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Power Quality Improvement By Using DVR By Energy Optimal Technique.

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Abstract— Power quality is one of 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. Sensitive industrial loads and utility distribution networks suffer from various types of outages and service interruptions which may result in a significant financial loss.

To improve the power quality, custom power devices are used. The device considered in this work is Dynamic Voltage Restorer. This thesis presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) constructed in Simulink environment. In this work, composite observer based controller are used for the control purpose. Here, different supply voltage conditions are considered for linear loads and sensitive load. The major problems dealt here are voltage sag, voltage and voltages unbalances. The role of DVR to compensate load voltage is investigated during the different supply conditions.

Keywords— Power quality, custom power devices, DVR, voltage sag and supply voltage unbalance.

I. Introduction

The voltage disturbances like sag-swell deteriorates performance of industrial loads as well as it can cause extra burden to the users(2) The DVR is able to absorb or generate real and reactive power at the output terminal with independent control in dynamic condition.(5-6)The Dynamic Voltage Restorer (DVR) is used for protection of critical loads from voltage quality problems with accurate response(4) Power quality issues are normally generated by an increasing use of electronics based system in domestic and industrial applications. Source voltage quality problem involves voltage sag-swell, voltage unbalance, voltage distortion(1) Monitoring of voltage and current based power quality problems are discussed in the literature(3). This paper deals with improving the voltage quality of sensitive loads from voltage sags using dynamic voltage restorer (DVR). The higher active power requirement associated with voltage phase jump compensation has caused a substantial rise in size and cost of dc link energy storage system of DVR.(7) Babaei and Kangarlu [8] have proposed a new topology of DVR based on direct ac/dc conversion. Main advantage of this topology is reduced number of switches and it is not required energy storage element. Roncero-Sanchez and Acha [10] have discussed topology of DVR based on multilevel converter with flying capacitor. It is useful in medium power application. Response of DVR mainly depends upon control algorithm and power circuit design.

In this paper, new control algorithm based on composite observer has been proposed for the quadrature phase control in time domain. The Quadrature phase voltage injection of DVR has been discussed using simulation results. It is based on voltage source converter with self supported DC link.

II. Topology Of DVR

In three wire supply DVR, VSC based topology are shown in fig. 1. It is connected between critical loads and point of common interface with self supported dc bus voltage (V_{dc}). The interfacing inductor (L_f) is used to remove current ripples. To inject voltages three single phase transformers are used into lines and high voltage winding connected in series between load & PCC. R_f -C_f is a first order high pass filter used to filter switching noise. The load voltages (V_{la}, V_{lb}, V_{lc}), load currents (i_{la}, i_{lb}, i_{lc}) and PCC voltages (V_{sa}, V_{sb}, V_{sc}) are sensed and provided to controller as an input signals. Under ideal condition, the DVR do not supply any voltage. Moreover, non ideal grid condition it injects compensating voltages (V_{inj}) to restore load side voltage as well as makes it distortion free. The ripple filter provides very high impedance at fundamental frequency hence draws negligible current.

$$V_{inj} = V_l^* - V_s \qquad (1)$$

where V_l^* and V_s are reference load voltage and supply voltage respectively.

III. Control Strategy

The strategy of composite observer is modelled in three wire system. The control strategy is developed for quadrature control compensation of voltage. The modelling and strategy for this is discussed below:

