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Reduction of Voltage Disturbances Using Dynamic Voltage Restorer to Improve the Power Quality

Dr.K.Ravichandrudu [1], K.Jeevitha Reddy [2],Mr. P.Yohan babu[3],Mr.G.V.P.Anjaneyulu[4]

[1,2,3]Krishnaveni Engineering College for women, Narasarao pet, A.P, India.

[4]Reaserch scholar SV University College of Engineering, S.V.U, Thirupathi

ABSTRACT:

This project presents based on PI controller to minimize voltage disturbances using dynamic voltage restorer. The voltages disturbances are reduced in this project. The voltage disturbances are voltage sags, voltage harmonics and voltage imbalances. The control scheme deals with all three disturbances simultaneously within a bandwidth. The control structure is quite simple and yet very robust; it contains a feed forward term to improve the transient response and a feedback term to enable zero error in steady state. The well-developed graphical facilities available in MATLAB/SIMULATION are used to carry out all modelling aspects of the repetitive controller and test system. Simulation results show that the control approach performs very effectively and yields excellent voltage regulation.

INTRODUCTION:

The importance of power quality (PQ) has risen very considerably over the last two decades due to a marked increase in the number of equipment which is sensitive to adverse PQ environments, the disturbances introduced by nonlinear loads, and the proliferation of renewable energy sources, among others. At least 50% of all PQ disturbances are of the voltage quality type, where the interest is the study of any deviation of the voltage waveform from its ideal form. The best well-known disturbances are voltage sags and swells, harmonic and inter harmonic voltages, and, for three-phase systems, voltage imbalances. A voltage sag is normally caused by a short circuit faults in the power network, or by the starting up of induction motors of large rating. the DVR is essentially a voltage-source converter connected in series with the ac network via an interfacing transformer, which was originally conceived to ameliorate voltage sags. The basic operating principle behind the DVR is the injection of an in phase series voltage with the incoming supply to the load, sufficient enough to reestablish the voltage to its pre sag state.

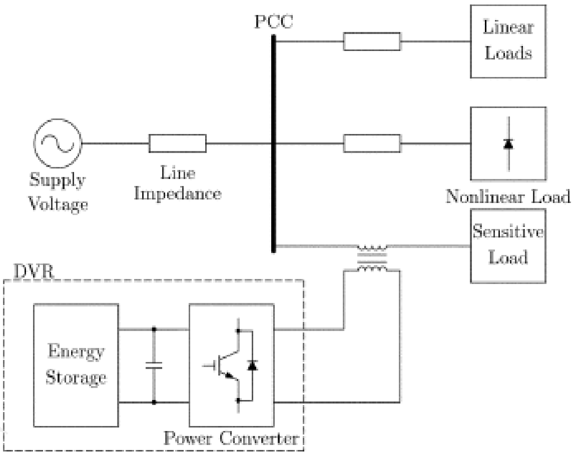

Fig. 1. System configuration with a DVR

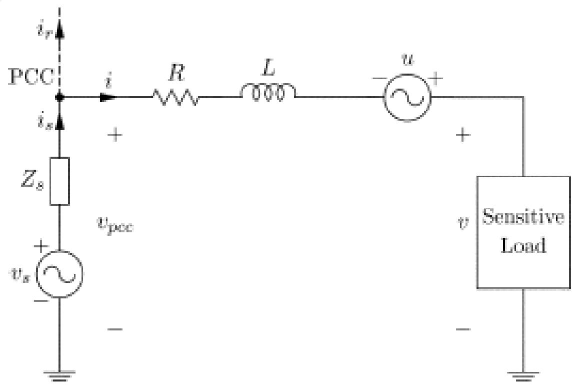

Fig.2. single-phase equivalent circuit for the DVR

MODEL OF THE DYNAMIC VOLTAGE RESTORER:

