert a voltage identically equal to zero by properly controlling semi-conductor components.

2.3 Series Injection Transformer

As far as the rating of transformer is concerned, the following considerations can be done. Supposing to compensate a voltage sag of max depth $V_{i.max}$ ($Vgr/\sqrt{3}$) (i.e., $V_{i.max}$ (pu) <1, the maximum series injection voltage and V_{gr} is the grid-rated line-to-line voltage), the transformer power is given by

$$A_t = \sqrt{3}\, V_{i.max}\, V_{gr}\, I_{lr} \tag{5}$$

where I_{lr} is rated load current.

As the voltage sags are short compared to thermal time constant of a transformer, one can choose the rated power smaller than above calculated value. As well known(Newman et.al., (2005)), the RMS value of the fundamental frequency component $V_{c.1}$ of the VSC output phase voltage can be expressed as a function of PWM modulation index m_a (i.e., m_a <1) and of dc side voltage vdc

$$V_{c.1} = m_a\, v_{dc} / 2\sqrt{2} \tag{6}$$

Similarly

$$V_{c.1max} = m_{ar}\, v_{dcr} / 2\sqrt{2} \tag{7}$$

where m_{ar} modulation index at rated value.

Since the DVR has to compensate a voltage sag of max depth $V_{i.max}$ ($Vgr/\sqrt{3}$), the transformer turn ratio K_t can be determined

$$K_t = \frac{V_{i.max}\,(V_{gr}/\sqrt{3})}{V_{c1.max}} = \frac{2\sqrt{2}}{\sqrt{3}}\, V_{gr}\, \frac{V_{i.max}}{m_{ar}\, V_{dcr}} \tag{8}$$

In the present work, the modulation index at rated value m_{ar} = 0.8 has been chosen in order to work in linear region when the maximum series injection voltage is required. It is to be noted that during compensation process, the dc side voltage falls below its rated value when a compensation of voltage sag of larger depth is needed.

2.4 Harmonic Filter

A passive filter is needed for blocking the high-frequency harmonics generated by PWM switching. This filter can be connected either on converter side or on line side. The small voltage drop on DVR represents the great advantage of the line-side filter during normal operation due to transformer leakage operation. On the other hand, with such filter configuration high order harmonics current will flow through the series transformer causing stress on it and requiring a higher transformer rating. In order to determine rating of the harmonic filter connected on line side as shown in Figure 1, the network can be simplified shown in Figure 2.

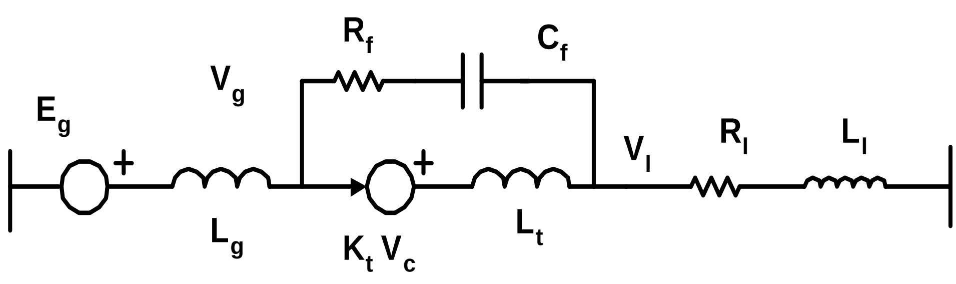


Figure 2 : Harmonic filter connected on line side (i.e., across the secondary of injected transformer)

In this case, the VSC is considered as a voltage source with amplitude K_tV_c, L_t is leakage inductance of series transformer referred to network side, v_t is the voltage drop on it and R_f and C_f are the filter resistance and capacitance. Furthermore, the network has been represented by its Thevinin's equivalent consisting of an ideal voltage source (amplitude E_g and inductance L_g) and load is modeled as the series resistance R_l and an inductance L_l. The single-phase equivalent circuit at steady-state for h_{th} harmonic voltage order is reported in Figure 3, where $L_s = L_g + L_l$.

