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VOLTAGE QUALITY ENHANCEMENT IN DISTRIBUTION SYSTEMS USING DYNAMIC VOLTAGE RESTORER WITH ADAPTIVE FUZZY PI CONTROLLER

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Abstract: Distribution of quality power to the consumers is one of the greatest challenges in power industry. In practice, the presence of various nonlinear/sensitive loads disturbs the quality of power supplies in distribution system. Dynamic voltage restorer (DVR) is a custom power device which helps to improve voltage quality in distribution system. In this paper three single phase H-Bridge PWM inverters are used for each phase so as to reduce the voltage rating of the series converters. Synchronous Reference Frame (SRF) theory along with In-phase compensation and Adaptive Fuzzy PI is used as control strategy for DVR. The poor performance by conventional PI controller with fixed gains when the system parameters and operating condition changes is improvised using Adaptive Fuzzy PI controller. The proposed DVR with control strategy is able to improve voltage quality by mitigating voltage sag, voltage swell, phase shift and harmonic problems.

Keywords: Adaptive Fuzzy PI Controller; Dynamic Voltage Restorer (DVR); Synchronous Reference Frame Theory; Voltage quality.

I. INTRODUCTION

Quality and reliability of power supply are of great concern for utilities as well as consumers at various load centers. The generation of power in most well-developed countries is fairly reliable, but the quality of the supply is not so trustworthy. In recent years, the tremendous increase in linear (resistive devices -heaters, incandescent lamps etc, induction motors) and non-linear loads (computers, TV monitors, lighting, DC drives and AC drives etc) create considerable concern about power quality. These draw harmonic currents and have effects such as communication interference, loss of reliability, increased operating costs, equipment overheating, inaccurate power metering etc.

Voltage sag and voltage swells are two main power quality issues in the distribution side. According to IEEE standard 1159 voltage sag is defined as "a decrease in rms voltage between 10% to 90% at a power frequency for duration from 0.5 cycles to 1 min". Voltage sags are usually associated with system faults. Voltage sag can also occur in the system due to starting of large motors, energization of heavy loads or unbalanced loading. [1-3]

Voltage swell is defined as "an increase in rms voltage between 10 % to 90% at a power frequency for a duration from 0.5 cycles to 1 min". Voltage swell can be caused by energizing a large capacitor bank, removal of a large load or temporary overvoltage on healthy phases during a single-line-to-ground (SLG) fault and are characterized by their magnitude and duration. The voltage swell severity is a function of the location of fault, system impedance and grounding [1-5].

Various voltage quality improvement methods are available such as tap changing transformer, Capacitor banks, reactors etc. But the use of custom power devices is turned to be the most efficient, e.g. Flexible AC Transmission Devices (FACTS) can be used to improve power transfer capabilities and stability margins[16]. DVR is one such device which basically supplies the difference in pre-sag/swell and sag/swell voltage to the transmission line and maintains the pre-sag voltage. DVR is smaller in size and cost is less compared to Uninterrupted Power Supply (UPS) and other custom power devices such as DSTATCOM. There are different topologies for DVR with and without energy storage. In this work DVR topology with energy storage is chosen so that the deep voltage sag can be compensated and the voltage stress on the grid can be reduced [4-7, 10, 12].

The proportional-integral (PI) control scheme is commonly used in conventional control system due to its simplicity. But PI controller have various drawbacks such as unreliable operation in real time processing, settling time increases if K_p and K_i are not tuned properly, uninterrupted usage of controller with fixed PI parameters will not show required control performance when system parameters and operational conditions changes and thus reduce the life of DVR. These drawbacks can be overcome by using Adaptive Fuzzy PI controller where the gain of the PI controller is adjusted repeatedly with change in the control signal and thus provide robustness. A fuzzy logic system design does not require a mathematical model. [8-11,15,18]

In this paper we present DVR in which the control is based on Synchronous Reference Frame (SRF) theory along with In-phase compensation and Adaptive Fuzzy PI. The proposed DVR with control strategy is able to improve voltage quality by mitigating voltage sag, voltage swell, phase shift and harmonic problems and thus shows good performance in various operating conditions [8-9, 11]. The section 2 of this paper provides basic configuration and working of DVR. In section 3 pro-posed topology and control strategy is explained. Section 4 and 5 describes the simulation results and the conclusions drawn from the simulation studies.

