Modelling and Simulation for Voltage Sags/Swells Mitigation using Dynamic Voltage Restorer

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Abstract— In the recent past, one of the problems that got wide attention is the power system instabilities with the lack of new generation and transmission facilities and increase in the load demand of electrical power is continuously rising at a very high rate, due to rapid industrial development. Power quality is the main problem that the industry is facing today. Power electronics and advanced control technologies have made it possible to reduce the power quality problems. Among power system disturbances, voltage sags, swells and harmonics are some of severe problems to the Sensitive loads. Present work deals with the Modelling and Simulation for Voltage Sags/Swells Mitigation using dynamic voltage restorer.

Key words: Dynamic Voltage Restorer, Voltage Sags/Swells Mitigation

I. Introduction

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sags are not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly. Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions.

II. Literature survey

O. Anaya-Lara et.al. present the simulation of dynamic voltage restorer and suggests four different methods to inject the voltage using DVR, which are categorized such as presage compensation, phase advance method, voltage tolerance method and in phase voltage injection method. In presage compensation method injected DVR voltage is the difference between the sag and pre-fault voltage. In order to minimize the real power injected by DVR, phase advance method is used. For a small percentage of the voltage sag which does not affect the system then voltage tolerance method with minimum energy injection [1].

S.F. Torabi et.al. deals with modeling and simulation technique of a Dynamic Voltage Restore (DVR). The DVR is a dynamic solution to protect sensitive loads against voltage sags and swells. The DVR can be implemented to protect a group of medium voltage or low voltage consumers. The new configuration of DVR has been proposed using improved d-q-0 controller technique. This study presents compensation of sags and swells voltage during single line to ground (SLG) fault and three-phase fault. Simulation results carried out by Matlab/Simulink verify the performance of the proposed method [2].

V.K. Ramachandaramurthy et.al. represents additional supervisory control method during voltage sag and swell. The scheme must set the DVR to operate without exceeding its rating so that it maintain load voltage within acceptable limits and sensible point is set to 0.9 pu voltage level as a compensation for voltage sag, likewise the compensating swell to 1 pu is not most effective solution. If 1.1pu is sufficient. And this paper also explains how to calculate injected DVR voltage according to its rating and compensation set point.Inphase and presage compensation techniques are dependent on the magnitude of the retained supply voltage and the load power factor [3].

John Godask Nielsen et.al. represent the different topologies can be used to provide the dc supply to DVR .John Godsk Nielsen and Frede Blaabjerg proposed four different topologies in order to provide dc supply. Comparisons are made between those topologies that can be realized with minimum amount of energy storage, which can be summarized as follow. In first case DVR is performed without any energy storage system. A passive convertor is used because only unidirectional power flow is necessary. The convertor may either place at the load side or placed at the source side. And in other case the DVR is performed with the energy storage system. The energy is stored either in the dc link capacitor or in the form of constant dc link. Experimental test using a 10KVA DVR shows that the no. of energy storage concept is feasible but an improved performance can be achieved for compensating voltage sag using stored energy topology [4].

Jose M. Lozano et.al. presents a concept for the use of matrix converter which consists of nine bidirectional switches arranged in three groups each being associated with an output line. This matrix converter is used in DVR based on a matrix converter without energy storage device is proposed to cope with voltage fluctuation Direct Space Vector Pulse Width Modulation (DSVPWM) techniques used for unbalanced and distorted voltage supply. Among the exiting DVR topologies with energy storage in ac form, various different types of switching power converters have been employed, being the matrix converter an attractive solution due to its operating advantages [5].

Michael John Newman et.al. suggest that it would be advantageous if the series connected inverter of a DVR could also be used to compensate for any steady state load voltage harmonics, since this would increase the power quality value added benefit to the grid system in order to add voltage harmonics compensation scheme has a net real power flow of zero to minimize the net real power flow, narrow bend resonant based controllers are used to compensate for each selected harmonics with no proportional term. Resonant controllers are used instead of synchronous frame d-q integral control at each frequency [6].

Amr Elnady et.al. introduce the robust control technique to add more functionality to the DVR. They develop the adaptive perceptron based control algorithm in order to discriminate and mitigate a power quality problem. According to that sampled signal is transferred to the classifier. As a rule based classification module to recognize disturbances like harmonics unbalanced and balanced voltage sags and swells. And DVR takes the action according to the disturbance occurs in the system. In conventional algorithm used for DVR used for DVR the response of the voltage injection algorithm in response to well defined sag return to 1 pu network voltage but in many practical cases a return to 1 pu is not necessary [7].