Assuming the network voltage without harmonics, the Milliman theorem applied to Figure 3 for h_{th} harmonic voltage order (h > 1), gives

$$V_{i,h} = \frac{K_t V_{c,h} / jh\omega L_t}{\frac{1}{jh\omega L_t} + \frac{1}{R_f + \frac{1}{jh\omega C_f}} + \frac{1}{R_l + jh\omega L_s}} \tag{9}$$

In order to properly design the filter one should impose the following requirements.

$$\frac{|V_{i,h}|}{K_t |V_{c,h}|} << 1 \quad \text{for } h = h_{min} \tag{10}$$

where h_{min} is the lowest harmonic order present in the PWM harmonics spectrum and:

$$\frac{|V_{i,h}|}{K_t |V_{c,h}|} \quad \text{with } (E_{g,1} = 0) \cong 1 \quad \text{for } h = 1 \tag{11}$$

By imposing the above two conditions (10) and (11), the value of R_f and C_f can be calculated.
On primary side of injection transformer, a LC filter is provided across the output of VSC to eliminate the high order harmonics

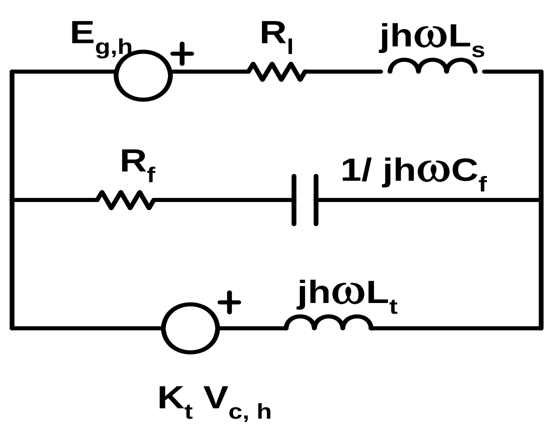


Figure 3: Single-phase h_{th} harmonic equivalent circuit

3. DVR Control System

In present case, a complete control scheme will be defined for a DVR, which is connected to a linear load consisting of a resistance – inductance load.

3.1 Model of Control System

The system under study is shown in Figure 2 and the variables used here are defined as follows. $v_l(t)$: load phase voltage, $i_l(t)$: load phase current

In order to set up an effective control system, it is first of all necessary to adequately model the system to be controlled. To do this, the following hypotheses have been done.

A first dynamic model is considered with the filters neglected.

The VSC is modeled as an ideal voltage source (i.e., with no delays)

$$L\frac{di_{li}}{dt}+R_l\, i_{li}(t)=v_{gi}(t)+K_t\ v_{ci}(t) \qquad \text{where } i=a,b,c;\quad L=L_t+L_l \tag{12}$$

$$v_{li}(t)=L_l\frac{di_{li}}{dt}+R_l\, i_{li}(t) \qquad i=a,b,c \tag{13}$$

Applying Park's transformation to above two equations, one has following d-q equations from (12)

$$L\frac{di_{ld}}{dt}+R_l\, i_{ld}(t)-\omega L\, i_{lq}(t)=v_{gd}(t)+K_t\ v_{cd}(t) \tag{14}$$

$$L\frac{di_{lq}}{dt}+R_l\, i_{lq}(t)+\omega L\, i_{ld}(t)=v_{gq}(t)+K_t\ v_{cq}(t) \tag{15}$$

and d-q equations from (13)

$$v_{ld}(t)=L_l\frac{di_{ld}}{dt}+R_l\, i_{ld}(t)-\omega L_l\, i_{lq}(t) \tag{16}$$

$$v_{lq}(t)=L_l\frac{di_{lq}}{dt}+R_l\, i_{lq}(t)+\omega L_l\, i_{ld}(t) \tag{17}$$

where 'ω' is the system angular frequency and having indicated with x_d and x_q, the d- and q-axis components of each quantity.
A symmetrical voltage sag occurs at $t=t_0$ can be represented in this reference system with a step-variation of the network voltage $\Delta v_{gd}(q)$; therefore, during the sag, the equations (14) and (15) can be rewritten in terms of variations with respect to pre-sag conditions, obtaining a system of ordinary differential equations, with initial conditions $\Delta i_{ld}(t_0) = \Delta i_{lq}(t_0) = 0$.
This allows to apply the Laplace Transform and write as shown in the following equations from (14) and (15).

$$sL\,\Delta i_{ld}(s)+R_l\Delta i_{ld}(s)-\omega L\Delta i_{lq}(s)=\Delta v_{gd}(s)+K_t\ \Delta v_{cd}(s) \tag{18}$$

$$sL\,\Delta i_{lq}(s)+R_l\Delta i_{lq}(s)+\omega L\Delta i_{ld}(s)=\Delta v_{gq}(s)+K_t\ \Delta v_{cq}(s) \tag{19}$$

and from (16) and (17)

$$\Delta v_{ld}(s)\ =\ sL_l\ \Delta i_{ld}(s)+R_l\Delta i_{ld}(s)-\omega L_l\Delta i_{lq}(s) \tag{20}$$

$$\Delta v_{lq}(s)\ =\ sL_l\ \Delta i_{lq}(s)+R_l\Delta i_{lq}(s)+\omega L_l\Delta i_{ld}(s) \tag{21}$$