II. DYNAMIC VOLTAGE RESTORER

Dynamic Voltage restorer is a series connected custom power device generally installed in a distribution system between the supply and the sensitive load feeders. DVR is used to protect the sensitive and critical loads by injecting the required amplitude, phase and harmonic content into the line. The main purpose of DVR is to protect the sensitive loads from voltage sag/swell occurring in the distribution network [19]. DVR also serves to reduce voltage transients, voltage harmonics compensation, and fault current limitation. Several circuit topologies and control schemes are available for the implementation of DVR [1-7,14]. The basic configuration of a DVR is shown in the Fig.1.

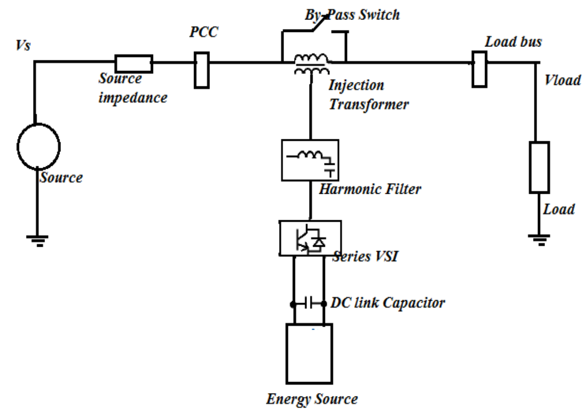

Fig. 1: Basic configuration of DVR

The general configuration of DVR includes the following components,

DC charging circuit/Energy storage Unit: The purpose is to supply necessary energy through DC link capacitor to VSI to generate injected voltage. The DC link capacitor provides ripple free stiff voltage to VSI. The various energy storage devices are Superconductive magnetic energy storage (SMES), Batteries, Ultra Capacitors, renewable energy coupled sources etc.

Voltage source inverter (VSI): This is used to convert DC voltage into sinusoidal volt-age at any required frequency, magnitude and phase angle.

Harmonic filters: Filter eliminates the voltage harmonics present in the generated voltage to a permissible level.

Injection Transformer: This connects DVR to distribution network transforms and couples the compensating voltage produced from VSI to the incoming supply. In addition, this also isolates the load from the system.

By-pass switch: This is to provide over current protection for the VSI. During faulty conditions the load current will exceed the permissible value then DVR will be isolated from the supply by using By-pass switch.

III. DYNAMIC VOLTAGE RESTORER WITH PROPOSED ADAPTIVE FUZZY PI CONTROLLER

3.1. Three Phase system with DVR

The system configuration of the proposed DVR with load is shown as in Fig.2. DC supply provides required power to VSI. Here three single phase H-Bridge PWM inverters are used for each phase so as to reduce the voltage rating of the series converters. DC side of DVR is connected to Battery Energy Storage to provide required power support. Each single phase H-Bridge inverters are connected to corresponding power line through single phase transformers.

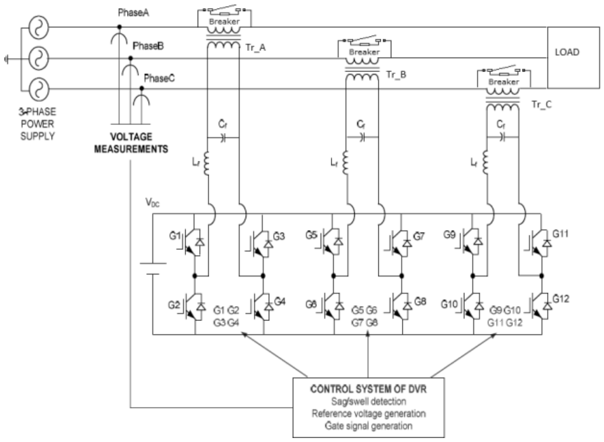

Fig. 2: Configuration of DVR

3.2. Proposed Adaptive Fuzzy PI Control Strategy

The key objective of the control system of DVR is to maintain constant voltage magnitude and frequency at the load side under various system disturbances. Various control methods have been reported for DVR which mainly provide voltage sup-port for voltage sag/swells. The increase in sensitive loads demands for harmonic and phase shift elimination [1-9]. In this paper synchronous reference frame with Adaptive Fuzzy PI controller is used to generate voltage reference for H Bridge based DVR. Compensation voltage is injected in Phase with the pre-fault voltage. The proposed control strategy is shown as in the Fig.3.

