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Modified Power Balance Theory to Control Dynamic Voltage Restorer (DVR) for Power Quality Enhancement

Prof. Prince Sinh[1], Prof. Henal Bhagatwala[2]
[12]EE Department Vadodara institute of engineering Vadodara, Gujarat, India

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Abstract- This paper mainly focuses on usages of dynamic voltage restorer (DVR) to mitigate various power quality problems. Recent years the various power quality problems like voltage sag, voltage swell and harmonic are major issues for consumers due to continuous growth of sensitive loads in the industrial and commercial areas. The Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. The performance of Dynamic Voltage Restorer is depends on control algorithms, which is used to generate switching pulses. In this paper, power balance theory is used to extract reference signal and further switching signal generated by hysteresis band technique. The Proposed controller system is modelled under MATLAB environment and Simulink toolbox. The DVR is simulated for three-phase linear resistive inductive lagging power-factor loads for harmonic mitigation, voltage regulation and load balancing for improving the quality of power system.

Keywords: Dynamic Voltage Restorer, hysteresis band controller, Power Quality, power balance theory

I. INTRODUCTION

The most immense topic in distribution grids is power quality issues nowadays. One of the reasons is the emerging technologies like power electronic and micro processers based automation and smart systems which are create power quality issues [1]. Some major Power quality problems like voltage sag, voltage swell and harmonic. These disturbances in quality of power are arises various deviations in power system such as unwanted tripping of circuit breakers, or blowing of HRC fuses, equipment overheating or malfunctioning, equipment light flickering, inaccurate readings shows in power meters, neutral conductor overheating and electronic communication interferences, these results heavy losses sometimes shut down of the plant or lifespan reduction of various equipment [1]-[2]. Power quality disturbances can be a cause for electronic communication interferences too. Therefore to maintaining a good power quality is a challenge for all the utilities providing power supply. The literatures on power quality enhancements are introduced about various suitable, corrective and preventive. The variety of custom power devices such as the distribution static compensator (DSTATCOM), the dynamic voltage restorer (DVR), Unified Power Quality Conditioner (UPQC), Interline Power Flow Controller (IPFC), Distributed Power-Flow Controller (DPFC) introduced recently [3]. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. The effectiveness and performance of dynamic voltage restorer (DVR), depends upon the control methods for the control algorithms of dynamic voltage restorer (DVR). various control algorithms are mentioned in the various literatures such as the instantaneous reactive power theory (instantaneous p-q theory), modified power balance theory, Synchronous reference frame control technique (SRFT), Artificial Neural Network and fuzzy based controller, PWM hysteresis current, etc [4]-[7]. This paper proposed an advanced control strategy which can compensate the distortion in voltage and current waveforms. A simulation model is established in under the MATLAB/ Sumlink environment with the help of sim-power system Toolbox (PST), the power balanced theory based algorithm is used to extract the active power and reactive power components for reference signal to control switching and obtain a better dynamic performance. Simulation results verify the effectiveness and correctness of the proposed control scheme.

II. CONFIGURATION OF DVR

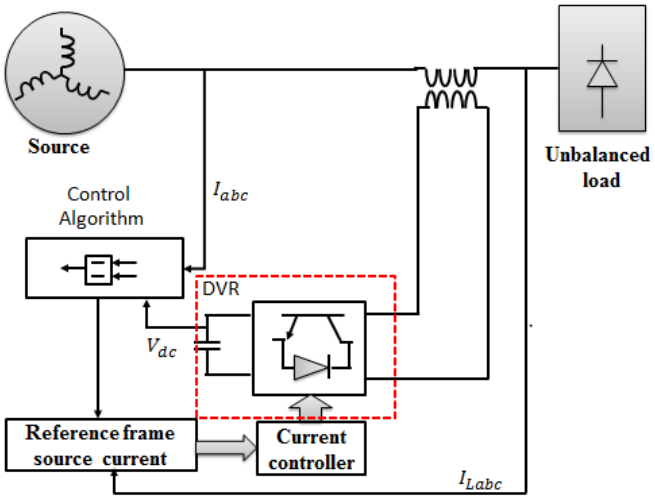

Figure 1: Block Diagram of DVR

The basic concept of DVR is depicted in Fig. 1. The Dynamic Voltage Restorer (DVR) is series connected active device. The DVR is belongs to the family of custom power Devices. The static series compensator (SSSC) is acknowledged as Dynamic Voltage Restorer (DVR) when it is used at distribution network side. It is connected near the load in the distribution systems. The DVR has ability to inject additional voltage into the system to regulate system voltage and control active power flow. It has less cost compared to the UPS and super conducting magnetic energy storage (SMES) device. The major components of a DVR are shown in Figure 1. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, coupling transformer, coupling transformer, and ac filter a control strategy. The basic electronic block of the DVR is the voltage sourced inverter that converts an input dc voltage into a three phase ac output at fundamental frequency. The controller of the DVR is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the DVR produces or absorbs the desired Reactive Power (VAR) at the PCC.

