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A FLC Based DVR by Employing Z-Source Inverter For Voltage Sag/Swell Reduction

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Abstract- **Today Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive power electronic equipment and non-linear loads are widely used in industrial, commercial and domestic applications leading to distortion in voltage and current The analysis of power disturbance characteristics and finding solution to the power quality problems have resulted in an increased interest for power quality. The most concerning disturbances affecting the quality of the power in the distribution system are voltage sag/swell. The DVR is used to mitigate the voltage sag/swell on sensitive load. In this paper Z-source inverter (ZSI) based DVR is proposed to enhance the voltage restoration property of the system. The ZSI uses an LC impedance grid to couple power source to inverter circuit and prepares the possibility of voltage buck and boost by short circuiting the inverter legs. Z source DVR is proposed to obtain the desired injected voltage with the control scheme of pi and fuzzy logic simulated in the MATLAB/SIMULINK environment**

I INTRODUCTION

Every year demand for electrical energy is increasing as a result power systems are becoming complex consisting of more number of generating stations and load centers which are interconnected through the power transmission lines. There are many issues involved here such as maintenance of the power apparatus in the system and maintaining the stability of the system operation during fault condition. The power system especially the distribution system, have numerous non linear loads which significantly affect the quality of power supply. The deviation of voltage, current or frequency which can be described as a power quality problems results in collapse or incorrect operation of customer equipment [1-3].

The major power quality problems are Voltage sag/swell, flicker, harmonics distortion, impulse transients and interruptions are the various power quality problems addressed in the distribution system. Of the above power quality problems, a voltage sag/swell disturbance poses a series threat to the industries. It can occur more frequently than any other power quality phenomenon. Voltage sag is defined by the IEEE 1159 as the decrease in the RMS voltage level to 10%-90% of nominal, at the power frequency for duration of half to one minute. Voltage swell is defined by IEEE 1159 as the increase in the RMS voltage level to 110%-180% of nominal, at the power frequency for duration of half cycles to one minute [4].

Dynamic voltage restorer (DVR) is one of the power electronic devices connected in series to the distribution system [5]. It compensates the voltage disturbances by injecting the voltage of suitable magnitude and phase in series with the line. The DVR, with its excellent capabilities, when installed between the supply and the sensitive load, can compensate voltage sag/swell [6-7].

In this paper Z-source inverter based DVR is proposed. It employs a unique X-shaped impedance network on its DC side for achieving both voltage buck and boost capabilities This unique features of ZSI cannot be obtained in the traditional voltage source and current source inverters [8].

Here the control scheme used employed in Z-source inverter based DVR is fuzzy controller. The most common choice controller of the DVR is the PI controller since it has simple structure and it can offer relatively satisfactory performance over a wide range of operation. But by using fixed gains, the controller may not provide the required control performance, when there are variations in the system parameters and operating conditions. It appears that the non linear controllers are more suitable than the linear type since the DVR is truly a non linear system. The proposed fuzzy controller will provide the desired injecting voltage [9 – 10].

The main objective of this paper is to improve the voltage quality in distribution system. The Z-source inverter based DVR is used to mitigate the voltage sag/swell and the compensation is further improved by using fuzzy controller.

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II. METHODOLOGY

The flow chart presents the methodology of the application. (fig. 1), which starts from power quality identification, the appropriate device to improve the quality of power followed by DVR and fuzzy controller design and analysis. Finally the comparison of results is proposed.

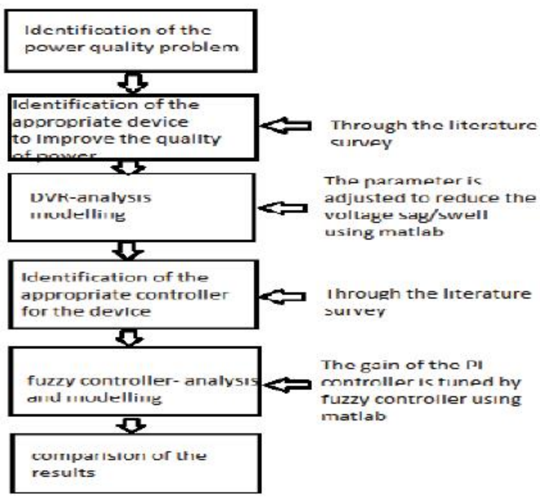

Figure 1: Flow chart for the methodology used

III. DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer is a power electronic converter based series compensator that can protect the critical loads from all the supply side disturbances other than outages. This device employs solid state power electronic switches in the inverter structure. It injects a set of three phase AC output voltage in series and synchronism with the distribution feeder voltages. The DC input terminal of the restorer is connected to an energy storage device of appropriate capacity [11, 12]. The DVR consists of the following major components which includes Z-source inverter, injection transformer, harmonic filter, energy storage device as shown in figure 2.