A. Extraction of Fundamental Component using Composite Observer:

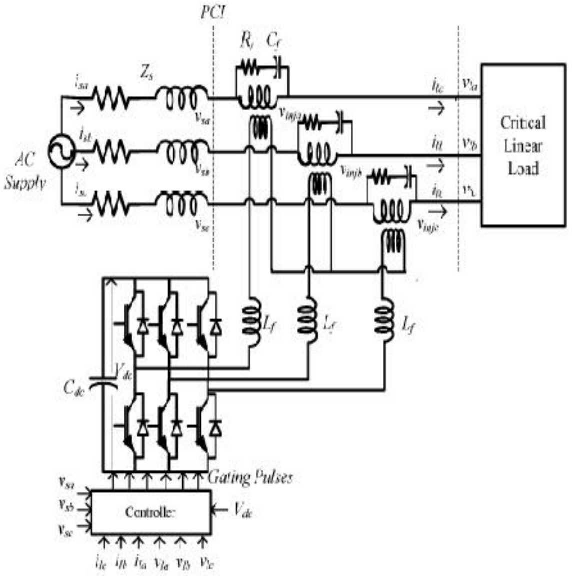

Fig.1. Three leg VSC based topology of DVR

The distorted supply voltage consists of various harmonic components with multiple of frequencies (nω1) The block diagram of composite observer is shown in fig. 2. From this figure, for voltage signal (V_{sn}) , V_{s1}, V_{s2} are considered as state variable of continuous composite observer.

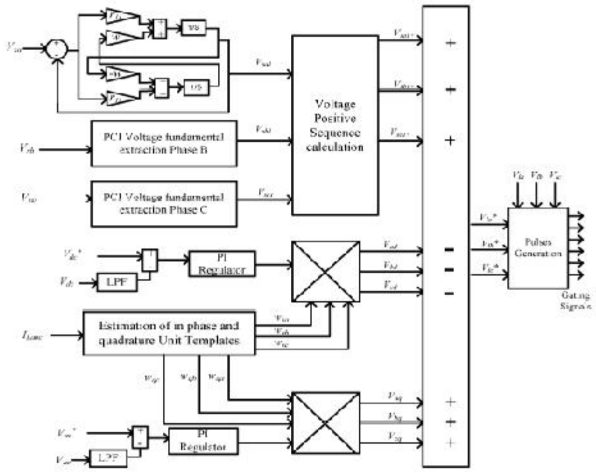

Fig. 2. Quadrature control of DVR with composite observer

$$V_{s1} = R_{11} (V_{SA} - V_{SA1}) + \mu V_{s2} \qquad (2)$$

$$V_{s2} = R_{12} (V_{SA} - V_{SA1}) - \mu V_{s1} \qquad (3)$$

State equations becomes,

$$\begin{bmatrix} Vs1 \\ Vs2 \end{bmatrix} = \begin{bmatrix} 0 & \mu \\ \mu & 0 \end{bmatrix} \begin{bmatrix} Vs1 \\ Vs2 \end{bmatrix} + \begin{bmatrix} r11 \\ r12 \end{bmatrix} [Ve] \qquad (4)$$

Where, Ve = Vsa - Vsa1

$$Vsa1 = [1 \quad 0] \begin{bmatrix} Vs1 \\ Vs2 \end{bmatrix} \qquad (5)$$

The values of r11, r12 decides dynamic response and quality of extracted signals. The dynamic response of composite observer increases as values of gains r11, r12 increases. On the same time, the quality of extracted signal deteriorates because of increase in bandwidth.

The normally supply voltages are not more prone to distortion hence values of r11, r12 are selected as 100 and -5 respectively.

The system will be controllable if, S = [B AB]

$$S = \begin{bmatrix} 100 & 314*-5 \\ -5 & -314*100 \end{bmatrix} \qquad (6)$$

Which is non singular, Hence system is controllable.

Similarly system will be observable if,

$$V = \begin{bmatrix} C \\ C_A \end{bmatrix} \text{ is non singular} \qquad (7)$$

$$V = \begin{bmatrix} 1 & 0 \\ 0 & 314 \end{bmatrix} \qquad (8)$$

From eqn. (8), *V* is non singular hence system is observable.

IV. DVR Quadrature Phase Control:

For shorter duration events there is no requirement of energy storage element. Since, DC link capacitor can supply or absorb energy for short duration without much change in its output voltage. DVR energy optimization technique control was proposed on fact that DVR can restore load voltages under events of sag-swell by injecting voltages in quadrature with load currents. Load voltage restoration is done by exchanging reactive power from supply system only. DVR do not contribute to active power exchange, which reduces need of large energy storage unit even small capacitor can also serve the purpose. No requirement of storage unit and other auxiliary circuit which reduces cost. Virtually DVR can compensate voltage sag for infinite duration. But this technique causes phase jump in load voltages at the start and end of events. This phenomenon limits application of this control to loads sensitive toward magnitude as well as phase angles. The magnitude of sag should not be smaller than load power factor. Fig.3. shows the quadrature phase compensation through phasor diagram.

