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Single Phase to Three Phase Drive System Using High Power Density Single Phase Pwm Rectifier with Active Ripple Energy Storage

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Abstract: The main objective of this project is single-phase to three-phase drive system composed of High power density PWM rectifiers with active ripple energy storage.The proposed topology permits to reduce the rectifier switch currents, the harmonic distortion at the input converter side and presents improvements on the fault tolerance characteristics. With the decrease in the number of switches, the total energy loss of the proposed system may be lower than that of a conventional one. It is well known that there exist second-order harmonic current and corresponding ripple voltage on dc bus for single phase PWM rectifiers. The low frequency harmonic current is normally filtered using a bulk capacitor in the bus which results in low power density. This proposed an active ripple energy storage method that can effectively reduce the energy storage capacitance. The feed-forward control method and design considerations are provided. The circuit employs conventional PWM switching strategy to control its output voltage. With a suitable control strategy, including the pulse width modulation technique (PWM) is developed and simulation results are presented as well in order to known about the important characteristics features of the proposed system.

Key words: High power density converter % Single phase rectifier % Three phase inverter Induction motor % Ac-dc-Ac power converter

INTRODUCTION

Severalsolutions have been proposed when the objectiveis to supply a three-phase motorfrom a single-phase ac main. It is quite common to have only a singlephasepower grid in residential, commercial, manufacturing,and mainly in rural areas,while the adjustable speed drives mayRequest a three-phase power grid. Fault-tolerant multi-phase converter systems have been extensively researched for aircraft application because of their inherent fault tolerance capability [1].

Accordingly,high power density single phase converter modules are desirable for such systems. One of the importantcharacteristics of the single-phase system is the low-frequency ripple on the dc link when the ac inputvoltage and current are sinusoidal. To limit this low-frequency ripple, abulk electrolytic dc-link capacitoris usually required, which results in large converter volume,low power density and poor life-time due to the electrolytic capacitors needed. To improve the power density of a single-phase converter, it is essential to reduce the dc-link capacitor required for filtering the low-frequency rippleenergy [2].

In addition, the previous work verified the feasibility of increasing the system power density by using active ripple energy storage method. In this paper, a high power density single phase PWM rectifier is proposed and a feed-forward control method is provided. This feed-forward method can help the auxiliary active energy storage circuit working as a parallel active power filter for filtering out the low frequencyripples current from the H-bridge rectifier proposedsinglephase PWM rectifier. The proposed topology of the ripple energy storageMethod is depicted in a bidirectional buck-boost converter is connected as auxiliary circuit at the output of a typical single-phase bidirectional PWM rectifier [3].

Since second-order harmonic current is generated from the single phase H-bridge rectifier, the auxiliary circuit is used as aparallel current filter. The proposed system is conceived to operate where the single-phase utility grid is the unique option available. Compared to the conventional topology, the proposed system permits: to reduce the rectifier switch currents; the total harmonic distortion (*THD*) of the grid current with same switching frequency or the switching frequency with same *THD* of the grid current; and to increase the fault tolerance

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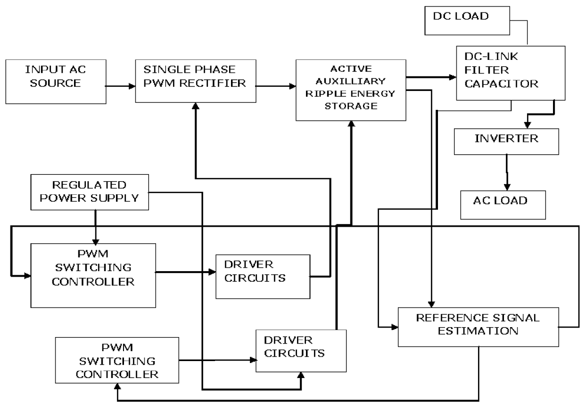