After some algebraic manipulations, one easily gets from equations (18,19) and (20,21) as follows.

$$\Delta v_{ld}(s)\ =\ G(s)\left[\Delta v_{gd}(s)+K_t\,\Delta v_{cd}(s)+G_i(s)\Delta i_{lq}(s)\right] \tag{22}$$

$$\Delta v_{lq}(s)\ =\ G(s)\left[\Delta v_{gq}(s)+K_t\,\Delta v_{cq}(s)-G_i(s)\Delta i_{ld}(s)\right] \tag{23}$$

where G(s) and $G_i(s)$ are defined as

$$G(s)=\frac{sL_l+R_l}{sL+R_l} \qquad \text{and} \qquad G_i(s)=\frac{\omega L_t\ R_l}{sL_l+R_l} \tag{24}$$

Hence defining the system

$$\Delta v'_{cd}(s)\ =\ \Delta v_{gd}(s)+K_t\,\Delta v_{cd}(s)+G_i(s)\Delta i_{lq}(s) \tag{25}$$

$$\Delta v'_{cq}(s)\ =\ \Delta v_{gq}(s)+K_t\,\Delta v_{cq}(s)-G_i(s)\Delta i_{ld}(s) \tag{26}$$

to be controlled is simply described by

$$\Delta v_{ld}(s)=G(s)\ \Delta v'_{cd}(s) \quad \text{and} \quad \Delta v_{lq}(s)=G(s)\ \Delta v'_{cq}(s) \tag{27}$$

The above pair of equations in (27) can be written as a single one.

$$\Delta v_{ldq}=G(s)\ v'_{cdq}(s) \tag{28}$$

3.2 Control Scheme

The feedback control scheme referred to equation (28) has been shown in Figure 4. The transfer functions of the voltage controller (i.e., R_d (s) and R_q(s) for both d- and q-axis) have been chosen in order to meet the requirements of stability of the system and make the steady-state error to be zero. In this case, two proportional -integral (PI) controllers have been designed and expressions are respectively.

$$R_d(s) = K_d(1+sT_d)/s \quad \text{and} \quad R_q(s) = K_q(1+sT_q)/s \tag{29}$$

On setting $T_d = T_q = L/R_l$, it is possible to cancel the pole of the function G(s). Furthermore, the phase diagram of the whole system never goes under $-\pi/2$, the model is stable for any value of gains. Still, the gains should be selected with moderate value such that stability is to be maintained.

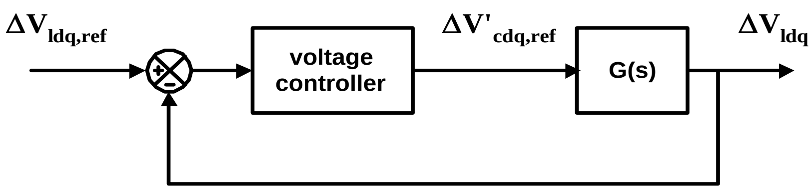


Figure 4: Feedback control loop of DVR

Since the outputs of the control system must be modulating signals for the PWM logic, one has to solve (25) and (26) with respect to $\Delta v_{cd}(s)$ and $\Delta v_{cq}(s)$, thus obtaining

$$\Delta v_{cd,ref}(s) = \left\lfloor \Delta v'_{cd,ref}(s) - \Delta v_{gd}(s) - G_i(s)\,\Delta i_{lq}(s) \right\rfloor / K_t \tag{30}$$

$$\Delta v_{cq,ref}(s) = \left\lfloor \Delta v'_{cq,ref}(s) - \Delta v_{gq}(s) - G_i(s)\,\Delta i_{ld}(s) \right\rfloor / K_t \tag{31}$$

So the final control scheme is depicted in Figure 5. In this scheme, the term $v^{ff}_{cdq,ref}$ represents the so-called feed forward contribution.

$$v^{ff}_{cdq,ref} = -\frac{\Delta v_{gdq}}{K_t} \tag{32}$$

As a matter of fact, this contribution should be sufficient to prevent the load voltages from being affected by voltage sag. Also a feedback channel (i.e., $v^{fb}_{cdq,ref}$) is necessary in order to compensate the non-idealities of the model itself.

The control algorithm in dq-reference frame has been chosen mainly for two reasons:

(i) The control methods based on RMS calculations of the measured variables are not suitable and compensation based on instantaneous quantities is instead required due to fast response of the system.

(ii) In control algorithms, the dc signals are much more feasible than those based on sinusoidal signals.