The real and reactive power supplied to load are formulated as,

$P_L = V_L I_L \cos Ø_S$ and $Q_L = V_L I_S \sin Ø_S$
(9)

Active and reactive power supplied by DVR is given as,

$P_{DVR} = V_{inj} I_S \cos Ø_S$ and $Q_{DVR} = V_{inj} I_S \sin Ø_S$
(10)

From equation (9) it can be realized that power ratings of DVR depend on load parameters and another side, voltage rating depends on sag magnitude.

Composite observers are used for extraction of fundamental component of supply voltages V_{sa1}, V_{sb1}, V_{sc1}. The reference load voltages are determined compared with supply voltages RMS values. The PI controllers are used to correct error of an individual phase and outputs of them are multiplied with supply voltage templates. The amplitude of PCC voltage (V_{ac}) is written as,

$V_{ac} = \sqrt{(2(V^2_{sa1}, V^2_{sb1}, V^2_{sc1}) / 3)}$
(11)

The per unit value of load voltage is Vload p.u.= 1, consider Vbase = Vload the Sag magnitude is defined as,

$b = (V_s / V_{nominal})$
(12)

Also $V_s\,(p.u) = V_s / V_{load} = b$
(13)

Power supplied by DVR

$P_{DVR} = V_{load} I_s \cos Ø_{LD} - V_s I_s \cos Ø_{sd}$
(14)

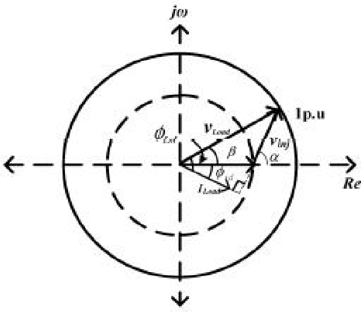

Fig. 3. Phasor diagram of quadrature phase compensation

Since, active power flow due to DVR (P_{DVR}) = 0

$V_{load} I_s \cos Ø_{LD} = V_s I_s \cos Ø_{SD}$ (15)

Putting per unit values, eqn becomes,

$\cos Ø_{Load} = b \cos Ø_{LD}$ (16)

$\cos Øsd - (\cos Øload / b)$ (17)

range of cosine function is [1 0]

$\cos Øs \le 1$ Hnce $(\cos Ø_{load} / b) \le 1$

$b \ge \cos Ø_{load}$ (18)

Quadrature phase control technique is applicable only when magnitude of sag is greater than load power factor. Fig. 3. shows composite ob server based control algorithm where composite observer are used to extract fundamental component of supply voltages (V_{sa1}, V_{sb1}, V_{sc1}). The positive sequence components of extracted fundamental components of supply voltage are calculated by instantaneous symmetrical component theory.

$$\begin{bmatrix} Vsa0 \\ Vsa1 \\ Vsa2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \sim & \sim^2 \\ 1 & \sim^2 & \sim \end{bmatrix}\begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix} \qquad (19)$$

The sensed load currents (i_{sa} , i_{sb} , i_{sc}) are used to calculate in phase and quadrature unit templates as follow

$$i_l = \sqrt{\frac{2(i^2_{sa} + i^2_{sb} + i^2_{sc})}{3}} \qquad (20)$$

The V_{dc} is regulated by PI controller and its output V_{de} is multiplied with in phase templates. Amount of power drawn for regulating DC bus voltage is very small. Similarly, second PI controller is used to regulate amplitude of load voltages V_L by comparing it with reference voltage $V_{ac}{}^*$. The V_{ac} is calculated as by eqn. (11). The output component of PI controller is multiplied by quadrature templates. The reference load voltages are calculated as follow.

