Dynamic Voltage Restorer, a Power Quality Conditioner for Voltage Stability Enhancement

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Abstract — As the load type switched to sensitive one with the use of Power Electronics technology (PET), hence power quality of the supply is utmost important. The sensitive loads are predominantly vulnerable to Voltage Fluctuations and Surges (VFS). These types of loads typically require stable and reliable power in order to function properly, and may include equipment such as computers, medical equipment, telecommunications systems, and other electronic devices. Hence a power conditioner is required to protect these loads against the VFS. Dynamic Voltage Restorer (DVR) is one such conditioner used to mitigate VFS in power distribution system. This paper presents a brief review on various topologies of DVR available in literature. Also, the principle of operation, circuit topology and control architecture are systematically reviewed.

Keywords: Dynamic Voltage Restorer (DVR), Power Electronics technology (PET), Power quality (PQ), Voltage Fluctuations and Surges (VFS)

I. INTRODUCTION

The concept of Power Quality (PQ) has become an indispensable criteria for the suppliers and consumers in order to protect the sensitive loads connected in the Electrical Distribution Network (EDN). A Dynamic Voltage Restorer (DVR) is a power electronics device that can be used to enhance PQ in EDN [1]. The availability of fast switching, high power, self-commutating devices in-conjunction with fast computing elements and controller have paved the way for wide spread use of voltage/current source converter (VSC/CSC) based custom power devices. The DVR is one such device, specifically designed to mitigate Voltage Fluctuations and Surges (VFS). VFS are voltage disturbances such as sags, swells, and interruptions that can cause damage to sensitive equipment. The use of a DVR to enhance PQ involves the installation of the series power converter in EDN to improve the voltage profile and reduce the impact of voltage disturbances [2].

Basic concept of DVR is that it uses VSC/CSC along with several low rated power semiconductor switches as per the design of VSC/CSC to inject the required reactive power so as to enhance the PQ under the condition of VFS. As the power converter technology matures, there has been developments in the DVR design [3]. There are numerous types of DVR topologies available based on the inverter configuration which has been listed in figure 1. They are broadly classified into inverter source topology as VSC/CSC, phases as single/three or modular topologies [4]. All these topologies have specific application and orientation as they DVR can be customized as per the demand or application where it needs to be installed. A brief overview on theses topologies are presented in next section.