Fig. 1: Functional Block Diagaram

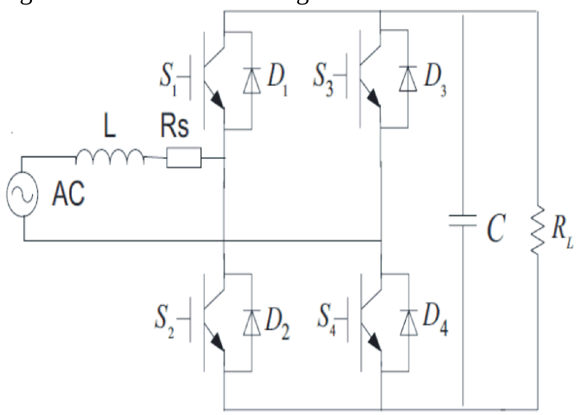

Fig. 2: Conventional Single Phase PWM rectifier

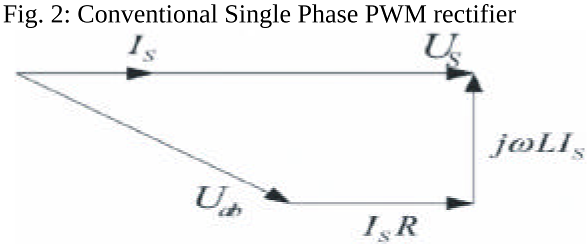

Fig. 3: The state vector of AC-Side of rectifier

characteristics. In addition, the losses of the proposed system may be lower than that of the conventional counterpart [4].

Single Phase Pwm Rectifier: It is an Ac to Dc power converter,which is implemented using forced commutated power electronic semiconductor switches. Today, insulated gate bipolar transistors are typical switching devices. Different from diode bridge rectifiers, PWM rectifiers achieve bidirectional power flow. The application of PWM rectifier topology includes:

- In frequency converters this property makes it possible to perform regenerative braking.
- PWM rectifiers are also used in distributed power generation applications, such as micro turbines, fuel cells and windmills.
- Adjustable speed drives including harmonic filtering function.

The Mathematical Model: The circuit of single-phase bridge rectifier is shown in Figure 2 because the output voltage contains the harmonic, whose frequency is 100Hz; add resonant circuit as its filter. In order to establish the mathematical model of the main circuit, we firstly make the following assumptions:

The grid-side voltage was sinusoidal,

$u_s = U_s \sin(T_s t)$

U_s is the peak voltage of the grid-side voltage and T_s is its angular frequency.

In unity power factor conditions the switches are ideal devices and the load is purely resistive load,

$i_s = I_s \sin(T_s t)$

where i_s is the current peak

From the above analysis as well as the circuit shown in Figure 2, the mathematical model of rectifier can be obtained

$$u_s = L_s \frac{di_s}{dt} + i_s R_s + u_{ab} = L_s \frac{di_s}{dt} + i_s R_s + u_{dc}\, s(t)$$

The state vector relationship of rectifier

The loss of the converter can be supposed to ignore, so input and output power balance, the circuit equation of single-phase PWM rectifier model is shown as follow.

$I_s U_I = I_{dc} U_{dc}$

In the above equation, Us, Is, are the grid-side voltage and grid-side current, U_{dC}, I_{dc} are the voltage and current of DC side Thus the following conclusions can be drawn: we can control the DC side through the control of the AC side; and control the AC side through the control of the DC side. If the fundamental harmonic is only considered, the relationship between steady-state vectors in AC side is shown in Figure.

The rectifier state is shown in Figure 3, grid current Is, has same phase with the grid voltage Us, the grid side shows positive resistance

