Sliding Mode Controller And Its Application To Dynamic Voltage Restorer (DVR)

Rohini Telu, Balamurali Surakasi, Prasad Chongala, Nalini Telu

ABSTRACT- Sliding Mode Control (SMC) is a robust control scheme based on the concept of changing the structure of the controller in response to the changing state of the system in order to obtain a desired response. A high speed switching control action is used to switch between different structures of the controller and the trajectory of the system is forced to move along a chosen switching manifold in the state space.This report deals with the Sliding Mode Control of single phase DVR for voltage sag/swell correction. A Sliding Mode Controller is designed and developed for a single phase DVR. The dynamic voltage restorer (DVR) is known as an effective device to mitigate voltage sags and swells as they are vital power quality problems . Using SMC to the DVR, additional sag/swell detection method is eliminated. This improves the dynamic response of the DVR and also DVR is able to compensate for any variation in source voltage. Usage of Sliding Mode Control to DVR, makes it multifunctional, such as compensation for voltage sag, swell,voltage flicker and voltage harmonics as well. Validity of the proposed control is verified through extensive simulation and experimental results.

KEYWORDS – DVR, Sliding mode control, Voltage sag.

I. INTRODUCTION:

Power quality problems in the distribution systems are interruption, voltage sag and voltage swell due to the increased use of sensitive and critical equipments in the system. Some examples are equipments of communication system, process industries, precise manufacturing processes etc.Power quality problems such as transients, sags, swells and other distortions to the sinusoidal waveform of the supply voltage affect the performance of these equipments. The technologies like custom power devices are emerged to provide protection against power quality problems. Custom power devices are mainly of three categories such as series-connected compensator like dynamic voltage restorer (DVR), shunt connected compensator such as distribution static compensator (DSTATCOM), and a combination of series and shuntconnected compensators known as unified power quality conditioner (UPQC). A DVR is used to compensate the supply voltage disturbances such as sag and swell. The DVR is connected between the supply and sensitive loads, so that it can inject a voltage of required magnitude and frequency in the distribution feeder. The DVR is operated such that the load voltage magnitude is regulated to a constant magnitude, while the average real power absorbed/ supplied by it is zero in the steady state. The capacitor supported DVR is widely addressed in the literature [8-13]. The instantaneous reactive power theory (IRPT) [6], sliding mode controller [9], instantaneous symmetrical components [2,13] etc., are discussed in the literature for the control of DVR. In this project a new control algorithm is proposed based on the current mode control and sliding mode controller for the control of DVR. The extensive simulation is performed to demonstrate its capability, using the MATLAB with its Simulink and Power System Blockset (PSB) toolboxes.

II. DYNAMIC VOLTAGE RESTORER:

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. 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. DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

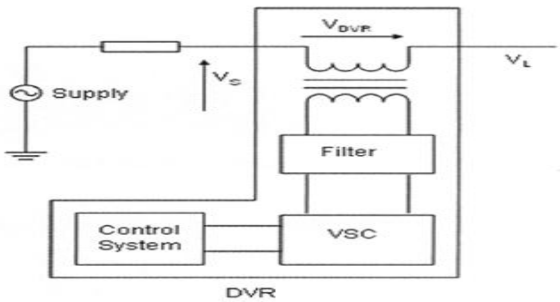

Fig.1: Equivalent Circuit diagram of DVR

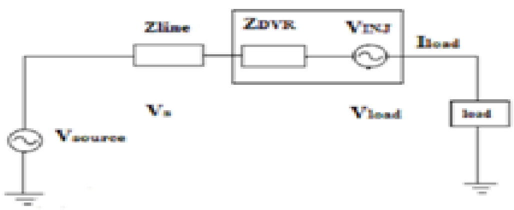

Fig.2: Equivalent Circuit diagram of DVR

The system impedance Zth depends on the fault level of the load bus. When the system voltage (Vth) drops, the DVR injects a series voltage VDVR through the injection transformer so that the desired load voltage magnitude VL can be maintained. The series injected voltage of the DVR can be written as

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

2.1. PRINCIPAL OF OPERTION OF DVR:

The DVR injects a voltage (Vc) in series with the terminal voltage (Vt) so that the load voltage (VL) is always constant in magnitude. The source impedances (Za, Zb, Zc) are between the source and the terminal.The DVR uses three single-phase transformers (Tr) to inject voltages in series with the terminal voltage. A voltage source converter (VSC) along with a dc capacitor (Cdc) is used to realise a DVR. The inductor in series (Lr) and the parallel capacitor (Cr) with the VSC are used for reducing the ripple in the injected voltage. Fig.3(b) shows the phasor diagram for the injected voltage and the fundamental voltage drop to maintain the dc bus voltage of DVR. VL' and IL' are the load voltage and current before the sag occurred in the supply system. After the sag event, themagnitude of the load voltage (VL), the load current (IL) and the power factor angle (Θ) are unchanged, but a phase jump is occurred from the pre-sag condition. The injected voltage (Vc) has two components. The voltage injected at quadrature (Vcq) with the current is to maintain the load voltage at constant magnitude and the in-phase voltage (Vcd) is to maintain the dc bus of VSC and also to meet the power loss in the DVR.

