A Survey on the Custom Power Device Dynamic Voltage Restorer Structure, Principle and Control Strategy

D.C. Kumaresan and Dr.P. Selvan

Abstract--- *In recent years Power Quality (PQ) and dynamic voltage problem issues have received much more attention with the development of information and automation techniques. All categories of power consumers are becoming increasingly sensitive to PQ problems. The increasing use of all electronic voltage sensitive devices has made industrial processes susceptible to the sag. The dynamic PQ problems like voltage sag are always occurring in electrical power distribution system. These are caused by switching of large loads, capacitor switching and remote faults. When such PQ disturbances occur, results in damage to all voltage sensitive equipments, the production which results in huge financial loss. These Power quality based problems are solved by using Dynamic Voltage Restorer (DVR), which is the most powerful device in solving these types of power problems. Here in this DVR based study, the structure and principle of DVR, control strategy of DVR are reviewed in detail. After introducing the operation principles and structures of DVR, the paper highlights on the latest study results based on the DVR using for maintaining the power quality. Meanwhile the application future of DVR in power system and several problems which need to be solved are proposed.*

Keywords--- *Power Quality Problems, Dynamic Voltage Restorer (DVR), Dynamic Voltage Problems, The Structure and Principle of DVR, Control Strategy of DVR.*

I. INTRODUCTION

Recently, the demand for high power quality (PQ) and voltage stability has increased significantly. PQ characteristics include frequency variations, voltage variations, voltage fluctuations, unbalance in three-phase voltages, flicker[1] and harmonic distortion. One serious threat for sensitive equipment is voltage sag (drop between 60% and 90% of the nominal voltage) lasting between 10 and 100 ms. Voltage sags originate from faults which are caused by various events, such as animal contact, storms, equipment failure, insulator failures, short circuits, inrush currents when large machines are switched on, or in switching actions [2]. It results in production losses and subsequent monetary costs.

The DVR, which is the most efficient and effective modern custom power device, has been used in power distribution networks to mitigate voltage sag [3]. These PQ disturbances are caused by remote faults or switching of large loads (e.g. motor starting and energize capacitor or transformer). Even though the voltage sag lasts within a few cycles, they can disrupt some sensitive loads such as adjustable speed drives (ASD), programmable logic

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controllers (PLC), and fine industrial process like semiconductor plants. It was observed that for a load up to few MVA, good solution for sag mitigation is the installation of custom power device such as DVR [4].

In 1996, Westinghouse Electric Corporation in-stalled world's first dynamic voltage restorer in Duke Power Company's 12.47KV substation in Anderson, South Carolina. This was installed to provide protection to an automated manufacturing plant. Then ABB, Siemens and other companies have also developed their own products to ensure the quality of voltage-sensitive load [5], [6]. So, the structure [6], parameters [8], [9], detection [10], lock-in [11], compensation control strategy [12], [13] of DVR are carried out by lots of electric power system researchers. In this work based on the research of DVR, different control strategies of DVR have been reviewed.

II. A SURVEY ON THE DYNAMIC VOLTAGE RESTORER

2.1. DVR Structure and Operation Principle

DVR structure is shown in Fig. 1. In general, during voltage Vs sag, the energy storage device supplies energy Vdvr to the distribution system to compensate the sag. Fig.1. Simplified schematic diagram has three main DVR structures, which are applied in medium/low voltage distribution networks [14], [15].

The series DVR structure, which is adopted nowadays by almost all the industry applications. However, the continuous compensation time to the voltage sag is decided by the DC energy storage which is influenced by the development of technology, price of energy storage unit and the costs of maintenance operation.

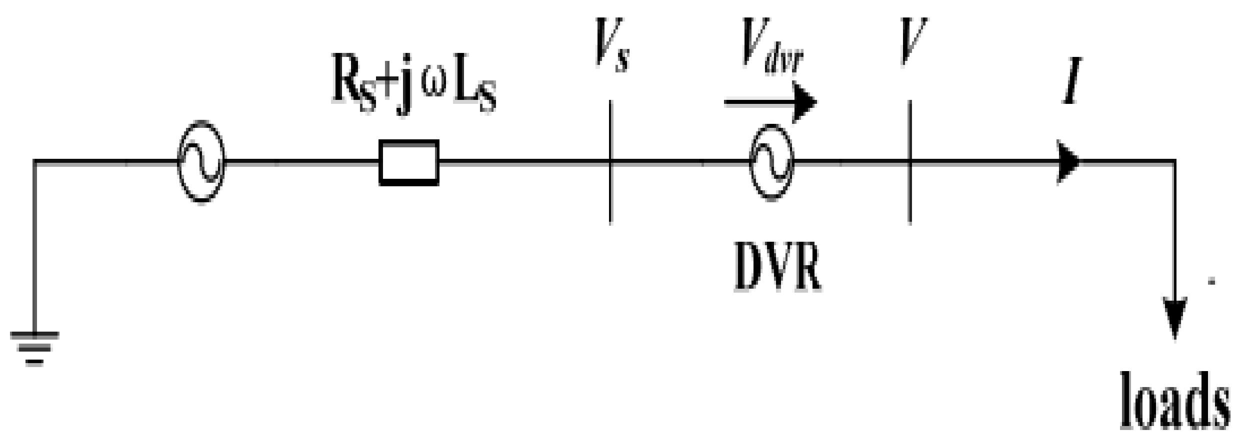

Fig. 1: DVR Structure

2.2. Control Strategies

The main considerations of the control system of a DVR include: detection of the start and finish of the sag, voltage reference generation, transient and steady-state control of the injected voltage, and protection of the system. The Fig 2. Shows overall control strategies of the DVR.