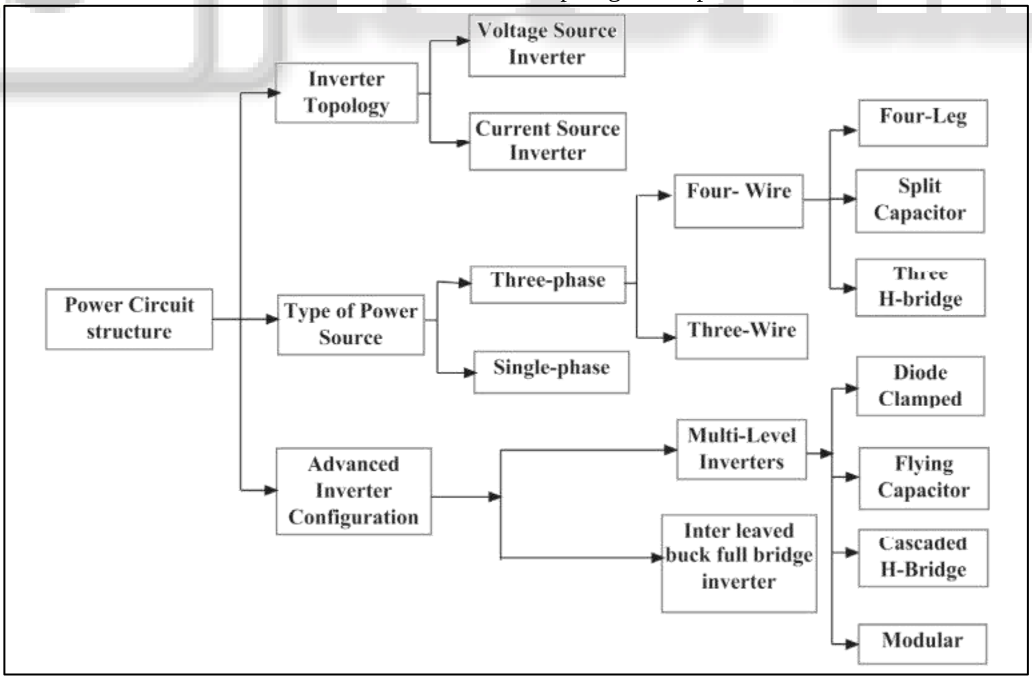

Fig. 1: Classification of power converters used in DVR

II. LITERATURE REVIEW

DVR is widely adopted for improving the PQ at both utility and grid side system specifically under the condition of VFS. The various aspects of DVR for its versatile applications have motivated researchers to develop numerous topologies based on power circuit design, control techniques and PWM techniques. Some of the recent work done on the topological advancement in DVR is discussed briefly in this section.

In early phase of development, DVR is installed as a series active power filter control via conventional three-phase two level VSC/CSC. They are connected in series in-between the source and the sensitive loads and operated as a voltage regulator as well as isolates the harmonics propagation between the load and the source. As the researchers explore the utility of the DVR not just as the voltage regulator or harmonics isolator but also in a way to control the active and reactive power flow to maintain the system reliability and stability. A lot of research since then has been performed for the advancement in the DVR topology. The DVR monitors the voltage at the terminal where it is installed, this involves the use of a controller which compares the sensed voltage with a reference voltage. When the voltage deviates from the reference one, the control system adjusts the output of the VSC/CSC to inject the appropriate voltage/current waveform to restore the nominal rated voltage. In [5] author modifies the control strategy for DVRs in-order to mitigate VFS. The proposed strategy is based on a new reference voltage calculation method and can mitigate voltage sags/swells more effectively than traditional DVRs. There are numerous filters available such as kalman filter, Fast Fourier and wavelet transform based filters [6-8] which can more efficiently extract the signal and can remove the harmonics from the polluted signal. Researchers had also explored the optimization based techniques to detect and classifying voltage sags in power systems [9]. After sensing the VFS and extracting the reference signal, the next step in DVR operation is to generate the gate pulses for the power converters connected. In literature numerous topologies are available for referencing and generating the gate pulses and the conventional ones are; The time-domain techniques based P-Q theory which is also commonly known as instantaneous reactive power theory (IRPT) [10], unit template technique [11], power balance theory [12], Synchronous reference frame (SRF) theory [13], Instantaneous symmetrical component theory (ISCT) [14], Enhanced phase locked loop (EPLL)-based control algorithm [15]. The SRF converts the three-phase voltage/current waves in to two-phase by using Clark transformation [16]. Another popular technique is Proportional Integral (PI) based controller which is very simple and robust. This control technique is effective in distorted supply voltage condition [17]. While designing PI controller, PLL plays an important role in synchronization/tunning of the system, and for tuning of the PLL block parameters like K_p, K_d, are the big challenge for the researchers [18]. Some more research available based on soft computing techniques are; fuzzy based controller as mentioned in [19] where a novel control strategy for DVRs using a fuzzy logic controller. The simulation results showed that the proposed control strategy can mitigate voltage sags more effectively than traditional DVRs. In [20], A neural network control is proposed. As is known, the PWM converter is actually nonlinear, but the PI is a linear controller, so it can only guarantee the stability of this converter in a local area.

Apart from the controller required for precise and efficient controlling of the DVR, there has been a lot of innovation and development in DVR's converter topologies. The problems associated with the classical VSC/CSC topologies are for medium and high power level system, they require devices of high power rating which is many times not available also they have High total voltage blocking capability and switching losses at fundamental frequency. Hence academsians and researchers have gone for new multilevel topologies. Ebrahimi et al. [22] presented a Multilevel Module (MLM) based multilevel inverter for high power quality applications which utilizes combination of both unidirectional and bidirectional switches of different ratings and requires considerable number of DC sources along with reduction in power losses for same number of levels. Buticchi et al. [23] have presented a single phase transformerless grid connected multilevel inverter topology for photovoltaic system which is based on two cascaded two-full bridges with different DC link voltages and one bridge supplied with flying capacitor. Converter is switched suitably so as to improve efficiency, reduce common mode voltage, harmonics and ground leakage current [24]. In addition to the MLI based converter topologies for DVR, a lot of research is available for advanced and mofified topologies. The topological survey for the DVR are briefly discussed in the next section