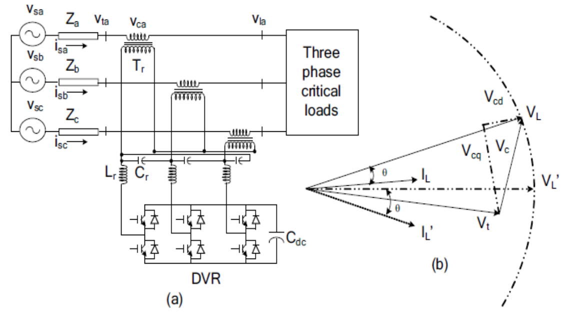

Fig.3: (a) Three-phase DVR scheme and (b) Phasor diagram

The control strategy of the DVR is to achieve these two components of the injection voltage and this is achieved by controlling the supply current. The currents are sensed and the two components of currents, one is the component to maintain the dc bus voltage of DVR and the second one is to maintain the load terminal voltages, are added with the sensed load current to estimate the reference supply current.

2.2. DVR CONTROL STRATEGY:

The proposed algorithm is based on the estimation of reference supply currents. It is similar to the algorithm for the control of a shunt compensator like DSTATCOM for the terminal voltage regulation of linear and nonlinear loads [6]. The proposed control algorithm for the control of DVR is depicted in Figs 4,5,6.

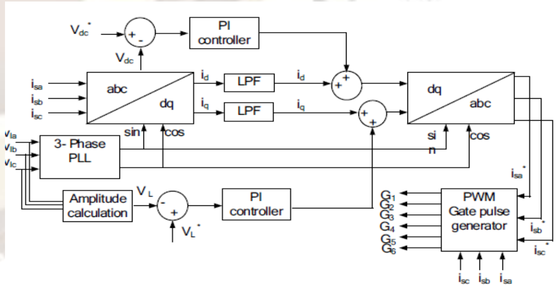

Fig. 4: Control scheme of the DVR-PI

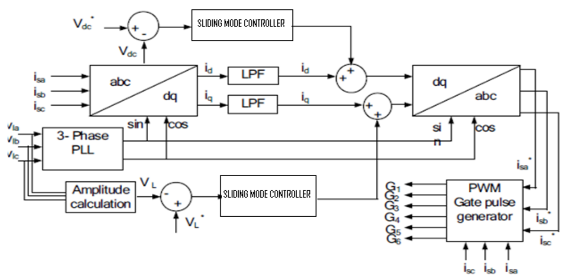

Fig.5: Control scheme of the DVR-SMC

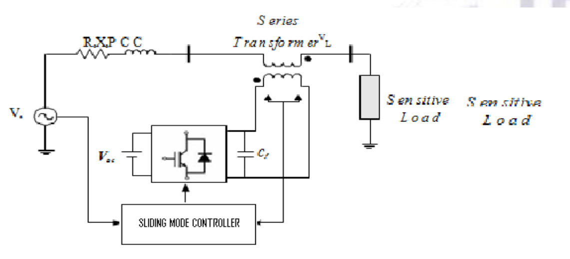

Fig.6: Schematic diagram of a typical DVR-SMC connected to pwm-inverter

The series compensator known as DVR is used to inject a voltage in series with the terminal voltage. The sag and swell in terminal voltages are compensated by controlling the DVR and the proposed algorithm inherently provides a self-supporting dc bus for the DVR. Three-phase reference supply currents (isa*, isb*,isc*) are derived using the sensed load voltages (vla, vlb, vlc), terminal voltages (vta, vtb, vtc) and dc bus voltage (vdc) of the DVR as feedback signals. The synchronous reference frame theory based method is used to obtain the direct axis (id) and quadrature axis (iq) components of the load current. The load currents in the three-phases are converted into the d-q-0 frame using the Park's transformation as,

