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Alleviation of Power Quality Tribulation Using Series Active Power Filter

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Abstract: **This paper presents a control strategy Synchronous Reference Frame Theory (SRF) for three phase Dynamic Voltage Restorer (DVR) using MATLAB/SIMULINK. DVR is a three phase converter coupled with a DC Capacitor, which acts as Series Active Power Filter (SAPF). Since, power quality focuses on distribution side, the quality of power interns of voltage should not distorted by different faults. Hence, DVR plays an important role with the control strategy to make DVR active during fault conditions. Simulation results are carried out for LLL-G (Voltage Sag), L-G (Voltage Unbalance), increase in supply voltage (Voltage Swell), and distortion fluctuations in voltage (Voltage flickering) using MATLAB/SIMULINK**

***Index Terms*— Series Active Power Filter (SAPF), Dynamic Voltage Restorer (DVR), Synchronous Reference Frame (SRF), Voltage Sag, Voltage Swell, Voltage Un-Balance, Voltage Flickering, Total Harmonic Distortion (THD)**

I. INTRODUCTION

Power Quality is obtaining increasing attention by the utilities as well as both industrial and commercial electrical consumers [1]. Electronics systems operate properly as long as the supply voltage stays within a consistent range. There are several types of voltage fluctuations that can cause the systems to malfunction, including surges, spikes, sags, harmonic distortion & momentary disruptions. Among them, voltage sag, voltage swell, voltage un-balance, voltage flickering are the major power quality problem [2].

Voltage distortions and fluctuations are frequently encountered in the weak grid network systems. The distorted currents cause non sinusoidal voltage drops as a result the network voltages become distorted. On the other hand, voltage sag, voltage swell, voltage un-balance, voltage flickering problems are usually caused by short circuit current flowing into a fault. Voltage sag & swell are defined as a sudden reduction or rise of grid voltage which may vary from 10% - 90% during sag and 110% - 180% during swell of its normal value [3].

Typical loads include variable speed drives, motor starter contacts, control relays and programmable logic controllers. Such an unplanned stoppage can cause the load to take a long time to restart and can lead to high cost of loss production [2].

A Dynamic Voltage Restorer (DVR) is a power electronic converter based device that has been designed to protect critical loads from all supply side disturbances other than outages. It is connected in series with a distribution feeder and is capable of generating or absorbing real and reactive power at its AC terminals. The basic principle of DVR is simple by inserting a voltage of required magnitude and frequency, the DVR can restore the load side voltage to the desired amplitude and waveform even when the source voltage is un-balanced or distorted. Usually a DVR is connected to protect sensitive loads during faults in supply system [4].

The DVR was installed in North Carolina, for the Bug Manufacturing industry [5]. Another was installed to provide service to a large dairy food processing plant in Australia [6]. A DVR is usually built round a DC – AC power converter that is connected in series with a distribution line through three single phase transformers. The DC side of the converter is connected to a DC energy storage device.

Among the several APF control methods, SRF based control method I s one of the most conventional and the most practical methods [7-10]. SRF method presents excellent characteristics but it requires decisive PLL techniques. This paper presents a new technique based on the SRF method under balanced and distorted load conditions.

Synchronous reference Frame theory (SRF) is used to generate the reference voltage signals for the series active power filter which converts the three phase into two phase stationary co-ordinates and therefore transferred into synchronous rotating frame using Phase Locked Loop [11].

The system configuration of Dynamic Voltage Re-Storer is explained in section – II. The control system for proposed system is explained in Section – III. Simulation results are depicted in Section – IV. Performance is evaluated in Section – V.

II. SYSTEM CONFIGURATION

The block diagram representation of DVR is shown in fig.1 and MATLAB simulation model of DVR connected to three phase, 415V (1 P.U) distribution system is shown in fig. 2

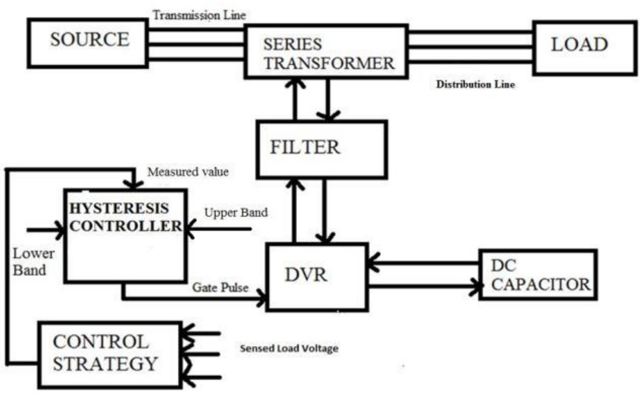

Fig.1 Block Diagram

The sensitive loads include a linear RL Load, a Non-linear Rectifier RL load, Sensitive Active load (DC Motor). A series transformer is connected to the system via filters is shown in fig. 2.