II. CONTROL ALGORITHM

For load balancing and reactive power compensation, a DVR injected current as needed by the utility system, and therefore, thus the source is being supplied only real. Hence, source current remains at unity power factor. The switching of the DVR depends on reference current of control strategy. If the source reference current is balanced its helps to achieved load balancing in system [7]. These Reference source current for switching purpose of the DVR is being extracted by below technique.in these paper we are used power balance theory is based control scheme

Power balance theory method (PBT):

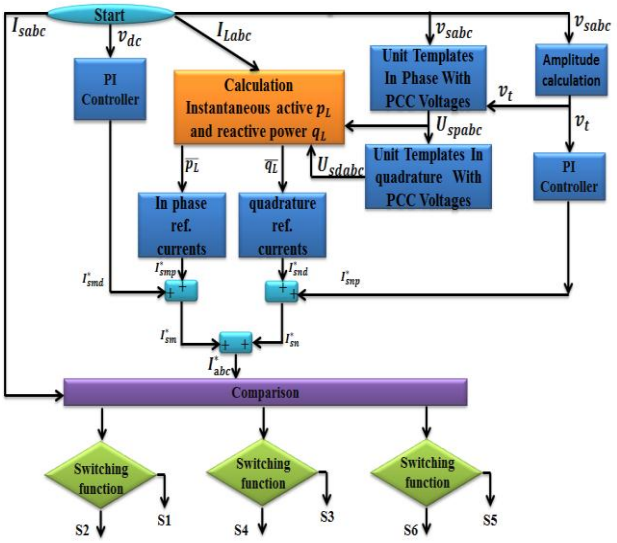

Figure 2: Basic block diagram of power balance theory method.

The figure 3 illustrates the modified power balance theory based control algorithm. For extracting reference source currents, source currents (i_{sa} , i_{sb}, i_{sc}), PCC voltages (V_{sa}, V_{sb}, V_{sc}), load currents (i_{La} , i_{Lb}, i_{Lc}), and DC bus voltage (v_{dc}) of the DVR are used in this algorithm. The amplitude of the PCC voltages (V_{sa}, V_{sb}, V_{sc}) calculated by eqs. (5.10).The unit templates in phase with PCC voltages (V_{sa}, V_{sb}, V_{sc}), are obtained from following eqs.

$$u_{sap} = v_a/V_t ; u_{sbp} = v_b/V_t ; u_{scp} = v_c/V_t \quad (1)$$

The unit templates in quadrature with the PCC voltages (V_{sa}, V_{sb}, V_{sc}), are obtained from following eqs.

$$u_{saq} = (-u_{sbp} + u_{scp})/\sqrt{3} \quad (2)$$

$$u_{sbq} = (u_{sap}\sqrt{3} + u_{sbp} - u_{scp})/2\sqrt{3} \quad (3)$$

$$u_{scq} = (-u_{sap}\sqrt{3} + u_{sbp} - u_{scp})/2\sqrt{3} \quad (4)$$

The instantaneous active and instantaneous reactive powers of the load are calculated from above eqs and V_t.which is expressed as follows

$$p_L = V_t(u_{sap}i_{La} + u_{sbp}i_{Lb} + u_{scp}i_{Lc}) \quad (5)$$

$$q_L = V_t(u_{saq}i_{La} + u_{sbq}i_{Lb} + u_{scq}i_{Lc}) \quad (6)$$

$$p_L = \bar{p} + \tilde{p} \quad (7)$$

$$q_L = \bar{q} + \tilde{q} \quad (8)$$

This instantaneous active and reactive power of the load has two components.

