SURVEY ON DYNAMIC VOLTAGE RESTORER FOR POWER QUALITY IMPROVEMENT

Manish Singh Chauhan, Parikshit Bajpai
Electrical Engineering Department, Shri Ram Institute of Technology, Jabalpur (M.P.)

ABSTRACT

Improved and controlled power quality is one of the essential and fundamental need in any power driven industry for optimum utilization of resources. However critical problems in power quality have been recognized such as sags, swells, harmonic distortions and other interruptions. Out of these sags and swells are predominantly found and have severe impact on the electrical devices or electrical machines and therefore needs to be compensated at an earliest to ensure any mal-operation or failure. To crack these problems custom power devices are used like unified power-quality conditioner (UPQC), distribution- STATCOM (DSTATCOM) and dynamic voltage restorer (DVR). The DVR is a one of the custom power device used for the compensation of voltage sag and swell with an advantage of active/reactive power control. A major volume of literature reported in past several years on different configurations of DVR and different control technique used in it. In context of this a detailed review on DVR has been presented with different possible power circuit topologies and control techniques available to reconcile these power quality issues. This review article will contribute in better selection of control strategy and power circuit for optimum performance of DVR for a particular requirement. Also it presents a very helpful investigation for the researcher in this field.

KEYWORDS

DVR, Power system, Power quality, Voltage sag, Compensation Technique.

INTRODUCTION

Power quality is of immense importance in all modern environments where electricity is involved. Power quality can be essentially influenced by important factor like quality service. Power quality problems were categorized by five major events; sags, swells,transients, interruptions and harmonics. These problems may cause degradation in services which can cost economic losses to both utility and consumers. Deregulating of electric power system market has made power quality a parameter of consideration to achieve a higher price per kilowatt, to increase the revenue and share of the market. The power quality problems emanate from various events ranging from switching events at the end user facility or faults on transmission lines. The extensive use of equipment sensitive to voltage deviation has made industrial applications more susceptible to voltage sags and swells. Among these the sags appeared as a top issue. Voltage sags can cause improper functioning and eventual tripping of industrial equipment, resulting in loss of production and hence profit. There are two general approaches to mitigate power quality disturbances. One approach is to ensure that the process equipment is less responsive to disturbances, allowing it to ride-through the disturbances. The other approach is to install a custom power device to suppress or neutralize the disturbances at the customer end. The DVR is a power electronic device used to inject voltage in series with distribution feeder in order to compensate for voltage sag/swell. This paper will provide an insight on various power quality problems and introduce custom power device DVR for mitigation of such problems.

DYNAMIC VOLTAGE RESTORER (DVR)

The DVR (Dynamic Voltage Restorer) is a series connected solid state device that injects additional voltage into the system in order to regulate the load side voltage to the desired magnitude and waveform even when the source voltage is unbalanced or distorted as shown in figure 1. This process involves injection of active/reactive power from DVR to distribution feeder.

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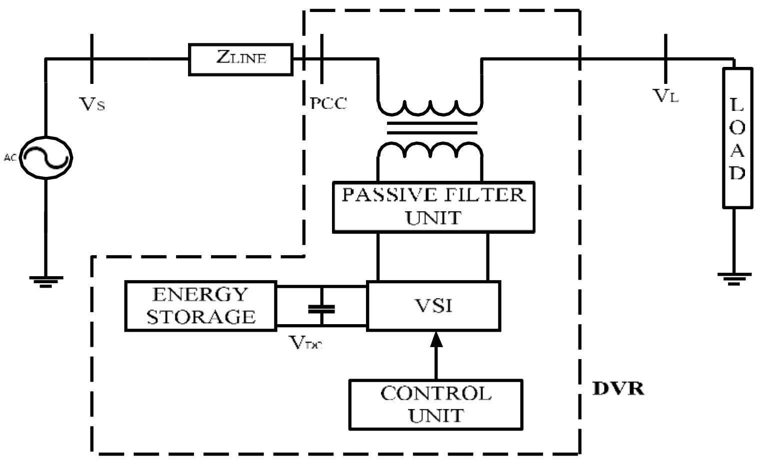

Figure 1. Basic structure of DVR

The general configuration of the DVR consists of power circuit and control circuit. Equivalent circuit as shown in Figure 1 and equation is as under:

$$V_{DVR} = V_L + Z_{TH} I_L + V_{TH} \quad (1)$$

Where V_L is desired load voltage magnitude, Z_{TH} is load impedance, I_L is load current and V_{TH} is system voltage (during faulty condition).