III. DVR TOPOLOGIES;

The DVR can be installed at medium or low voltage level LV) in the distribution side. The choice is governed by the number or type (either commercial/industrial) of end-user customer. The configuration of the MV-DVR and LV-DVR is presented in figure 2 and figure 3 respectively. The DVR is also designed with and without energy storage element. In case of no-storage device as shown in figure 4, the DVR draws power from the mains. In case of storage device as shown in figure 5, the DVR is supplied via storage device. The conventional AC-DC-AC (DC link) DVR topologies have dc-link and two stage power conversion, which increase its size, cost and associated losses. Besides the conventional topologies, there are some topologies have been introduced for DVR which make use of direct AC-AC (AC link) converters without the need for energy storage elements and intermediate dc link. By using a direct AC-link converter instead of the conventional DC link converters as shown in figure 6.

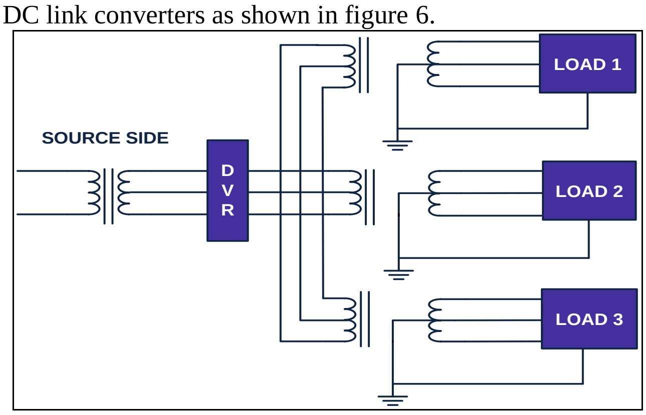

Fig. 5: Configuration of MV-DVR

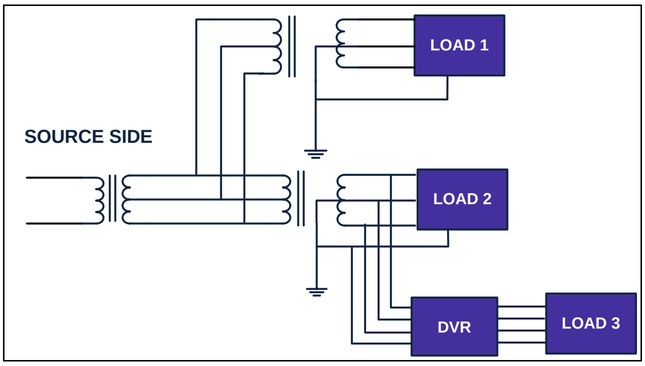

Fig. 6: Configuration of LV-DVR

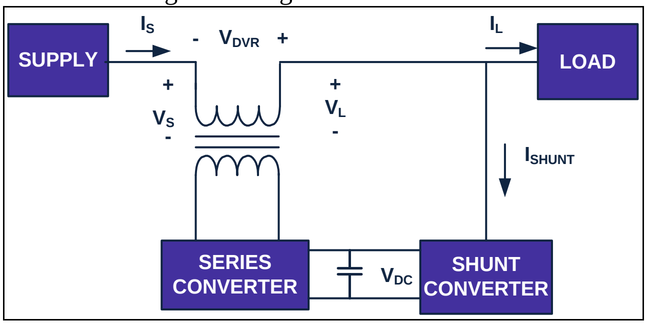

Fig. 7: Configuration of without energy storage

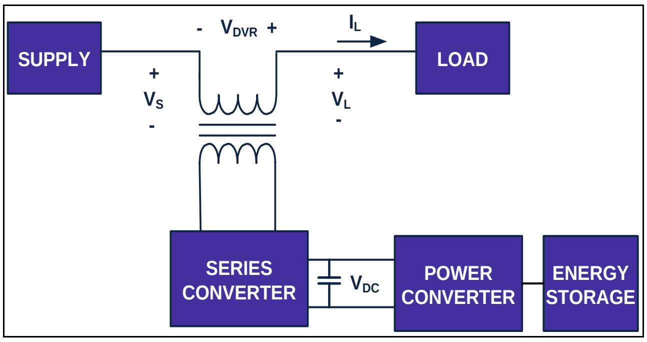

Fig. 8: Configuration of with energy storage

One more topology available in literature is interline-DVR. IDVR consists of several DVRs on lines sharing a common DC link, which enables active power exchange between two or more DVR as shown in figure 7. Now a days with the development in multi-level inverters (MLI), an MLI-DVR is also becoming popular. In this DVR topology the conventional VSI in replaced by MLI. The popularly adopted MLIs are neutral-point clamp and cascaded topology.

