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A New control Scheme for a Dynamic Voltage Restorer for Power Quality improvement

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ABSTRACT: Power quality is one of the major concerns in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipment's. This paper presents a control system based on a repetitive controller to compensate for key power-quality a disturbance, namely voltage sags, harmonic voltages, and voltage imbalances, using a dynamic voltage restorer (DVR). 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 are used to carry out all modeling aspects of the repetitive controller and test system. Simulation results show that the control approach performs very effectively and yields excellent voltage regulation.

KEYWORDS*:* Dynamic voltage restorers (DVR), harmonic distortion, power quality (PQ), repetitive control, voltage sag.

I. INTRODUCTION

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipment's. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling.[1-3]

The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching maybe on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. [4]The disadvantage is that, high speed transients cannot be compensated. Some sags are not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly. Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR).

DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage. This paper focuses on the design of a closed-loop control law for a two-level DVR, based on the so-called repetitive control, aiming at compensating key voltage-quality disturbances, namely, voltage sags, harmonic voltages, and voltage imbalances.

A voltage sag is normally caused by short-circuit faults in the power network or by the starting up of induction motors of large rating. The ensuing adverse consequences are a reduction in the energy transfers of electric motors and the disconnection of sensitive equipment and industrial process brought to a standstill. Harmonics are produced by nonlinear equipment, such as electric arc furnaces, variable speed drives, large concentrations of arc discharge lamps, and loads which use power electronics. Harmonic currents generated by a nonlinear device or created as a result of existing harmonic voltages will exacerbate copper and iron losses in electrical equipment. In rotating machinery, they will produce pulsating torques and overheating. Voltage imbalances are normally brought about by unbalanced loads or

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unbalanced short-circuit faults, thus producing overheating in synchronous machines and, in some extreme cases, leading to load shutdowns and equipment failure. [5]

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 presage state.[6-8]

The repetitive controller presented in this paper has a wider range of applicability; it is used in a DVR system to ameliorate voltage sags, harmonic voltages, and voltage imbalances within a bandwidth. Unlike other schemes, which also have a comparable range of applicability, only one controller is needed to cancel all three disturbances simultaneously. The control structure contains a grid voltage feed forward term to improve the system transient response, and a closed-loop control which comprises a feedback of the load voltage with the repetitive controller in order to warrant zero tracking error in steady state. The repetitive control was originally applied to eliminate speed fluctuations in electric motors but it has since been adopted in a wide range of power-electronics applications.[9]

Fig.1 shows the schematic diagram of DVR. The DVR essentially consists of a series inverter (VSI), inverter output filter and an energy storage device connected to the DC link. The basic operation principle of the DVR is to inject an appropriate voltage in series with the supply through injection transformer whenever voltage sag or voltage swell is detected. In addition to voltage sags and swells compensation, DVR can also perform other tasks such as harmonic compensation and Power Factor correction. Compared to the other Custom Power devices, the DVR clearly provides the best economic solution for its size and capabilities. This paper is organized as follows. The DVR model is presented in Section II. The fundamentals of the control system and the proposed control scheme are studied in Section III. The modeling of the repetitive controller using the well-developed graphical facilities available in MATLAB and simulation results are presented in Section IV. The main conclusions of the current investigation are drawn in Section V.[10]