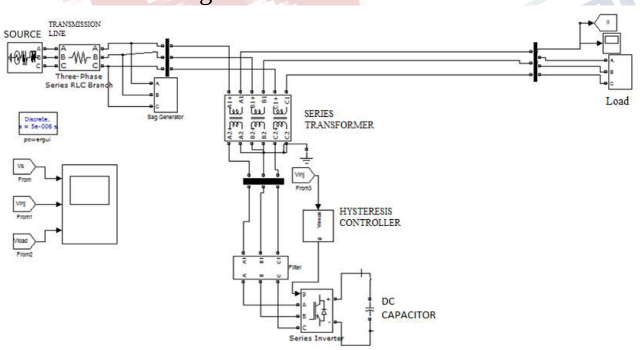

Fig.2 DVR Connected to Distribution System

The Point of Common Coupling (PCC) Voltage is considered as the input supply for the other sensitive loads connected at PCC through DVR. The DVR should be controlled in making the voltage at the load bus always sinusoidal with desired magnitude. Therefore, the voltage injected by SARF must be equal to the difference between PCC voltage and desired load voltage. Hence, the SAPF acts as control voltage source.

The series injected voltage should be in-phase with PCC voltage to compensate voltage sag, voltage unbalance, voltage flickering and out-of-phase with PCC voltage to compensate voltage swell. The system parameters are shown in Table I.

Table I. System Parameters

System Parameters	**Values**
System Voltage	415V[L-L rms]
System Frequency	50Hz
Linear Load	50+j18.8 Ω/phase
Non-Linear Load [Rectifier Fed]	50+j3.14 Ω
Dynamic Load	6+j0.0314 Ω
DC-Capacitor	0.05F,700volts

III. CONTROL STRATEGY

The control strategy is basically the way to generate reference signal for SAPF, The DVR should be able to compensate any Power Quality problem depending on its ability by following the reference signals. The control system of SAPF is used to control the series voltage.

The proposed SRF based DVR control algorithm can be used to solve the power quality problems related with voltage sag, voltage unbalance, voltage swell, voltage flickering at the same time for SAPF. In the proposed method SAPF controller calculates the reference value to be injected by the switches, comparing the positive sequence component of source voltage with load side line voltage. The SAPF reference signal generation algorithm is shown in fig.3.

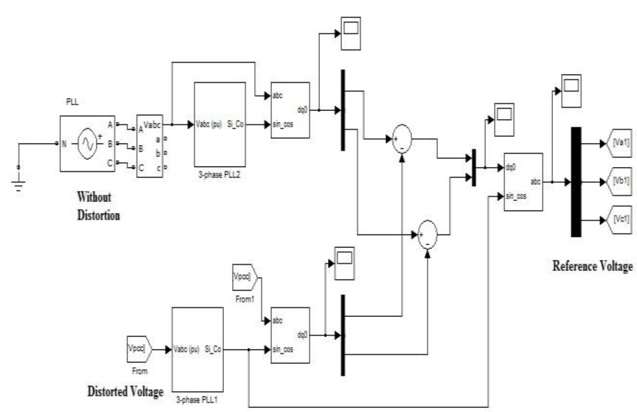

Fig. 3 SAPF Reference Signal Generation

The supply voltage is Vabc are transforms into d-q-0 using transformation matrix T is given below in addition the modified Phase Locked Loop (PLL) conversion is used for reference voltage calculation.

A separate programmable voltage source without distortion is designed and compared with the sensed load voltage. Hence, error voltage is generated and by use of inverse transformation matrix (T-1) the axis changes from d-q-0 to a-b-c.

The produced load reference voltage are compared with the measured voltages to generate the switching signals for SAPF using Hysteresis Voltage Controller BY appropriate Upper Band (UB) and Lower Band (LB) to compensate all voltage related problems such as voltage sag, voltage swell, voltage unbalance, voltage flickering.