INJECTION TRANSFORMER:

The injection transformer is connected in series with the sensitive load which is to be protected by the DVR. The basic function of this transformer is to connect the DVR to the distribution system and the injected voltages generated by the inverter are introduced into the distribution system.

FILTER:

The main task of the filter is to keep the harmonic voltage content generated by the inverter within the permissible (i.e, it eliminates high frequency switching harmonics) level.

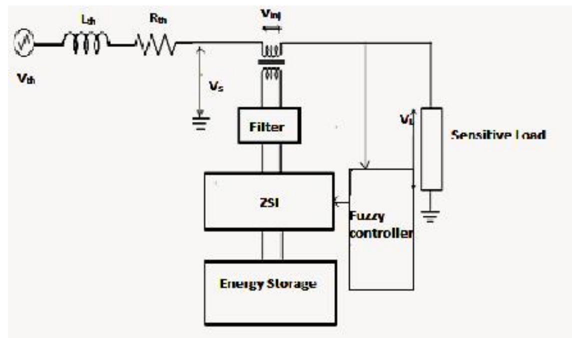

Figure 2. DVR general configuration

Z-SOURCE INVERTER:

Z-Source inverter are the buck- boost inverters that contain unique passive input circuits (impedance networks) and utilize the shoot-through of the inverter bridge to boost the DC input voltage.

ENERGY STORAGE DEVICE:

It provides the real power requirement of the DVR during compensation. It is responsible for the energy storage in DC form. Flywheels, lead acid batteries, superconducting magnetic energy storage (SMES) and super capacitors can be used as energy storage devices. Here in the form of DC supply from the energy storage system is given to the inverter.

BASIC OPERATION OF DVR:

The main function of the DVR is to inject proper series voltage to the grid in order to restore the load voltage level to its desired level.

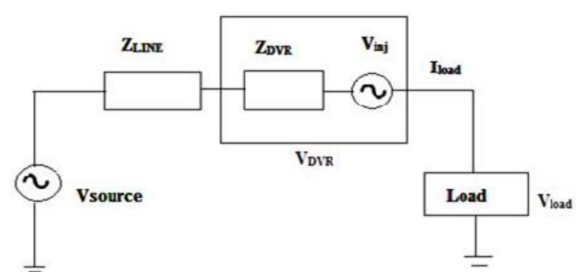

Figure 3: Equivalent circuit

As shown in figure3 the Z- impedances Zth depends on the fault level of load bus. When the system voltage Vth drops, DVR injects the series voltage VDVR through the injection transformer so that the desired voltage magnitude VL can be maintained. The series injected voltage of DVR can be written

As

VDVR = VL + Zth IL - Vth

VL : Desired load voltage magnitude

Zth : Desired load impedance

IL : Desired load current

Vth : System voltage during fault condition.

IV Z-SOURCE INVERTER

The inverter topology used in conventional DVR is both VSI and CSI. The VSI topology based DVR has buck type output voltage characteristics thereby limiting the maximum voltage that can be attained. Therefore the use of VSI topology alone in DVR systems with dwindling dc-link voltage in the energy storage device would pose a problem. The main disadvantage of CSI topology is it's basically a boost converter. For applications where a wide voltage range is required, extra circuitry has to be used to obtain the required voltage. However, this increases the circuit complexity and reduces the efficiency as well as the reliability [7]-[13].