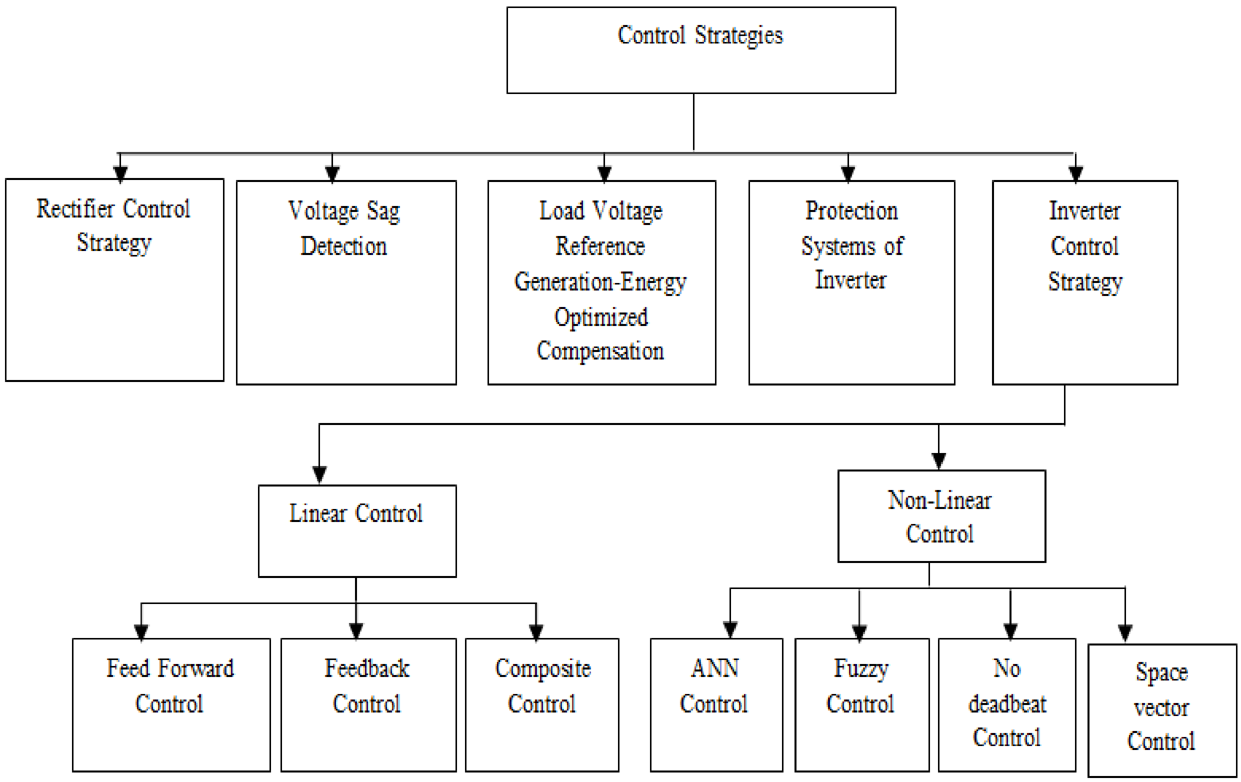

Fig. 2: Control Strategies of DVR

A. Voltage Sag Detection

Voltage sag is defined as a dropping of root-mean square (rms) voltage value from 0.9 pu to 0.1pu of nominal value for durations from 0.5 cycle to 1min, which can be caused by many reasons such as motor starting and short circuits. In generic situation, even a short duration of voltage sag is detrimental to the stable operation of sensitive loads. Dynamic voltage restorer (DVR) is an effective way to minimize the negative impact of voltage sag. Once the voltage sag is detected, the DVR will compensate the voltage of loads. Therefore, quick detection of voltage sag is the key issue for a DVR to function properly.

Review of Voltage sag detection methods: (i) Peak value monitoring (PVM): The PVM is the simplest conceptual method that calculates the peak value at the moment at which the gradient of voltage is zero [16]. (ii) RMS calculation: The most common and traditional method used for voltage measurement in power system is calculation of the rms voltage and its performance is analyzed in [17] and investigated in detail regarding the frequency variation, synchronized and desynchronized calculation in [18]. (iii) d-q Transformation (DQT): Since DQT is a powerful tool in three-phase systems, the voltage sag detection based on DQT has been proposed and analyzed in [19]. (iv). Wavelet transform (WT) [20], (v) Kalman filtering (KF) The KF, which uses a mathematical model of the signal in state variable form, is another accurate algorithm for signal tracking and has been utilized in the power system studies for disturbance detection [21], and (vi) Hybrid methods: Several hybrid methods of voltage sag detection have been reported in [22].