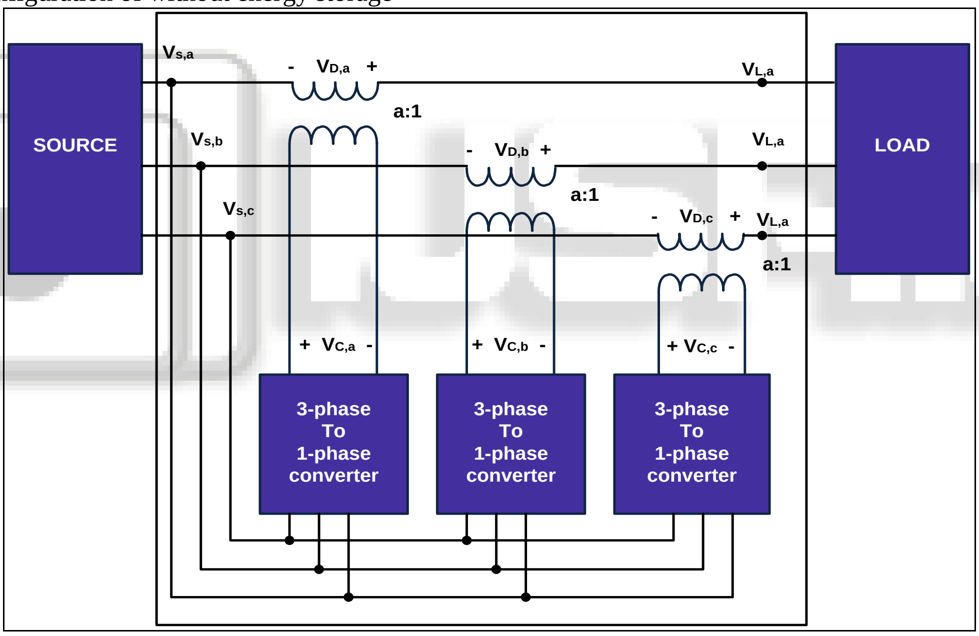

Fig-9: Configuration of AC link-DVR

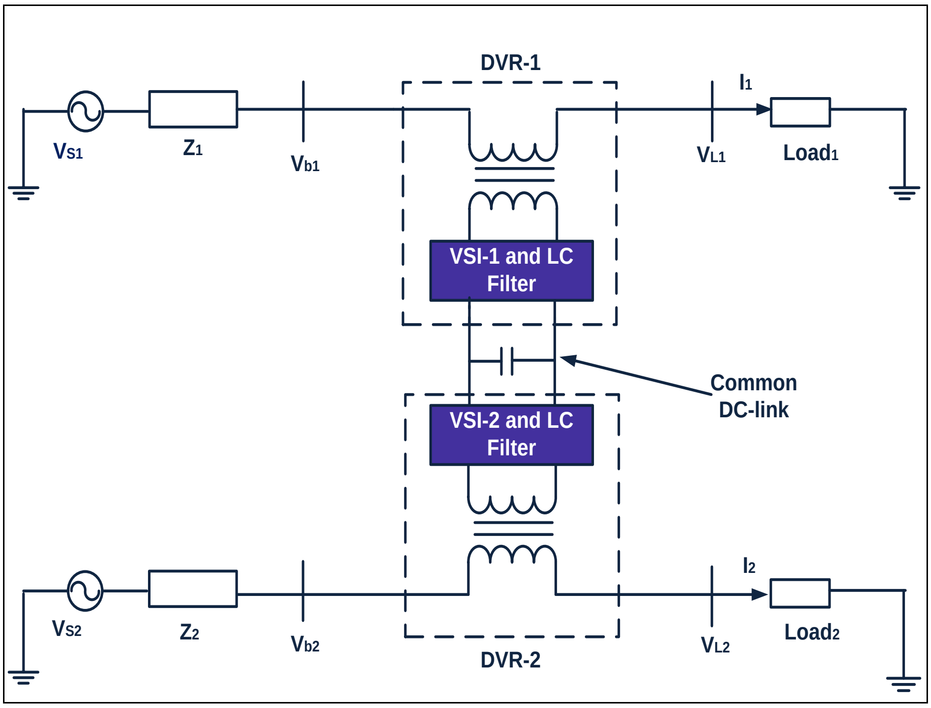

Fig. 10: Configuration of IDVR

IV. CONCLUSION

DVR is an effective means for mitigating VFS in power distribution systems. Researchers are continuously working on improving the control strategies and the performance of DVRs to make them more effective and efficient. DVR is a customized power quality improvement device generally installed to regulate the voltage at consumer end and also to mitigate the harmonics in the voltage-current waveforms. The DVR is advantageous in various aspects which includes its ability to provide accurate and fast voltage compensation, its compatibility with a wide range of loads, and its ability to operate in real-time. This paper presents the application oriented literature survey for various DVR topologies. Several papers are discussed in brief with their topological architecture and applications. Advantages and disadvantages of all the presented topologies in literature are also discussed in this paper.

REFERENCES

[1] J. S. Lai and F. Z. Peng, ``Multilevel converters_A new breed of power converters,'' *IEEE Trans. Ind. Appl.*, vol. 32, no. 3, pp. 509_517, May/Jun. 1996.

[2] L. Tolbert, F. Zheng Peng, and T. Habetler, ``Multilevel converters for large electric drives,'' *IEEE Trans. Ind. Appl.*, vol. 35, no. 1, pp. 36_44, Jan./Feb. 1999.