The Z-source inverter has been an alternative to the existing inverter topologies with many inherent advantages [14]. The Z source inverter has an additional zero vector, the shoot-through switching state, which is forbidden in the traditional voltage and current source inverter [15]. Compared to VSI and CSI, Z source inverter is less affected by the EMI noise

In this paper, voltage type Z-source inverter based topology is proposed where the storage device can be utilized during the process of load compensation along with the use of buck boost property of the inverter. A series diode is connected between the impedance network is the combination of two inductors and capacitors. This combination network circuit is the energy storage are filtering element for the impedance source inverter. The impedance source inverter provides the second order filter. This is more effective to suppress voltage and current ripples. The inductor and capacitor requirement should be smaller compared to the traditional inverter [14].

When the inductors are small and approach zero, the impedance source network reduces to two capacitors in parallel and becomes traditional voltage source. Considering additional filtering and energy storage provided by the inductors, the impedance source network should require less capacitance smaller size compare with the traditional voltage source inverter.

Similarly when two capacitors are small and approach zero, the impedance network reduces to two inductor in series and becomes traditional current source. Therefore a current source inverter's inductor requirements and physical size is the worst case [14]. The simulation model of ZSI is shown in figure4.

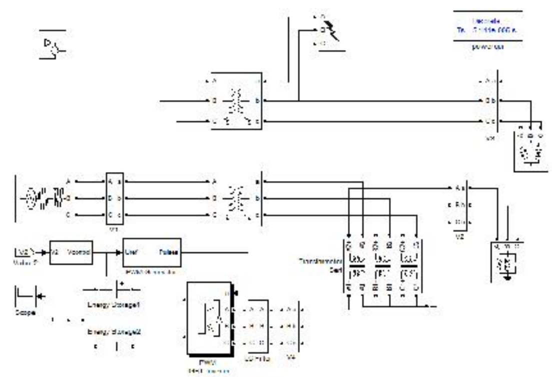

Figure 4: Z-source inverter

V CONVENTIONAL PI 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 can be adjusted by multiplying the error by constant KP, called proportional gain. The contribution from integral term is proportional to both the magnitude of error and duration of error. The error is first multiplied by the integral gain, Ki and then was integrated to give an accumulated offset that have been corrected previously.

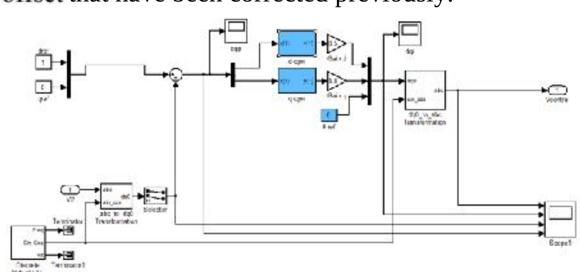

Figure 5 shows the control circuit designed in MATLAB/SIMULINK.

The output voltage 'V2' measured at the load is fed as the input to the PI controller. The same voltage is then transformed into dq term. The voltage sag is detected by measuring the error between the

dq voltage and the reference values. The d – reference is set to rated voltage while q – reference is set to zero. The dq components of load voltage are compared with the reference values and the error signal is then fed to PI controller. Two PI controller block are used for error signal – q respectively. For error signal – d, Kp is set to 40 and Ki is set to 154 while for error signal – q, Kp and Ki are set to 25 and 260 respectively. All the gains selected use to tune up the error signal ‘d’ and ‘q’ so that the signal is stable and well responses to system disturbances. The output of the PI controller are then transformed back to Vabc and then fed to PWM generator

VI FUZZY LOGIC CONTROLLER

The fuzzy logic controller does not require a mathematical model of the system process being controlled like conventional controllers. However, an understanding of the system process and the control requirements is necessary. The fuzzy controller designs must define what information data flows into the system (control input variable), how the information data is processed (control strategy and decision) and what information data flows out of the system (solution output variables) [16].