CONTROLCIRCUIT

In DVR the control circuit is used to derive the parameters such as magnitude, frequency, phase shift etc. Control of compensating device is implemented in 3 steps, detection of voltage sag/swell occasion in the system, comparison with reference value and generation of gate pulses to the VSI to generate the DVR output voltages which will compensate the voltage sag/swell.

Sag/Swell Detection Techniques

The accurate detection and classification of disturbances can help in taking effective countermeasure(s) to maintain adequate power quality. To detect the voltage sag, the starting point and the ending point of sag, depth of sag and phase shift, information are required. There are some detection techniques which are summarized below:

Fourier Transform (FT)method

To achieve the FT we use the orthogonal decomposition of power system signal. When we apply the FT to each supply phase, it is possible to get the magnitude and phase of each of the frequency components of the supply waveform. The demerit of FT is that it takes one complete cycle to give the accurate information about the sag depth and its phase. The realization in real time control is possible.

Phase Locked Loop (PLL) method

PLL is applied to each supply phase independently and is tuned to respond to phase jumps in the supply quickly. In this method it is required to freeze the pre-sag magnitude and phase. The PLL generates the voltage in same phase with the supply voltage. It takes time delay up to half cycle. The implementation in real time control system is more difficult.

Peak value detection method

Peak detection method is the very simplest method to observe the crest of the supply voltage. In this we find the point where the gradient of supply voltage phases is zero, and then we compare the supply value at that instant with a reference value and sense the sag. A controller could be set to distinguish if there is a deviation greater than a specified value. This method provides the information of sag depth, start and end time, although to extract phase shift information is difficult since a reference waveform is required. The drawback of this method is that it can take up to half a cycle for the sag depth information to become available.

Root mean square (RMS) method

It detects the start and end points of sag/swell. RMS value detection is an accurate way to detect the voltage sag or interruption, but it does not give phase angle shift information. It takes more time to calculate the RMS value.

Space Vector control

This method gives the both voltage magnitude and angle shift information. Three phase voltages V_a, V_b, V_c are transformed into a two dimension voltage V_d, V_q which in turn can be transformed into magnitude and phase angle. It is faster but requires complex controller. This can be easily realized in real time control system.

Wavelet Transform (WT) method

WT performs better with non-periodic and non-stationary signals. It detects change in the state of the supply phases quickly. In wavelet analysis procedure we design a wavelet prototype function, or the mother wavelet. The disadvantage of this method is selection of appropriate mother wavelet for each application, since the related filter bank coefficients are dependent on selected mother wavelet. There is also a delay associated with many mother wavelets as data either side of a time instant may be required in the convolution process. The implementation in real time control is difficult.

Control Strategies

The inverter control strategy includes of two types of control linear and non linear.

Linear Controller

The linear controllers used in DVR are feed forward, feedback and composite control. The comparison among these controllers is tabulated in Table 3.

Feed forward

The feed forward controller is the prime option for the DVR, because of its ease and fastness. The feed forward control technique does not sense the load voltage rather it calculates the injected voltage on the basis of the difference between the pre-sag and during-sag voltages. The drawback of this controller is the high steady state error.

Feed back

The feedback controller measures the load voltage and the difference between the voltage reference of the load and actual load voltage is injected. The feedback controller has the benefit of exact response, but it is complex and time-delayed.

Composite

Composite control strategy is a control method with grid voltage feed forward and load side voltage feedback, which has strength of feed forward and feedback control strategies. If the feedback control in the composite control is designed to double-loop, it can improve system stability, system performance and the adaptability of dynamic load. The combination with feed forward control can improve the system dynamic response rate, shortening the time of compensation significantly.

Non –Linear Controller

The DVR is a non-linear device due to the power semiconductor switches in the inverter circuit. It appears that the nonlinear controller is more appropriate than the linear type since the DVR is actually a non-linear system.

LITERATURE REVIEW

This chapter presents a comprehensive review of the development in the area of dynamic voltage restorer (DVR) for improving the power system performance. The emphasis has been given on the recent advances that have taken place in various fields of DVR performance. Recent advances in the field of DVR are also highlighted.