III. MATHEMATICAL

A three-phase PLL (phase locked loop) is used to synchronies these signals with the terminal voltages (vta, vtb, vtc). The d-q components are then passed through low pass filters to extract the dc components of id and iq. The error between the reference dc capacitor voltage and the sensed dc bus voltage of DVR is given to a SMC (Silding Mode Controller) of which output is considered as the loss component of current and is added to the dc component of id. Similarly, a second PI controller is used to regulate the amplitude of the load voltage (Vt). The amplitude of the load terminal voltage is employed over the reference amplitude and the output of PI controller added with the dc component of iq. The resultant currents are again converted into the reference supply currents using the reverse Park's transformation. Reference supply currents (isa*, isb*,isc*) and the sensed supply currents (isa, isb, isc) are used in PWM current Controller to generate gating pulses for the switches. The PWM controller operates at a frequency of 10 kHz and the gating signals are given to the three-leg VSC for the control of supply currents.

3. SLIDING MODE CONTROL:

Sliding Mode Control is a robust control scheme based on the concept of changing the structure of the controller in response to the changing state of the system in order to obtain a desired response [1,2,3,4].A high speed switching control action is used to switch between different structures and the trajectory of the system is forced to move along a chosen switching manifold in the state space. The behaviour of the closed loop system is thus determined by the sliding surface. The biggest advantage of SMC is its insensitivity to variation in system parameters, external disturbances and modelling errors.Sliding mode control enables separation of overall system motion into independent partial components of lower dimensions and low sensitivity to plant parameter variations and disturbances.The condition for the existence of the sliding mode relates to the stability of the represen- tative point (RP) around the switching line. This means, under any circumstances, the RP should stick to the sliding surface. In case of ideal sliding mode motion the switching line and its phase velocities should be identically zero i.e

$$s = Cx_1 + x_2 = 0$$

$$s = Cx_2 + \dot{x}_2 = 0$$

where, $\dot{x}_1 = x_2$

In other words it means that the state trajectories $x_1(t)$ and $x_2(t)$ of the controlled plant satisfies the equation $s = 0$ at every $t \geq t_h$. But in actual practice it is very difficult to tune to this due to various types of uncertainties, inertia of the physical system and unrealizability of infinitely fast switching.The second stage of the design procedure involves the selection of the control which will ensure that the chosen sliding mode is attained. For this reason, the problem of determining a control structure and associated gains, which ensure the reaching or hitting of the sliding mode, is called the reach ability problem.

ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 3, May-Jun 2012, pp.562-567

IV.SIMULINK IMPLIMENTATION OF DVR-SMC:

The DVR is modeled and simulated using the MATLAB and its Simulink and Power System Block set (PSB) toolboxes. The MATLAB model of the DVR connected system is shown in Fig.7. The three-phase source is connected to the three-phase load through series impedance and the DVR. The considered load is a lagging power factor load. The VSC of the DVR is connected to the system using an injection transformer.

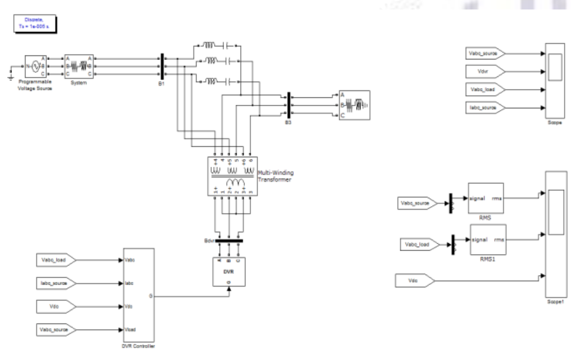

Fig.7: MATLAB based model of the three-phase DVR-smc connected system

The proposed control algorithm is modeled in MATLAB as shown in Figs.8,9,10. The reference supply currents are derived from the sensed load voltages, supply currents and dc bus voltage of DVR. The output of the PI and sliding mode controllers used for the control of dc bus voltage of DVR is added with the direct axis component of current.

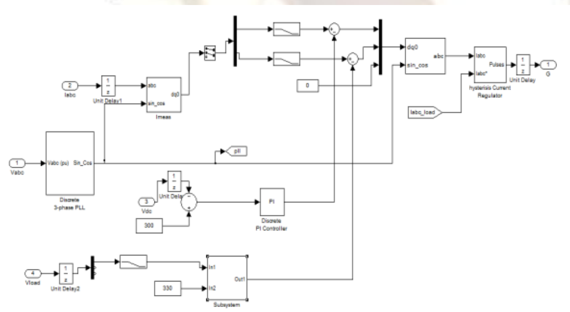

Fig.8: MATLAB based model of the proposed control method.

