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Synchronous Reference Frame Control Algorithm Based Four -Leg Inverter DSTATCOM For Power Quality Improvement

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Abstract— This paper presents a three-phase, four-wire, four-leg voltage source inverter and its controller for a distribution static compensator (DSTATCOM) application. The DSTATCOM is operated in current controlled mode by a suitable control strategy, which inject compensating current in order to achieve harmonic compensation, load balancing, power factor correction and neutral current elimination. The four-leg compensator topology is controlled by synchronous reference frame (SRF) based control algorithm. In order to calculate harmonics, current imbalance and reactive power of the load currents are extracted and transformed in to dq0 variables. By using a low pass filter the fundamental active power current can be separated from d axis current. Reactive current can be extracted from q axis current and neutral current from zero axis current. The commanded current of controller consist of d-axis harmonics current, q axis current and zero axis current. These components are regulated by a PI controller with a feed forward utility voltage control. A sinusoidal PWM is used to generate triggering pulses for the inverter switches .The proposed system and controller is validated using MATLAB/simulink. The simulation results expresses a low THD and a perfect compensation.

Keywords— Distribution static compensator (DSTATCOM), SRF(synchronous reference frame), total harmonic distortion(THD), Dynamic voltage restorer(DVR), unified power-quality conditioner(UPQC)

I. Introduction

Nowadays power quality has become a major issue of concern for power generating companies. Distribution systems are facing severe power-quality (PQ) problems, such as poor voltage regulation, high reactive power and harmonics current burden, load unbalancing, excessive neutral current, etc[1]. The source voltage of distribution system are also facing problems such as harmonics, flicker, low power factor etc. Reactive power compensation is an important issue in control of distribution systems. The reactive current increases the distribution system losses, reduces the system power factor, shrink the active power capability and can cause large amplitude variations in the load-side voltage.

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The conventional methods for reactive power compensation are use of capacitor banks, new parallel feeders and Uninterruptible Power Supply (UPS). However, the power quality problems are not completely solved due to uncontrollable reactive power compensation and high cost of new feeders and UPS. Normally custom power devices are used for power quality improvement in distribution system. The distribution static compensator (DSTATCOM) is proposed for compensating PQ problems in the current, and the dynamic voltage restorer (DVR)is used for mitigating the PQ problems in the voltage while the unified power-quality conditioner (UPQC) is proposed for solving current and voltage PQ problems[2].

The DSTATCOM has emerged as a promising device to provide not only PQ problems in current but also for a host of other power quality solutions such as voltage stabilization, flicker suppression, power factor correction and harmonic control. Three phase four wire distribution system is used for supply of single phase loads. The typical loads may be computer loads, office automation machines, lighting ballasts, adjustable speeds drives (ASDs) in small air conditioners, fans, refrigerators, and other domestic and commercial appliances, etc., and generally behave as nonlinear unbalanced loads. These loads may create high input current harmonics and neutral current. Neutral current contains triplen harmonics current. The zero sequence neutral current obtains a path through the neutral conductor. The unbalanced single phase load also results in serious zero sequence fundamental current. The total neutral current is the sum of the zero-sequence harmonic component and the zero-sequence fundamental component of the unbalanced load current, and this may overload the neutral conductor of the three-phase four-wire distribution system. In extreme cases the neutral current causes damage to neutral conductor and the transformer[3]. The three- phase three wire converter based DSTATCOM cannot adequately reduce or eliminate line harmonics in this situation. To eliminate this problem three phase four wire converter based DSTATCOM have been proposed.

The algorithms used to extract the three-phase compensation reference currents are based on the SRF (synchronous reference frame). SRF-based algorithms are used to extract the three-phase compensation reference currents[4]. A feed forward voltage controller is used to convert reference current to voltage for PWM based pulse generation. The new carrier-based sinusoidal PWM is used for the generating the gate signal to the switches (MOSFETS) of the inverter [5].

II. FOUR-LEG INVERTER DSTATCOM

The four-leg DSTATCOM, shown in Fig. 1, is a three-phase four-wire voltage source PWM inverter. It is shunt-connected through three inductors to a three-phase unbalance industrial load with connected neutral, which produces current type harmonics and requires reactive power and zero-sequence load current.