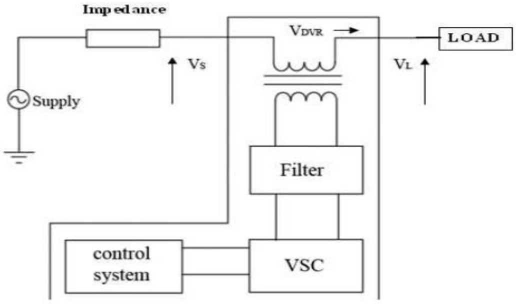

Fig.1 schematic diagram of DVR

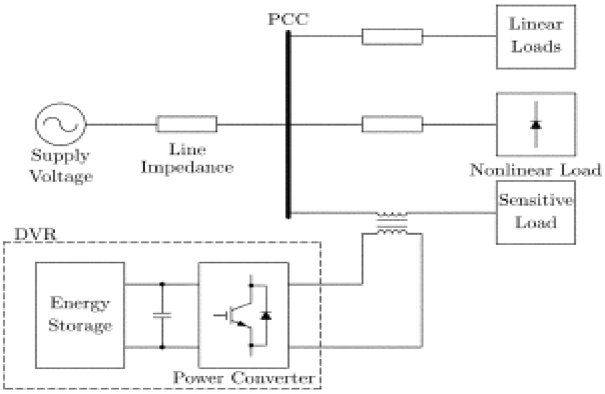

Fig.2 System Configuration with a DVR

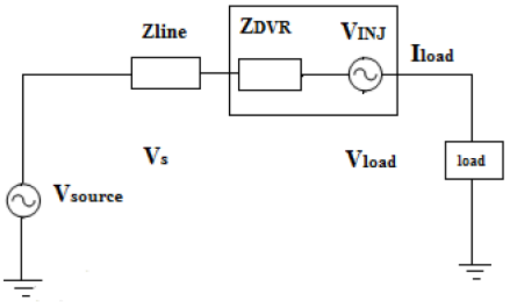

Fig.3 Equivalent circuit of a DVR

II. MODEL OF THE DVR-CONNECTION SYSTEM

A typical test system, incorporating a DVR, is depicted in Fig.2. Various kinds of loads are connected at the point of common coupling (PCC), including a linear load, a nonlinear 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. Although a passive LC filter is normally used to obtain a switching-ripple-free DVR voltage, in this paper, this filter is not considered in order to fully assess the harmonic cancelling properties of the repetitive controller. Fig.3 shows the equivalent circuit of DVR

Where V_s is the supply voltage,V_L is the desired load voltage magnitude,Z_{TH} is the load impedance,I_L is the load current,V_{TH} is the system voltage during fault then
The series injected voltage of the DVR can be written as

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH}$$

The load current I_L is given by $I_L = [P_L + jQ_L]$

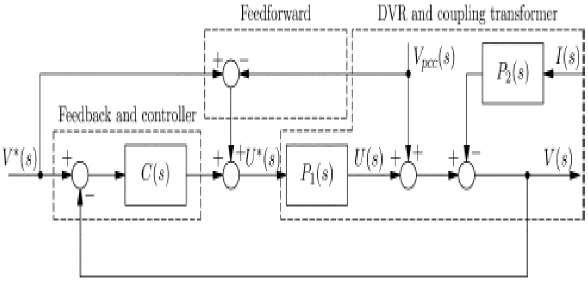

Fig.4 Closed –loop control scheme

III. DESIGN OF THE CONTROL SYSTEM

The aim of the control system is to regulate the load voltage in the presence of various kinds of disturbances. The control structure proposed in this paper is based on the use of a feed forward term of the voltage at the PCC to obtain a fast transient response, and a feedback term of the load voltage to ensure zero error in steady state. The continuous time of the whole control system is depicted in Fig.4 where $c(s)$ represents the controller. If the switching frequency is high enough, the DVR can be modeled as a linear amplifier with a pure delay $P_1(s) = e^{-t_0 s}$. This delay is the sum of one-sample-period plus the time delay of the inverter due to PWM switching. The former applies in cases of microprocessor - based implementations and the latter can be taken to be half the switching period. The transfer function P_2(s) is equal to $Ls + R, V^*(s)$ is the reference voltage for the load, ,$U^*(s)$ is the control output, whereas $U(s)$ is the output voltage of the DVR and $V(s)$ is the load voltage. The inputs $V_{Pcc}(s)$ and $I(s)$stand for the grid voltage and the current through the load, respectively. Both inputs are assumed to be measurable. The model may be extended with ease to three-phase applications.

The load voltage is

$$V(s) = F(s)V*(s) + F_w(s)V_{pcc}(s) + Fi(s)I(s) \qquad (1)$$

Where

$$F(s) = \frac{[1+C(s)]P_1(s)}{1+C(s)P_1(s)} \qquad (2)$$

$$F_w(s) = \frac{1-P_1(s)}{1+C(s)P_1(s)} \qquad (3)$$

$$F_i(s) = \frac{P_2(s)}{1+C(s)P_1(s)} \qquad (4)$$

Repetitive control is a contemporary control technique that may be used to cancel out, simultaneously, voltage sags, voltage harmonic, and voltage imbalances, characteristics rarely achieved with other control techniques, such as PI controllers. As a first approximation, as described in conventional repetitive-control theory, the controller can be written as