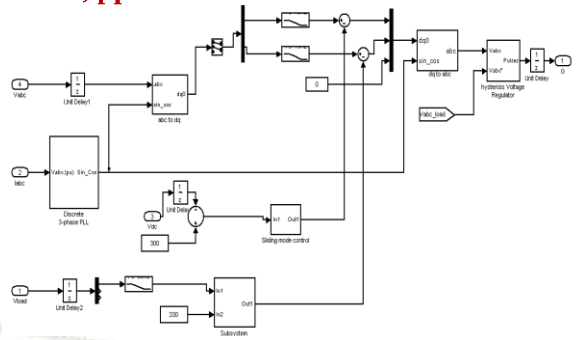

Fig.9: MATLAB based model of the proposed control method(smc)

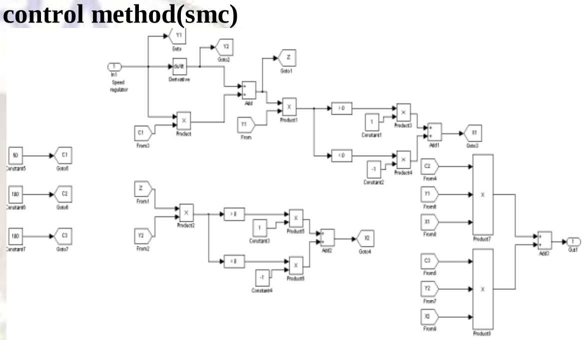

Fig.10: Simulation block for sliding mode controller

4.1. RESULTS AND DISCUSSION

The proposed control scheme of DVR is verified through simulation using MATLAB software along with its Simulink and Power System Blockset (PSB) toolboxes. The DVR is tested under different operating conditions like sag (Fig.11) at the terminal voltages (Vta, Vtb, Vtc). In Fig. 11, the terminal voltage has a sag of 30% with a magnitude at 70% of rated value at 0.22 sec and occurs up to 0.32 sec. The DVR injects fundamental voltage (Vc) in series with the terminal voltages (Vla, Vlb, Vlc). The load voltage is maintained at the rated value. The terminal voltage (Vt), supply current (is), amplitude of terminal voltage (Vt) the amplitude of load voltage (VL) and the dc bus voltage (Vdc) of DVR are also shown in the Fig.11. It is observed that the dc bus voltage of DVR with smc is maintained at reference value.

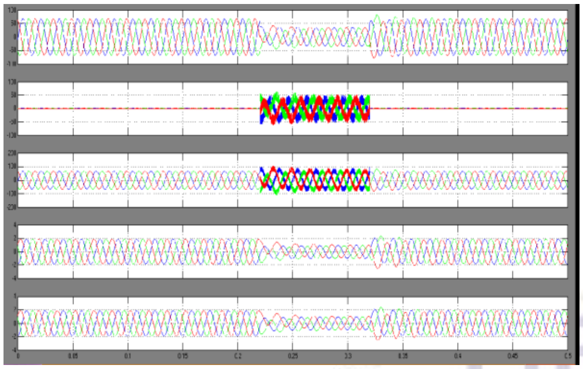

Fig.11: (a) Dynamic behavior of DVR with PI for voltage sag compensation

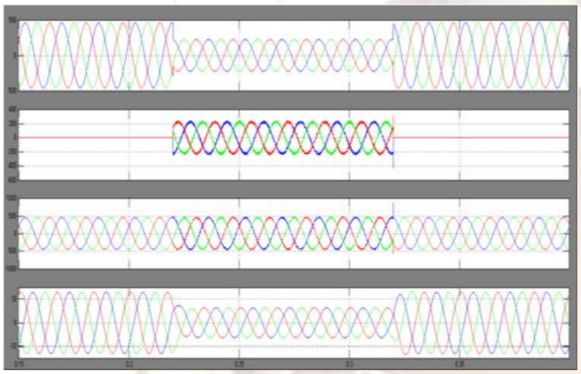

Fig.11 (b) Dynamic behavior of DVR with SMC for voltage sag compensation

It is observed that the dc bus voltage of DVR with sliding mode controller is much better than the results obtained from pi controller is maintained at reference value. The harmonic content is reduced with sliding mode control.

VII. CONCLUSIONS:

A new control strategy based on sliding mode control for Dynamic Voltage Restorer (DVR) has been proposed to mitigate the power quality problems in the terminal voltages. The DVR is controlled indirectly by controlling the supply current. The reference supply currents are estimated using the sensed load terminal voltages and the dc bus voltage of DVR. The control scheme is based on sliding mode theory (SMT) for the operation of a capacitor supported DVR. The proposed control scheme of DVR has been validated the compensation of sag and swell in terminal voltages. The performance of the DVR has been found very good to mitigate the voltage power quality problems. Moreover, it has been found capable to provide self supported dc bus of the DVR through power transfer from ac line at fundamental frequency.