[3] J. Rodriguez, J.-S. Lai, and F. Zheng Peng, ``Multilevel inverters: A survey of topologies, controls, and applications,'' *IEEE Trans. Ind. Electron.*, vol. 49, no. 4, pp. 724_738, Aug. 2002.

[4] L. Franquelo, J. Rodriguez, J. Leon, S. Kouro, and R. Portillo, ``The age of multilevel converters arrives,'' *IEEE Ind. Electron. Mag.*, vol. 2, no. 2, pp. 28_39, Jun. 2008.

[5] Babaei, E., Kangarlu, M. F., & Sabahi, M. (2010). Mitigation of voltage disturbances using dynamic voltage restorer based on direct converters. IEEE Transactions on Power Delivery, 25(4), 2676-2683.

[6] A. M. Massoud, S. J. Finney and B.W. Williams, "Review of harmonic current extraction techniques for an active power filter", 11th Int. Conf. Harmonics Quality Power, pp. 154–159,12–15, 2004.

[7] A.A. Girgis, W.B. Chang and E.B. Makram, "A digital recursive measurement scheme for online tracking of power system harmonics", IEEE Trans. Power Del., vol. 6, no. 3, pp. 1153–1160, 1991.

[8] X. Lu, K.L.V. Iyer, K. Mukherjee and N.C. Kar, "A wavelet/PSO based voltage regulation scheme and suitability analysis of copper and aluminum-rotor induction machines for distributed wind power generation", IEEE Trans. Smart Grid., vol. 3, no. 4, pp. 1923–1934, 2012.

[9] Moghassemi, A., & Padmanaban, S. (2020). Dynamic voltage restorer (DVR): a comprehensive review of topologies, power converters, control methods, and modified configurations. Energies, 13(16), 4152.