Ahmed Hossam-Eldin et.al. represent there are many devices which may be used to compensate the voltage sag such as tap changer, Uninterrupted Power Supply (UPS), Static var Compensator (STATCOM), dynamic voltage restorer (DVR). He has made the comparison between those devices and concludes that UPS cannot be used because it carries the entire load without any contribution from the grid. Due to the bulky construction of tap changer it is rarely used, STATCOM is installed to support those have poor power factor and often poor regulation. The DVR is most economical device for voltage sag mitigation in distribution system [8].

D. MhindaVilathgamuwa et.al. proposed a new concept of the DVR where two or more DVRs in different feeders connected to the common DC link. One of the DVR compensates for voltage sag and the other replenish the DC link energy storage. The limiting factor of the proposed system is that the amount of real power transfer that one line can transfer to the dc link energy storage is depends on load power factor. The control strategy is one of the important parts of the DVR operation. The injected voltage of the DVR depends on the accuracy and dynamic behavior of the pulse width modulated (PWM) voltage synthesis scheme and control system adopted [9].

Kasuni Perera et.al. suggest a control strategy for single phase voltage sag based on in- phase compensation technique in which DVR initially tracks the phase angle of the supply voltage and produce reference voltage signal with the rated voltage magnitude. If any phase jump occurred at the supply voltage, phase angle of the reference voltage signal is adjusted slowly to track the phase difference between the reference and measured voltage injected by the DVR. Therefore with this technique the load will no experience any phase jump or dip [10].

Tariq Masood et.al. principal objective of this paper is to investigate the behavior of STATCOM against SVC controller by setting up new control parameters. Essentially, STATCOM, and SVC linear operating ranges of the V-I and V-Q as well as their functional compensation capabilities have been addressed to meet operational requirement with certain degree of sustainability and reliability. Hereby, the other operating parameters likewise transient stability, response time, capability to exchange real Power and Power Losses have also been addressed in STATCOM against SVC control models. In addition to that, STATCOM-Controller’s pragmatic response has been identified and determined reliability level to maintain full capacitive output current at low system voltage. [11].

Mahmoud A. El-Gammal1 et.al. Represent the Dynamic Voltage Restorer (DVR) is fast, flexible and efficient solution to voltage sag problem. The 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 is designed for protecting the whole plant with loads in the range of some MVA. The DVR can restore the load voltage within few milliseconds. Several configurations and control methods are proposed for the DVR. In this paper, an overview of the DVR, its functions, configurations, components, compensating strategies and control methods are reviewed along with the device capabilities and limitations [12].

Dong-Jun Won et.al. presents a new definition of voltage sag duration which takes into consideration of the voltage tolerance characteristics of individual electrical equipment. The magnitude and the duration of voltage sag are important parameters which characterize the voltage sag event. The conventional voltage sag characterizing method can overestimate the voltage sag in case of non-rectangular sag. Furthermore it does not take the voltage tolerance characteristics of each equipment into account. Therefore the proposed method in this paper utilizes the minimum voltage (Vmin) of voltage tolerance curve of each equipment. [13].

John Godsk Nielsen et.al. represent the DVR is a series connected device, which primarily can protect sensitive electric consumers against voltage dips and surges in the medium and low voltage distribution grid. The thesis first gives an introduction to relevant power quality issues for a DVR and power electronic controllers for voltage dip mitigation. Thereafter the operation and the elements in a DVR are described. The advantages and disadvantages are treated by inserting the DVR in either the medium voltage distribution system or in the low voltage distribution system. Different topologies for a DVR are investigated on a converter and system level and the protection issues are treated. The design of a DVR is treated and two prototype DVRs are designed and specified. The first DVR is a low voltage DVR (LV-DVR) rated for 10 KVA for insertion in a 400 V low voltage grid and the second DVR is a high voltage DVR (HV-DVR) rated for 200 KVA for insertion in a 10 KV medium voltage\distribution system. [14].

Mehmet Tumay, Ahmet Teke, et.al. Represents modeling and analysis of a Dynamic Voltage Restorer (DVR) with sinusoidal pulse width modulation (SPWM) based controller by using the Matlab/Simulink. The proposed control scheme is simple to design and allows flexibility in cost or robustness constraints. In addition, the performance of the designed DVR is examined under different sag conditions. DVR has become a cost effective solution to voltage for the protection of sensitive loads from voltage sags. The DVR is fast, flexible and efficient solution to voltage sag problems. DVR consists of energy storage unit, PWM inverter, and filter and infection transformer. DVR is categorized into three operation mode: protection mode, standby mode and injection mode. [15].