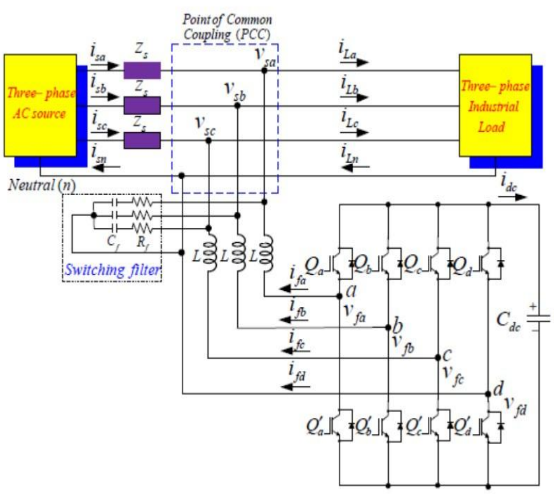

Figure.1 schematic diagram

The three principal legs that are connected to each phase are controlled mainly for harmonics and reactive power compensation. The aim of the fourth added leg is to cancel the zero-sequence current in the utility. Under these considerations, the mains currents would become practically sinusoidal and in phase with the corresponding phase voltages.

III. DESIGN OF DC LINK CAPACITOR

The parameters of the Voltage source converter (VSC) need to be designed carefully for better tracking performance. The most important parameters that need to be taken into consideration while designing conventional VSC are dc-link voltage V_{dc} , dc storage capacitor C_{dc} interfacing inductance L_f , and switching frequency f_{sw} . A detailed design procedure of Voltage source converter (VSC) topology and the parameter are chosen based on the equation 4.1. The dc-link capacitor value is given by

$$C_{dc} = \frac{(2X-(X/2))nT}{((1.8V_m)^2-(1.4V_m)^2)}$$

Where V_m is the peak value of the source voltage, X is the KVA rating of the system, n is the number of cycles, and T is the time period of each cycle.

IV. SIMULATION BLOCK DIAGRAM

The proposed system is composed of a 25kV primary distribution system which is stepped down by a delta-star transformer to 400V. Secondary distribution is through a three-phase four-wire distribution line. At load side, unbalanced nonlinear load and switching rectifier loads which are switching at the instant of 3 sec are connected. The D-STATCOM is connected at the point of common coupling. The performance of the system is checked under nonlinear, unbalanced and switching load conditions, where the specification of the loads chosen is given in table I and the Simulink blocks of switching loads is shown in fig 3. The overall simulation diagram is shown in fig 2. The simulation parameters are given in table II

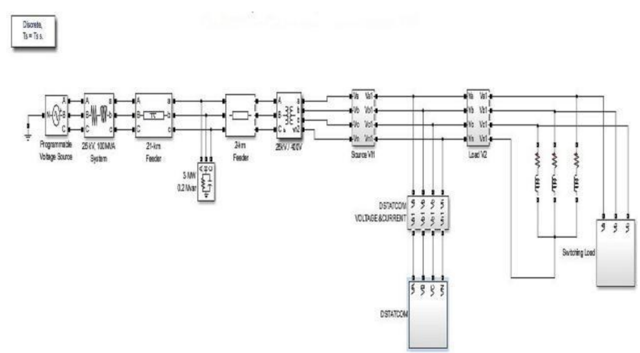

Figure. 2 Simulation block diagram of proposed system

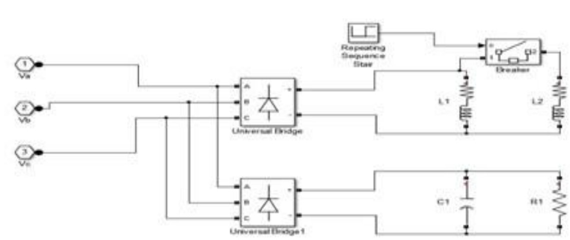

Figure. 3 Switching load

TABLE. I .LOAD SPECIFICATIONS

Nonlinear static loads(RL)	A phase:250 KW,60 Kvar B phase:200KW,70 Kvar C phase:300KW,100Kvar
Nonlinear switching loads(RL&RC)	Load L1 R=50Ω L=500mH Load L2 R=100Ω C=100μF

V.DSTATCOM CONTROLLER

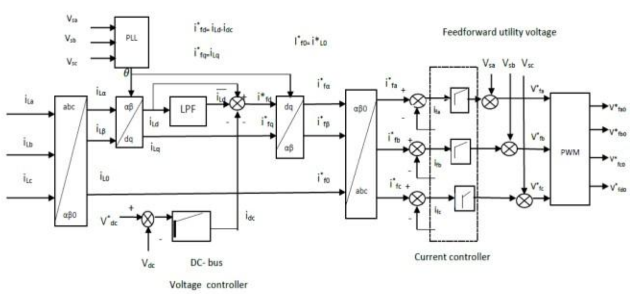

Figure. 4 Controller block diagram

Figure. 4 shows the controller block diagram of four-leg inverter DSTATCOM and figure 5 shows the MATLAB/Simulink block diagram of controller.