$$C(s) = \frac{M(s)}{1-e^{-\frac{2\pi}{\omega 1}s}} \qquad (5)$$

Where $M(s)$is a transfer function chosen so that the closed-loop stability is always fulfilled and ω_1 is the fundamental frequency at the mains,
The substitution of (6) into (3)–(5) yields

$$F(s) = \frac{\left[1-e^{-\frac{2\pi}{\omega 1}s}+M(s)\right]P_1(s)}{1-e^{-\frac{2\pi}{\omega 1}s}+M(s)P_1(s)} \qquad (7)$$

$$F_w(s) = \frac{[1-P_1(s)]\left[1-e^{-\frac{2\pi}{\omega 1}s}\right]}{1-e^{-\frac{2\pi}{\omega 1}s}+M(s)P_1(s)} \qquad (8)$$

$$F_i(s) = \frac{\left[1-e^{-\frac{2\pi}{\omega 1}s}\right]P_2(s)}{1-e^{-\frac{2\pi}{\omega 1}s}+M(s)P_1(s)} \qquad (9)$$

In order to calculate the frequency response of (7)–(9), the variable s is substituted by $j\omega$. It should be noticed that the term is always zero whenever is an integer multiple of the frequency (e.g., $\omega = 3\omega_1$, then$\left(1 - e^{-j6\Pi)} = 0\right)$.Hence, the frequency response shows that $F(j\omega_h)$ =1,$F_\omega(j\omega_h) = 0$ and $F_i(j\omega_h) = 0$ for frequencies $\omega_h = h\omega_1$with $h = 0,1,2, \dots, \infty$.Therefore, if theclosed-loop system is stable, the error in steady state is zero for sinusoidal reference inputs or sinusoidal disturbance inputs of frequency $.\omega_h$. Since the delay is smaller than the grid-voltage period$\left(t_0 < \frac{(2\Pi)}{\omega_1}\right)$, the transfer function can be chosen

$$M(s) = e^{-\left(\frac{2\pi}{w1} - t_0\right)s} \qquad (10)$$

With the substitution of (7)–(9) and (10) into the load voltage (2) yields

$$C(s) = e^{\frac{-2\pi}{\omega 1}s}V^*(s) + \left[1 - e^{\frac{-2\pi}{\omega 1}s}\right]e^{-t_0 s}V^*(s) + \left[1 - e^{\frac{-2\pi}{\omega 1}s}\right](1 - e^{-t_0 s})V_{pcc}(s) - P_2(s)I(s) \qquad (11)$$

Unfortunately, the delay 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 $t_0 \neq t_0$ to tackle this problem, a modified controller is proposed as

$$C(s) = \frac{Q(s)e^{-(T-t_0)s}}{1-Q(s)e^{-Ts}} \qquad (12)$$

Where $Q(s)$ the transfer function of a low-pass filter is, t_0 is the estimated value for the DVR delay, with and β is a design parameter which is smaller than the period of the grid voltage$\left(\beta < (2\pi)/(\omega_1)\right)$.
The transfer functions (3)–(5) are

$$F(s) = \frac{e^{-T_0 s} + Q(s)e^{-Ts}\,[e^{-\delta s} - e^{-t_0 s}]}{1 + Q(s)e^{-Ts}\,(e^{-\delta s} - 1)} \quad (13)$$

$$F_w(s) = \frac{[1 - e^{-t_0 s}][1 - Q(s)e^{-Ts}]}{1 + Q(s)e^{-Ts}\,(e^{-\delta s} - 1)} \quad (14)$$

$$F_i(s) = -\frac{[1 - Q(s)e^{-Ts}]\,P_2(s)}{1 + Q(s)e^{-Ts}\,(e^{-\delta s} - 1)} \quad (15)$$

With $\delta = t_0$-t

The characteristic equation of the resulting closed-loop system is

G(s)

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

A low-pass filter, which is approximated by a constant time$(Q(j\omega) \approx 1e^{-j\beta_Q})$ delay within its pass band, can be designed with β_Q being the time delay of the filter. For continuous systems,

Bessel filters can be used because they can be approximated by a constant time delay, while for discrete time systems, finite-impulse-response (FIR) filters with a linear phase in their pass band can be used . Therefore, the design parameter β can be chosen to cancel out the filter time delay$(\beta = \beta_Q)$; and under such conditions, the closed-loop-system frequency response will satisfy $F(j\omega_h) = 1$,and $F_\omega(j\omega_h) = 0$ and $F_i(j\omega_h) = 0$ while the approximation of a constant time delay is valid.