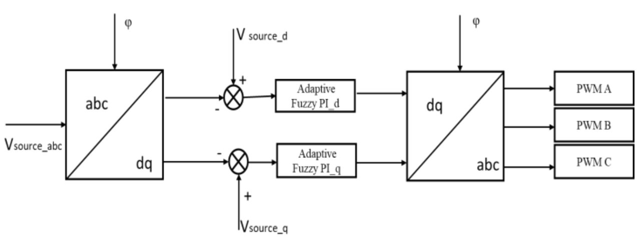

Fig. 3: Proposed Control Strategy of DVR

The phase lock loop (PLL) uses three-phase supply voltages to calculate the phase angle information (φ).In the SRF, the source voltage signals are transformed into the conventional rotating frame d-q [13]. The d-axis voltage is equal to nominal line-to-line voltage and q -axis voltage equals to zero when three phase supply voltages are sinusoidal and in balanced conditions. Hence the d-axis (Vsource_d *) and q axis (Vsource_q*) voltages are set to nominal line-to-line voltage and zero respectively. A voltage sag depth in d-q reference frame can be denoted as ΔVsource_d and ΔVsource_q, which is obtained as in equation 1 and 2

$$\Delta Vsource\_d = Vsource\_d^{*} - Vsource\_d \quad (1)$$

$$\Delta Vsource\_q = Vsource\_q^{*} - Vsource\_q \quad (2)$$

Adaptive fuzzy PI controllers are used for d-axis and q-axis to reduce the steady state error and to improve system stability. The inputs to the Fuzzy PI for d-axis is ΔVsource_d and its rate of change of error. The inputs to the Fuzzy PI for q- axis is ΔVsource_q and its rate of change of error. There are basically four essential segments in Fuzzy Logic Controller, namely; Knowledge base (Rule Base), Fuzzification block, Inference System and Defuzzification block. Fuzzy Logic Controller consists of 3 linguistic variables for input such as Z (Zero), PL (Positive Large), NL (Negative Large) and 5 linguistic variables for output gain are Z, NB (Negative big), PB (positive big), NS, and PS, NS (Negative small), PS (positive small). Membership function uses trapezium and triangular shape. The membership function for d-axis for error in voltage and rate of change of error in voltage and the output gains are shown in fig.4 to fig.6.

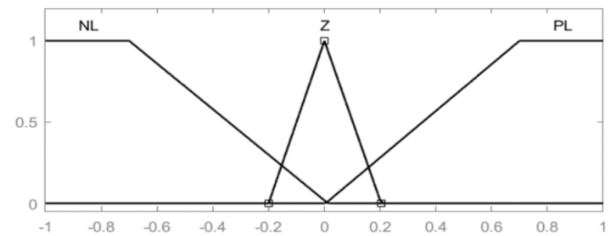

Fig. 4: Membership function of ΔVsource_d

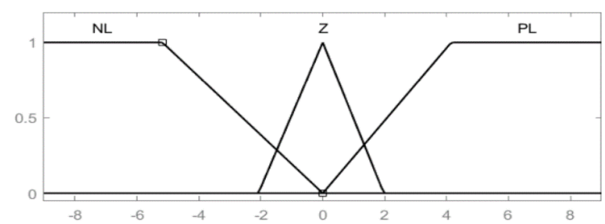

Fig. 5: Membership function of rate of change of ΔVsource_d

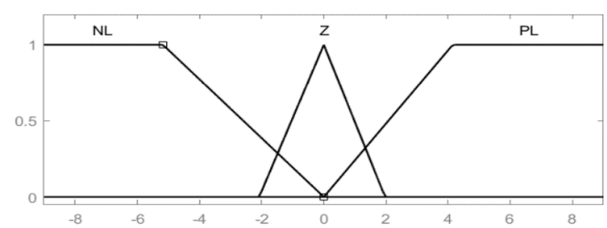

Fig. 6: Membership function for the output gain

Fuzzification is using done by Mamdani method and de-fuzzification using centroid method. The fuzzy control rules are shown as in Table 1. The d-q reference voltage generated from Adaptive Fuzzy PI controller is again transformed to abc frame by inverse d-q transformation. This reference voltage is used for PWM generation for the H Bridge inverters.