Bingsen Wang, Giri Venkataramanan, et.al. Represent the DVR as a means of series compensation for mitigation of voltage sags for improving power quality at sensitive load conditions. The detailed design of a closed regulator to maintain load voltage within acceptable levels in a DVR using transformer coupled H-bridge converters DVRs deals with a voltage source converter realized using two level converters, which are well suited for 480V systems. While in high power applications such as at distribution voltage levels, a multilevel converter is a more attractive solution, whose application in a DVR has not been well addressed [16].

From the literature reviews, it is observed that the work on the investigation on voltage in transmission system large voltage drop occur in nonlinear and sensitive load condition system performance is very much diversified. It is observed that there is a scope to investigate the effectiveness of compensating device for different load and with different loading condition in transmission system. Voltage sags can occur at any instant of time, with amplitudes ranging from 10 to 90% and a duration lasting for half a cycle to a one minute. Voltage swell is defined as a swell as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1min typical magnitudes are between 1.1 and 1.8pu.Swell magnitude is always greater than 1.0.Voltage swells are not as important as voltage sags because they are less common in distribution systems. Voltage sag and swell can cause sensitive equipment to fail or shutdown, as well as create a large current unbalance that could blow fuses or trip breakers. This paper introduces dynamic voltage restorer and its operating principle. A simple control based on dqo method is used to compensate voltage sags/swells. DVR are now becoming more established in industry to reduce the impact of voltage dips on sensitive loads. At present, a wide range of very flexible controllers which capitalize on newly available power electronics components are emerging for custom power applications. Among these, the distribution static comparator and the dynamic voltage restorer are most effective devices, both of them based on the voltage source converter principle.

III. PROPOSED SYSTEM

The technological development, maintaining the power quality is one of the major requirements. The reason is modern technology demands for an un-interrupted, high quality electricity supply for the successful operation of voltage sensitive devices such as advanced control, automation, precise manufacturing techniques. Power quality may be degraded due to both the transmission and the distribution side abnormalities. The abnormalities in the distribution system are load switching, motor starting, load variations and non-linear loads, whereas lightning and system faults can be regarded as transmission abnormalities. To overcome the power quality related problems occurring in transmission system, FACTS (Flexible AC Transmission System) devices play a major role. Custom power devices which normally targeted to sensitive equipped customers, are used to overcome power quality problems in the distribution network. The main advantages of the FACTs devices is that they allow for increased controllability and optimum loading of the lines without exceeding the thermal limits.

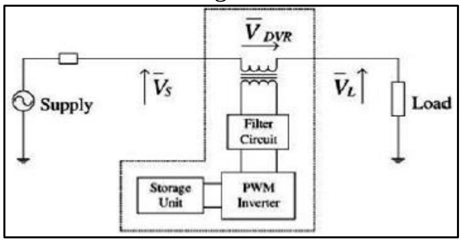

Fig. 1: DVR series connected circuit diagram

A. Control Algorithm

The basic function of a controller in a DVR are the detection of voltage sag/swell events in the system, commutation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells. The dqo transformation or park's transformation is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. First convert the voltage from a-b-c reference frame to d-qo reference. For simplicity zero phase sequence component is ignored. The flow chart shows the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases.

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

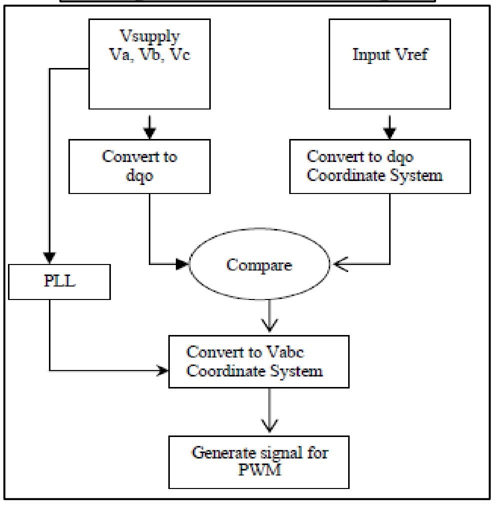

Fig. 2: Flow chart of feed forward control technique for DVR based on dqo transformation

B. PWM Inverter

Voltage source inverter generally pulse width modulated voltage source inverter is used .The basic function of the VSI is to convert the DC voltage supplied by the energy storage device into an AC voltage .In the DVR. power circuit step up voltage injection transformer is used .Thus a VSI with a low voltage rating is sufficient The common inverter connection methods for three phase DVRs are three phase graetz bridge inverter, neutral point clamp inverter and H bridge inverter for single phase DVRs.

