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Design and Simulation of Advanced DVR for Multifunctional Purpose

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Abstract:

Electronic devices function properly as long as the voltage of the supply system feeding the device stays within a consistent range. There are different types of voltage fluctuations that can cause Power quality problems, including, sags, harmonic distortions, surges and spikes and momentary disruptions, nonstandard voltage, current or frequency that results in a failure or miss operation of end user equipment. The steady-state PQ characteristics of the supply voltage include surges and spikes. Voltage sags and swells are the common events on the electric power network. Voltage sags and swells are the common events on the electric power system. The common causes of voltage sag are short circuit or faults in power system, at starting of large loads and faulty conductor. These problems can be mitigated with voltage injection method using custom power device, Dynamic Voltage Restorer (DVR). A DVR is connected in series with the linear load to compensate for the harmonics and unbalance in the source voltages and improve the power factor on the source side A series connected converter based mitigation device, the Dynamic Voltage Restorer(DVR), is the most economical and technically advanced mitigation device proposed to protect sensitive loads from voltage sags. In this paper, DVR which consists of injection transformer, filter unit, Pulse Width Modulation (PWM) inverter, energy storage and control system is used to mitigate the voltage flickers in the power distribution system. Here we propose two control techniques which are the Proportional Integral (PI) Controller and Fuzzy Logic (FL) Controller. In this Project we are design a Dynamic Voltage Restorer (DVR) with Proportional Integral (PI) Controller and Fuzzy Logic (FL) Controller, to improve power quality in power system by using MAT Lab/Simulink.

Keywords:
Dynamic Voltage Restorer, Energy storage System, Total Harmonic Distortion, Fuzzy Logic Controller.

I. INTRODUCTION:

Voltage sags are now one of the most important power quality problems in the power distribution systems. A voltage sag is a momentary decrease in rms ac voltage (0.1-0.9 p.u. of the nominal voltage), at the power frequency, of duration from cycles to a few seconds. Most voltage sags are caused by remote faults, such as single line- to-ground fault, double line to ground fault and three phase fault on the power distribution system. [2] Recently, power quality problems become a major concern of industries due to massive loss in terms of time and money. Hence, there are always demands for good power quality, which positively resulting in reduction of power quality problems like voltage sag, harmonic, flicker, interruptions and harmonic distortion. Preventing such phenomena is particularly important because of the increasing heavy automation in almost all the industrial processes. High quality in the power supply is needed, since failures due to such disturbances usually have a high impact on production costs.

There are number of methods to overcome voltage sags. One approach is to use Dynamic Voltage Restorers with energy storage. The DVR is a power electronics device that is able to compensate voltage sags on critical loads dynamically. By injecting an appropriate voltage, the DVR restores a voltage waveform and ensures constant load voltage. The DVR consists of Voltage Source Converter (VSC), injection transformers, passive filters and energy storage (lead acid battery). The Dynamic Voltage Restorer (DVR) with the lead acid battery is an attractive way to provide excellent dynamic voltage compensation capability as well as being economical when compared to shunt-connected devices. The DVR is a custom power device that is connected in series with the distribution system. The DVR employs MOSFETs to maintain the voltage applied to the load by injecting three-phase output-voltages whose magnitude, phase and frequency can be controlled. [3] .

A. Voltage quality in electrical power system:

The most severe power quality problems are voltage sags, swells, interruption, harmonics and flickers [2]. Failures due to such disturbances cause a huge impact on production cost. Especially, modern industrial equipment is more susceptible to power quality problems. STN EN 50160 defines voltage sag as a short term reduction in voltage magnitude to a value in the range 5 to 90% of the supply voltage. Voltage sag means that the required energy is not being delivered to the load and this can have serious consequences depending on the type of load involved. Reference [2] defines power quality problems as follows: computers or other electronics damage, lights dim and flickers, loss of synchronization of processing equipment, motors or other process equipment malfunctions, transformers and cables overheating, problems with power factor correction equipment, noise interference to telecommunication lines and many more. Since the whole electrical power network represents a very complex structure, there is no way to control it without any faults and disturbances. Thus, companies are often forced to save its facilities on their own. One of the options for power quality and system stability improvement is to introduce FACTS devices [3].

