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Performance of Dynamic Voltage Restorer by Using Fuzzy Controller with Battery Energy Storage System

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ABSTRACT:

The Dynamic Voltage Restorer (DVR) has recently been introduced to protect the sensitive industrial loads from the detrimental effects of voltage sags/swells and other voltage disturbances. Configurations and control schemes for the DVR varies depending upon the nature and characteristics of the load to be protected. Industries with induction motors loads require a complete different approach for the design and control of a suitable DVR owing to the inherit inertia of the induction motors and their capability to withstand short-duration, shallow sags/swells, in addition to its tolerance to phase angle jumps. In this paper, a DVR with fast response, simple and efficient controller is proposed for fulfilling the voltage restoration requirements for industrial induction motor loads. The proposed DVR utilizes the energy from available supply line feeders through a rectifier to feed the inverter. Modeling and simulation of the proposed DVR is implemented in MATLAB/SIMULINK platform. Simulation results have shown that the proposed DVR was efficient in mitigating balanced, unbalanced, multistage and consecutive sags, as well as swells.

KEYWORDS: Dynamic voltage restorer (DVR), power quality, unit vector, voltage harmonics, voltage sag, voltage swell. Harmonics, Fuzzy Logic Controller.

I.INTRODUCTION

Power quality problems in the present-day distribution systems are addressed in the literature. Due to the increased use of sensitive and critical equipment pieces such as communication network, process industries, and precise manufacturing processes. Power quality problems such as transients, sags, swells, and other distortions to the sinusoidal waveform of the supply voltage affect the performance of these equipment pieces. Technologies such as custom power devices are emerged to provide protection against power quality problems. Custom power devices are mainly of three categories such as series-connected compensators known as dynamic volt-age restorers (DVRs), shunt connected compensators such as distribution static compensators, and a combination of series-and shunt-connected compensators known as unified power quality conditioner. The DVR can regulate the load. Two of the main problems in the field of power quality are voltage sag and instantaneous power loss. In addition, voltage sag has two main parameters including magnitude and time duration. Typically, DVR voltage injection method is used to compensate the difference between voltage when sag occurs and when before sag occurs, using AC voltage in series. Another method is to inject voltage in phase with supply voltage when sag occurs. The advantage of both methods is that it uses economical energy storage, yet it has disadvantage of the occurrence of phase shift Voltage sag caused by symmetrical 3 phase fault can be overcome by DVR employing back propagation neural network control. This method compensates very well, but it needs a relatively long time Conventional fuzzy logic controller can reduce the time needs; however this controller needs many membership functions. Some researchers have been done to decrease the number of membership functions, for example by the use of fuzzy controller. Fuzzy polar

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controller method could decrease the number of conventional fuzzy logic membership functions. Many previous researchers used zero sequence blocking system, by installing wyes-delta transformer to block zero current or voltage so that the sensitive load will not be affected. This was done because of the difficulty to eliminate zero sequence. Using the blocking transformer will make it easier to eliminate zero sequence effect, but this solution is relatively expensive. For this reason, another solution without blocking transformer is developed.This paper presents DVR with fuzzy polar controller which concerns on zero sequence voltage compensation to compensate voltage sag in low voltage distribution system by employing zero sequence unblocking system. This paper also compensates voltage distortion caused by harmonics. Simulation result shows that this controller could compensate voltage sag and harmonics very well under the condition of symmetrical and unsymmetrical fault without using zero sequence blocking . Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [1] however, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality problems [2].Power quality phenomenon or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also, under heavy load conditions, a significant voltage drop may occur in the system. Voltage sag and swell can cause sensitive equipment to fail, shutdown and create a large current unbalance. These effects can incur a lot of expensive from the customer and cause equipment damage [1]. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min and swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. Typical magnitudes are between 1.1 and 1.8 p.u[2-5]. There are many different methods to mitigate voltage sags and swells, but the use of a custom power device is considered to be the most efficient method, There are different types of Custom Power devices used in electrical network to improve power quality problems. Each of the devices has its own benefits and limitations. A few of these reasons are as follows. The SVC predates the DVR, but the DVR is still preferred because the SVC has no ability to control active power flow [3]. Another reason include that the DVR has a higher energy capacity compared to the SMES and UPS devices. Furthermore, the DVR is smaller in size and cost is less compared to the DSTATCOM and other custom power devices. Based on these reasons, it is no surprise that the DVR is widely considered as an effective custom power device in mitigating voltage sags. In addition to voltage sags and swells compensation, DVR can also add other features such as harmonics and Power Factor correction. Compared to the other devices, the DVR is clearly considered to be one of the best economic solutions for its size and capabilities [4-5].