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

IV. CASE STUDY

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 with an inductive-resistive load, uncontrolled three-phase rectifier and 3) a three-phase sensitive load which consists of a star made up 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.

Simulation Results

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=0.2s to 0.28s via a fault resistance of 0.2 .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=0.4s with a constant rotor speed of 0.97 p.u. The total simulation time is 0.8 s.

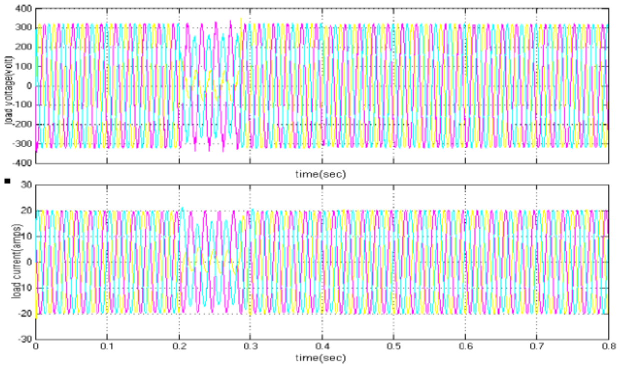

Fig.5 Load Voltage And Load Current Waveform With DVR

First the block is simulated without using DVR and the waveforms for load voltage and load current are shown in Fig 5.The waveforms for load voltage and load current using DVR is shown in Fig 6. The line-to-line voltage waveform at

PCC is shown in Fig.7.The voltage across sensitive load when only non-linear load is connected is shown in Fig.8.The waveforms in Figs 5 and 6 shows how effectively DVR compensates Voltage sags. The THD values reduce when DVR is used.

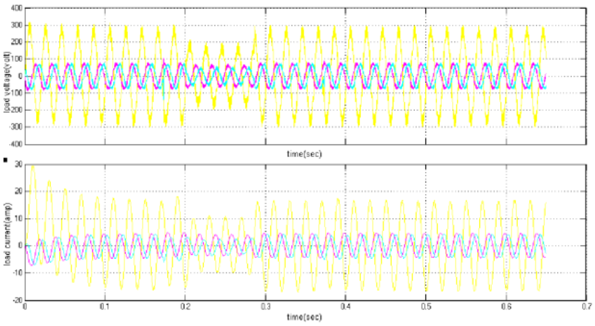

Fig.6 Load voltage and load current waveform without DVR

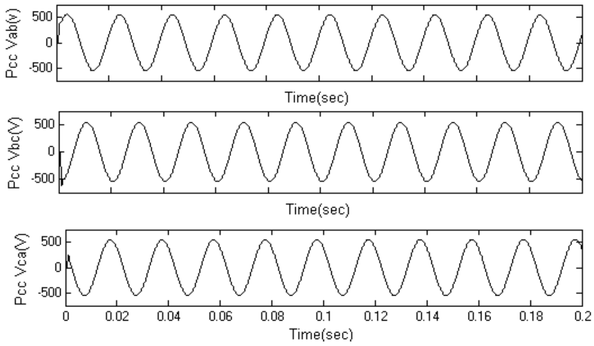

Fig.7 Line-to-line voltage at the PCC

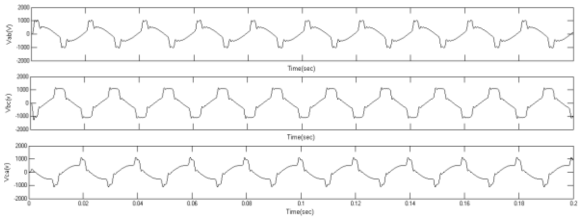

Fig.8 voltage across sensitive load

V. CONCLUSION

The use of dynamic voltage restorers in PQ-related applications is increasing. The most popular application has been on voltage sags amelioration but other voltage-quality phenomena may also benefit from its use, provided that more robust control schemes than the basic PI controller become available. The main advantage of this scheme is its simplicity and only one controller is required to eliminate three Power-quality disturbances, namely voltage sags, harmonic voltages and voltage imbalances.

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