B. FACTS controllers:

FACTS (Flexible Alternating Current Transmission systems) are alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability [4]. The major advantages of FACTS are [5]: power lines transmission capabilities improvement, power flow control, static and dynamic stability enhancement, secure interconnections between neighboring utilities. FACTS controllers are able to control and regulate one or several key parameters in power transmission, such as current, voltage, active, reactive power, frequency or phase angle. Reference [5] divides FACTS into four basic types – series connected, shunt connected, combined series-series and combined series-shunt controllers. The main disadvantage of implementing FACTS is very a high price of these devices and economic requirements. The series controller can be variable impedance, such as capacitor and reactor, or a power electronics based variable voltage source. In general, all series controllers inject voltage in series with the line. They are able to compensate voltage sags or swells and eliminate harmonic distortion as well. These are static synchronous series controller (SSSC), thyristor-controlled series capacitor (TCSC) or dynamic voltage restorer (DVR). As in the case of series controllers, the shunt controllers may be variable impedance, variable source, or a combination of these. In basic principle, all shunt controllers inject current into the system at the point of connection. These are static thyristor controlled reactor (TCR), synchronous controller (STATCOM) or static var compensator (SVC). Combined series-shunt controllers are the most flexible and sophisticated FACTS devices. They are able to regulate and affect many different parameters at the same time. One of these devices is unified power flow controller (UPFC).

II. DYNAMIC VOLTAGE RESTORER:

Dynamic Voltage Restorer (DVR) belongs to series connected FACTS controllers. The primary function of a DVR is to compensate voltage sags and swells but it can also perform tasks such as harmonics elimination, reduction of voltage transients and fault current limitation [6]. DVR is usually installed between a source and a critical load that should be protected. Even the shortest voltage sag can cause serious equipment damage, interruption of production cycles and thus financial losses as well. In general a DVR consists of three parts (Fig. 1.): measuring unit, control, power circuit. The measuring unit provides voltage and current measurements. The outputs are voltage and current analog signals (u, i), which enter the control unit. The control unit converts these signals to their digital representation using A/D converter so that they can be processed by a microprocessor (DSP – digital signal microprocessor). Next part is a voltage sags detection algorithm followed by compensating voltage calculation U_com, which is the voltage needed to be injected into the system in order to remain the load side voltage of purely sinusoidal waveform. Power section consists of a voltage source converter (VSC) equipped with a LC filter to smooth the output voltage, a DC energy storage and an injection transformer (TR) – booster. The basic principle of DVR function is to inject or draw the compensating voltage U_inj to or from the supply voltage U_s in order to mitigate voltage sags or swells on the load side U_load. At every moment the control algorithm compares desired voltage and actual measured voltage. The difference between these two signals is considered as a compensating voltage signal

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(control signal) U_com, which is directly proportional to compensating voltage U_inj (power circuit). U_com is a digital input signal for a pulse width modulation (PWM) to control the voltage source converter. The VSC converts DC energy stored in an energy storage device (such as batteries or super capacitors) to injecting AC voltage that is to be superimposed to the source voltage. DVR power output depends on the amount of energy that can be stored in the energy storage unit. DVRs are normally installed to protect large electrical energy consumers with the sensitive technologies and devices (2 MVA or more) connected at distribution voltage [9].