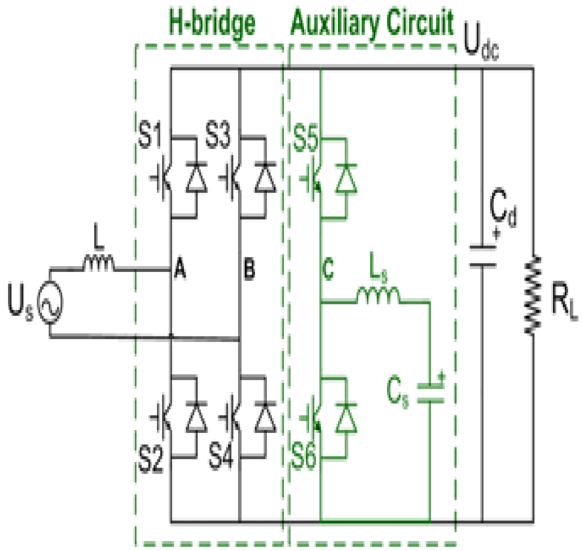

Fig. 4: High power density single phase rectifier

characteristics, to achieve the operation with unity power factor, the load absorbs active power from the grid.

Proposed Model of Single Phase Pwm Rectifier:

Operations of the Proposed Model of Single Phase PWM Rectifier: The proposed topology of the ripple energy storage method is depicted in Fig 4. A bidirectional buck-boost converter is connected as auxiliary circuit at the output of a typical single-phase bidirectional PWM rectifier. Since second-order harmonic current is generated from the single phase H-bridge rectifier, the auxiliary circuit is used as a parallel current filter. An auxiliary capacitor, with capacitance Cs, is used as an energy storage element; while the inductor Ls is used as an energy transfer component. A dc-link capacitor, with capacitance Cd, is still needed at the output of the PWM rectifier to filter the switching ripple energy and the residual second-order harmonic ripple energy not fully absorbed by the auxiliary capacitor Cs. S5 is controlled as a buck switch for charging and S6 is controlled as a boost switch for discharging. The current of switch S5 is discontinuous, so this auxiliary circuit can only be used as low frequency current filter which is typical for single phase. Meanwhile, there is no voltage higher than the dc bus existing in this system and the auxiliary circuit can be integrated together with the main circuit easily as one additional phase leg.

Control Analysis: As mentioned above, there exists second-order ripple power in the single phase system. The ripple power after the H-bridge can be expressed as:

$$p_r = p_{r_{-peak}\sin(2wt)}$$

where Tis the supply frequency.

Assume all the ripple energy is stored in the auxiliary capacitor

$$\frac{du_{cs}^2}{dt} = \frac{2.p_{r-peak}}{c_g}\sin 2wt$$

With this, the low frequency ripple current and ripple voltage in the capacitor are shown in equation

$$u_{cs} = \sqrt{const - \frac{p_{r-peak}}{c_{sw}}\cos 2wt}$$

$$i_{cs} = \frac{P_{r_{peak}}\sin 2wt}{\sqrt{const - \frac{p_{r-peak}}{c_{sw}}\cos 2wt}}$$

where constant 'Const' is given by:

$$const = k \times \frac{p_{r-peak}}{c_{sw}}(k \geq 1)$$

The energy storage capacitor Cs is selected as 140ìF to meet the minimum requirement and the energy transfer inductor Ls is designed as 40 ìH according to in the design consideration section. Due to that, the switching frequency 20 kHz is much higher than the Ls and Cs resonant frequency. At each switching period, the dc-link voltage and auxiliary capacitor voltage can be considered as quasi-static. This means the inductor charging slope and discharging slope can eachbe considered as a fixed value within each switching period.

Then, the duty cycle for the charging and discharging phases can be derived and the second-order ripple energy can be accurately filtered out from the H-bridge.

A more straightforward, the compensation current is used to regulate the low frequency ripple current (shown in (Fig 5). Using the previous method, the average compensation current within one switching period should be equal to the low frequency ripple current, then the duty cycle for the charging and discharging phases are derived as

The control schematic of the system is shown in Fig. 5. The rectifier duty cycle and the measured ac-side current are used to generate the ripple current reference for the auxiliary circuit. The dc link voltage and auxiliary capacitor voltage are sensed to generate the duty cycle for both charging and discharging phases. Within the duty cycle generation block, if the compensation current