II.DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic Voltage Restorer (DVR) is power electronic device installed in series with distribution system line as can be seen in Figure 1. DVR uses semiconductor device to maintain voltage of sensitive load by injecting voltage whose magnitude, phase, and frequency can be controlled. How a DVR works to compensate harmonics is shown in Figure 2. From Figure 1 and Figure 2 it can be seen that, the topology of DVR as voltage sag compensator is similar to that of as harmonics compensator. Therefore, the DVR can compensate both voltage sag and voltage distortion caused by harmonics.

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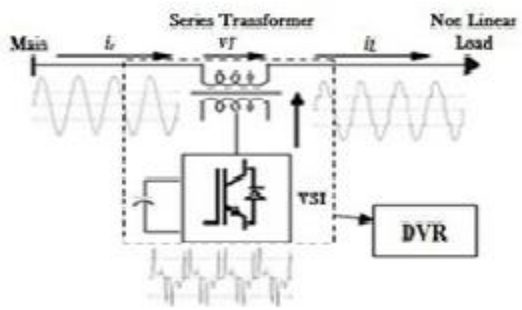

Fig 1: Schematic Diagram of DVR Configuration

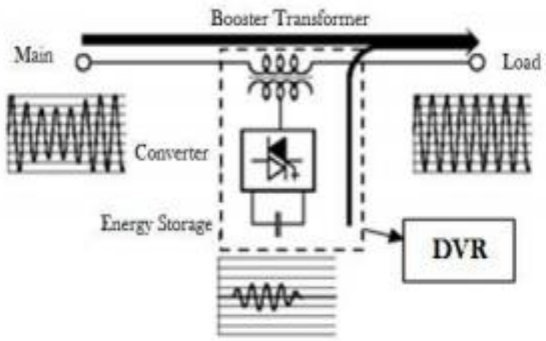

Fig 2. Phase diagram of the DVR voltage injection schemes

2.1 Configuration of DVR

The general configuration of the DVR consists of an Injection transformer, a Harmonic filter, a Voltage Source Converter (VSC), Energy Storage Unit and a Control and Protection unit as shown in Fig 3.Energy Storage Unit in DVR can be external batteries or capacitors charged from the supply line feeder through a rectifier. Generally the energy storage unit of a DVR can be divided into two parts (i.e. Storage devices and DC Charging Circuit). The purpose of energy storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. Energy Storage Unit in DVR can be external batteries or capacitors charged from the supply line feeder through a rectifier. Generally the energy storage unit of a DVR can be divided into two parts (i.e. Storage devices and DC Charging Circuit).

The purpose of energy storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are superconductive magnetic energy storage (SMES),batteries, and capacitors. In fact, the capacity of the stored energy directly determines the duration of the sag which can be mitigating by the DVR. Batteries are the common choice and can be highly effective if a high voltage battery configuration is used. However, batteries in general have a short lifetime and often require some type of battery management system, which can be quite costly. An interesting alternative to batteries is the use of super capacitors, which have a wider voltage range than batteries and can be directly paralleled across the input bus. Super capacitors have a specific energy density less than that of a battery, but a specific power greater than a battery, making them ideal for short (up to several seconds) pulses of power. Certain super capacitors can hold charge over extended periods of time, so as to act like a battery. However, unlike batteries, these super capacitors have a short charging time and much longer lifetime. The purpose of the DC Charging Circuit is to charge the energy storage devices after the compensation of a voltage sag/swell event as well as maintain a nominal dc link voltage. The charging circuit can be an external power supply or a rectifier fed from the supply mains of the distribution network. A Voltage Source Converter is a power electronic system capable of generating a sinusoidal voltage at any required frequency, magnitude, and phase angle. DVR configurations use the VSC to generate the voltage required to compensate for the voltage sag/swell events. Since the majority of the voltage sags/swells observed on distribution systems are unbalanced, the VSC will often be required to operate with unbalanced switching functions for the three phases and must therefore be able to treat each phase independently. Moreover, sag on one phase may result in swell on another phase, so the VSC must be capable of handling both sags and swells simultaneously. The output voltage of the inverter is varied by using different PWM schemes available.