C. Voltage Injection Transformer

The high voltage side of the injection transformer is connected in series to the distribution line, while the low voltage side is connected to the DVR power circuit. For a three-phase DVR, three single –phase or three-phase voltage injection transformer can be connected to the distribution line and for single phase DVR one single phase transformer is connected. The basic function of the injection transformer is to increase the voltage supplied by the filtered VSI output to the desired level while isolating the DVR circuit from the distribution network. The transformer winding ratio is predetermined according to the voltage required in the secondary side of the transformer (generally this is kept equal to the supply voltage to allow the DVR to compensate for full voltage sag). A high transformer winding ratio will increase the primary side current which will adversely affect the performance of the power electronic devices connected in the VSI.

D. DVR Operating States during Voltage Sag/Swell

The DVR injects the difference between the pre-sag and the sag voltage by supplying the real power requirement from the energy storage device together with the reactive power. The maximum injection capability of the DVR is limited by the ratings of the DC energy storage and the voltage injection transformer ratio. In the case of three single-phase DVRs the magnitude of the injected voltage can be controlled individually. The energy storage device can be charged either from the power supply itself or from a different source. The by-pass switch is activated to provide an alternate path for the fault currents. Hence the inverter is protected from the flow of high fault current through it, which can damage the sensitive power electronic components Most of the commercially available DVRs use either the in phase compensation technique or energy optimization technique, owing to minimal requirement of real power injection. Hence it reduces the capacity of the energy storage needed. Control technique describes the method used to quantify the DVR control voltage injected during the compensation. In simple terms it basically detects the occurrence of voltage sag. Some common control techniques used by DVR manufactures are described in this section.

- Voltage Sag Detection Techniques
- Fourier transform
- Phase locked loop (PLL)
- Vector control (Software phase locked loop-SPLL)
- Peak value detection applying the wavelet transform to each phase.

IV. SIMULATIONS AND RESULTS

A detailed system as shown in Figure 3 has been modeled by MATLAB/SIMULINK to study the efficiency of suggested control strategy. The system parameters and constant value are listed in Table I. The results of the most important simulations are represented. The load has been assumed nonlinear with power factor pf =0.85 lagging and its capacity of 5 KVA.

Main Supply Line Voltage	440 V
Line Impedance Ls	Ls =0.5mH Rs = 0.1 Ω
Series transformer turns ratio	1:1
DC Bus Voltage	100V
Filter Inductance	1mH
Filter capacitance	1uF
Load resistance	40 Ω
Load inductance	60mH
Line Frequency	50Hz

Table 1: System Parameters and Constant values

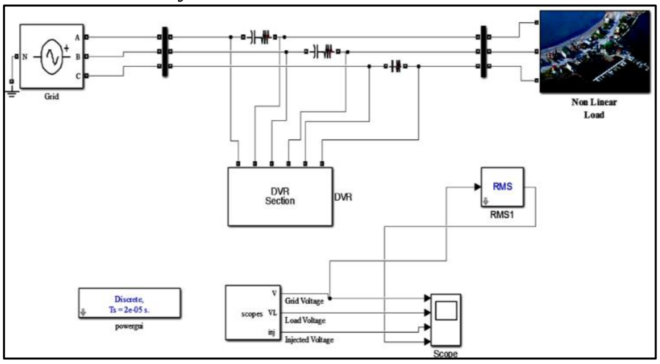

Fig. 3: Simulink block diagram of Proposed System

A. Voltage Sag Analysis

The simulation started with the supply voltage 30% and sagging at 0.1s and it is kept until 0.2s, with total voltage sag duration initiated of 0.1s.