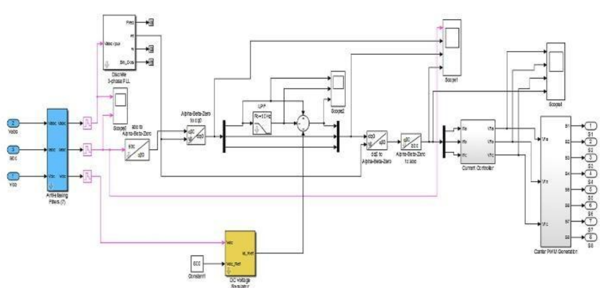

Figure. 5 MATLAB/Simulink block diagram of controller

VI. DC-BUS VOLTAGE CONTROLLER

The DC-bus voltage is expected to be constant in steady state, then a proportional integral (PI) can be used as the DC-bus voltage controller. The reference voltage for DC voltage controller is set as 800V.

VII. SRF-BASED ALGORITHM APPLIED TO FOUR- LEG TOPOLOGY

In this method, the load currents (i_{La}, i_{Lb} , i_{Lc}) are measured and transformed from a three-phase stationary reference frame (abc) into two-phase stationary reference frame αβ0. Thus, the current quantities of the ab -axes can be transformed into two-phase synchronous reference frame (dq -axes) Now, the dq currents are composed by dc and ac parts. A phase locked loop (PLL) is used to get the utility voltage information such as frequency.

The dc part represents the fundamental load currents (active and reactive), and the ac part represents the harmonic components that can be extracted using a low pass pass filter (LPF), as implemented in Fig. 5. The d-axis current id represents the sum of the fundamental active current (id_{dc}) and a parcel of the load harmonic current (id_h). By filtering id, the current dc id is obtained, which represents the fundamental active load currents in the synchronous frame. Thus, the ac component h id is obtained by subtracting the dc id component of the total current in d- axis (id), which allow to achieve the harmonic parcel of the load current. In the synchronous frame the q-axis current (i_q) represents the sum of the fundamental reactive load currents and part of the load harmonic currents. It can be totally used to calculate the reference compensation currents.

VIII. CURRENT CONTROLLER

In order to control the D-STATCOM currents and reduce the PI gain of current controllers, the feedback and feed-forward control are introduced. Fig 6 shows the a phase current control loop.

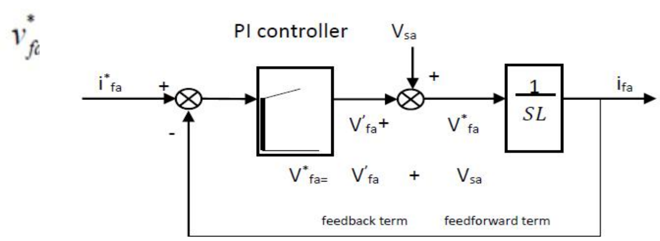

Figure 6 current controller

IX. FOUR-LEG CARRIER PWM FOR INVERTER

For the space vector PWM of the four-leg inverter, by considering all four pole voltages including that the neutral phase simultaneously in the determination of zero-sequence voltage, a new and natural standpoint for the carrier-based PWM have been proposed in[5] . The commanded pole voltages are given by the equations (1) and (2).

X. SIMULATION RESULTS

The system configuration shown in Fig. 1 is considered for simulation. The simulation study is carried out using MATLAB/ SIMULINK. The system parameters are given in Table II

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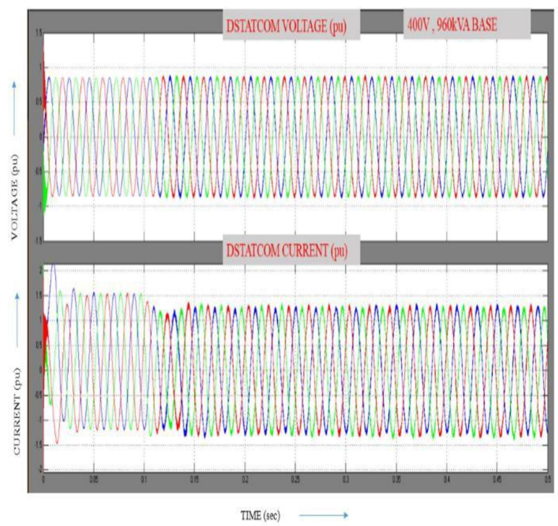

Figure 7 DSTATCOM voltage and current

It is noted from figure 7 that DSTATCOM voltage and current are sinusoidal, which is inphase with utility voltage and current.