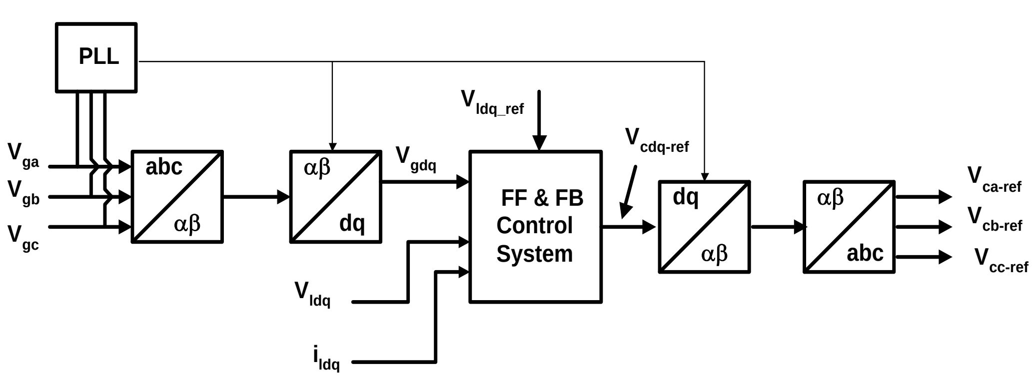


Figure 5: Final control scheme of DVR under feedback and feedforward control scheme

The feedforward and feedback control block of Figure.5 is expanded and shown in Figure 6.

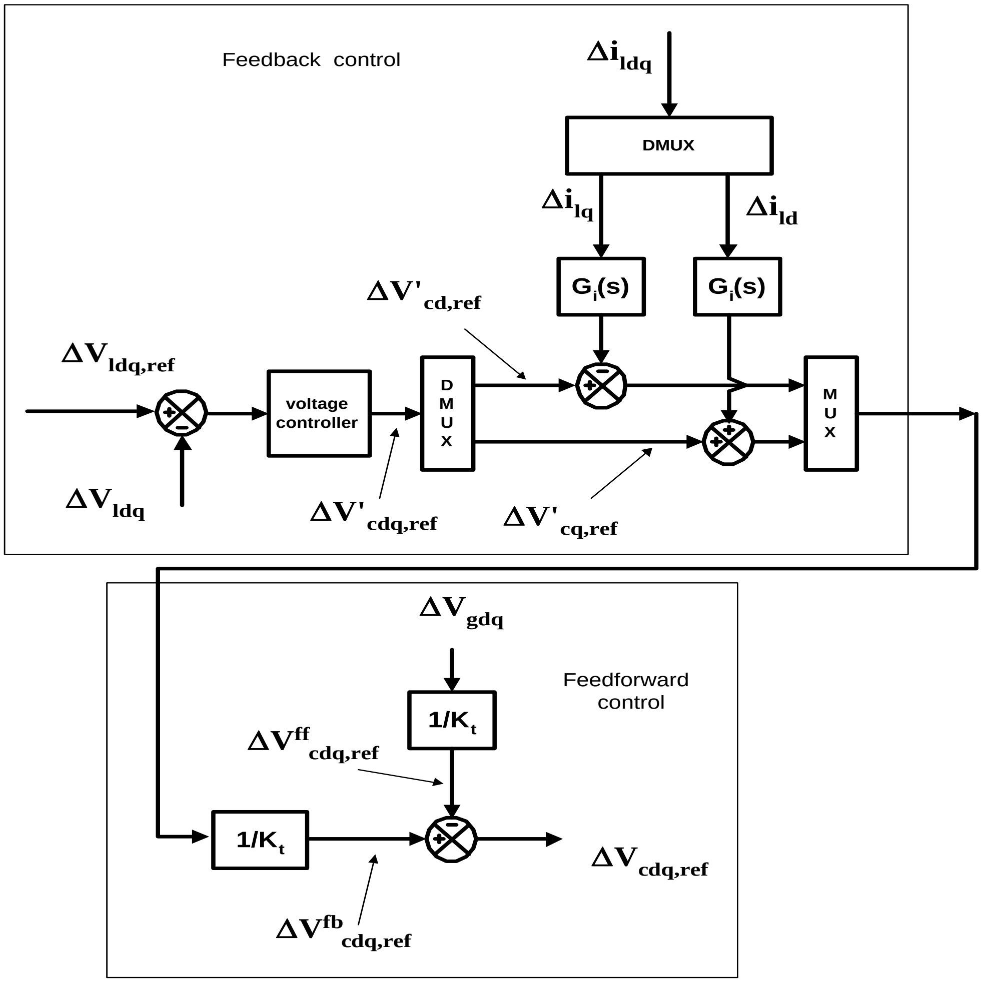
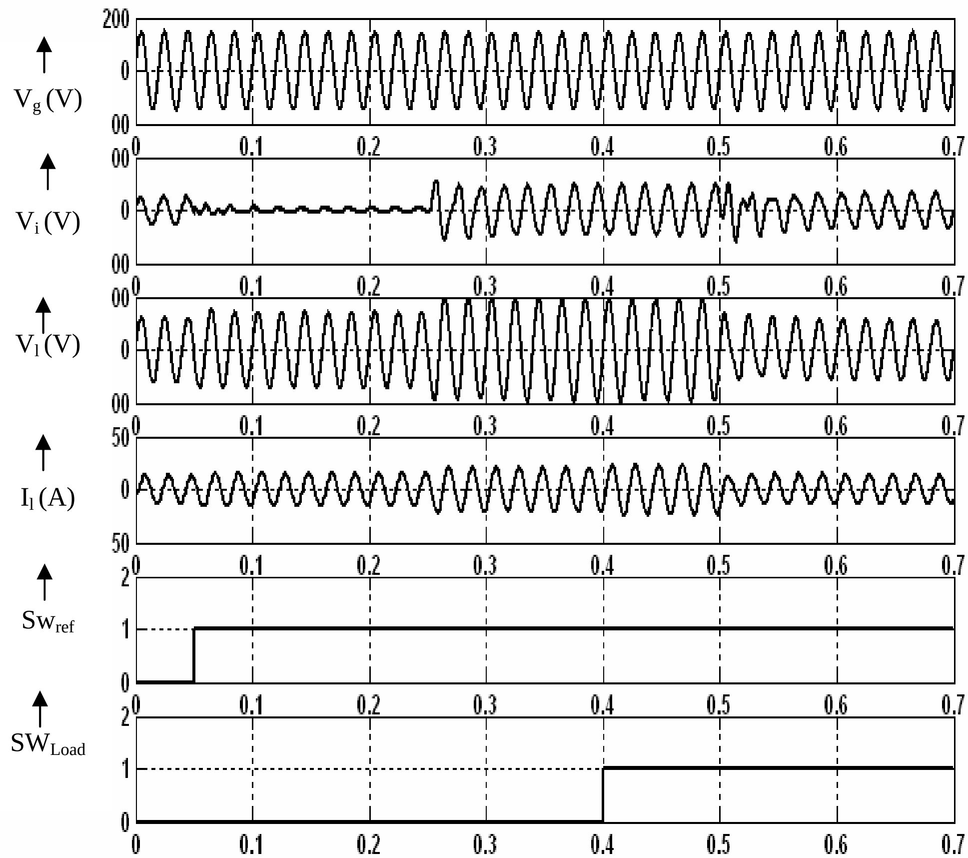