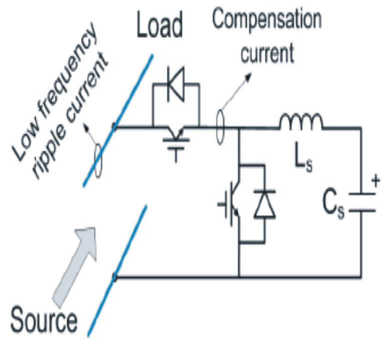

Fig. 5: Auxiliary circuit working as parallel active ripple Current filters

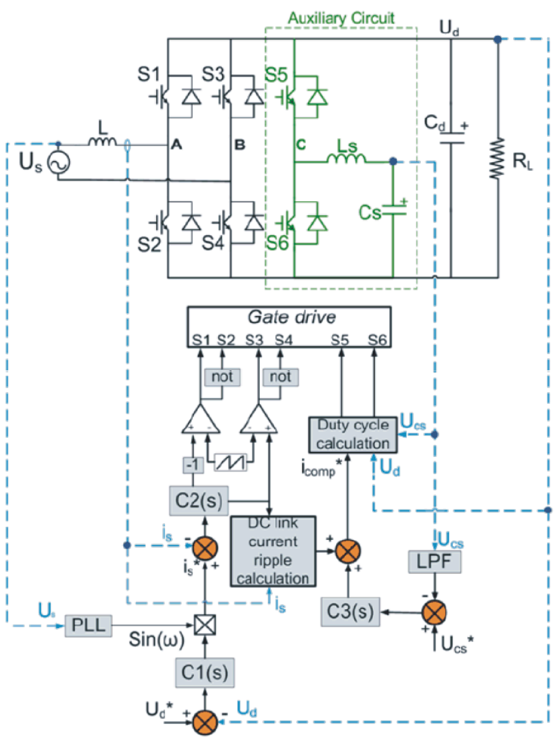

Fig. 6: Control schematic figure for the system

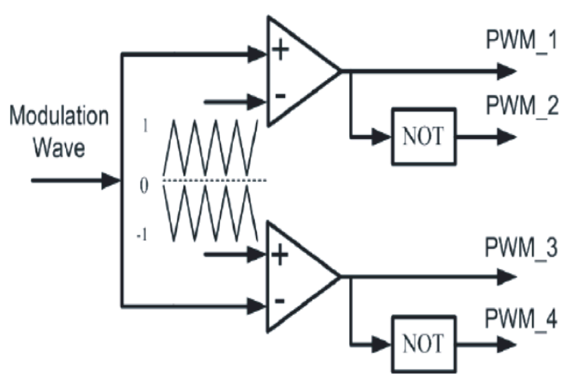

Fig. 7: Single phase discontinuous PWM modulation metho

is positive, the auxiliary circuit is controlled in buck mode to assimilate the ripple power from the dc link charging the auxiliary energy storage capacitor. Similarly, when the compensation current is negative, the auxiliary circuit is controlled in boost mode to release the ripple energy stored back into the dc link.

The auxiliary capacitor mean voltage control loop is required to prevent the Cs from over charging or under charging. The PLL block is designed as shown in Fig 6.

Design Considerations: For single phase H-bridge rectifier, the modulation method is specified to achieve both the minimum loss and balanced temperature distribution.

For the auxiliary circuit, the auxiliary capacitor is selected according to the ripple energy requirements and the auxiliary inductor is designed as below.

Modulation Method: The single phase discontinuous PWM modulation. One phase leg will not switch within half of the supply frequency. It can lead to the minimum switching loss.