Table 1: Fuzzy Rule Base

ΔVsource_d/ rate of change of ΔVsource_d	NL	Z	PL
NL	NB	NS	Z
Z	NB	Z	PS
PL	Z	PS	PB

In phase compensation is used for the injection of Compensation voltage. Fig.7 shows in-phase compensation method. In this method injected voltage will be in phase with the source voltage irrespective of pre-fault voltage. The phase difference will exist between pre-fault load voltage and post-fault load voltage. But the compensation in voltage magnitude is satisfied. This method results in injection of low voltage during voltage unbalance.

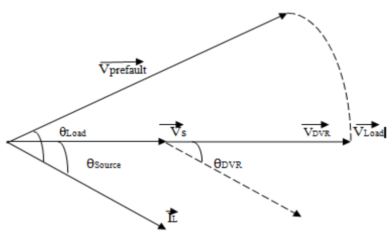

Fig. 7: In phase Compensation

IV. Voltage Quality Enhancement using DVR with Proposed Adaptive Fuzzy PI Controller

The effectiveness of DVR control strategy has been verified using MATLAB simulation. The system parameters for the simulation are shown as in the Table 2. Performance of DVR has been studied for various cases such as voltage sag, swell, harmonics and phase shift elimination for linear and non-linear loads. The various test cases are analyzed in this section are:

Case 1: Balanced Voltage Sag
Case 2: Unbalanced Voltage Sag
Case 3: Balanced Voltage Swell
Case 4: Unbalanced Voltage Swell
Case 5: Voltage Harmonics
Case 6: Phase Shift.

Table 2: System Parameters

Parameter	Value
Nominal Source Voltage (RMS line voltage)	220V
Resistive load	1kW
Inductive load	100VAR
Non-linear load (Diode)	1.5kW
DVR injection Transformer Ratio	1:1
System frequency	50Hz
Switching frequency	4kHz
DC Bus Voltage(VDC)	200V
LC filter	L_f=1mH, C_f= 10mF

A. Case 1

3-phase balanced sag voltage of 0.7 p.u is created at the source side from 0.02s to 0.1s. The source side voltage and load side voltage are shown in Fig.8. During normal condition the DVR is not operating, when there is a sag in voltage the DVR comes in action and compensate for voltage sag. Thus the load voltage is maintained at 1 p.u.

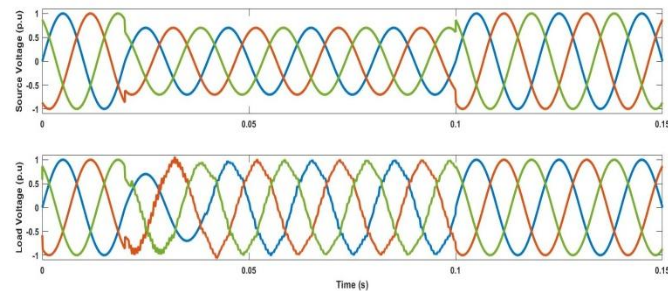

Fig. 8: Source Voltage and Load Voltage for a balanced sag voltage of 0.7 p.u

B. Case 2

Single phase sag voltage of 0.7 p.u is created at the source side on phase 'A' from 0.02s to 0.1s. The source side voltage and load side voltage are shown in Fig.9. The load voltage is maintained at 1p.u during the sag.

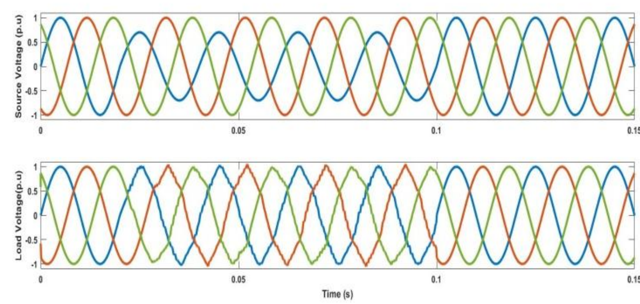

Fig. 9: Source Voltage and Load Voltage during an unbalanced sag voltage of 0.7 p.u on Phase A

C. Case 3

Balanced three phase swell in voltage of 1.2 p.u is created at the source side from 0.02s to 0.1s. The source side voltage and load side voltage are shown in Fig.10. The load voltage is maintained at 1p.u.