IV. SIMULATION RESULTS

The Effective performance of DVR with SRF connected to a three phase distribution system is evaluated by means of simulation results in presence of sensitive linear, non-linear, active loads. The percentage Total Harmonic Distortion (THD) values of voltage at the terminals of sensitive load (Referred as load voltage (VL)).

THD values are restricted within 5% after compensation using SAPF under voltage sag, voltage swell, voltage unbalance, voltage flickering. In same case active load is taken into consideration under the same voltage related faults and is it being restricted with in the THD limits. The simulation results are shown for 0.1s duration (0.01s - 0.1s).

A. Linear Load And Non-Linear Load Conition

The steady state performance of DVR during fault conditions with proposed controller under linear and non-linear load condition is analyzed. A three phase to ground fault LLL-G (Voltage sag), LL-G fault (voltage unbalance), voltage flickering is simulated during t=0.03s-0.07s depicted in fig. 4 and SAPF provides compensation by injecting in-phase voltage is introduced into the system by increasing the source voltage in all three phases during t=0.03s-0.07s .Where SAPF provides the required compensation by injecting out-of-phase.

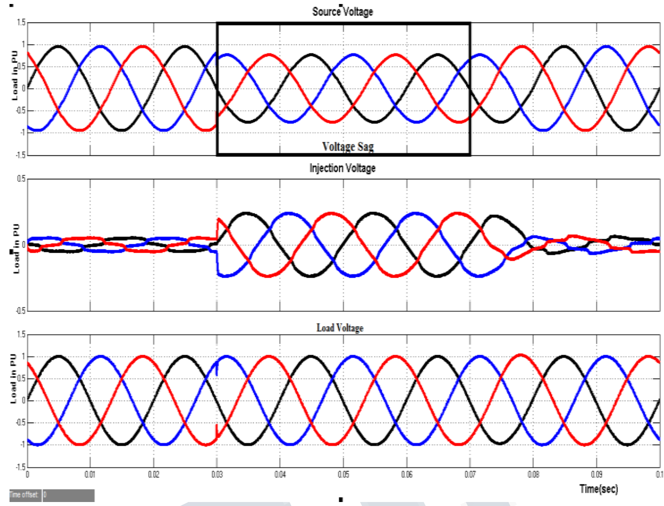

Fig. 4 Simulation Results of Voltage Sag using MATLAB

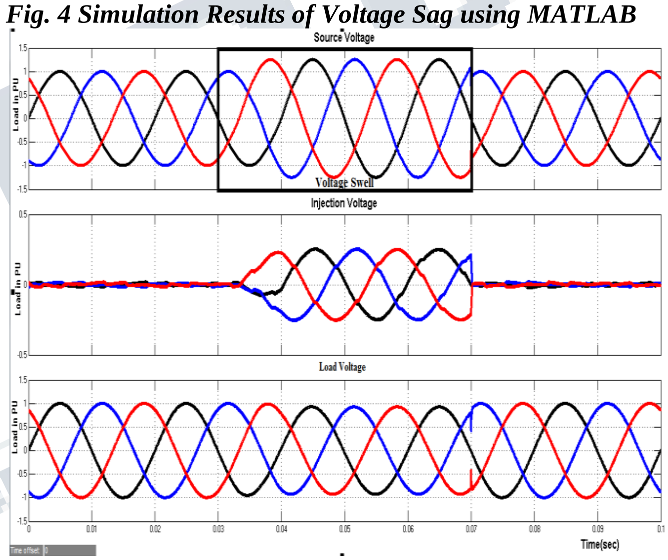

Fig. 5 Simulation Results of Voltage Swell using MATLAB

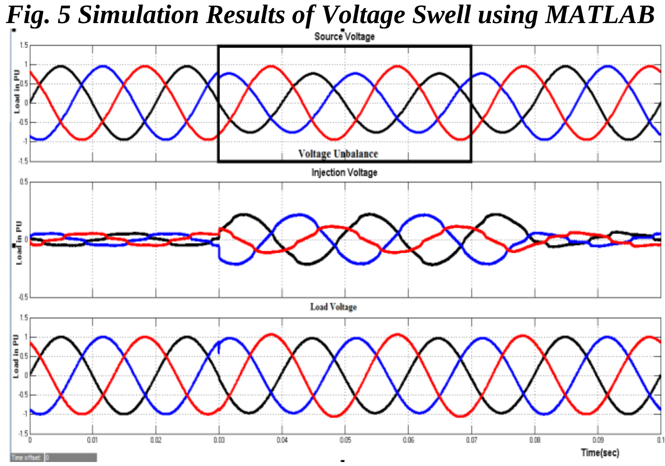

Fig. 6 Simulation Results of Voltage Unbalance using MATLAB

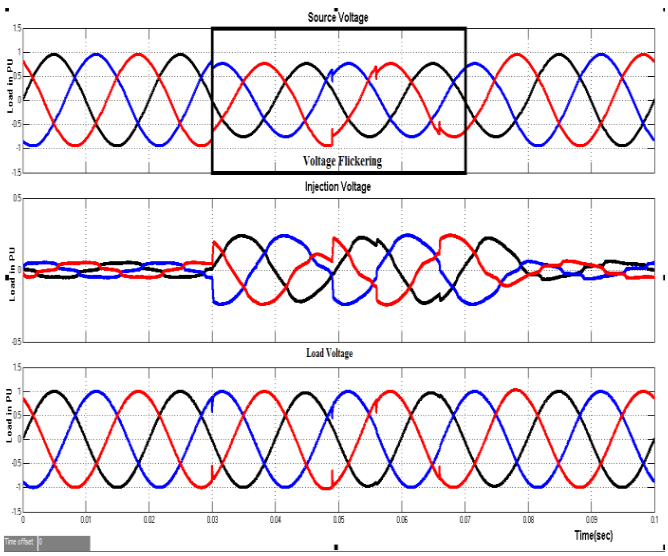

Fig.7 Simulation Results of Voltage Flickering using MATLAB

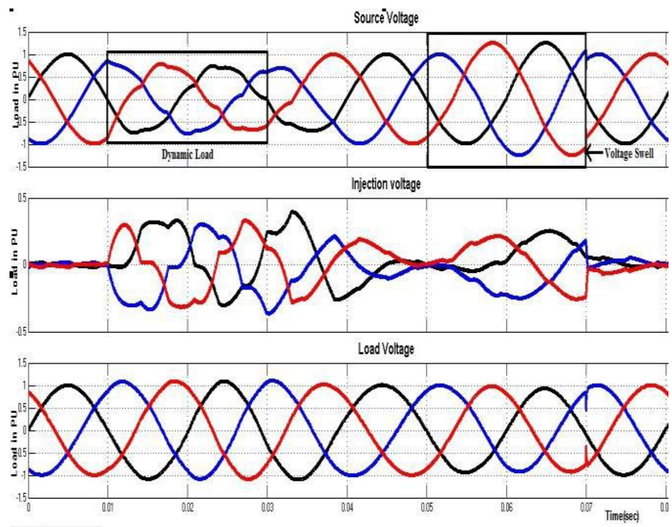

Fig. 9 Simulation for Active Load under Voltage Swell.

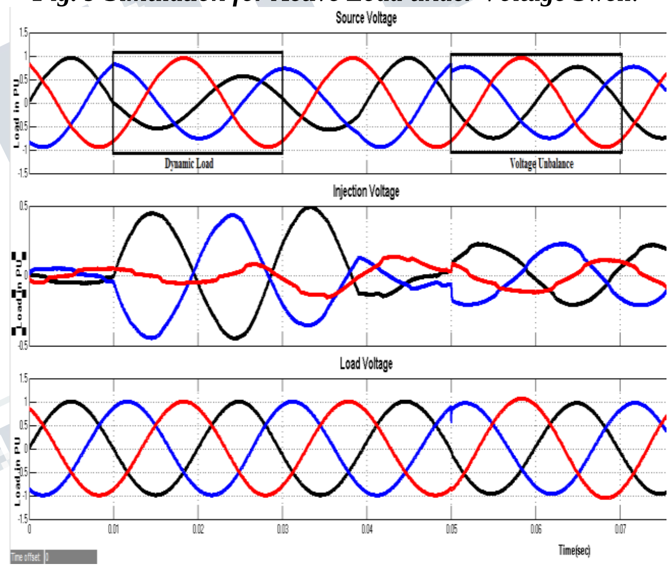

Fig.10 Simulation Results for Active Load under Voltage Unbalance

B. Active Load Condition

An RL load fed by an uncontrolled rectifier with DC motor is connected as an active load in the proposed system. The DVR with the proposed control scheme is able to reduce the voltage harmonic from 13.72% and 4.93% values through SAPF which is restricted within the acceptable limit of IEEE 519 standard. It is clear from fig. 8, fig. 9, fig. 10, fig. 11 that distorted voltage due to active load under LLL-G fault, LL-G fault; distortion fault condition at the load voltage becomes sinusoidal, when the DVR comes into operation.