2.2 Compensation Methods

Compensation of voltage sags/swells is dependent upon a number of factors including DVR power rating,

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different load conditions and different types of voltage sags/swells. Some loads are very sensitive to phase angle jump while others are tolerant to it. Therefore, the compensation strategy depends upon the type and characteristics of the load connected to DVR. There are three different methods for DVR voltage injection which are presented below.

2.2.1 Pre-Fault Compensation

The DVR injects the difference voltage between during fault and pre-fault voltages to the system. In this method the DVR compensates for both magnitude and Phase angle. The main drawback of this technique is it requires a higher capacity energy storage device [23]. Fig 4a shows the vector diagram fothe pre-fault control strategy for a voltage sag event. This method is best suited to loads sensitive to phase angle jumps as it compensates for both the magnitude and phase angle.

2.3 Control Methods for DVR

DVR Control strategies fall mainly in one of the two categories namely linear control methods and Non-linear control methods. Linear control methods can be employed with the feedback, the feed-foreword and the combined feed controllers.

On-Linear control methods comprising the Artificial Neural Networks (ANN), the Fuzzy Logic (FL) and the Space Vector (SV) controllers. Although feedback controllers are popular, they require load and source tracking, whereas feed-foreword controllers are much simpler yet open-looped, there is no feedback from the load voltage or current. The proposed DVR utilizes capacitors as the energy storage units fed through the supply mains via the rectifier. The compensation strategy is chosen to be the in phase compensation method due to its simplicity of implementation and induction motor no being sensitive to phase angle jumps. And the control of the proposed DVR is based on a fuzzy logic based feedback controller.

III. MATERIALS AND METHODS

This study proposes a fuzzy logic controlled DVR with in-phase compensation strategy for voltage sag/swell compensation for industrial induction motor loads. Since the in-phase compensation strategy is simpler and efficient, the operation of the proposed DVR is simpler and its response time is also faster. Fig 5 shows the block diagram of the proposed controller for the DVR.

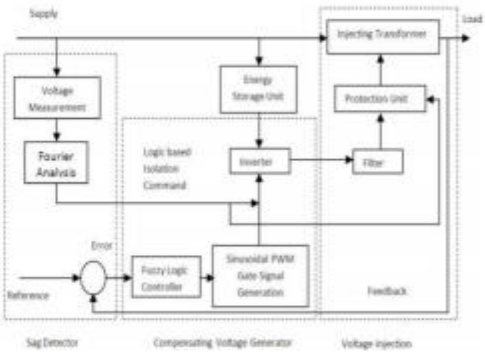

Fig 3: Block diagram of the proposed DVR control scheme.

3.The controller of the proposed DVR consists of the following blocks:

3.1. Detection of Sag and Swell Events

Sag/Swell detection includes determination of the instants when a sag/swell event starts and ends, magnitude of the variation and the phase angle jumps. Several approaches for detection of sag/swell events available are Classical Fourier Transform method, Wavelet analysis, use of RMS values, use of peak values, the transformation of the three phase voltages to a two dimensional frame (dq frame) and therefore to one phasor etc. In this study, the proposed DVR uses the traditional Fourier Transform method to detect the voltage sag/swell events. The Fourier transform based sag/swell detector associated with the proposed DVR can track the magnitude and the phase angle of the fundamental frequency component of the supply voltage simultaneously in order to make sure that the injected sine wave will be in-phase with the remaining sine wave during the sag/swell events, to have a constructive vector addition of the DVR and the supply voltages. Since the compensation strategy used in the proposed DVR is in-phase method, computation of the compensating voltage magnitude is done using a comparator with one input as the variable load voltage

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and the other being the reference voltage for each of the three phases independently. The output of the comparator determines the magnitude of the voltage required to be injected by the DVR and is called the error signal which is the input to the fuzzy logic based feedback controller used for controlling the output voltage of the inverter through the control of the modulation index for each of the three phases of the inverter independently.