Figure 6: Feedback and feedforward control scheme

4. Simulation Results

In order to study the scheme both analytically and experimentally, a small prototype model is thought up and considered. The simulation is carried out with MATLAB/Simulink based on data as given Appendix-I. The program for MATLAB/Simulink is given in Appendix-II. The relevant results are presented in Figures 7~10 for a single-phase circuit. In Figure 7, the waveforms of source voltage (V_g), the injection voltage (V_i), load voltage and load current are shown. Input is maintained at 150 V at t=0. The reference voltage of the controller is set at 150V. The controller is activated at t= 0.05 sec. Before this activation, the load voltage becomes less than source due to impedance drop across secondary of the series injection transformer. This drop could be avoided using a switch across secondary of injection transformer before activation of controller, but this has not been considered in present case. When the controller is activated at 0.05 sec, the load voltage sticks to reference value till the reference value is increased to 200V at 0.25 sec. This reference value of 200 V is maintained till t=0.5 sec. Between t=0.25 and 0.5 sec, the load voltage sag is created at t=0.4 sec due to sudden rise in load. But it is found that the load voltage decreases slightly for a quarter cycle, but then it follows the reference command due to action of the controller. At 0.5 sec, the reference load voltage command is decreased to 120V from 200V. The actual load voltage follows the reference command and so the load current follows the load voltage. Figure 8 repeats the load voltage and load current of Figure 7 along with instant of activation of controller at 0.05 sec and the instant of increase in load at 0.4 sec.