Auxiliary Inductance Selection: There are two criteria for selecting the auxiliary inductance:

C Peak current boundary
C The Discontinuous Current Mode (DCM) boundary,

The maximum current in the auxiliary circuit must be smaller than the peak current requirement of the selected power semiconductor:

$$Buck\_Slope \times D1 \times T_s \# I_{peak} \, Boost\_Slope \times D1 \times T$$

Then, the auxiliary inductance selection based on the peak current requirement is calculated as:

$$L_g \geq \frac{2.i_{cg}.T_s}{I_{peak^2}} . \frac{U_d U_{cg} - U_{cs}^2}{U_d}$$

Then, the auxiliary inductance selection based on the DCM requirement is calculated as:

$$L_g \leq \frac{T_S}{2.i_{CS}} . \frac{U_d U_{CS} - U_{CS}^2}{U_d}$$

Simulation Results: The proposed rectifier system is constructed using Matlab/Simulink tools and simulated in order to achieve the performance characteristics under

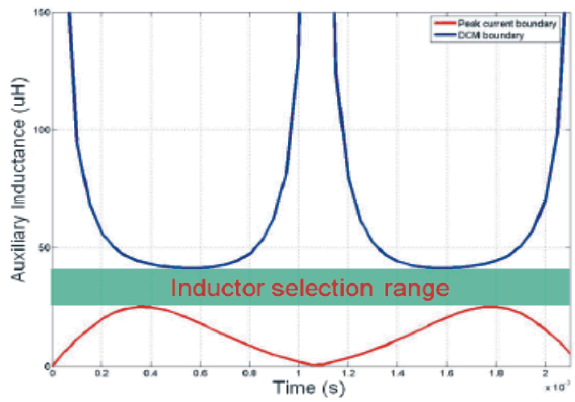

Fig. 8: The auxiliary inductance selection range

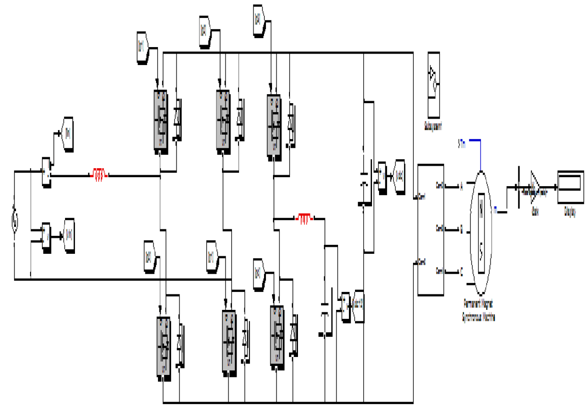

Fig. 11: Simulation of proposed model of single phase to three phasedrive system using high power density single phase PWM rectifier with active ripple energy storage

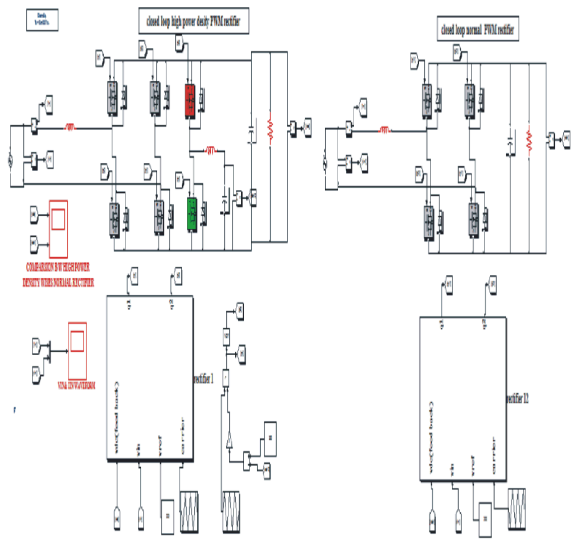

Fig. 9: Simulation of with and without auxiliary circuit of high power density single phase PWM rectifier