3.2 Compensating Voltage Generation

The inverter circuit in DVR is responsible for generation of the compensating voltage. Hence the control of the inverter will directly affect the performance of the DVR. The inverter used in the proposed DVR is a three phase six pulse inverter. The thyristors used in the inverter circuit are chosen to be Insulated Gate Bipolar Transistors (IGBT) for their fast response and robust operation. The inverter uses Sinusoidal Pulse Width Modulation (SPWM) for controlling the modulation index hence controlling the output voltage of the inverter.

In SPWM, a sinusoidal reference signal of supply frequency (i.e. 50 Hz) is compared with a high frequency triangular carrier waveform (i.e. 1080 Hz for this study). When the sinusoidal reference signal is greater than the triangular carrier wave, a batch of three IGBT switches out of the six are turned on and the counter switches are turned off and when the reference sinusoidal signal is smaller than the triangular carrier waveform in magnitude then the second batch of three IGBT switches are turned on and the first batch of switches are turned off. The magnitude of the sinusoidal reference signal determines the modulation index of the PWM signal generator which is dependent upon the error signal. The magnitude of the sinusoidal reference signal is controlled by the fuzzy logic based feedback controller which adjusts the magnitude according to the error magnitude and hence control the modulation index. The proposed DVR utilizes large capacitor banks for storing dc energy. Supply line voltage is rectified and used to charge the capacitor banks. DC voltage from alternative supply sources can also be utilized with the proposed configuration of DVR.

3.3 Fuzzy Logic Controller

Fuzzy logic theory is considered as a mathematical approach combining multi-valued logic, probability theory, and artificial intelligence to replicate the human approach in reaching the solution of a specific problem by using approximate reasoning to relate different data sets and to make decisions. The performance of Fuzzy Logic Controllers is well documented in the field of control theory since it provides robustness to dynamic system parameter variations as well as improved transient and steady state performances. In this study, a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed Dynamic Voltage Restorer (DVR). Fuzzy logic controller is preferred over the conventional PI and PID controller because of its robustness to system parameter variations during operation and its simplicity of implementation. Since the proposed DVR uses energy storage system consisting of capacitors charged directly from the supply lines through rectifier and the output of the inverter depends upon the energy stored in the dc link capacitors. But as the amount of energy stored varies with the voltage sag/swell events, the conventional PI and PID controllers are susceptible to these parameter variations of the energy storage system; hence the control of voltage injection becomes difficult. The proposed FLC scheme exploits the simplicity of the Madman type fuzzy systems that are used in the design of the controller and adaptation mechanism that can be identified by level of memberships in the fuzzy sets. The inference mechanism uses the collection of linguistic rules to convert the input conditions to fuzzified output. Finally, the defuzzification converts the fuzzified outputs to crisp control signals using the output membership function, which in the system acts as the changes in the control input (u).

The typical input membership functions for error and change in error are respectively, whereas the output

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membership function for change in control input. The output generated by fuzzy logic controller must be crisp which is used to control the PWM generation unit and thus accomplished by the defuzzification block. Many defuzzification strategies are available, such as, the weighted average criterion, the mean-max membership, and center-of-area (centroid) method. The defuzzification technique used here is The set of fuzzy control linguistic rules is given in Table 1. The inference mechanism of fuzzy logic controller utilizes these rules to generate the required output based upon centroid method.DVR is generally connected in feeders having sensitive loads whose terminal voltage has to be regulated. The SIMULINK model of proposed fuzzy logic controller.

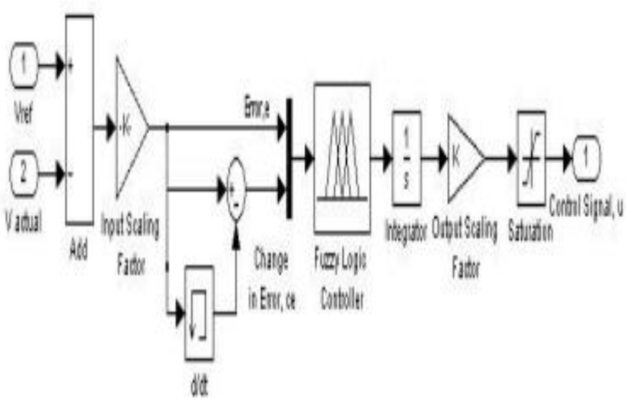

Fig 4: SIMULINK model of proposed FLC.