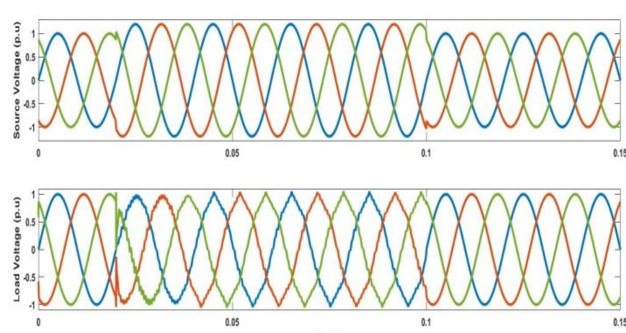

Fig. 10: Source Voltage and Load Voltage during a balanced voltage swell of 1.2 p.u.

D. Case 4

Single phase swell of 1.2p.u is created at the source side on phase 'A' from 0.02s to 0.1s. The source side voltage and load side voltage are shown Fig.11. The load voltage is maintained at 1p.u even during voltage unbalance.

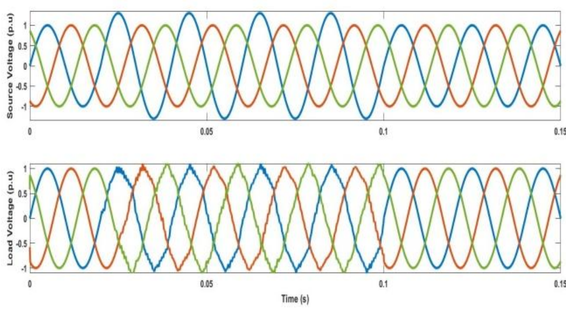

Fig. 11: Source Voltage and Load Voltage during an unbalanced voltage swell of 1.3 p.u on Phase A

E. Case 5

Source voltage with balanced voltage sag of 0.8 p.u is imposed with 3rd order harmonics in phase ‘A’ and ‘B’. The Source voltage and load voltage are shown in Fig.12. DVR is able to eliminate the effects of harmonics and maintains voltage at1 p.u on load side.

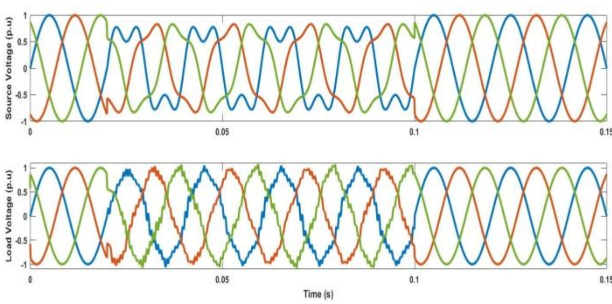

Fig. 12: Source voltage and load voltage during balanced voltage sag with 3rd order harmonics

F. Case 6

An unbalanced source voltage is phase shifted by 30deg on phase A and 45 deg on phase B. The source voltage and load voltage are shown in Fig.13. DVR is able to eliminate the effects of voltage unbalance and phase shift and load voltage is maintained at 1 p.u.

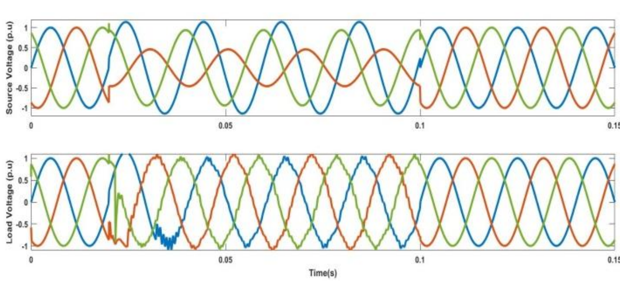

Fig. 13: Source Voltage and Load Voltage during unbalanced source voltage and phase shift on Phase A and Phase B.

V. CONCLUSION

This paper focused on modelling and simulation of DVR to mitigate voltage quality problems such as voltage sag, swell, harmonics and phase shift. An adaptive Fuzzy PI controller along with the synchronous reference frame theory and in-phase compensation increases the reliability and stability of the distribution sys-tem. Simulation results shows that proposed control strategy adapted for the DVR performs satisfactorily in injecting the appropriate voltage component to correct any anomaly in the supply voltage in the case of voltage sag, swell, harmonics and phase shift problems under balanced and unbalanced conditions even for nonlinear loads. This study also gives useful knowledge for the researchers to develop and design a DVR for voltage disturbances in electrical system. DVR along with Adaptive fuzzy PI for voltage transient reduction and fault current limitations will be of future scope.

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