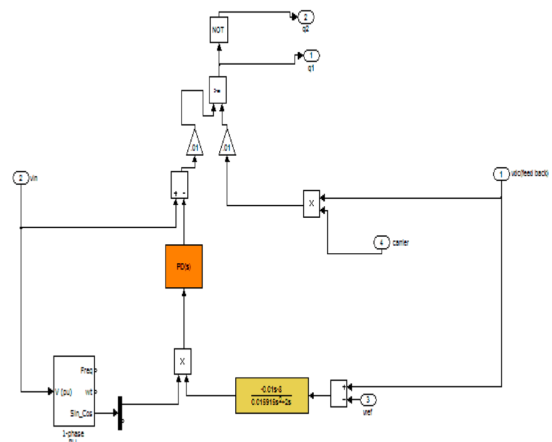

Fig. 12: Closed loop system of high power density single phase PWM rectifier

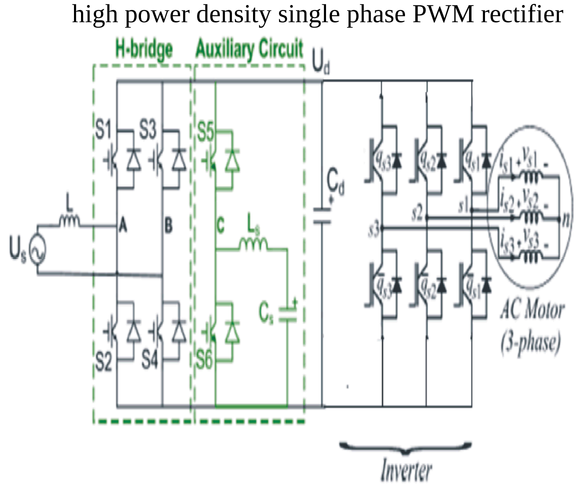

Fig. 10: Proposed model of single phase to three phase drive system using high power density single phase PWM rectifier with active ripple energy storage

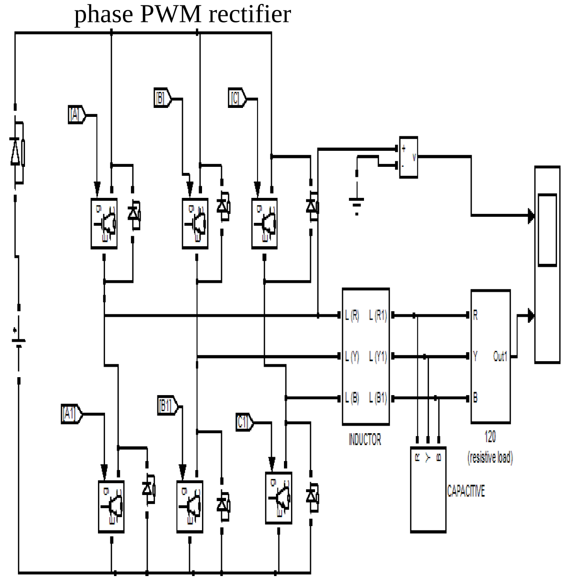

Fig. 13: Three phase inverter connected with load

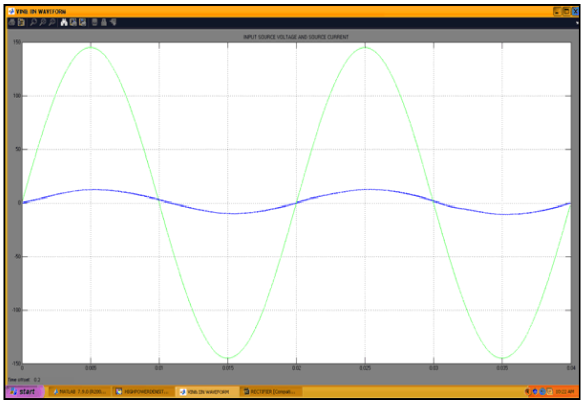

Fig. 14: Simulation result of source voltage and source current normal rectifier and high power density single phase PWM rectifier