DC component ($\tilde{p}$, $\tilde{q}$)

AC component ($\bar{p}$, $\bar{q}$)

Out of this the DC component of the load powers can be extracted by using the low pass filter. Same way as above SRFT theory, here in this algorithm has also two modes. First one is Power Factor Correction (PFC) mode, for this mode only the instantaneous active power must be supplied from control algorithm and second one is Zero Voltage Regulation (ZVR) mode, some extra reactive power in addition of reactive component of load is feed by the DVR to resolve the drop in source impedance.

The active power component and reactive power component of the load currents has two parts. The active power component of the source currents are as follows:

I^*_{smp}: It is required DC component of the active power of load

I^*_{smd}: It is required for the self-supporting DC bus of DVR

The above both active power component of the load current be expressed as

$$I^*_{smp} = \left(\frac{2}{3}\right)\bar{p}_L/V_t \quad (9)$$

$$I^*_{smd} = K_{pd}V_{dce} + K_{id}\int V_{dce}dt \quad (10)$$

Here $V_{dce} = V^*_{dc} - V_{dc}$ is the error between the reference dc voltage ($V_{dc\,ref}$)and sensed dc voltage (V_{dc}) at the nth

sampling instant. The K_{pd} & K_{id} are proportional and integral gains of the dc bus voltage regulator PI controller. The amplitude of the active power component of the reference source currents I^*_{sm} is given by using eq

$$I^*_{sm} = I^*_{smp} + I^*_{smd} \quad (11)$$

The Three phase active power component of reference source currents are given as,

$$I^*_{sap} = I^*_{sm} u_{sap}; I^*_{sbp} = I^*_{sm} u_{sbp}; I^*_{scp} = I^*_{sm} u_{scp} \quad (12)$$

Moreover, the reactive component of the source currents are as follows:

I^*_{snq}: It is required DC component of the active power of load

I^*_{sna}: It is required for maintaining the amplitude of the PCC voltage

The above both reactive power component of the load current be expressed as

$$I^*_{snq} = \left(\frac{2}{3}\right) \bar{q}_L / V_t \quad (13)$$

$$I^*_{sna} = K_{pa} V_e + K_{da} \int V_e dt \quad (14)$$

Where $V_e = V^*_t - V_t$ is the error between the reference of PCC voltage amplitude (V^*_t)and the actual amplitude of PCC voltage(V_t).The K_{pa} & K_{da} are proportional and integral gains of the PCC voltage regulator PI controller. The amplitude of the reactive power component of the reference source currents I^*_{sn} is given by using following eq.

$$I^*_{sn} = I^*_{sna} + I^*_{snq} \quad (15)$$

The Three phase reactive power component of reference source currents are given as

$$I^*_{saq} = I^*_{sn} u_{saq}; I^*_{sbq} = I^*_{sn} u_{sbq}; I^*_{scq} = I^*_{sn} u_{scq} \quad (16)$$

Total three phase reference source currents are calculated from above two eqs.5.31 & 5.32.

$$I^*_{sa} = I^*_{sap} + I^*_{saq}; I^*_{sb} = I^*_{sbp} + I^*_{sbq}; I^*_{sc} = I^*_{scp} + I^*_{scq} \quad (17)$$

So from eq.5.33 we extract reference source currents ($I^*_{sa}, I^*_{sb}, I^*_{sc}$) from the modified Power Balance Theory for switching purpose of VSC of DVR.

III. SIMULATION RESULTS

The proposed model of DVR and its control strategy, which based on principle of Power balance theory, are modelled in MATLAB. The proposed system is modelled at 3- phase 415V, 50Hz. This system is simulated for variety of PQ problems such as Voltage sag and swell, harmonics reduction, compensating reactive power. The results of simulation are illustrated in figure 3 to figure 11 to check performance of DVR along with load unbalancing. Fig. 3 depicts the MATLAB/ Simulink simulation result of voltage swell and sag due to at t = 0.1 s, phase A taking off from3 phase linear load and at t = 0.4 s, nonlinear load is connected in test system respectively.

