A Novel Active Current Injection Circuit For Adjustable Speed Drives

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Abstract : This paper introduces a novel active current injection circuit to mitigate harmonics and to amend the power factor of a three phase front-end uncontrolled rectifier. The high PF is achieved by injecting HF current, from the HF inverter, at the input of the front- end three-phase rectifier the inverter switches are in zero voltage switching. The front- end rectifier diodes are working in zero current transition. It results a current waveform is continuous and sinusoidal in shape and current harmonics reduced significantly . The fixed duty ratio with varying switching frequency, regulates the output voltage. The input current THD and power factor are 5.76 % and 0.99 respectively. The results are verified through PSIM simulation and compared with an experimental prototype of 2.5Kw.

Keywords: ASD, Three phase rectifiers, THD, Current Injection Technique, high power factor

I. INTRODUCTION

Due to the remarkable progress made in the high power electronic devices, power converters are widely used in industrial applications. In most the AC-DC power converters, pulse width modulated voltage source inverters are getting supply from a smooth DC link voltage. In these circuits, large output capacitors are used to keep the voltage constant. The AC currents, with a capacitive load, wave forms are discontinuous and high level of harmonics. Due to the non-linear loads, harmonic currents are increasingly considered to be undesirable, as they penetrate into the supply system and affect the voltage waveforms at the Point of Common Coupling (PCC). So, input power factor is reducing and THD is increasing. Therefore, pollution of power is introduced in the system. In the passive current injection method, the capacitors and inductors have been used to eliminating current harmonics and enhancing the system power factor. These capacitors and inductors are bulky, costly and sensitive to the line frequency. In addition to they have a narrow input voltage range, occupy a significant area of space, poor dynamic response and they do elimination effectively only for certain harmonic current components. The paper presents the high-power-factor operation of AC-to-DC converter. The high PF is achieved by injecting HF current, from the HF inverter, at the input of the front- end three-phase rectifier. All the switches of the inverter show zero voltage switching. The diodes of the front- end rectifier works with zero current transition.

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2 PRINCIPLE OF OPERATION

An AC-to-DC converter is shown in Figure 2.1 In this converter, the active power factor correction circuit (APFCC) introduced. APFCC increases the power factor by using active electronic circuits with feedback that control the shape of the drawn current.

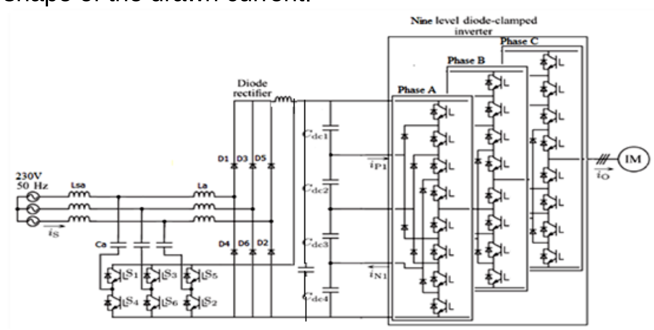

***Figure 2.1** PSIM model of DCMLI using a high frequency front-end rectifier and current injection*

APFCC constitutes a three-phase inverter (S_1–S_6), inductors (L_a–L_c) and feedback capacitors (C_a–C_c). These elements are designed for high-frequency operation. Therefore, the feedback capacitor gives low impedance for high switching frequency (50 kHz) and it gives a very high impedance to supply (50 Hz). Therefore, the voltage across the capacitor C_a, (v_{Ca}) has modulation at 50 Hz i.e. at any instant the voltage across C_a is equal to the supply voltage, v_a as the capacitor carries high-frequency current, the v_{Ca} has HF voltage ripples superimposed on the power frequency component. Also, these capacitors also provide dc blocking for injected current.