A typical test system, incorporating a DVR, is depicted in Fig 1. Various kinds of loads are connected at the point of common coupling (PCC), including a linear load, a non linear load, and a sensitive load. The series connection of the voltage-source converter(VSC) making up the DVR with the ac system is achieved by means of a coupling transformer whose primary is connected in series between the mains and the load. Fig. 2 shows the equivalent circuit for the DVR, The sensitive-load voltage can be obtained as

$$V(t) = v_{pcc}(t) + u(t) - Ri(t) - L\frac{di}{dt} \qquad (1)$$

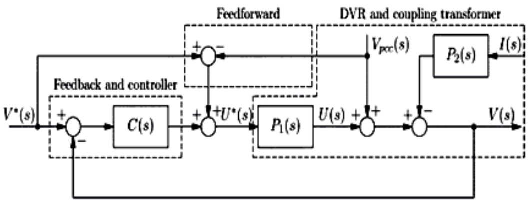

Fig. 3. Closed-loop control scheme

The load voltage is

$$V(s)=F(s)V^*(s)+F_w(s)V_{pcc}(s)+F_i(s)I(s) \quad (2)$$

Where

$$F(s)=\frac{[1+C(s)]P_1(s)}{1+C(s)P_1(s)} \quad (3)$$

$$F_w(s)=\frac{1-P_1(s)}{1+C(s)P_1(s)} \quad (4)$$

$$F_i(s)=-\frac{P_2(s)}{1+C(s)P_1(s)} \quad (5)$$

$$C(s)=\frac{M(s)}{1-e^{-\frac{2\Pi}{w1}s}} \quad (6)$$

$$F(s)=\frac{\left[1-\exp^{\frac{(-2\Pi s)}{w_1}}+M(s)\right]P_1(s)}{1-\exp^{\frac{(-2\Pi s)}{w_1}}+M(s)P_1(s)} \quad (7)$$

$$F_w(s)=\frac{[1-P_1(s)]\left[1-\exp^{\frac{(-2\Pi s)}{w_1}}\right]}{1-\exp^{\frac{(-2\Pi s)}{w_1}}+M(s)P_1(s)} \quad (8)$$

$$F_i(s)=-\frac{\left[1-\exp^{\frac{(-2\Pi s)}{w_1}}\right]P_2(s)}{1-\exp^{\frac{(-2\Pi s)}{w_1}}+M(s)P_1(s)} \quad (9)$$

In order to calculate the frequency response of (7)-(9), the variable S is substituted by jw. Therefore, if the closed-loop system is stable, the error in steady state is zero for sinusoidal reference inputs or sinusoidal disturbance inputs of frequency wh. The transfer function N(s) can be chosen as

$$M(s)=\exp^{-\left(\frac{2\Pi}{w_1}-t_0\right)s} \quad (10)$$

With the substitution of (3)-(5) and (10) into the load voltage, (2) yields,

$$V(s)=e^{\frac{-2\Pi s}{w_1}}V^*(s)+\left[1-e^{\frac{-2\Pi}{w1}s}\right]e^{-t08}V^*(s)$$

$$+\left[1-e^{\frac{-2\Pi}{w1}s}\right]\left[\left(1-e^{-tos}\right)V_{pcc(s)}-P_2(s)I(s)\right] \quad (11)$$

Unfortunately, the delay to is not exactly known and the closed loop system will not be stable if a controller is used with (6) and (10) designed for an estimated. To tackle this problem, a modified controller is proposed as

$$C(s)=\frac{Q(s)e^{-(T-\hat{t}_0)s}}{1-Q(s)e^{-Ts}} \quad (12)$$

Where Q(s) is the transfer function of low pass filter.

The Transfer functions (3)-(5) are

$$F(s)=\frac{\exp^{-t0s}+Q(s)\exp^{-Ts}\left[\exp^{-\delta s}-\exp^{-t0s}\right]}{1+Q(s)\exp^{-Ts}(\exp^{-\delta s}-1)} \quad (13)$$

$$F_w(S)=\frac{\left[1-\exp^{-t0s}\right]\left[1-Q(s)\exp^{-Ts}\right]}{1+Q(s)\exp^{-Ts}(\exp^{-\delta s}-1)} \quad (14)$$

$$F_i(s)-\frac{\left[1-Q(s)\exp^{-Ts}\right]P_2(s)}{1+Q(s)\exp^{-Ts}(\exp^{-\delta s}-1)} \quad (15)$$

The characteristic equation of the resulting closed-loop system

$$1+Q(s)\exp^{-Ts}(\exp^{-\delta s}-1)=0 \quad (16)$$

Obviously, the bandwidth of the controller will be limited because the magnitude characteristic of the filter will decrease as frequency increases.

