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Design and Implementation of Sensor Less Voltage Control Technique for Power Quality in Telecom

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Abstract - **In this paper, a three-phase three-switch three-level boost (Vienna) type PWM rectifier is proposed as an active front-end power factor correction (PFC) rectifier for power quality improvement in telecom load. The sensor less voltage control technique is proposed and it does not rely on any input voltage information results in reliable and robust operation. A brief description on the principle of operation and the most advantageous modulation method of the proposed system is discussed. The feasible switching states are identified for the proposed active front-end converter resulting in reduced switching stress and DC ripples. A triangular carrier based control logic is applied and the input current reaches sinusoidal shape without the need of sensing the input voltage. The detailed analysis of front-end PFC converter is carried out by equivalent circuit analysis. Also, the complete loss and efficiency calculation of the converter is explicitly carried out with the help of hardware design guidelines. The performance of the proposed system and its capability to operate satisfactorily in the event of failure of one-phase of the mains is verified through MATLAB Simulation and results obtained are presented. The experimental setup rated for 9 kW is developed in the laboratory to validate the simulation results. From the simulation and hardware results, it is observed and recorded that the power quality parameters are improved and are well within the IEEE, IEC standards.**

Keywords - **Front-end PFC rectifiers, modulation technique, power quality, single-phase outage, switched mode telecom power supplies, THD, sensor less voltage control.**

I. INTRODUCTION

In India, currently 82 percent of the urban and 18 percent of the rural population are dependent upon mobile and internet, while the subscriber count is rapidly increasing for services such as fixed line, wireless, and broadband services. Due to this increasing importance of telecom sector, power supply to the telecom load is very crucial. For lower power level generally, less than 5 kW single-phase power converters have been adopted. Normally, telecom system requires high-current low-voltage rectifiers. The typical power rating of these rectifiers varies from tens of kW to hundreds of MW. In case of higher power levels, three-phase power converters are to be employed.

The conventional front-end six-pulse diode rectifier with capacitive DC-link voltage, results in distortion of mains voltage and current thereby leading to power quality problems. One of the methods to improve input power quality is by using multi-pulse converter based front-end AC-DC converter system. Also, current injection in DC side through active devices is commonly employed in low and medium power applications to draw near sinusoidal currents from the utility along with the multi-pulse transformer. The advancement of the multi-pulse technique leads to the betterment of input power quality even though; the main issues with this technique are increased magnetic rating, weight, and volume of the system. Furthermore, efforts have also been made to develop efficient control methods using space vector modulation and carrier based modulation and modified one cycle control strategy, which improves the DC-link voltage utilization and neutral balancing.

This sensor fewer techniques are proposed for reducing the cost and also the control scheme for regulating DC-link voltage, controlling complexity in control. Hybrid input current and maintain neutral point voltage in balanced condition. In addition, the analysis is extended to mixed conduction mode (MCM), a state in which transition between discontinuous conduction mode and continuous conduction mode have taken place. A feed forward compensator is proposed for MCM by considering input inductance value, switching frequency and system power level. The interleaved Vienna rectifier with high efficiency and its switching frequency circulation current reduction technique is developed, which discusses the loss calculations in detail. In order to reduce the losses associated with the rectifier, output ripples and operating with unity power factor (PF), the most advantages modulation techniques are presented. The comparative evaluation of modulation methods and its advantages are investigated. Higher device stress, low frequency distortion, difficulties in neutral point balancing, less efficient utilization of DC-link voltage, increased control complexity and cost, limited dynamic performance during transients/low PF are the associated drawbacks of the existing control techniques.

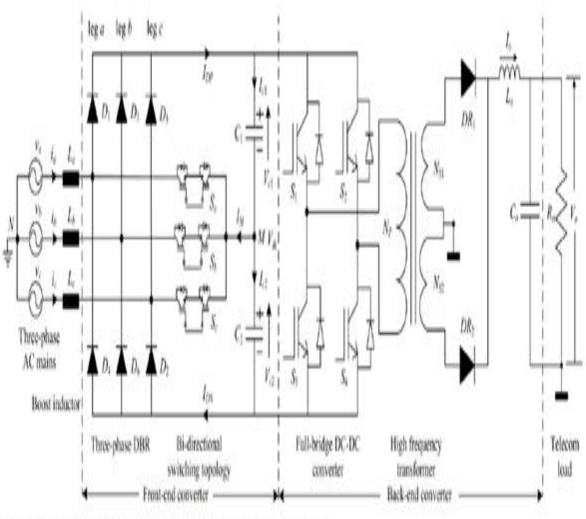


Fig 1. Schematic diagram of the proposed front-end PFC rectifier for telecom application.