IV. RESULTS AND DISCUSSIONS

Results are obtained by simulating the proposed DVR system in MATLAB/SIMULINK software. The minimum operation time of the DVR is 1 cycle or 20 milliseconds. Several power quality phenomena associated with voltage sag and swell have been simulated and the results are arranged in the following sequence for all cases: (a) the supply voltage (VSupply), (b) the DVR voltage (VDVR) and (c) the load voltage (VLoad).5.1 Simulation Results 4.1.1. Three Phase Balanced Sag

A three phase balanced voltage sag is simulated by reducing the line to line voltage on each phase to 60% of the normal value for a duration of 0.3 seconds from t=0.4 sec till t=0.7 sec as shown in Fig 10. The simulation duration was 1 second.

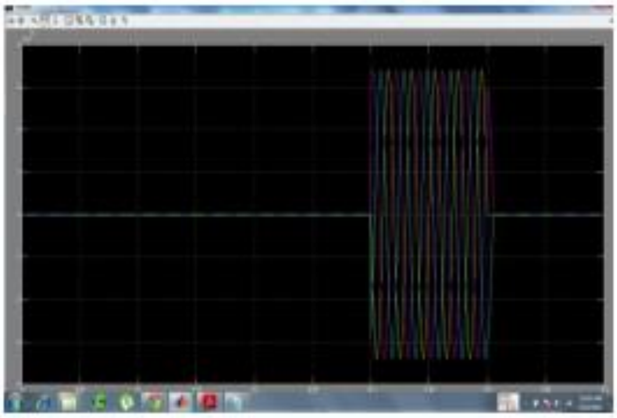

Fig 5: Three Phase Balanced Voltage Sag

4.1.2 Three Phase Balanced Swell

A three phase balanced voltage swell is simulated by increasing the line to line voltage on each phase to 140% of the normal value for a duration of 0.3 seconds from t=0.4 sec till t=0.7 sec . The simulation time was 1 second.

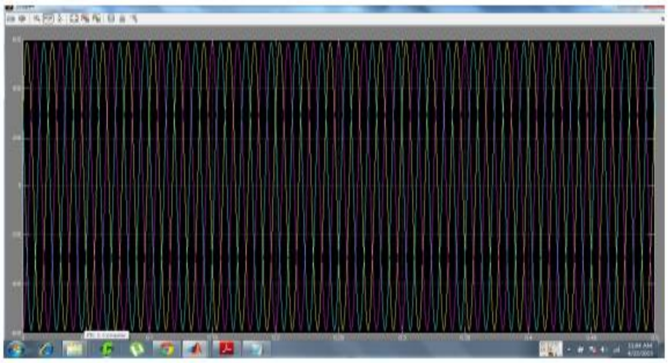

Fig 6 Three Phase Balanced Swell

V. CONCLUSIONS

In this study, a simple, fast and efficient Dynamic Voltage Restorer (DVR) is proposed for mitigation of power quality problem associated with voltage sags/swells in industrial distribution systems with a large portion of its load comprising of induction motors. The proposed DVR employs the classical Fourier Transform technique for detection and quantification of voltage disturbances (sags/swells) events. Since induction motors are not sensitive to changes in phase angle, in phase compensation method is used for calculation of the compensating voltage since it is fast and simple and finally a fuzzy logic based feedback controller is used to control the voltage injection of the proposed DVR system in case of voltage disturbances. The proposed DVR utilizes energy drawn from the supply line source during normal operation and stores in capacitors and which is converted to an adjustable three phase ac voltage suitable for mitigation of voltage sags/swells. The modeling and simulation of the proposed DVR using MATLAB/SIMULINK had been presented. The simulation shows that the DVR performance is efficient and satisfactory in mitigating voltage sags/swells. The DVR handles both balanced and unbalanced situations with sufficient efficiency and accuracy and injects the appropriate voltage component to correct rapidly any deviation in the supply voltage to keep the load voltage constant at the nominal value. The main advantages of the proposed DVR are simple and efficient adaptive control and fast response. Future works will include a comparison with a laboratory experiments on a low voltage DVR in order to compare simulation and experimental results and estimate the cost of the practical system. Further issues associated with low pass filter construction and its parameters selection, injection transformer selection and its saturation and reduction in operational time of the entire DVR system will be investigated in future works.

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