STUDY CASE:

The Power system depicted in Fig. 1 and the controller shown in Fig. 3 have been implemented in MATLAB/SIMULATION. Fig. 4 and 5 show the test system and the control system, respectively. The test system is comprised of a 400-V, 50-Hz source which feeds three different loads: 1) a squirrel-cage induction machine, 2) a nonlinear load which consists of an uncontrolled three-phase rectifier with an inductive- resistive load, and 3) three-phase sensitive load which consists of a star made up a of a resistance connected in series with an inductance in each phase. A two-level DVR is connected between the PCC and the sensitive load by means of a 20-KVA coupling transformer with a unity turns ratio and a star connected secondary winding. The voltage of the dc storage device is 650V.

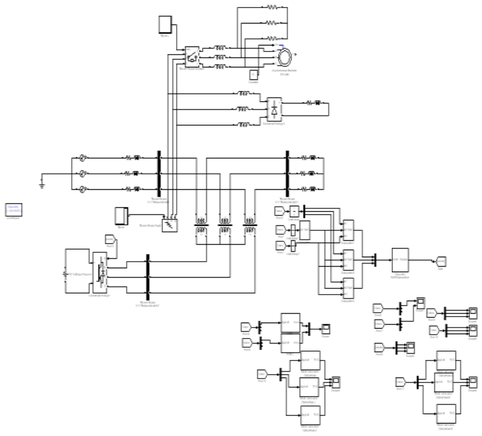

Fig. 4 Test system Implemented in MATLAB/SIMULATION model of DVR

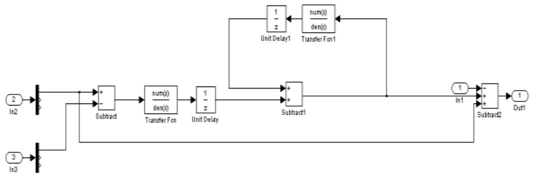

Fig. 5. Control System

The main parameters are summarized in Table I.

Parameter	Value
RMS line to line voltage	400 V
Resistance and inductance of the line	R_s=10mΩ, L_s=750mH
Motor connection inductance	L_1=50 μH
Non linear load connection inductance	L_2=40 μH
Mechanical power of the motor	Pm=40kw
DC load: resistance and inductance	R_{dc}=10 Ω, L_{dc}=0.4H
Sensit load : resistance and inductance	R_{sl}=1 Ω, Lsl=750mH
Transformer: resistance and inductance	R=0.02 Ω, , L=0.08H
Transformer: no load losses	Po=0.02p.u.

Table. I. Parameters of the test system

Controller parameters:

A controller has been designed for each phase by using a three-phase a,b,c coordinate system. The a,b,c reference frame is perhaps the most popular alternative to control load voltages when operating under unbalanced conditions. Nevertheless, it should be recalled that the repetitive controller also guarantees zero-tracking error at zero frequency: the controller can be implemented by using a reference frame d-q rotating synchronously with the fundamental frequency since the fundamental harmonic transforms into a dc component in this reference frame.

Simulation Results:

The simulation is the one depicted in Fig. 4 where the simulation has been carried out as follows: the nonlinear load and the DVR are connected at t=0 s. A two-phase short-circuit fault is applied at the PCC from t=0.2 to t=0.28s. via fault resistance 0.2 ohms. This short circuit causes a 40% voltage sag in the two affected phases with respect to their nominal values. The induction machine is connected at t=0.4 s. with a constant rotor speed of 0.97 p.u.(the slip has a value of S=3 %), while the nonlinear load is disconnected at t=0.65s. The total simulation time is 0.8s. Fig. 6(a) shows the three-phase rms voltage across the sensitive load, while Fig. 6(b) shows the three-phase rms voltage at the PCC . Initially, the rms value at the PCC is 385 V and this falls to 270 V when the two-phase short-circuit fault is applied. When the induction motor is connected at t=0.4s, the voltage at the PCC decreases to 330 V, causing a voltage sag of 17.5% with respect to the nominal value. Finally, when the nonlinear load is disconnected at t=0.65s, the voltage at the PCC rises to 370 V. A comparison of Fig. 6(a) and (b) graphically shows that despite the many voltage variations at the PCC, the DVR is able to provide the sensitive load with necessary voltage, maintaining an almost constant voltage level of 400 V.
Fig. 7(a) and (b) line to line voltage at sensitive load and PCC where t=0sto t=0.2s . Fig. 8(a) and (b) line to line voltage at sensitive load and PCC where t=0.42s to t=0.65s.Fig. 9(a) and 9(b) shows the line to line voltage at sensitive load and PCC where t=0.65s to t=0.8s.Fig. 10 shows the control outputs . The Fig. 11. shows the Total harmonic distortion at sensitive load is 0.03pu. Fig. 12 shows the Total harmonic distortion at PCC is 0.1pu.Fig. 13 and 14 shows the line to line voltage at sensitive load and PCC where t=0s to t=0.8s. The fundamental-harmonic rms values of the line-to-line voltages at PCC are 225V, 363V, and 242V, where the superscript indicates the fundamental harmonic. The total harmonic voltage distortions are 6.71%, 4.07%, and 2.3%. The fundamental-harmonic rms values of the line-to-line voltages across the sensitive load are Vab=399V, Vbc=400V, and Vca=399V where as the total harmonic voltage distortions are 6.8%,6.56%, and 7.12%. In Fig. 8(a) and 8(b) shows the results when the induction motor is connected at t=0.42s. Notice that only 0.12s are plotted. At t=0.65s, the nonlinear load is disconnected from the system and only the motor and the sensitive load remain connected. The results obtained show that, as expected, the voltage at the PCC is sinusoidal (THD=0%) and the line-to-line voltage has an rms value of 370V (92.5% of the nominal value) due to the voltage drop in the line impedance. The control system and the DVR once again work properly, thus compensating the voltage drop in the sensitive load. The fundamental harmonic of the sensitive-load voltage has an rms value of 399.78V and the total harmonic distortion is 3.17%.

Fig. 6. 3 phase rms voltage at sensitive load and pcc, where t=0.1s to t=0.8s

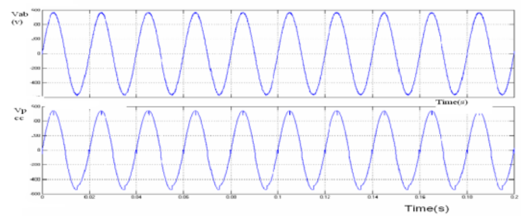

Fig.7. Line to line voltage at sensitive load and pcc where t=0s to t=0.2s

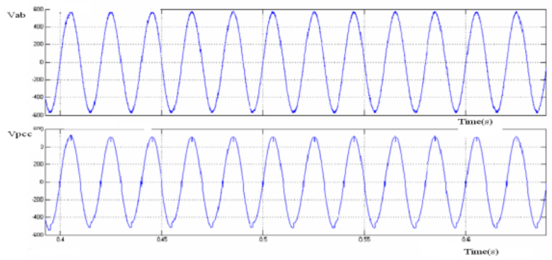

Fig.8. Line to line voltage at sensitive load at pcc where t=0.42sto t=0.65

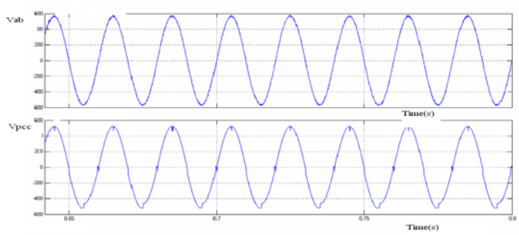

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Fig.9. Line to line voltage at sensitive load and pcc where t=0.65s to t=0.8 s