3 DESIGN OF CURRENT INJECTION

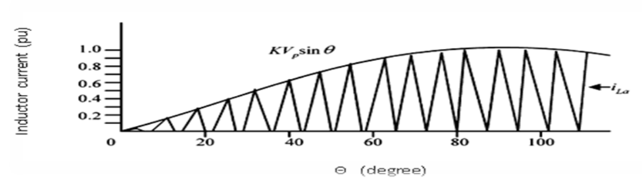

***Figure 3.1**. Inductor current (i_{La}) with the envelope of a supply voltage*

Hence, supply current peaks also vary sinusoidally. Furthermore, since the inductor current pulses always begin at zero, their average values also vary sinusoidally almost in phase with the supply voltage. The same action is taking place in other phases and a negative cycle of the supply voltage also. Therefore, the overall power factor is very close to unity. The HF switching of inductor forces diodes of the three-phase rectifier (D_{S1},D_{S4},D_1) to turn off and turn on at the switching frequency during the complete cycle of the supply voltage, including the region around zero-crossing (valley points) of a supply voltage. When none of the diodes are conducting, line current flows through the capacitor (C_a –C_c) and inverter switches (S_1 –S_6). Thus, maintains the continuous current through the source inductor. This removes the discontinuity in the supply current and hence source inductor (L_{Sa} –L_{Sc}) works in continuous conduction mode (CCM). The operation of source inductance in CCM leads to the inherent enhancement of the input power factor. In a switching cycle, even for unbalanced input supply voltages, the supply current (i_a) varies with the amplitude of the supply voltage (v_a) of the particular phase. The i_a always follow the v_a and varies in a sinusoidal envelope over a power frequency cycle and remains in phase irrespective of the unbalance or balance voltage, maintaining high-power-factor. Thus, active wave shaping of the input current waveform and operation at high-power-factor is obtained through APFCC. As the switching frequency is very high, the input supply current is given by (3.1)

$$i_a = i_{La(avg)} + i_{Ca(avg)} \qquad (3.1)$$

Where

i_a is line current of phase a,

$i_{La(avg)}$ is average currents through inductor L_a

$i_{Ca(avg)}$ is average currents through dc blocking capacitor C_a

When switch S_1 is turned on, during the positive cycle of supply voltage, the current i_{La} increases linearly from zero to peak value of inductor current, I_{Lap} ,whereas, the current i_{Ca} (through C_a), at the same time, decreases linearly from positive peak ($+I_{Cap}$) to zero and then to negative peak ($-I_{Cap}$). When S_4 is on, i_{La} starts decreasing from its peak value to zero. The i_{Ca} starts increasing from$-I_{Cap}$ to + I_{Cap} through zero, maintaining almost constant i_a, during a switching cycle. It is to be noted that, when none of the diodes is conducting, i_{La} is zero but a (non-zero) flows through C_a and the inverter. Thus discontinuity in the supply current, which is mainly responsible for deteriorating the quality of the supply current and power factor, is removed thereby leading to high PF operation of the circuit. All the inverter switches operate with Zero Voltage Switching (ZVS).The current i_{Ca} was flowing through S_4, switch S_4 is turned off. It flows through the body of the diode (D_{S1})switch S_1.Therefore, the voltage across the switch $S_1$is almost zero. Meantime, when the gate pulse is supplied to switch S_1, the current through D_{S1}decreases to"0" and S_1 starts conducting the current in the forward direction with almost "0" voltage across it. Hence, S_1 operates with ZVS. In the same way, when switch S_1 is turned off, the current which was flowing through it, flows through the body diode (D_{S4}) of switch S4. Therefore, the voltage across the switch S_4 is almost zero. When the gate pulse is supplied to it then, it starts conducting the current through it at almost zero voltage across it. Hence, S_4 also operates with ZVS. Thus switches operate with ZVS. The diodes of the front-end rectifier show zero current transition (ZCT). The diode conducts almost for a complete switching cycle except for a small period. The diode current falls to"0" and then the voltage across it rises. As the current through the diode (D_1) and the inductor (L_a) are same, the diode current falls to zero when the inductor completely releases its energy. The active wave shaping of the input current waveform is obtained by the use of HF injected current from HF inverter, the capacitor (C_a –C_c) and inductor (L_a –L_c).

4 RESULTS AND DISCUSSION

Three phase nine level DCMLI fed induction motor with front end rectifier and active network compensation is simulated with PSIM software. The sub-block consists of one arm of the nine levels DCMLI, where all switches are connected in series with the parallel combination of clamping diodes. The clamping diodes are joined with capacitors. Switching states of a positive arm are complimentary to the negative arm. Hence, the pulses generated for a positive arm is inverted and fed to the negative arm. Three phase nine levels DCMLI fed induction motor with active current injection is studied. The active current injection network is made up of resonating components and six IGBT switches. It improves the system performance. It limits the size of resonating components and the related losses (inverter switching loss, diode bridge conduction loss, gate control circuit losses and losses in parasitic elements). It offers a better dynamic response.

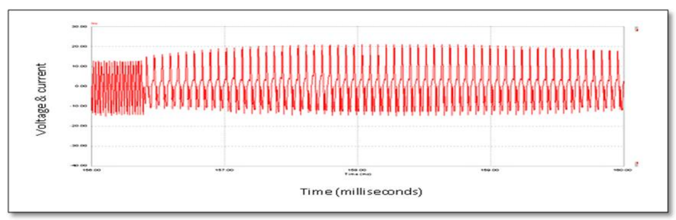

Figure 5.1 *Injected current Ira:10V/div ,Time: 1msec/div*

The Figure 5.1 shows the injected voltage, the current waveform to make the compensation on the distorted input current of diode rectifier. The active compensation network is added to inject the harmonic component in the diode rectifier input current. As a result, the harmonics present in the input current is reduced.