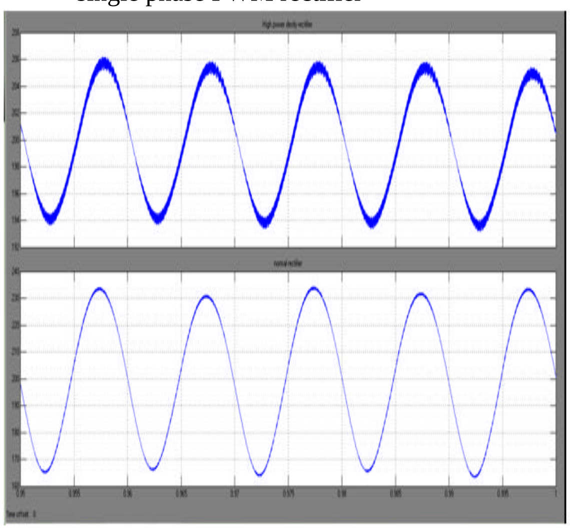

Fig. 15: Output voltage of normal rectifier and high power density single phase PWM rectifier

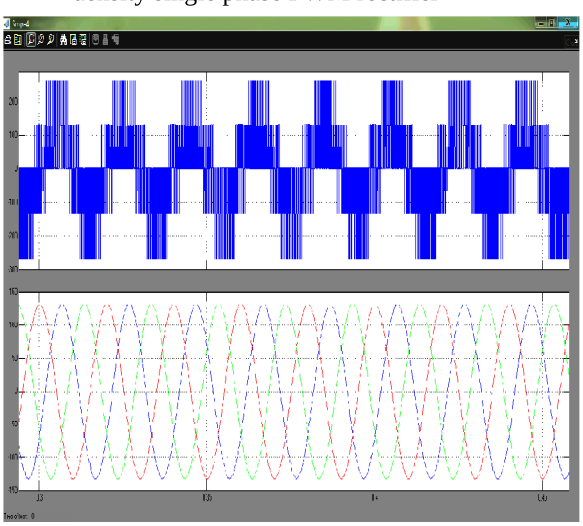

Fig. 16: Simulation result of three phase inverter

different parameters changes. Using Matlab/Simulink to simulate, the parameters of simulation are shown as follows.

- The switching frequency of device is 20 kHz,
- The grid-side AC voltage is E = 145V, 50Hz
- Input line inductance: 5mH
- The capacitor in DC side is C = 200uF,
- Capacitance in auxiliary storage: 1000uf
- Inductance in auxiliary circuit: 10uH
- Load: 50 ohm Resistive

CONCLUSION

In this work, an active ripple energy storage method is proposed to increase the single phase PWM rectifier's power density. Based on analysis, simulation and experiment, the following conclusions can be drawn:

- Firstly, the proposed auxiliary circuits will bring no voltage higher than the dc bus in the system and it can be easily integrated together with the H-bridge rectifier as an additional phase leg. Different from the traditional parallel active power filter, the auxiliary circuit compensation current is in discontinuous current mode so that it can only filter out the low frequency ripple current that dominates in single phase rectifier system.
- Secondly, the proposed feed-forward control method can generate the compensation current reference as fast as one switching period and can effectively filter out the low frequency ripple current from the H-bridge rectifier.
- Thirdly, although the total capacitance will decrease dramatically compared with traditional method, the total ripple current in capacitors will increase by using the active method. Finally, simulation results were provided for verification purposes.

REFERNECES

1. Cursino Brenda Jacobina, 2010. Single-Phase to Three-Phase Drive System Using Two Parallel Single-Phase Rectifiers Senior Member, IEEE, Euzeli Cipriano dos Santos Jr., Member, IEEE,Nady Rocha and Edgard Luiz Lopes Fabr´?cio, 25(5).
2. Ricardo Quadros Machado and Simone Buso, 2006. A Line-Interactive Single-Phase to Three-Phase Converter System, Member, IEEE and José Antenor Pomilio, Senior Member, IEEE, 21(6).

3. Dong-Choon Lee, 2007. Control of Single-Phase-to-Three-Phase AC/DC/AC PWM Converters for Induction Motor Drives Member, IEEE and Young-Sin Kim, 54(2).
4. Enjeti, P. and A. Rahman, a New Single Phase to Three Phase Converter with Active Input Current Shaping for Low Cost Ac Motor Drives Power Electronics Laboratory Department Of Electrical Engineering Texas A&M University College Station.