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 [17]. The proposed FLC scheme exploits the simplicity of the mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

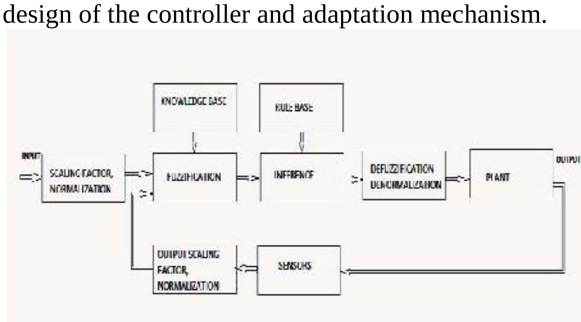

Figure 6: Fuzzy logic controller

The fuzzy logic control scheme (shown in figure 6) can be divided into four main functional blocks namely knowledge base, fuzzification, inference mechanism and defuzzification. The knowledge base is composed of database and rule base. Data base consists of input and output membership functions and provides information for appropriate fuzzification and defuzzification operations. The rule base consists of a set of linguistic rules relating the fuzzified input variables to the desired control actions. Fuzzification converts a crisp input voltage signals, error voltage signal (e) and change in error voltage signal (ce) into fuzzified signals 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 of fuzzified outputs to crisp control conditions using the output membership function, which in the system acts as the changes in the control input (u).

‘e’ / ‘ce’	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 1: Rule base for fuzzy logic controller

The set of fuzzy control linguistic rules is given in table 1. The inference mechanism in fuzzy logic controller utilizes these rules to generate the required output. The SIMULINK model of the proposed fuzzy logic controller is shown in figure 8.

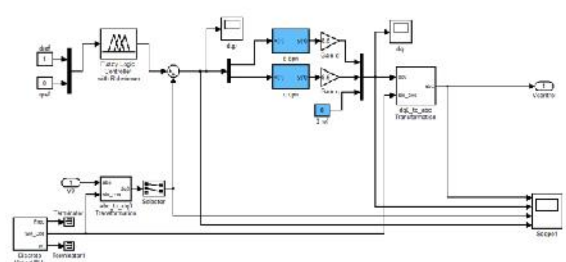

Figure 8: SIMULINK model of proposed FLC

VII MODELLING OF DVR

The modelling of DVR is done using MATLAB/SIMULINK platform. Here the modelled

DVR is installed into the power system in order to protect the sensitive load from voltage disturbances.
The performance of the DVR with proposed controller is evaluated using MATLAB/SIMULINK platform. The proposed DVR is connected at the load side of the distribution system.

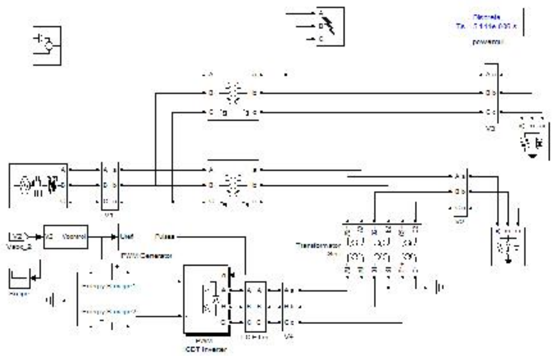

Figure 9: Simulation of DVR using Fuzzy controller

VIII SIMULATION RESULTS

The proposed power system consists of a three phase 440V/50Hz supply feeding two loads through distribution lines. A sudden three phase to ground fault generated in the system results in decrease of voltage. The above problem can be avoided by using load side compensation of DVR using Z – source inverter. The simulation is carried out on PI and fuzzy logic controller to check the validity of the scheme. Figure 10 shows the three phase voltage at the load point during three phase fault without DVR.

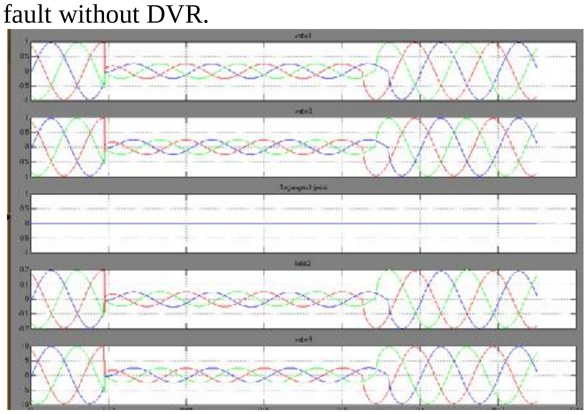

FIG 10 voltages and current measurement in a distribution system with out a DVR

In the above figure the five waveforms represent vabc1 voltage at the generating or at the source end shown in figure 9 Vabc2 voltage at the load end where the sensitive loads are connected and a DVR is used compensate the voltage sag/swell. Vabc4 voltage at the DVR. Iabc2 is the current drawn by the load2 .Vabc3 voltage measurement of the load 1 where the fault has occurred.