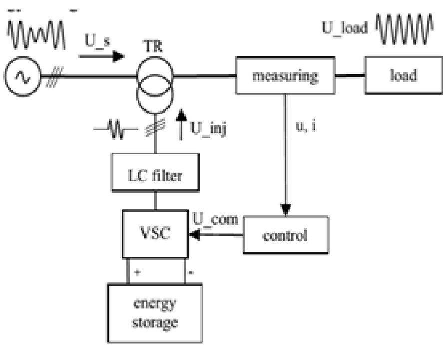

Fig. 1. Simplified scheme of a DVR

III. VOLTAGE SAGS DETECTION METHODS:

One of the most important requirements for DVR is that the controller should be able to operate in real-time manner. It means that the whole compensating process is carried out immediately, after a failure occurs, without any delay. The very important factor that influences the DVR speed most is the reaction time of the implemented voltage sag detection algorithm. The best DVR systems are able to react within 1 ms.

There are several voltage sags detection techniques, which can be used in DVRs, such as:

•Peak value method
•Missing voltage method,
•RMSmethod,
•Discrete Fourier transformation,
•DQ transformation,
•Hybrid methods.

A. DQ transformation:

In this paper the modeling of a DVR is proposed. Its control algorithm is based on DQ transformation. DQ transformation (dq0 – direct-quadrature-zero) is a mathematical transformation used to simplify the analysis of three-phase circuits [8]. d and q quantities represent rectangular two axis system, which rotates with angular frequency ω [7]. In the case of symmetric three-phase system, introducing of the dq0 transformation reduces three AC quantities (pu) to two DC quantities (d=1, q=0). Any deviations from the steady state condition in abc system reflect in changes of dq0 values in real-time.

For unbalanced and asymmetric three phases system applies d≠0, q≠0, 0≠0. According to this presumption it is possible to obtain the difference between desired and instant values dynamically. Therefore, the output compensating voltage can be controlled by PID regulators [3]. The resultant signal is converted back to abc values. DQ transformation can be applied in the case of three phase system and there is a phase-locked loop (PLL) required to lock the synchronization of the compensating voltage in phase with the line voltage before the fault.DQ transformation is calculated as follows [3], [7]:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin(\omega t) & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \cdot \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad (1)$$

IV.HYSTERESIS VOLTAGE CONTROL TECHNIQUE:

The control of dynamic voltage restorer is relates with the Detection of voltage sag/dip, voltage swell, and the generation of the reference voltages for injection purpose. The sag, swell detection technique is very important task for the appropriate working of dynamic voltage restorer. There are various techniques for the detection of voltage sag, swell. Some are given below. Measuring peak values of input supply, Measuring of voltage components in dq frame in a vector controller and applying phase locked loop to each phase.

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Structure of DVR by using Hysteresis Voltage Control Technique:

Following figure explains the main control diagram of dynamic voltage restorer with hysteresis voltage controller. It mainly consists of three phase IGBT inverter, Energy storage, booster transformer and the hysteresis voltage controller. The hysteresis controller mainly requires two voltage signals, one is from supply side voltage signal and another is from booster transformer which is voltage injected by dynamic voltage restorer. The controller compares these two signals and according to these signals switching pattern is established.The hysteresis switching method is well explained in fig.5.

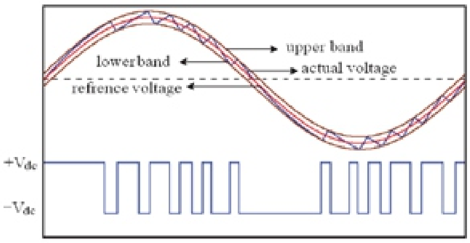

Fig.2 Hysteresis switching pattern

A. Proportional-Integral Controller:

PI Controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value. The proportional response will be adjusted by multiplying the error by constant KP, called proportional gain.[9] The contribution from integral term is proportional to both the magnitude of error and duration of error. First error will be multiplied by the integral Gain, Ki and integrated to give an accumulated offset that have been corrected previously.