To overcome the disadvantages of front-end multi-pulse converter and to subdue the disadvantages of control techniques, the active front-end converter with combined sensor less voltage control and optimized modulation techniques have been proposed in this paper. This active front-end converter is the advancement of the power factor correction (PFC) rectifiers, because of high reliability, efficiency, availability of suitable semiconductor devices, and is fault tolerant as it can continue to work even with single phase outage.

II. EXISTING SYSTEM

In existing method, the methods to improve input power quality are by using multi-pulse converter based front-end AC-DC converter system. Also, current injection in DC side through active devices is commonly employed in low and medium power applications to draw near sinusoidal currents from the utility along with the multi-pulse transformer. In addition, connecting Vienna rectifier in parallel with multi-pulse rectifier for active filtering The advancement of the multi-pulse technique leads to the betterment of input power quality even though, the main issues with this technique are increased magnetic rating, weight, and volume of the system.

III. PROPOSED FRONT-END PFC RECTIFIER CONFIGURATION

The proposed system consists of an active front-end PFC rectifier applicable to the telecom system is shown in Fig. 1. The front-end system consists of input side diode bridge rectifier (DBR) followed by the bi-directional three-leg switching circuit. One end of the bi-directional three-leg switching circuit is connected to a DBR and another end is connected to the DC-link midpoint. The proposed front-end PFC converter converts the DC-link voltage of higher voltage magnitude, but the telecom application requires low voltage high current. So, to step down the voltage, a back-end DC-DC converter is required. Back-end converter consists of IGBT based full-bridge converter feeding a telecom load through a high frequency transformer. This paper discusses only the front-end PFC converter and its control technique.

In the proposed active front-end PFC rectifier, input side voltage formation is dependent on the phase current sign and the input inductance value. This DBR with bi-directional switching topology will produce the three-level voltage at the input stage and hence it is also called three-level converter. The output side of bi-directional switching circuit has been connected to the centre-point (*M*) of two capacitors which produces the upper positive output voltage and lower negative output voltage. The advantage of three-level converter is that the blocking voltage of the switches is only half of the line-line voltage. As the number of levels increases the fundamental current ripples at the input side is reduced. And, also the size of the input boost inductance has been reduced. This results in lower switching loss and less electromagnetic interference. The DC output voltage V_{dc}, of the proposed system have minimum and maximum voltage of $\sqrt{2}\ v_{N,rms}$ and $2\sqrt{2}\ v_{N,rms}$ respectively. For a higher DC output voltage, minimum value of input inductance can be chosen. In the event of supply phase loss, the topology will operate under reduced output power and maintain sinusoidal input current on the remaining phases.

IV. SENSORLESS VOLTAGE CONTROL, MODULATION TECHNIQUE AND LOSS CALCULATION

The per phase equivalent circuit of the proposed front-end PFC rectifier is considered for understanding the basic principle of operation and finding the resultant current as shown in Fig. 2(a). In Fig. 2(b) the switch *Sa* is closed and the positive cycle of phase voltage *va* is applied to the leg a. During this positive cycle, the positive upper diode is in a conduction state and the upper capacitor is charged to the positive peak of the applied voltage. The return path is formed through the anti-serial connected bi-directional switch in which one switch and another switch anti-parallel diode is in conduction and thus close the current circulation path. During negative cycle of applied phase voltage *va*, the negative lower diode is in a conduction state and the lower capacitor is charged to a negative peak of the applied voltage. The current path is closed by an anti-serial connected bi-directional switch in which one switch anti-parallel diode and other switch is in conduction state as shown in Fig. 2(c). In the states the capacitor is charged to $+V_{dc}/2$ and $-V_{dc}/2$. All possible combinations of the switching states and respective voltage/current with respect to mid-point *M*