[10] R. S. Herrera, P. Salmeron and H. Kim, "Instantaneous reactive power theory applied to active power filter compensation: Different approaches, assessment, and experimental results," IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 184-196, Jan. 2008.

[11] V. Khadkikar, A. Chandra and B. N. Singh, "Generalised single-phase pq theory for active power filtering: simulation and DSP-based experimental investigation", IET Power Electronic., vol. 2, no. 1, pp.67- 78, 2009.

[12] S. Buso, L. Malesani and P. Mattavelli, "Comparison of current control techniques for active filter applications", IEEE Trans. on Ind. Electron., vol. 45, no. 5, pp. 722-729, Oct. 1998.

[13] M. I. Milanes, E. R. Cadaval and F. B. Gonzalez, "Comparison of control strategies for shunt active power filters in three-phase four-wire systems," IEEE Trans. Power Electron., vol. 22, no. 1, pp. 229-236, Jan. 2007.

[14] B. Singh, P. Jayaprakash and D. P. Kothari, " New control approach for capacitor support DSTATCOM in three-phase four-wire distribution system under non-ideal supply voltage conditions based on synchronous reference theory," Int. J. Electr. Power Syst., vol. 35, no. 5, pp. 1109- 1117, June 2011.
[15] M. A. Kabir and U. Mahabub, "Synchronous detection and digital control of shunt active power filter in power quality improvement," in Proc. of Power and Energy Conference at Illinois (PECI), pp. 1-5, pp. 1-5, Feb. 2011.
[16] S. Hirve, K. Chatterjee, B. G. Fernandes, M. Imayavaramban and M. Dwari, "PLL-Less Active Power Filter Based on One-Cycle Control for Compensating Unbalanced Loads in Three-Phase Four-Wire System," IEEE Trans. Power Del., vol. 22, no. 4, pp. 2457-246, 2007.
[17] U. K. Rao, M. K. Mishra and A. Ghosh, "Control strategies for load compensation using instantaneous symmetrical component theory under different supply voltages," IEEE Trans. Power Del., vol. 23, no. 4, pp. 2310-2317, Oct. 2008.
[18] A. J. Viji and T. A. A. Victoire, "Enhanced PLL based SRF control method for UPQC with fault protection under unbalanced load conditions", Inter., J., Electr., Power & Energy Syst., vol. 58, pp.319- 328, 2014.
[19] Sundarabalan, C. K., and K. Selvi. "Real coded GA optimized fuzzy logic controlled PEMFC based Dynamic Voltage Restorer for reparation of voltage disturbances in distribution system." International Journal of Hydrogen Energy 42.1 (2017): 603-613.
[20] B. Lin and C. Huang, ``Analysis and implementation of a single-phase capacitor-clamped inverter with simple structure," *IEE Proc._Electr. Power Appl.*, vol. 151, no. 5, pp. 555_562, Sep. 2004.
[21] Jurado, Francisco, and F. P. Hidalgo. "Neural network control for dynamic voltage restorer." In IEEE 2002 28th Annual Conference of the Industrial Electronics Society. IECON 02, vol. 1, pp. 615-620. IEEE, 2002.
[22] J. Ebrahimi, E. Babaei, and G. B. Gharehpetian, ``A new multilevel converter topology with reduced number of power electronic components," *IEEE Trans. Ind. Electron.*, vol. 59, no. 2, pp. 655_667, Feb. 2012.3
[23] G. Buticchi, D. Barater, E. Lorenzani, C. Concari, and G. Franceschini, ``A nine-level grid-connected converter topology for single-phase transformerless PV systems," *IEEE Trans. Ind. Electron.*, vol. 61, no. 8, pp. 3951_3960, Aug. 2014.
[24] M. D. Manjrekar and T. A. Lipo, ``A hybrid multilevel inverter topology for drive applications," in *Proc. 13th Annu. Appl. Power Electron. Conf. Expo. (APEC)*, Anaheim, CA, USA, vol. 2, Nov. 1998, pp. 523_529.
[25] M. Glinka and R. Marquardt, ``A new AC/AC multilevel converter family," *IEEE Trans. Ind. Electron.*, vol. 52, no. 3, pp. 662_669, Jun. 2005.