Results of world's first Dynamic Voltage Restorer (DVR) was installed on the major US utility system to protect a critical customer plant load from power system voltage disturbances ushers in a new era of power quality problem solution on the utility side of the revenue billing meter. It was verified by N.H. Woodley, L. Morgan and A. Sundaram, on a 12.47-kV system by building a prototype DVR and installing it on the utility side of weaving company where it provides protection from disturbances coming from the utility distribution system that serves the plant.[1-3]

Norbert EDOMAH in 20th International Conference on Electricity Distribution presented a paper in which he has surveyed the 15 multi-national companies in southwest Nigeria to ascertain the causes and effects of poor power quality on electrical equipment and its economic implications. The survey revealed that 9 out of 15 of those companies loose an average of 5 variable speed (AC) drives every year owing to poor power quality. It also revealed that the most common disturbances faced are voltage sag and swell. He has also explained some of the predominant power disturbance parameters, their sources and causes, the effect they have on electrical equipment, and their cost/economic implications. Thus he has given some practical solutions and methods of addressing poor power quality issue. [4-6]

Anita Pakharia and Manoj Gupta also M.Sharanya, B.Basavaraja and M.Sasikala presented comprehensive reviews on power quality over its various articles with solutions to it. In which they have mentioned the most popular methods of sag and swell compensation is Dynamic Voltage Restorer (DVR), which is used in both low voltage and medium voltage applications. They have explained the advantages and disadvantages of each possible configuration and control techniques pertaining to DVR. They found DVR to be most suitable due to its fast response, accurate compensation and low costs. There review helps the researchers to select the optimum control strategy and power circuit configuration for DVR applications. [7-9]

Mahinda Vilathgamuwa, A. A. D. Ranjith Perera, and S. S. Choi has also examined the performance of dynamic voltage restorer (DVR). They have shown through simulation that the open-loop control strategy used for the DVR to regulate load voltage can produce poorly damped response due to the presence of the switching harmonic filter in the restorer. Damping is shown to be improved if the multi loop controller is used. Furthermore, the new control scheme permits a closer tracking of the reference load voltage under varied load conditions. [10, 11]

Voltage Quality Improvement Using DVR has been simulated by Chellali BENACHAIBA and Brahim FERDI. They have discussed DVR principles and voltage restoration methods at the point of common coupling (PCC). Simulation results presented helps in understanding the performances of DVR in load voltage compensation. [12-14]

John Godsk Nielsen and Frede Blaabjerg has given a detailed comparison on System Topologies for Dynamic Voltage Restorer. They have described four different system topologies for dynamic voltage restorers (DVRs) and thus analyzed and tested, with particular focus on the methods used to acquire the necessary energy during voltage sag. Comparisons are made between two topologies that can be realized with a minimum amount of energy storage, with energy taken from the grid during the voltage sag, and two topologies that take energy from stored energy devices during the voltage sag. Hence, they have concluded that DVR show that the no-energy storage concept is feasible, but an improved performance can be achieved for certain voltage sags using stored energy topologies. Thus their results of this comparison rank the no-storage topology with a passive shunt converter on the load side first, followed by the stored energy topology with a constant dc-link voltage. [15, 16]

Woo-Hyun Kim and Chul-Woo Park has worked on the reliability of DVR in a 3-phase phasecontrolled rectifier. Their work investigated the relationship between the response time of DVR (Dynamic Voltage Restorer) and the possible compensation range for voltage dips by the DVR system which protects the 3-phase phase-controlled rectifier from said dips. As a result, the permissible range of voltage dip can be found in a 3-phase phase-controlled rectifier when the DVR compensates for voltage dip. The range of voltage dip can be compensated according to the DVR's response time, thus DVR response time can be determined. Therefore, the use of excessively fast equipment can be avoided, improving the stability of the overall system. [17, 18]

Antonio Moreno-Munoz, Daniel Oterino, Miguel Gonzalez, Fernando A. Olivencia and Juan J. Gonzalez-de-la-Rosa presented a voltage dip analysis in which they have worked with dynamic voltage restorer (DVR) which is a Static Series Compensator (SSC) suitable for protecting industrial plant against voltage dip. They have presented comparative analysis of three compensation techniques of DVR that is in-phase compensation method, pre-dip compensation method (called too voltage difference compensation), and phase advance compensation method. [19-22]

Dynamic Voltage Restorer (DVR) is a custom power device that is used to compensate voltage sag. The DVR generally consists of voltage source inverter (VSI), injection transformers, passive filters and energy storage (battery). The efficiency of the DVR depends on the efficiency of the control technique involved in switching the inverters. Agileswari Ramasamy, Vigna Kumaran Ramachandaramurthy, Rengan Krishna Iyer and Liew Zhan Liu have used new switching technique. The inverters are switched using Space Vector Pulse Width Modulation pulses (SVPWM) to maximize the usage of DC link voltage. They have used DSP board TMS320F2812. The implementation of the control using TMS320F2812 is tested using a 3kVA lab prototype and thus simulated. [23-25]