Time ------(s)

Figure 7: Waveforms of source voltage, injection voltage, load voltage, load current, instant of change in load reference command and instant of load switch for change in load

In Figure 8, it shows the variation in input voltage when the reference command of load voltage is maintained constant. The reference command of 160 V is initiated at 0.05 sec and is maintained throughout when the input voltage is maintained at 150V initially and then stepped up to 180V at 0.4 sec. It is found to be controller acting satisfactorily under both variations in input voltage and also during change in reference command. Figure 9 shows the two cycles of load voltage whose harmonic analysis is shown up to 500Hz. The predominant harmonic voltages are found to be at 300 and 350 Hz. Their magnitudes are found to be 2% and 3% of fundamental respectively and lie in safe limit of IEEE std. Later this test of single-phase circuit is extended to 3-phase circuit and the relevant result is shown in Figure 10, where the load voltage is regulated with the help of DVR. The input voltage is changed from 150V to 170V at 0.4 sec and the reference command of load voltage is maintained at 160V. It shows the controller acting satisfactorily.

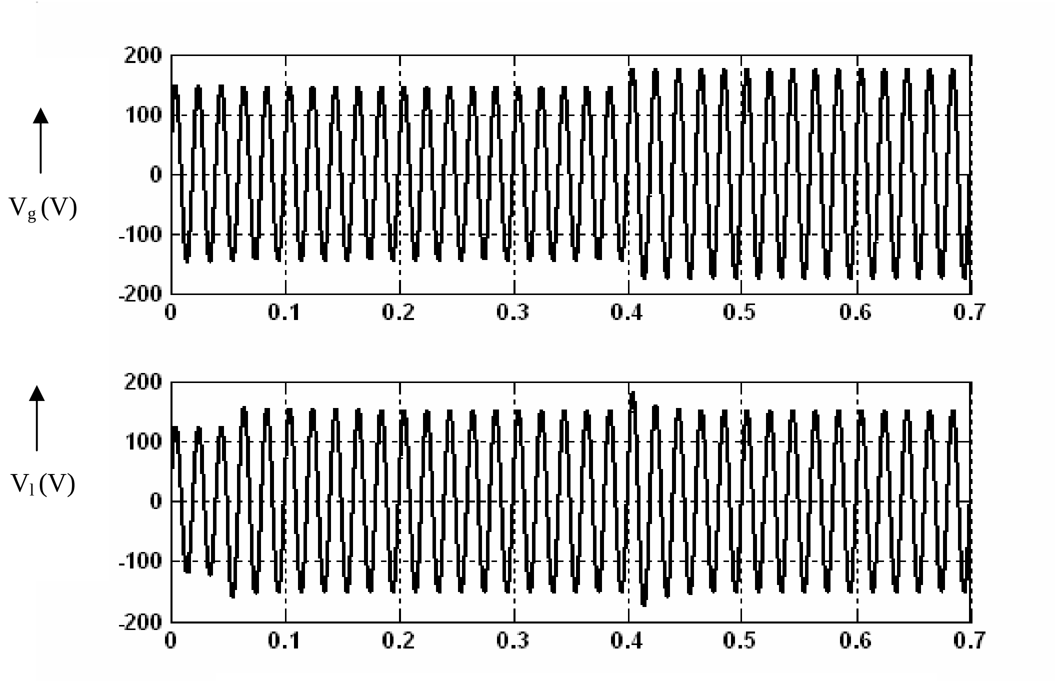


Figure 8 :Wave forms of source voltage and load voltage under variation in input voltage and reference command