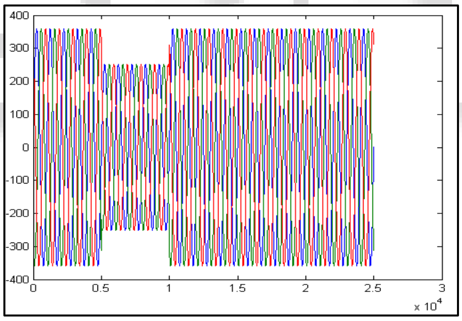

Fig. 4: Source voltage for 30% sagging

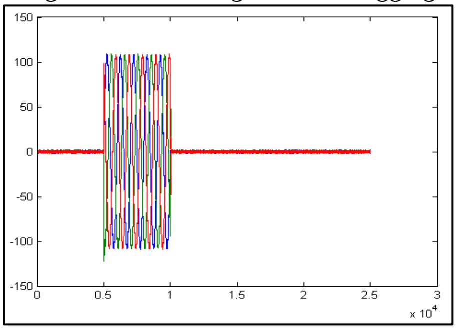

Fig. 5: Injected voltage by the DVR for 30% sagging

Voltage sag is studied for 30%. As it can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. The DVR reacts quickly to inject the appropriate voltage component to correct the supply voltage. The injected voltage that is produced by DVR in order to correct the load voltages and the load voltages maintain at the constant.

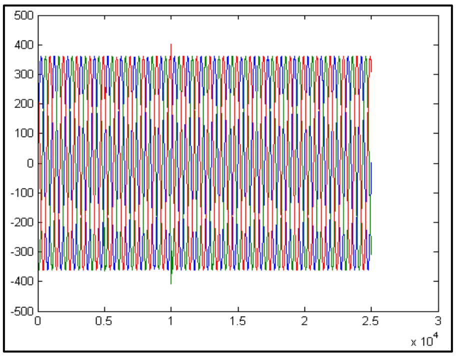

Fig. 6: Load voltage with compensation for 30% sagging

B. Voltage Swells Analysis

The second simulation shows the DVR performance during a voltage swell condition. In swell condition amplitude of supply voltage is increased about 10% from its nominal voltage. The voltage swell is initiated at 0.1s and it is kept until 0.2s, with total voltage swell duration of 0.1s.

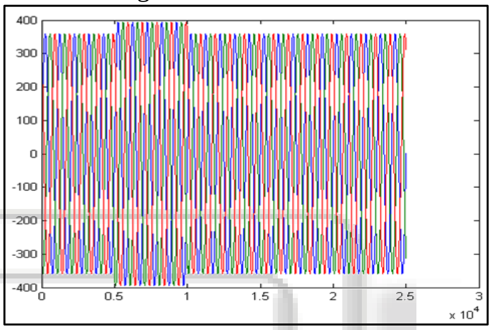

Fig. 7: Source voltage for 10% swelling

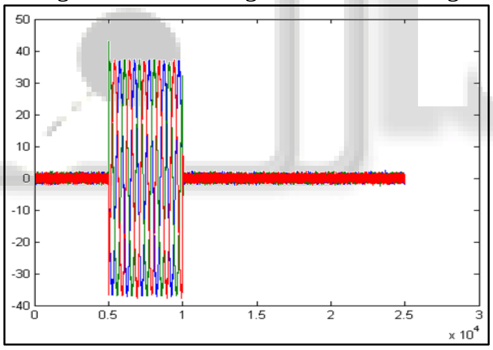

Fig.8. Injected voltage by the DVR for 10% swelling

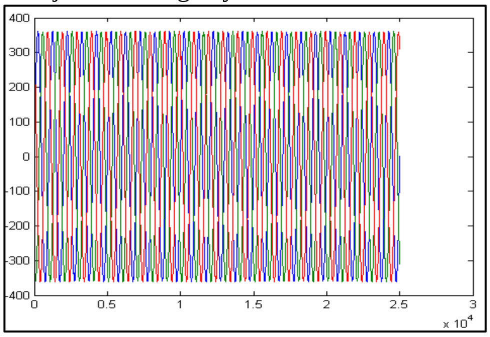

Fig. 9: Load voltage with compensation for 10% swelling

Voltage swell is studied for 10%. As it can be seen from the results, the load voltage is kept at the nominal value with the help of the DVR. The DVR reacts quickly to inject the appropriate voltage component (negative voltage magnitude) to correct the supply voltage. The injected voltage that is produced by DVR in order to correct the load voltages and the load voltages maintain at the constant.

V. CONCLUSION

The DVR handled both balanced and unbalanced situations without any difficulties and injected 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 efficiency and effectiveness in voltage sags/swells compensation showed by the DVR makes him an interesting power quality device compared to other custom power devices. A control system based on dqo technique which is a scaled error between source side of the DVR and its reference for sags/swells correction has been presented. From simulation results also show that the DVR compensates the sags/swells quickly and provides excellent voltage regulation. The DVR handles both balanced and unbalanced situation without any difficulties and injects 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.

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