John Godsk Nielsen, Michael Newman, Hans Nielsen, and Frede Blaabjerg have given a cost effective solution for the protection of sensitive loads from voltage sags. Implementations of the DVR have been proposed at both a low voltage (LV) level, as well as a medium voltage (MV) level; and give an opportunity to protect high power sensitive loads from voltage sags. They have performed a practical test whose results obtained on a medium voltage (10 kV) level using a DVR at a Distribution test facility in Kyndby, Denmark. The DVR was designed to protect a 400-kVA load from 0.5-p.u. maximum voltage sag. The reported DVR verifies the use of a combined feed-forward and feed-back technique of the controller and it obtains both good transient and steady state responses. The effect of the DVR on the system is simulated under both faulted and nonfaulted system states, for a variety of linear and nonlinear loads. Variable duration voltage sags were created using a controllable LV breaker fed by a 630 kVA Distribution transformer placed upstream of the sensitive load. The fault currents in excess of 12 kA were designed and created to obtain the required voltage sags. It is concluded the DVR works well in all operating conditions.[26-28]

The compensation strategy of the dynamic voltage restorer (DVR) has significant impact on the compensation result. Sun Zhe, Guo ChunLin, Xu YongHai, Xiao XiangNing, Liu Yingying and Tao Shun has presented a new analysis method which is based on pre-sag load voltage. The new method choosen by them takes the pre-sag load voltage phasor as the reference phasor and put the centre of the limit compensation voltage circle at the terminal of the system voltage phasor. It not only has definite physical concept but also is convenient to determine the compensation range. More importantly, it could be applied to unbalanced load. Using this new method, the minimum energy compensation strategy was realized through the simulation when unbalanced voltage sag happened in the case of the unbalanced load. The conditions for zero active power compensation were also analyzed by them which could prolong the compensation time of DVR. The simulation result presented by them shows the correctness of the theoretical analysis. [29-33]

Vijayan Immanue and Gurunath Yankanchi presents the development of a novel waveform synthesis technique for effective voltage sag compensation for multilevel inverter based Dynamic Voltage Restorer (DVR). An effective control algorithm for calculation of reference compensating voltages based on PQR power theory together with Space Vector Modulation (SVM) technique which is implemented using a three-level Diode Clamped Voltage Source Inverter (VSI) configuration. Their simulation results show that the proposed scheme for voltage sag compensation is seamless with negligible THD. [34-36]

Bingsen Wang, Giri Venkataramanan and Mahesh Illindala has also used the dynamic voltage restorer (DVR) as a means of series compensation for mitigating the effect of voltage sags. With the use of the cascaded multilevel type of power converter topology they have designed a closed loop regulator to maintain the load voltage within acceptable levels in a DVR using transformer coupled H-bridge converters, and thus simulated the system. [37-39]

Modelling and Simulation of Dynamic Voltage Restorer for Power Quality Improvement has been done by H.Lakshmi, T. Swapna, Rosli Omar, Nasrudin Abd Rahim, Marizan Sulaiman, Shazly A. Mohammed, Abdel-Moamen, B. Hasanin, B.vijayalakshmi, P. Jayaprakash, Bhim Singh, D. P. Kothari, Ambrish Chandra and Kamal-Al-Haddad. They all have used the dynamic voltage restorer (DVR) to regulate the voltage at the load terminals under various power quality problems like sag, swell, harmonics, unbalance etc., in supply voltage. They have discussed the control of the compensation voltages in DVR based on dqo algorithm. It first analyzes the power circuit of a DVR system in order to come up with appropriate control limitations and control targets for the compensation voltage control. Thus as we know, DVR is a power electronic based device that provides three-phase controllable voltage source, whose voltage vector (magnitude and angle) adds to the source voltage during sag event, to restore the load voltage to pre-sag conditions. The DVR can restore the load voltage within few milliseconds. They have used, different voltage injection schemes for dynamic voltage restorers (DVRs) ,and are analyzed with particular focus on the methods used to minimize the rating of the voltage source converter (VSC) used in DVR. [40- 42]

CONCLUSION

In this paper a brief literature review is done on DVR configurations and its control strategies. By selecting any one of them we can provide solution to various power quality problems like voltage harmonics, voltage sag/swell compensation. To improve the performance of DVR, efforts needs to be made on energy savings, reduced parts and losses, minimum power injection, reduced rating, and selective harmonicsmitigation.

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