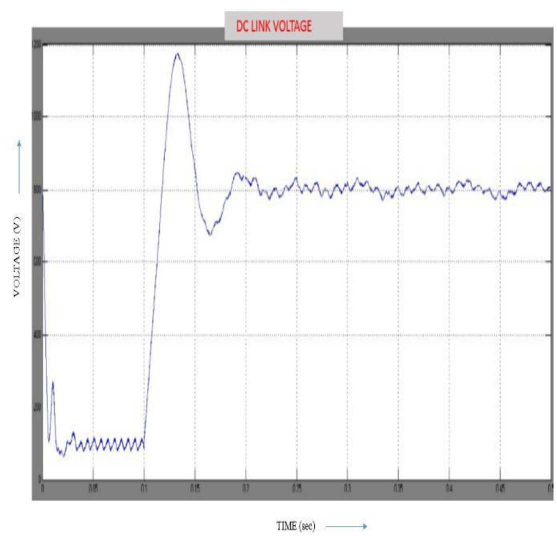

Figure 8 DC link capacitor voltage

It is noted from fig.8 that with a PI controller the dc link capacitor voltage is able to maintain at 800V, which is give as the reference value.

Fig.9 shows the reference voltage waveforms obtained from simplified PWM algorithm for four leg converter for each phase and neutral line.

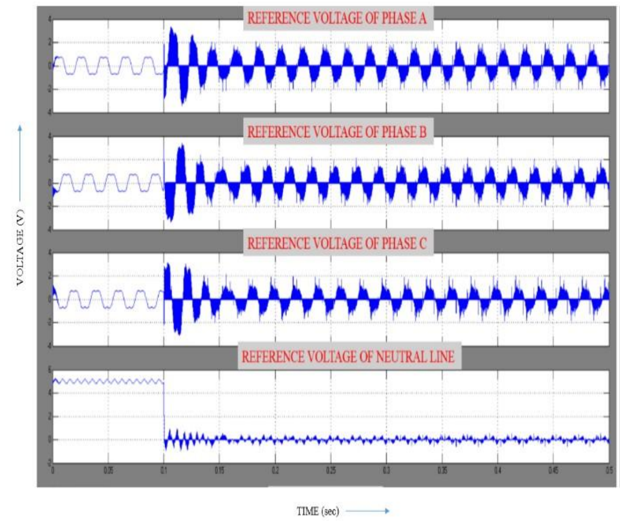

Figure 9 The reference voltage waveforms of each phase

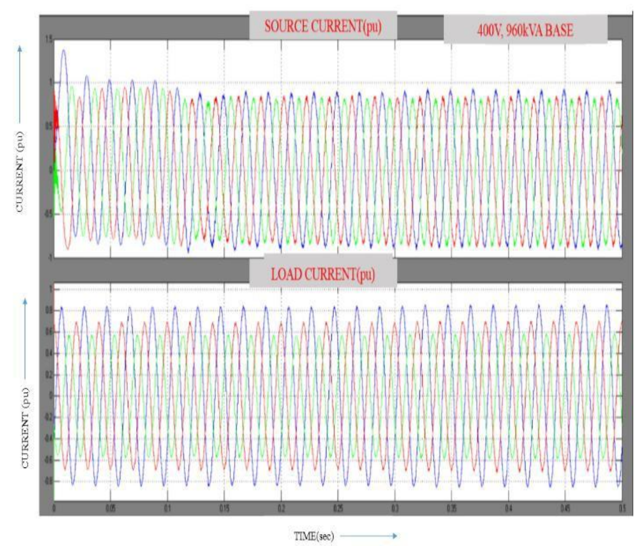

Figure 10 Source current and load current with DSTATCOM connected

From figure 10 it can be noted that with DSTATCOM connected the utility line currents are practically sine waves despite of the load currents are heavily unbalance and harmonic waveforms. Which shows that under heavily unbalanced condition also load balancing is done.

From figure 11 it can be noted that the voltage and current at each phase are almost in phase. Which implies that a unity power factor is maintained at PCC.