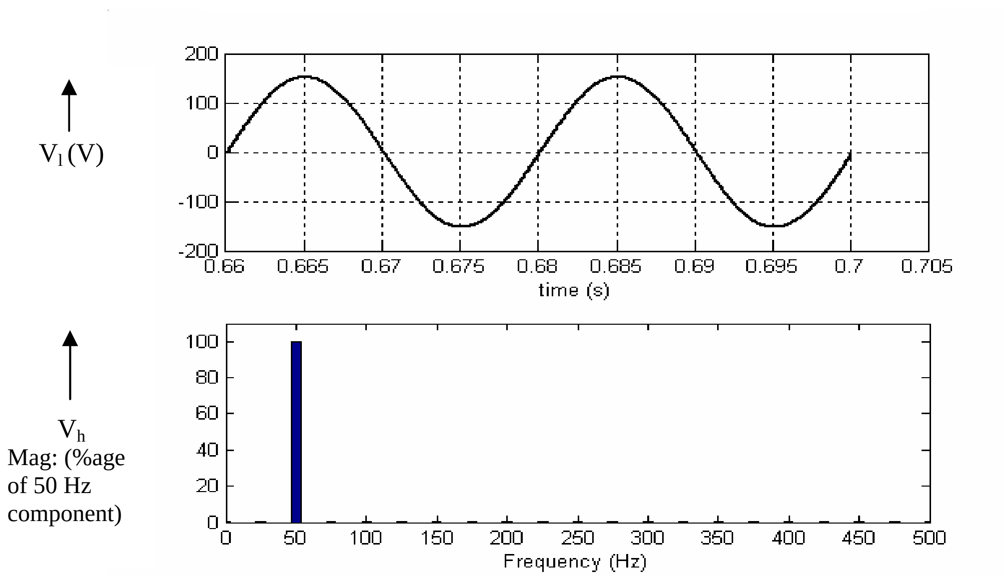
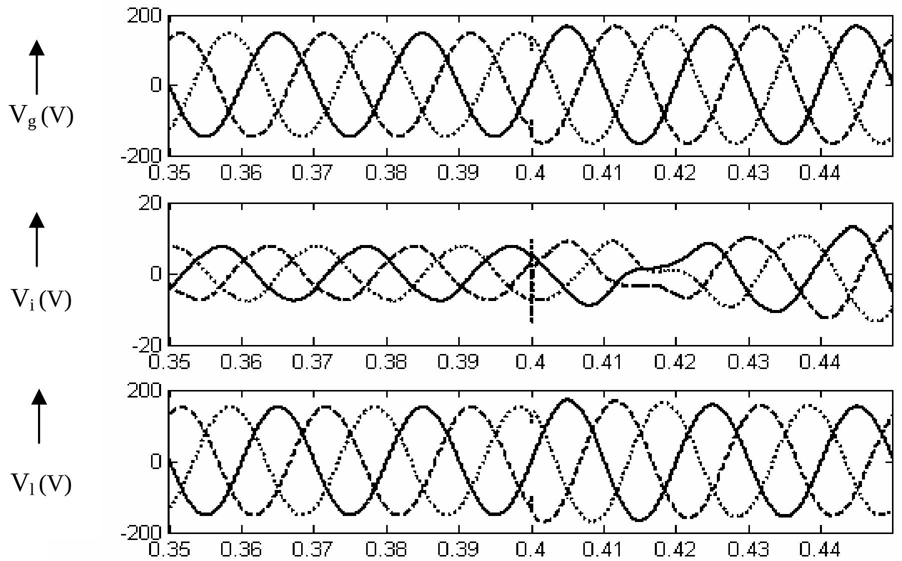


Figure 9 : Harmonic analysis of load voltage



Time-----(s)
Figure 10: Waveforms of source voltage, injected voltage and load voltage under 3-phase case

5. Conclusion

This paper deals with investigation of the Dynamic Voltage Restorer (DVR) which is inserted in a radial distribution network for the compensation of voltage sags. An effective algorithm has been developed in order to obtain the fast response of the device. The feedback and feedforward control schemes have been successfully analyzed. Initially the model has been developed for three-phase, but it has been analyzed with single phase. The simulations have shown good results, both in compensation during variation in input voltage and load. The proposed controller shows to be highly effective and robust to the variation in load as well as in input. Simultaneously it also ensures the stability for varying gains and provides faster controlling action for the device. Though the effective algorithm for the DVR has been developed successfully, but on the other hand this needs to be validated by experimentation.

Nomenclature

V_g , V_{gr}	: Source voltage, source rated voltage (V)
V_i, $V_{i.h}$, $V_{i.max}$	: Series injected voltage, series injected harmonic voltage, series injected max voltage (V)
V_l , V_{lr}	: Load voltage, load rated voltage (V)
$V_{c.1}$, $V_{c.1max}$	: Rms value and peak value of fundamental component of VSC output voltage (V)
$V_{c.h}$	: Harmonic components of VSC output voltage (V)
P_{DVR}	: Active power inected by DVR (W)
W_{DVR}	: Energy supplied by DVR (J)
Vdc, Idc	: Dc side voltage (V) and current (A) of DVR respectively
I_l, I_{lr}	: Load current and rated load current (A)
$\cos \phi_{lr}$	: Rated load power factor
V_{sag}	: Voltage sag (pu)
C_{dc}	: Equivalent capacitor on dc side (F)
K_{dc}	: Ratio of dc voltage to rated dc voltage
t_0, t_{sag}	: Instant of sag occurance, duration of sag (s)
m_a, m_{ar}	: PWM modulation index , Rated PWM modulation index
R_l, L_l	: Load resistance (ohm) and inductance (H)
L_g	: Source and line inductance before DVR (H)
L_t	: Leakage inductance of series transformer referred to network side (H)
L_s	: $L_g + L_l$, Combined inductance of L_g and L_l (H)