B. Load Voltage Reference Generation-Energy Optimized Compensation

To avoid tripping of the load, only the amplitude of the load voltage has to be restored by the DVR. Different strategies can be used to achieve this goal. Three basic strategies are pre-sag, in-phase and the energy-optimized compensation. The advantages of the third method have been particularly proposed in reference [23].

C. Protection Systems of Inverter

The voltage amplitude required active power and the maximum compensation time can be calculated. As a combination of pre-sag and in-phase large currents from faults downstream of the DVR, or from high inrush currents from loads (if the sag is not fully compensated) must be stopped from reflecting through the transformer to the inverter, and an appropriately rated alternative current path must be supplied. In [24], a downstream fault current limiting function is proposed and integrated in DVR operation, and restore the PCC voltage and protect DVR.

D. Inverter Control Strategy

Inverter is the core component of DVR. The control strategy of inverter will directly affect the performance of the DVR. Many scholars have studied the inverter control strategy for the exploration and research.

Linear Control

Linear control is a common method of control. Feed forward control, feedback control and composite control have been used in DVR.

Feed forward control is a simple method of DVR [25], while voltage-loop feedback control is the traditional way. In order to improve the compensation effect, in [17] presents a transient voltage value of feedback control methods. In [26] [27] [28] proposes a different types of feedback control methods of DVR. Composite control strategy is a control method with grid voltage feed forward and load side voltage feedback, which has the strengths of feed-forward and feedback control strategy, so it can improve voltage compensation effect. An improved control method has been proposed in [29]

Non-linear Control

The PI is a linear controller, so it can only guarantee the stability of converter in a local area. It appears that the nonlinear controller is more suitable than the linear type since the DVR is truly a non-linear system [30]. The DVR is a nonlinear device due to the presence of power semiconductor switches in the inverter bridge. When the system is unstable and has not clear control targets, several methods are limited. For the instability system, the model does not explicitly control target, all above methods have their limitations.

Neural networks such as Artificial Neural Network control (ANN) is a non-linear control method, in [30] it used ANN in the system of DVR. It appears logical that a back propagation-type NN which has high computational capability can implement an SVM algorithm.

Fuzzy control is a new addition to control theory. Its design philosophy deviates from all the previous methods by accommodating expert knowledge in controller design. It is derived from fuzzy set theory introduced by Zadeh in 1965[31], the application of FL in DVR is presented in [32] and in [33] an improved fuzzy control system, namely fuzzy PID control was presented. In general FL controllers are an attractive choice when precise mathematical formulations are not possible, no deadbeat control theory of the state variables is firstly proposed by Kalman in 1959, it achieved a rapid-response in a system with step signal. Until 1985, no deadbeat control for DVR proposed by Gokhale in PESC [34], however the method relies on the accuracy of parameters in state-space expression, and the major shortcomings are the poor robustness and the overshoot of transient response. Finally the space vector control such as Space Vector PWM (SVPWM) control strategy used in AC motor variable speed drives by Japanese scholars in the early 1980s. The main idea is to adopt a voltage inverter space vector of the switch to get quasi-circular rotating magnetic field instead of the original SPWM, so better performance of the exchange is gained in low switching frequency conditions and other non-linear control methods can be well remedy the above mentioned deficiencies.

One of the other DVR control strategy is based on the rectifiers. In recent times researchers and scholars have applied many control strategies in rectifier of series-parallel-DVR (UDVR), such as PID control, hysteresis control, CFHC control and sliding model control. In [35], has proposed that the PID regulator is used to control the DC voltage in the whole bridge of rectifier.

In [36], it presents that the structure of the rectifier has taken an account of low power factor of uncontrolled or semi-controlled rectifier, and the system of harmonic current which would interfere with control of DVR, affecting compensation effect. In order to improve the dynamic response to overcome the hysteresis current control switching frequency volatile shortcomings, the reference [37] has proposed direct current control of the rectifier based on a constant frequency hysteresis current control (CFHC). Sliding Mode Control (SMC) is also a non-linear method. The sliding mode control of single phase DVR and its advantages are discussed in reference [38].

III. INFERENCE OF THE WORK

From the study of different control strategies of DVR for PQ, voltage sag is a significant disturbance, DVR is generally considered as an effective device to compensate these disturbances. To reduce unit costs and improve economic of the DVR, the design is done without series transformer such as a novel photovoltaic fed Dynamic Voltage Restorer (PV-DVR) model to alleviate deep voltage sag and outage on a low voltage residential distribution system, which is an enhancement. In addition, the design of structure to obtain power energy from grid is also a better choice as it reduces storage unit capacity and cost of DVR.

IV. CONCLUSION

This work reviews the Dynamic Voltage Restorer (DVR) structure, principle and different control strategies. DVRs are effective recent custom power devices for voltage sags compensation. DVR inject the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. The Dynamic Voltage Restorer (DVR) is considered to be an efficient solution due to its relatively low cost and small size; also it has a fast dynamic response with photovoltaic.

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