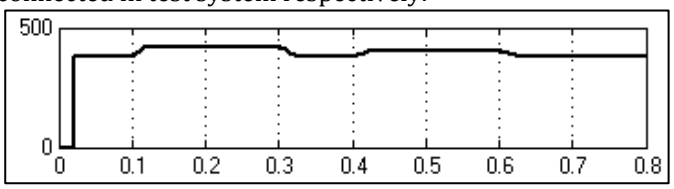

Fig.3. Voltage sags & swells in test system without DVR

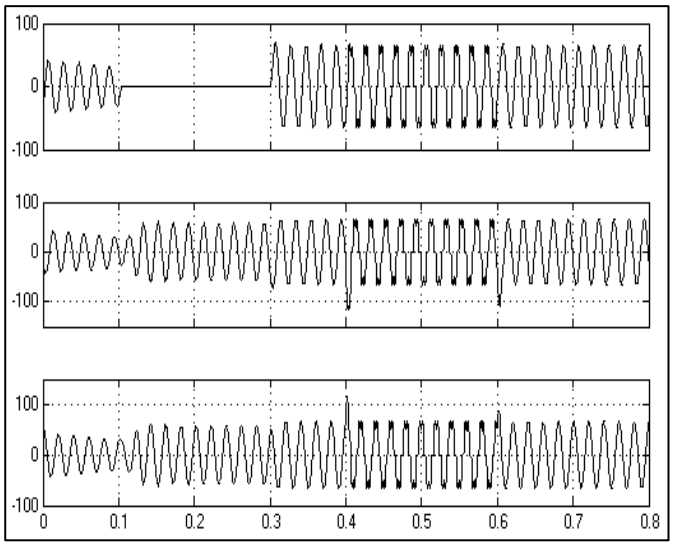

Fig.4. Three phase currents of test system without DVR

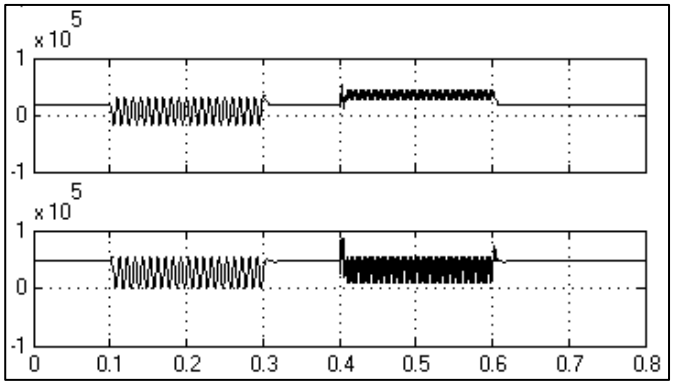

Fig.5. Active & Reactive power of test system without DVR

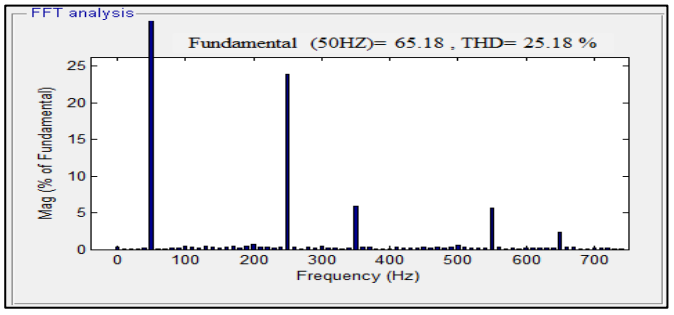

Fig.6. THD analysis of test system without DVR

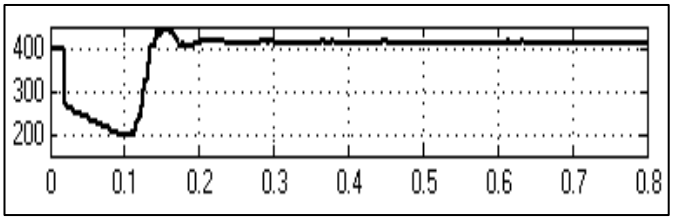

Fig.7. Voltage sags & swells free in test system with DVR

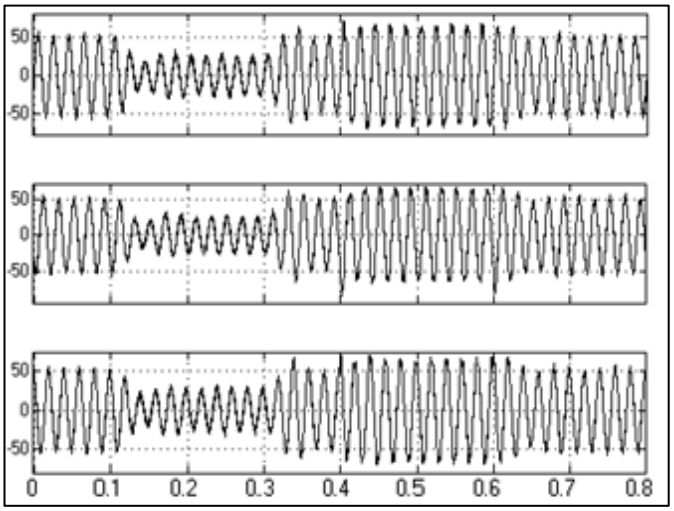

Fig.8. Three phase currents of test system with DVR

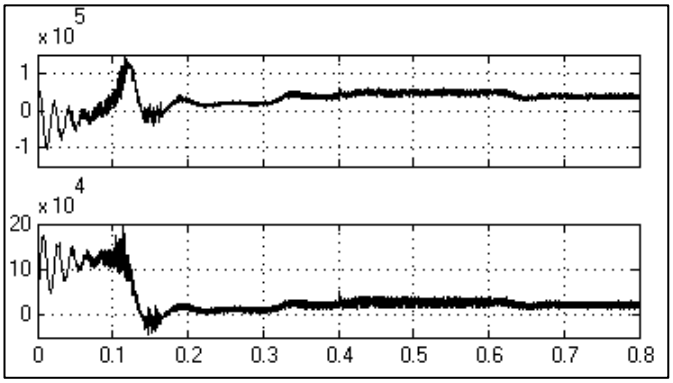

Fig. 9. Active & Reactive power of test system with DVR

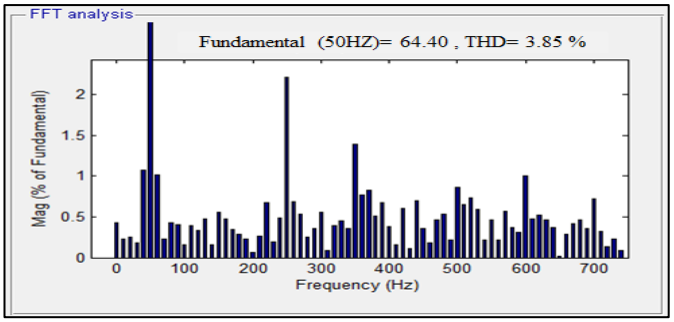

Fig.10. THD analysis of test system with DVR

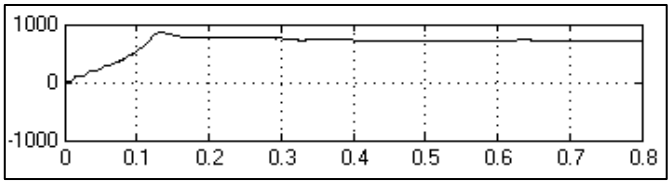

Fig.11. The DC link Voltage of DVR

Table I: Test system parameters

	Without DVR	With DVR
sag	415- 397= 18 V	415- 412= 3 V
Swell	435- 415 = 20 V	420-415=5V
THD (%)	25.48%	3.85%

So, the harmonic distortion induced in current. The harmonic spectra of the phase- a current are shown in figure 6 without DVR. At t = 0.1 s, the phase A is taken out from load, in this unbalance condition the DVR system is able to balance system currents and mitigate the voltage swell. After that when nonlinear load connected in system (for time t = 0.4 s to t = 0.6 s), even in these dynamics conditions DVR system capable to eliminate harmonics and mitigate the voltage sag which is clearly shows in figure 8. The harmonic spectra of the phase- a current are shown in Fig. 10 with DVR. The dc-bus voltages of VSC are well maintained at 700 V during the complete range of operation which is shown figure 11. Table no. I illustrate the results for without and with compensation. The table shows that sag, swell and Total Harmonic Distortion (THD) without compensation of DVR is 18 V, 20 V and 25.48% respectively, and after compensation of DVR its come reduced up to 3 V, 5 V and 3.85 % respectively.

IV. CONCLUSION

The compensator presented here to eliminate Power quality problems is VSC topology included DVR along with variable load. The proper operation of compensator device requires variation of dc link voltage and control strategy. A simple extrapolated algorithm has been established for the extraction of reference signal for controlling DVR, based on basic power balanced theory to protect quality of Power. It is observed from these studies that the proposed controller is gives fast transient response. By using the DVR enhancement of power quality in the distribution grids with unbalanced and nonlinear load is achieved.

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