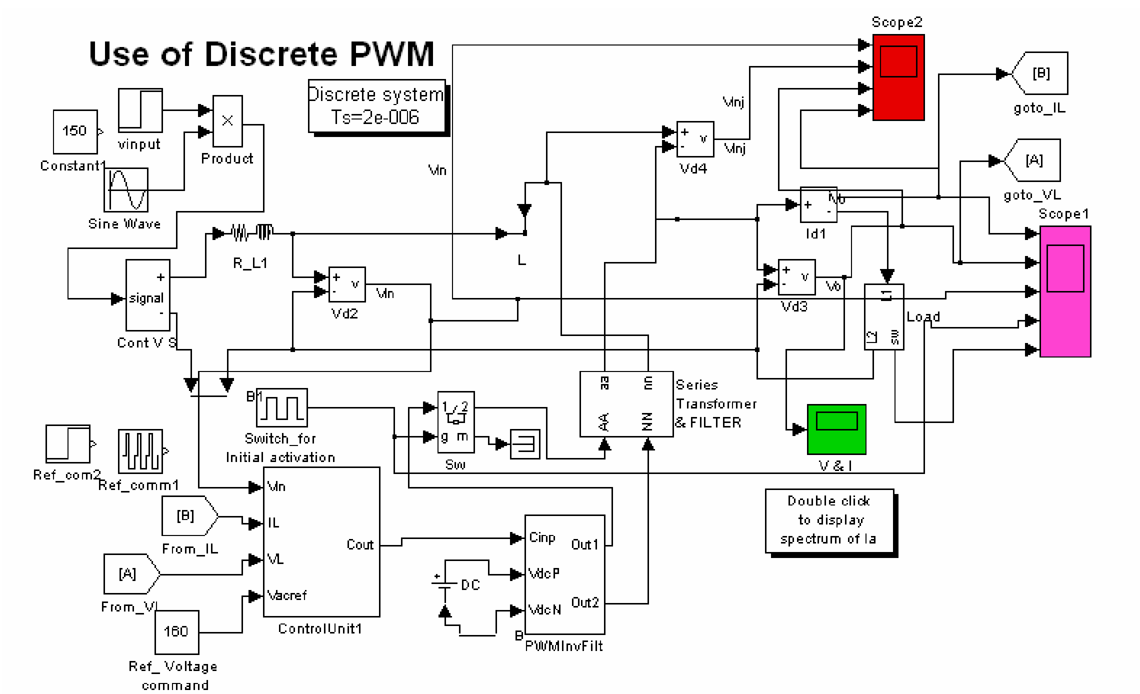
Nomenclature (cont'd)

L	: $L_t + L_l$, Combined inductance of L_t and L_l (H)
R_f, C_f	: Resistance (ohm) and capacitance (Farad) of filter capacitor respectively
K_t	: Transformer turn-ratio
ω	: System angular frequency (rad/sec)
$v_{gd}(t)$, $v_{gq}(t)$	: Instantaneous d- and q-component of source voltage (V)
$i_{ld}(t)$, $i_{lq}(t)$	: Instantaneous d- and q-component of load current (A)
$v_{cd}(t)$, .$v_{cq}(t)$	: Instantaneous d- and q-component of PWM fundamental output voltage (V)
$v_{ld}(t)$, $v_{lq}(t)$	: Instantaneous d- and q-component of load voltage (V)
v_{gdq}, v_{ldq}, v_{cdq}	: D-q pair of source, load and PWM fundamental output voltage (V)
T_d, T_q	: D-q axes time-constant of voltage controller
K_d, K_q	: D-q axes integral constant of voltage controller
αβ	: Transformation on stationary reference frame
dq	: Transformation on rotating reference frame
DVR	: Dynamic voltage restorer
STATCOM	: Static compensator

Appendix-I: Simulated Data

Supply System : Rated voltage= 150~200V/ph , Frequency = 50 Hz
Series Transformer: Rated power= 10KVA/3ph, Primary rated voltage=100V, Secondary rated voltage=100V;
Primary/secondary parameters: R (0.002 pu), L(0.005pu)
Magnetization reactance = 2pu, Magnetization resistance = 10 pu, Winding connection: Star/star
VSC: PWM Based, Dc side voltage= 100 V
Frequency modulation ratio = 40
Harmonic Filter: Primary side: (T-Filter): L_f =2mH/ph, C_f = 10kVAR/3ph
Secondary side/Line side: R_f = 1ohm ; C_f= 500 μF
Load: Load, R_l=5 ohm, L_l = 25 mH; Extra load for step change in load: R_{ext}=40 ohm. L_{ext} = 1mH

Appendix-II: (MATLAB/Simulink Program for a Single-Phase Case)



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Received October 2010
Accepted November 2010
Final acceptance in revised form December 2010