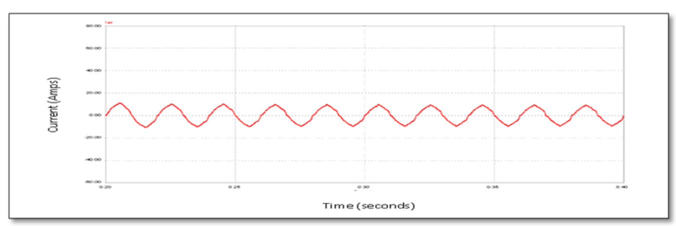

Figure 5.2 *Source current with compensation 20A/div. Time: 0.05s/div*

The Figure. 5.2 shows the per phase compensated input current of six-pulse diode rectifier. It is nearly sinusoidal when compared with passive compensation as shown in a Figure. 4.6

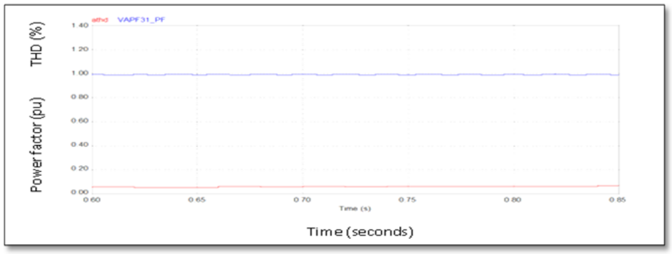

Figure 5.3 *THD and PF; a thd (THD): 0.2pu/div. Time: 0.05s/div*

The THD of supply current and PF obtained from simulation is shown in Figure 5.3.The total harmonic distortion of the compensated supply current is 5.76% and power factor is 0.99.

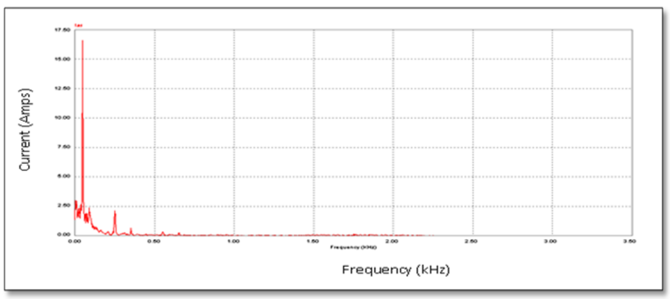

Figure 5.4 *FFT spectrum 2.5A/div. Frequency: 0.5kHz/div*

The Figure. 5.4 shows The FFT spectrum of the supply current is obtained from simulation. It explains the order of harmonics. Waveform clearly shows the absence of harmonic current.

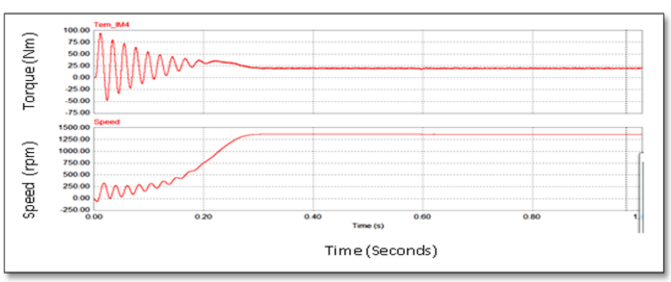

Figure.5.5. *Torque and Speed at full load (Simulation) Tem_IM4(Torque): 25Nm/div. Speed: 250rpm/div*

Figure.5.5 shows the mechanical characteristics of speed and torque of induction motor obtained from simulation. The inverter fed induction motor has smooth speed – torque characteristics. The speed of an induction motor is around 1350 rpm and 20 Nm torque is developed on the motor. The torque pulsation is almost zero. The settling time of the motor drive is about 0.3 Sec.

Table 5.1*Comparison between Simulation and Experimental Results*

Compensation technique	Simulation Results THD (%)	Experimental Results THD (%)
Active Current Injection	5.76	5.8

The simulation results and experimental results are compared in Table 5.1

5 CONCLUSIONS

A Nine level DCMLI with active current injection circuit is designed and its performance analyzed using PSIM simulation and experimentally verified. For the ease of understanding the operation of the active current injection network of the three phase AC-DC-AC converter, different modes of operation on the single-phase basis, are explained. Design equations of the active current injection network are derived which helps to design the vital components. The performance of the proposed system has been tested by experimentation. The results conformed to low THD and high-power-factor operation of the proposed system. The active current injection network of the three phase AC-DC-AC converter needs six active switches. But, it offers the following advantages. They are: less space requirement; soft-switching, reduction in filtering components size and EMI emissions, nearly Unity PF with regulated output voltage. The output voltage regulation at varying loads is obtained by controlling the switching frequency with fixed duty cycle in the proposed system. The converter can be utilized in medium to high power DC applications, variable DC drives, high current battery charger, etc.

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