$V_{la}{}^* = V_{sa1-} V_{ad} + V_{aq}$
(21)

$V_{lb}{}^* = V_{sb1-} V_{bd} + V_{bq}$
(22)

$V_{lc}{}^* = V_{sc1-} V_{cd} + V_{cq}$
(23)

Sensed load voltages (V_{la} , $V_{lb\,,}$ V_{lc}) are compared with reference load voltages and gating signals are generated using hysteresis current control switching.

V. Simulation Results & Discussion

Model of DVR with designed parameters and Composite observer based control algorithm is simulated in MATLAB. Results are discussed below based on quadrature phase control principle for compensation of voltage sang and unbalance. The performance of this algorithm is observed through simulation in three phase system under different type supply voltage disturbances.

(A) Under Balanced sag (LLLG)

Balanced sag is normally caused by symmetrical short circuit faults in the system or starting of heavy three phase loads fig. shows the performance of system when 255V of voltage sag are introduced in the system for near about 5 cycles each. It can be seen that DVR injects voltage only under the event of sag and load voltage is restored at 1 p.u. i.e. at 320V . DC link voltage controller also acts enough faster and recovers it.

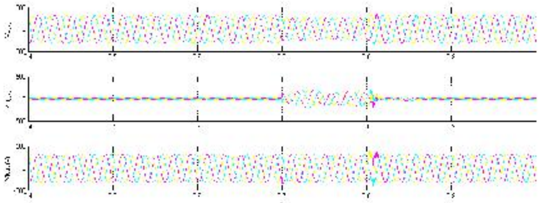

Fig. 4. Simulation results showing performance of DVR under balanced Sag

(B) Under Unbalanced sag (LG)

Voltage unbalance in the system is normally caused by unsymmetrical faults in the system or unbalance loading. fig 5 shows the performance of DVR when 255V of voltage sag are introduced in phase A. DVR compensates for negative sequence components and load voltage remains balanced as per standards, with magnitude of 1 p.u.

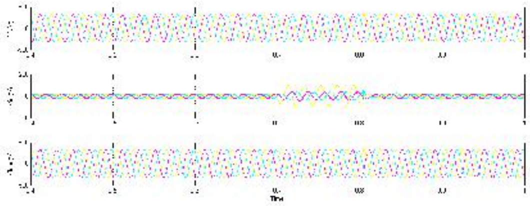

Fig. 5. Simulation results showing performance of DVR under unbalanced Sag(LG)

(C) Under Unbalanced sag (LLG)

Voltage unbalance in the system is normally caused by unsymmetrical faults in the system or unbalance loading.fig shows the performance of DVR when 255V of voltage sag are introduced in phase A and B. DVR compensates for negative sequence components and load voltage remains balanced as per standards, with magnitude of 1 p.u.

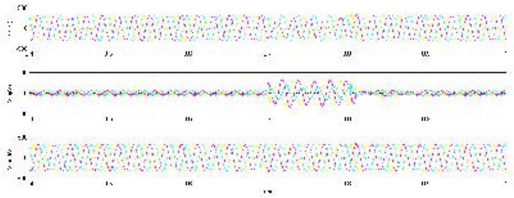

Fig. 4. Simulation results showing performance of DVR under unbalanced Sag(LLG)

VI. Conclusion

The quadrature phase based control on composite observer are discussed for voltage compensation. Applicability of quadrature phase control method depends on load power factor and sag magnitude. A large energy storage unit is not required in case of quadrature phase control, the small DC link capacitor can serve purpose. New control algorithm based on composite observer has been proposed and simulation results are discussed for compensation of voltage sag in balance and unbalance condition. DVR performance was found satisfactory for suppression of supply voltage disturbances without any delay.

APPENDIX

Supply system: 3 phase 50 Hz, 400V (non-ideal), source impedance R_S = 0.1Ω, L_S = 2 mH. Load rating 10 KVA.0.75 lag, Interfacing inductors = 2mH, Rating of injection transformer: 7 KVA 200/300V, DC Bus voltage =350 V, Ripple filter R_f = 6Ω, C_f = 10*10^-6F, Low pass filter cut of frequency = 10Hz.

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