The performance of DVR with active load, in presence of linear, non-linear conditions in proposed controllers is presented in the below figures.

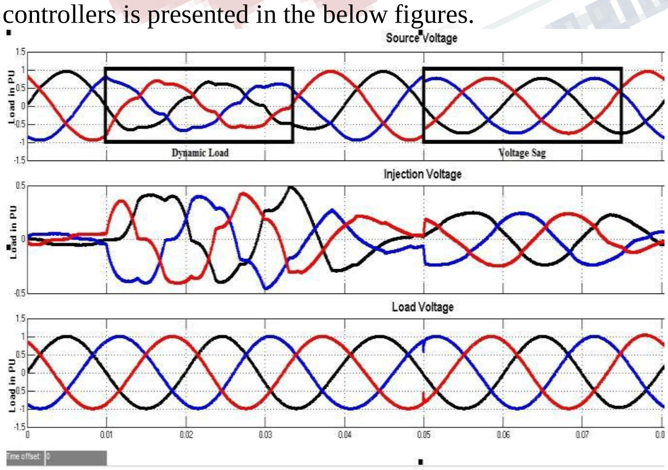

Fig. 8 Simulation Result for Active load under Voltage Sag.

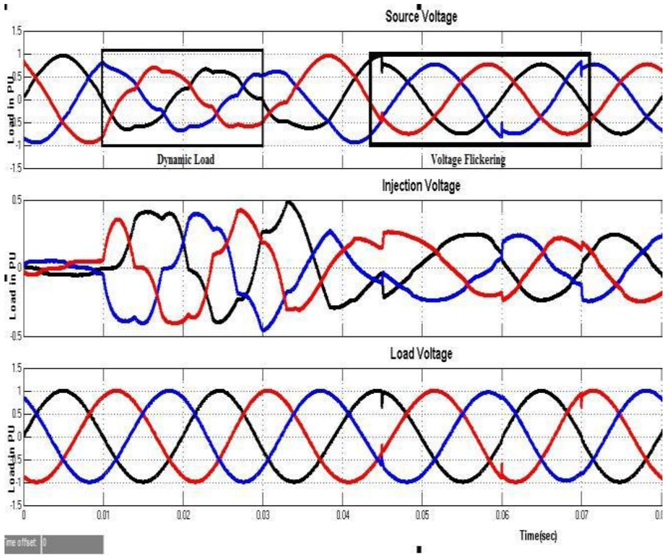

Fig. 11 Simulation Results for Active Load under Voltage Flickering

V. PERFORMANCE EVALUATION

The effectiveness of Synchronous Reference Frame Theory (SRF) in alleviation the power quality tribulations by Dynamic Voltage Restorer under linear, non-linear, and active load conditions can be evaluated interns of their Total Harmonic Distortion (THD) in load voltage with SRF the SAPF effectively compensates the power quality issues such as voltage sag, voltage swell, voltage unbalance, voltage flickering with voltage sag under active load.

The percentage of THD for load voltage through PCC is also well maintained within the IEEE power quality standards for linear load, non-linear load and active load is listed with the THD compensation percentage in Table II.

Table II. THD Compensation

FAULTS	LINEAR & NON – LINEAR LOAD		ACTIVE LOAD	
	Before Compen-sation (%)	After Compen-Sation (%)	Before Compen-Sation (%)	After Compen-Sation (%)
Voltage Sag	5.45	**0.37**	13.72	**4.93**
Voltage Swell	6.72	**2.25**	11.18	**4.5**
Voltage Un-Balance	5.78	**0.58**	4.67	**2.15**
Voltage Flicker	5.56	**1.17**	13.48	**4.57**

VI. CONCLUSION

The Dynamic Voltage Restorer is SAPF device to unify the treatment of several power quality problems. The SRF theory is adopted to control the SAPF connected to a distribution system with various loads is explained and demonstrated using simulation study. The SRF control employs hysteresis voltage controller for SAPF extensive simulation study is carried out using MATLAB/SIMULINK to mitigate various power quality problems. The performance evaluation is carried out in terms of power quality compensation in case of linear, non-linear and active loads condition. The performance of SAPF is found to be effective with SRF control under active load condition. Also the percentage for THD of load voltage is always maintained with the IEEE 519 standard.

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