In figure 10 the phase to ground fault has been created at 0.02 s. voltage and current values are noted down as in this case load2 is not being protected as it suffers from voltage sag shown in figure 10.

(a) Operation of DVR with PI controller:

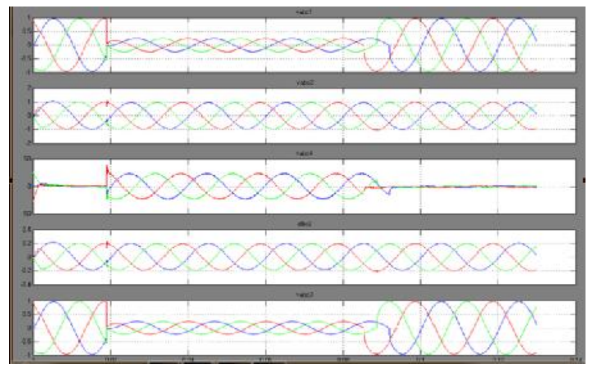

FIG 11 operation of DVR with PI controller

The performance of the DVR in a closed loop system along with PI controller effectively mitigates the occurrence of voltage sag and it is shown in figure 11. When the fault occurred at 0.02 sec the dvr generated the required amount of voltage to maintain the voltage profile stable in load2 when the fault got cleared at 0.08 sec. DVR voltage is reduced to its zero as shown in the simulated waveforms.

The DVR always generates or absorbs the required voltage to make a flat voltage profile near load 2

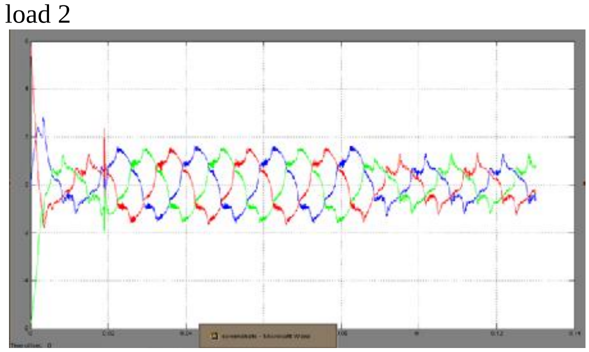

Fig 12 three phase voltage generated by the DVR

(b) Operation of DVR with fuzzy controller

From the figure 12 it is shown that the operation of DVR along with PI controller maintains the load voltage at 90%.

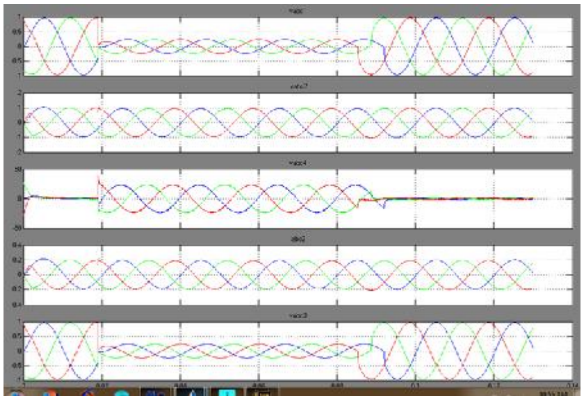

Fig 13 operation of DVR with fuzzy controller

When DVR and fuzzy controller are in operation the sensitive load is maintained at 98% as shown in figure 13. From the above discussion it is well understood that the DVR along with fuzzy controller gives better performance when compared to other controller.

IX CONCLUSION

DVR serves as an effective custom power device for mitigating voltage sag/swell in the distribution system. the proposed DVR injects appropriate voltage component in case of external disturbances to dynamically correct any deviation in supply voltage in order to maintain balanced and constant load voltage at nominal value. In this paper Z – source inverter based DVR along with fuzzy controller is modelled and the same is installed in the distribution system to provide required load side compensation. The simulation of the DVR along with the proposed controller is carried for a external phase to ground fault and the injections of the voltages by the DVR is simulated using MATLAB/SIMULINK platform. The simulation results shows that the performance of Z – source inverter based DVR along with fuzzy controller is better compared to PI controller.

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