V.MATLAB/SIMULINK RESULTS

Case 1: balanced sag compensation

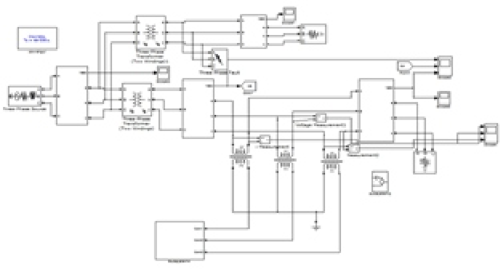

Fig.3.Matlab/Simulink circuit for proposed DVR

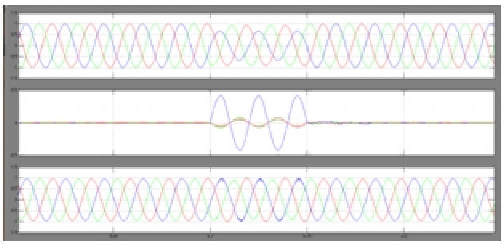

Fig.4. simulation results for balanced sag voltage, voltage injected by DVR, load voltage respectively for PI controller

Case 2 unbalance sag compensation

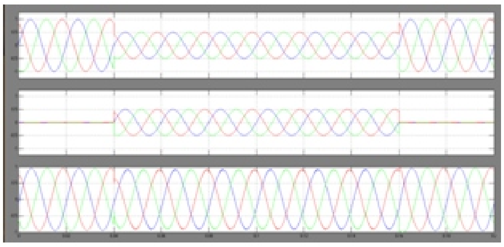

Fig.5.Simulation results for unbalance sag, DVR voltage,load voltage respectively for Three phase controller

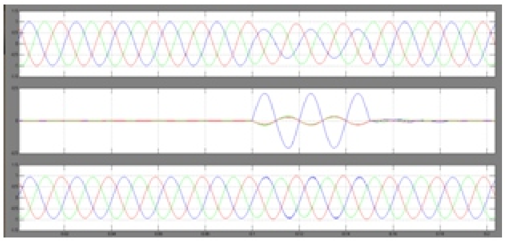

Fig.6.Simulation results for (a) unbalance swell (b) DVR voltage (c) load voltage for single phase Controller

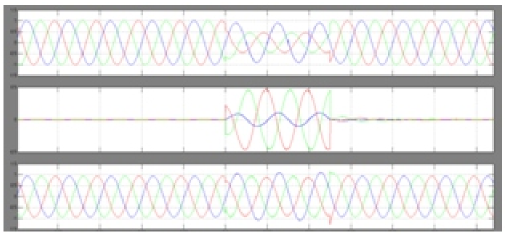

Fig.7.Simulation results for (a) unbalance swell (b) DVR voltage (c) load voltage for two phase Controller

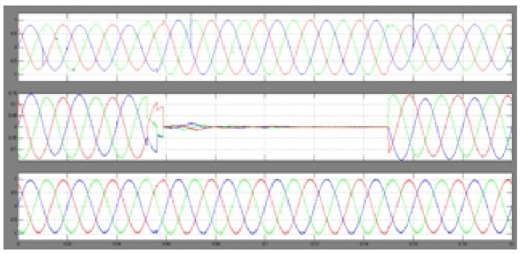

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Fig.8.Simulation results for (a) unbalance swell (b) DVR voltage (c) load voltage for multiple sag condition

V.CONCLUSION:

To sum up, the presented DVR simulation model is based on a DQ transformation control algorithm. The main advantages of this control technique are high speed, simplicity and it can be used even during distorted supply voltage waveform. On the other hand the disadvantages are that DQ transformation can be only applied on a three phase system and a reference sinusoidal signal is required (PLL) synchronized with the voltage before the fault. The entire DVR model was created in Matlab/Simulink and its correct function was verified by several simulation tests. The obtained results showed that, the proposed DVR mitigates voltage sags and harmonics very fast and reliably. Many other parameters and conditions influence the DVR operation. They are: sampling frequency, speed of the regulators, dynamic behavior of energy storage device, converter switching speed and the type of the disturbance. The right choice of a reliable voltage sag detection method and a proper design of the whole system is the very first step in the developing of a DVR. Thus, the proposed simulation model can support the next research in the field.

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