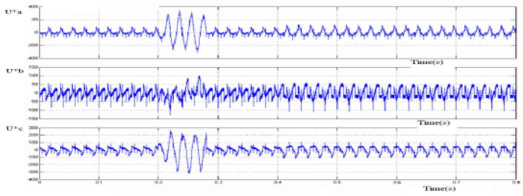

Fig.10. Control outputs

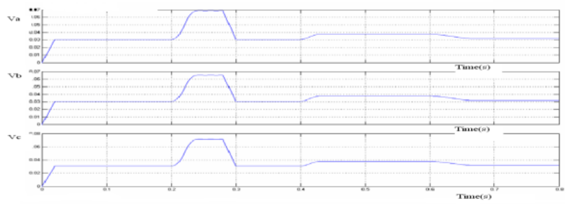

Fig.11. Total harmonic distortion at sensitive load is 0.03p.u.

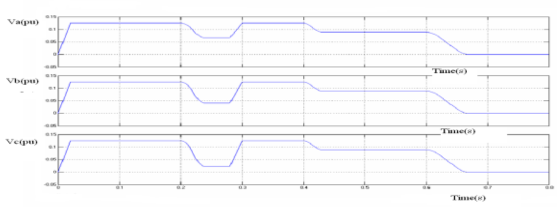

Fig.12. Total harmonic distortion at pcc is 0.1p.u.

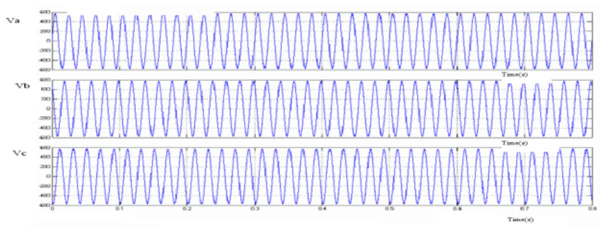

Fig.13.Line to line voltage at sensitive load where t=0.1s to t=0.8s

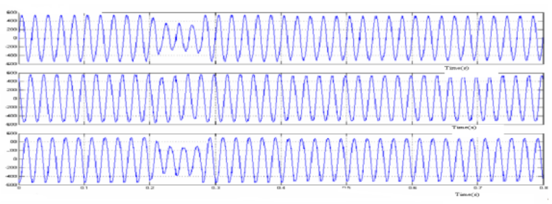

TABLE II

Fundamental Harmonic Rms Value And Voltage Total Harmonic Distortion Of The Line-To-Line Voltage At The Pcc And Across The Sensitive Load For Different Instants

	$V_{rms}^{(1)}(V)$	THDv(%)
Time interval (s):0≤ t< 0.2 (balanced condition)		
PCC (ab)	385	12.52
Sensitive load (ab)	399.63	3.07
Time interval(s):0.2≤ t< 0.28 (unbalanced condition)		
PCC (ab)	225.37	6.71
Pcc (bc)	363.23	4.07
Pcc (ca)	242.07	2.30
Sensitive load (ab)	399.77	6.88
Sensitive load (bc)	400.19	6.56
Sensitive load (ca)	399.77	7.12
Time interval(s):0.4≤t< 0.65 (balanced condition)		
PCC (ab)	365	8.91
Sensitive load (ab)	400.17	3.77
Time interval(s):0.65 ≤t< 0.8 (balanced condition)		
PCC (ab)	369	0.00
Sensitive load (ab)	399.78	3.17

CONCLUSION:

The use of dynamic voltage restorers in PQ-related applications is increasing. To achieve this, the controller has been provided with a feed forward term and feedback term. The design has been carried out by studying the stability of the closed-loop system including possible modelling errors, resulting in a controller which possesses very good transient and steady-state performances for various kind of disturbances. A key feature of this control scheme is its simplicity; only one controller is required to eliminate three PQ disturbances, namely, votage sags, harmonic voltages, and voltage imbalances. The controller can be implemented by using either a stationary reference frame or a rotating reference frame. In this project, the highly developed graphical facilities available in MATLAB/SIMULATION have been used very effectively to carry out all aspects of the system implementation. Comprehensive simulation results using a simple but realistic test system show that the repetitive controller and the DVR yield excellent voltage regulation, thus screening a sensitive load point from upstream PQ disturbances

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