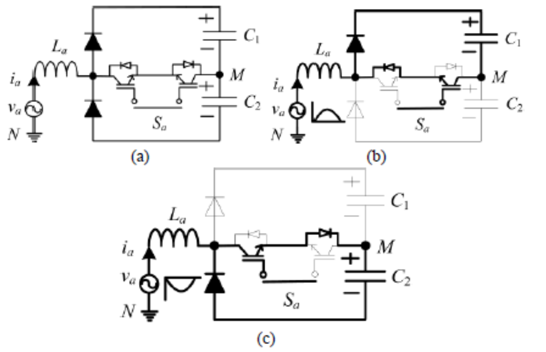


Fig. 2. (a) Single phase equivalent circuit of the proposed front-end converter and its operating modes when (b) Positive input cycle, (c) Negative input cycle.

1. Sensor Less Voltage Control Technique

The basic concept of sensor less voltage control is briefly summarized in order to provide an operating behavior of the front-end rectifier. The equivalent circuit diagram of the input stage of front-end rectifier is shown in Fig. 3(a). The phase voltage *va* is taken into discussion for further explanation of the proposed control technique. Considering the stationary equilibrium of the input phase voltage va_N, the corresponding average value *va'* across the bi-directional switch.

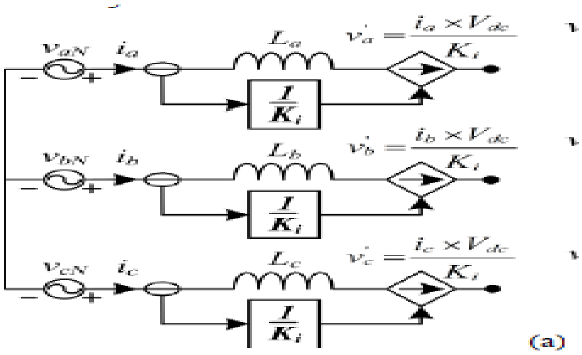


Fig. 3 Equivalent circuit of the input stage of front-end unity PF rectifier incorporating sensor less voltage control.

2. Modulation Techniques

In order to obtain the resistive fundamental behavior, i.e., the rectifier system has to emulate a symmetric three-phase star connection of ohmic resistor, there are several possibilities for organizing the switching states within one pulse period. The active switching states can either be arranged symmetrically or asymmetrically with reference to the middle of the pulse period, and the freewheeling state can be placed in the middle, or at the beginning and/or at the end of the pulse period. By various possible combinations, an optimized way to arrange the switching states can be identified to reduce the switching stress and DC ripples. Generally switching power loss is decided by the switching state sequence within one pulse period and/or by the line-to-line voltage being switched at the transition to a successive switching state. In this paper the sensor less voltage control technique is mainly proposed and incorporated in the system. Moreover, the switching power loss is only depending on the switching states. So, arranging the switch sequence in accordance with the minimum switching stress is the additional innovation of this paper. Furthermore, it is practicable to clamp one power switch in the on-state for a $\pi/3$ interval resulting in a reduced voltage stress on the switches and legs of three-phase DBR.

V. RESULTS AND DISCUSSION

1. Simulation Results

The proposed front-end PFC rectifier has been designed, analyzed and its performance is simulated in the MATLAB environment. Under balanced mains, the system has equal amplitudes of the phase voltages with phase displacement of 120o electrical. For the proposed modulation technique, the time response of the system is captured. Fig. 8 shows the input phase voltage, input phase current, input voltage and current, DC-link voltage, and DC current for the proposed front-end PFC rectifier at rated load conditions. To test the dynamic performance, the load has been reduced to lower level (20% of full load) at t = 0.2 s as shown in Fig. 4. The input current deviates from the normal sinusoidal waveform

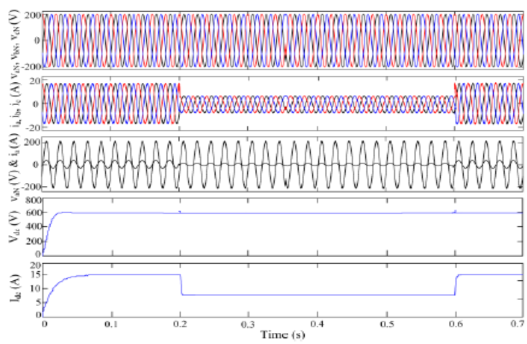


Fig. 4. Simulation results of input phase voltage, input phase current, input voltage and current, DC-link voltage, and DC current for the proposed front-end PFC rectifier under load variations.