From figure 12 It can be noted that the reactive power supplied by the source is less even when that load side reactive power is higher. This shows that the DSTATCOM is providing reactive power compensation at PCC

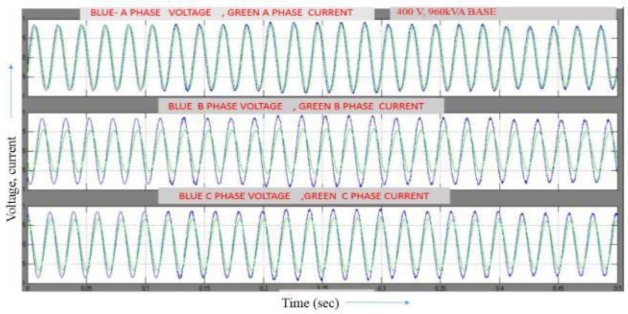

Figure 11 Voltage and current of each phase at PCC

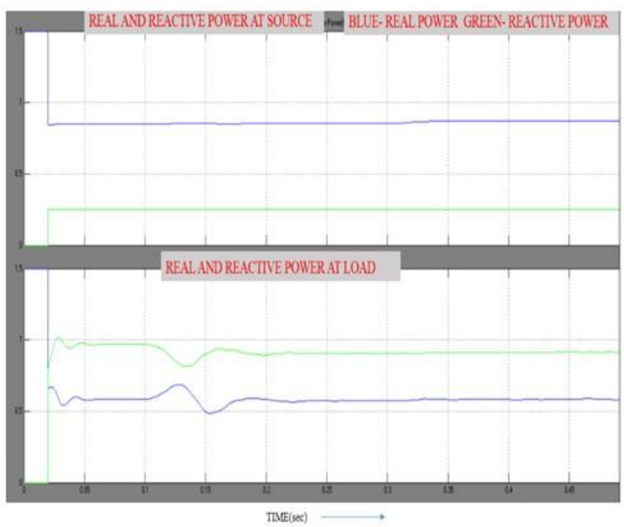

Figure 12 Real and reactive power at source and load

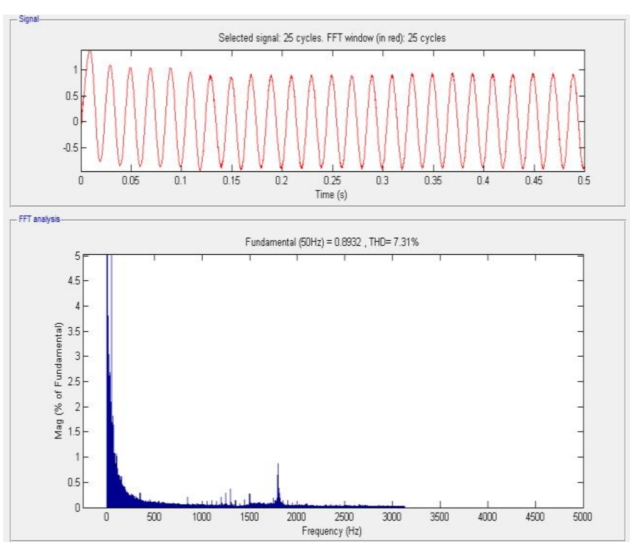

Figure 13 Source Current THD

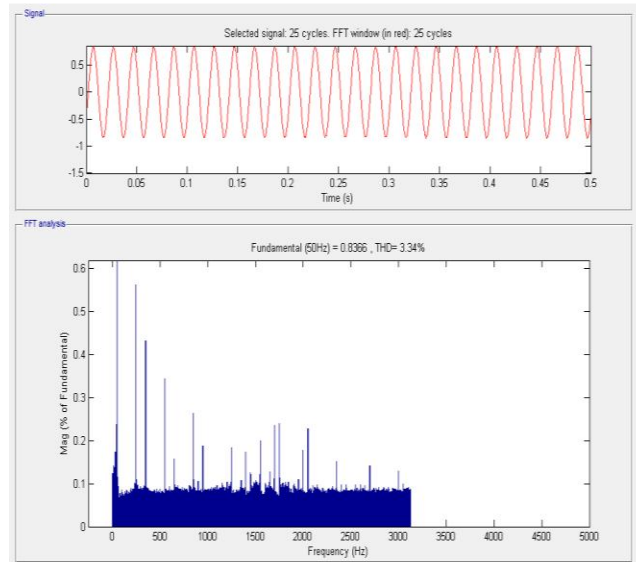

Figure 14 Load current THD

Figure 13 shows that the source current THD is 7.31%, and figure 14 shows the load current THD is 3.14%. It shows a better harmonic elimination at load side.

XI. CONCLUSION

This project presents a DSTATCOM model, developed with the necessary components and controllers in order to demonstrate its effectiveness in maintaining power quality at any point in the distribution line. The proposed DSTATCOM with is controller is used for current harmonic compensation, reactive power compensation, load balancing and neutral current compensation. The effectiveness of the system is checked under heavily unbalanced and switching loads. Acceptable level of power factor, harmonic elimination ,load balancing with neutral current elimination and reactive power compensation at load is also obtained using MATLAB/ Simulink.

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