VIII. REFERENCES:

[1] Math H.J. Bollen, Understanding Power Quality Problems-Voltage Sags And Interruptions, IEEE Press, New York, 2000.
[2] A. Ghosh and G. Ledwich, Power Quality Enhancement using Custom Power devices, Kluwer Academic Publishers, London, 2002.
[3] Math H. J. Bollen and Irene Gu, Signal Processing of Power Quality Disturbances, Wiley-IEEE Press, 2006
[4] R. C. Dugan, M. F. McGranaghan and H. W. Beaty, Electric Power Systems Quality. 2nd Edition, New York, McGraw Hill,2006.
[5] Antonio Moreno-Munoz, Power Quality: Mitigation Technologies in a Distributed Environment, Springer-Verlag London limited, London 2007.
[6] K.R. Padiyar, FACTS Controllers in Transmission and Distribution, New Age International, New Delhi, 2007.
[7] lEEE Recommended Practices and Recommendations for Harmonics Control in Electric Power Systems, IEEE Std. 5 19,1992.
[8] M. Vilathgamuwa, R. Perera, S. Choi, and K. Tseng, "Control of energy optimized dynamic voltage restorer", in Proc. of IEEE IECON'99, vol. 2,1999, pp. 873–878.
[9] B. N. Singh, A. Chandra, K. Al-Haddad and B. Singh, "Performance of sliding-mode and fuzzy controllers for a static synchronous series compensator", IEE Proc. on Generation, Transmission and Distribution, vol. 146, no. 2, pp. 200 – 206, March 1999.
[10] Il-Yop Chung., Dong-Jun Won, Sang-Young Park, Seung-Il Moon and Jong-Keun Park, "The DC link energy control method in dynamic voltage restorer system", International Journal of Electrical Power & Energy Systems, vol. 25, no. 7, pp. 525-531, Sept. 2003.
[11] A. Ghosh, A.K Jindal and A Joshi, "Design of a capacitorsupported dynamic voltage restorer (DVR) for unbalanced and distorted loads", IEEE Trans. on Power Delivery, vol. 19, no.1, pp. 405 – 413, Jan. 2004.
[12] A. Moreno-Munoz, D Oterino, M Gonzalez, F A Olivencia and J.J. Gonzalez-de-la-Rosa, "Study of sag compensation with DVR", in Proc. of IEEE MELECON,Benalmadena(Malaga Spain, May 2006, pp 990-993.
[13] Amit Kumar Jindal, Arindam Ghosh and Avinash Joshi, "Critical load bus voltage control using DVR under system frequency variation,"

ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 3, May-Jun 2012, pp.562-567
Electric Power Systems Research, 2007, doi: 10.1016/j.epsr. 2007.02.006.

IX. AUTHORS:

Rohini Telu is currently doing her Post Graduate course in Control Systems in Electrical and Electronics Engineering, department of Anil Neerukonda Institute of Technology and Sciences, Sangivalasa, Bhemunipatnam Mandal, Visakhapatnam dsit., Andhra Pradesh, India, Bachelor degree in Electrical and Electronics Engineering from Pydah College of Engineering and Technology, Boyipalem, Visakhapatnam,Andhra Pradesh, India, in 2010

Balamurali Surakasi received his master degree in Control Systems from Andhra University, visakhapatnam, in 2004, Bachelor degree from GITAM College of Engineering, Visakhapatnam, India, in 2001. He is currently working as an Associate Professor of Electrical and Electronics Engineering department at Anil Neerukonda Institute of Technology and Sciences, Sangivalasa, Bhemunipatnam Mandal, Visakhapatnam dsit., Andhra Pradesh, India.

Prasad Chongala is currently doing his Post Graduate course in Control Systems in Electrical and Electronics Engineering, department of Anil Neerukonda Institute of Technology and Sciences, Sangivalasa, Bhemunipatnam Mandal, Visakhapatnam dsit., Andhra Pradesh, India, Bachelor degree in Electrical and Electronics Engineering from S.R.K.R Engineering College,Andhra Pradesh, India, in 2009.

NaliniTelu is currently doing her Post Graduate course in Power And Industrial Drives in Electrical and Electronics Engineering, department of Dadi Institute Of Engineering And Technology,Anakapalle, Visakhapatnam, India, Bachelor degree in Electrical and Electronics Engineering from Vitam College Of Engineering,Parvatipuram, Andhra Pradesh, India, in 2005.