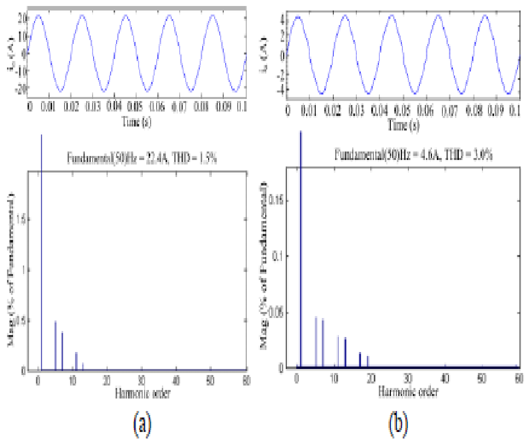


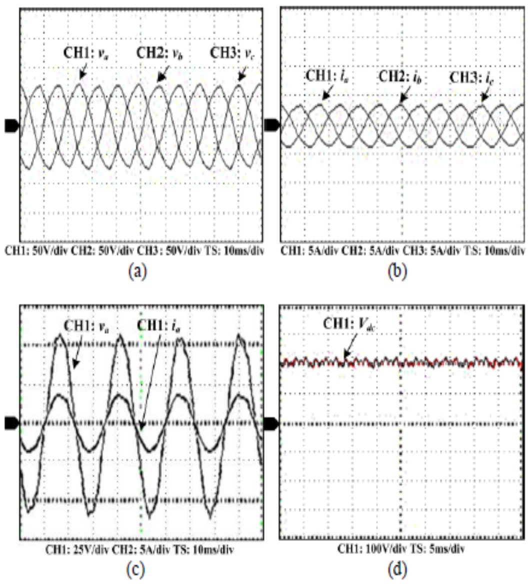
Fig 5. Simulation results of input AC mains current (i_a) along with its frequency spectrum for the proposed front-end PFC rectifier at (a) Full load and (b) Light load conditions.

2. Hardware Implementation

The digital control for the front-end PFC rectifier is carried out by using a fast-digital processor (Altera Cyclone-IV based FPGA Controller). The FPGA controller board consists of a EP4CE30F484 processor with associated on-chip peripherals. Fig. 12 show the schematic diagram of hardware implementation of an active three-phase three-switch three-level boost type PFC rectifier. The following peripherals of the processor are used for the implementation.

1) 16-channel, 12-bit analog to digital converter (ADC) is used to sense the input and output voltage/current.

2) 4-channel, 12-bit digital to bi-polar analog converter (DAC) is used to convert the digital data into an analog signal which take out the signals from the FPGA. The generated PWM pulses are given to the drivers of the IGBT's of the front-end PFC rectifier.



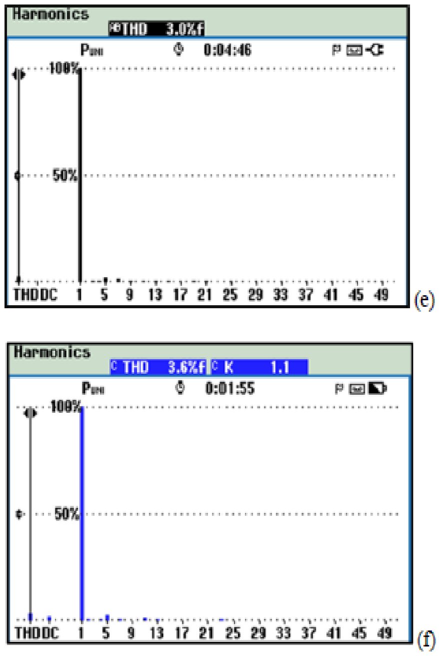


Fig. 6 . Hardware results of (a) Input line-to-line AC voltages (v_{L-L}), (b) Input phase currents, (c) Input voltage and current, (d) DC-link voltage, (e) Input voltage frequency spectrum and (f) Input current frequency spectrum for the proposed front-end PFC rectifier under steady state conditions.

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