SINGLE PHASE PULSE WIDTH MODULATION RECTIFIER

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Abstract

After the development of semiconductors, conversion from AC source to DC source is possible. Earlier, conventional diode rectifier does not offer the control ability of its operation. Later, advanced development of semiconductors has made the rectifier with control ability. Phase controlled thyristor rectifier became very popular but it was found that they also created negative side effects which injected current harmonics to the supply network which affected power quality. Nowadays, modern industrial demanded control features of power converters while new regulations impose more stringent limits to current harmonics injected by the power converters. The introduction of single phase PWM rectifier is present in this paper, its operation, switching technique and control technique was studied. The results of simulation by using Matlab Simulink software are shown.

Introduction

The other possible reduction or elimination technique for harmonics pollution in the power conversion is the application of a PWM rectifier. PWM rectifier constructed with power semiconductor devices that can be switched on and off called Insulated Gate Bipolar Transistor (IGBT). PWM rectifier is controlled by pulse width modulation. Rectifier controlled by this method consumes current with demanded waveform that is mostly sinusoidal. It enables control of power factor, and has minimal effects on the supply network.

Main features of PWM rectifiers are bi-directional power flow, nearly sinusoidal input current, regulation of input power factor to unity, low harmonic distortion of line current (THD below 5 %), adjustment and stabilization of DC link voltage (or current), reduced capacitor (or inductor) size due to the continuous current. There are two types of PWM converters, the voltage source output, and the current source output. From these two types, the voltage source output type PWM rectifier is present.

PWM Rectifier

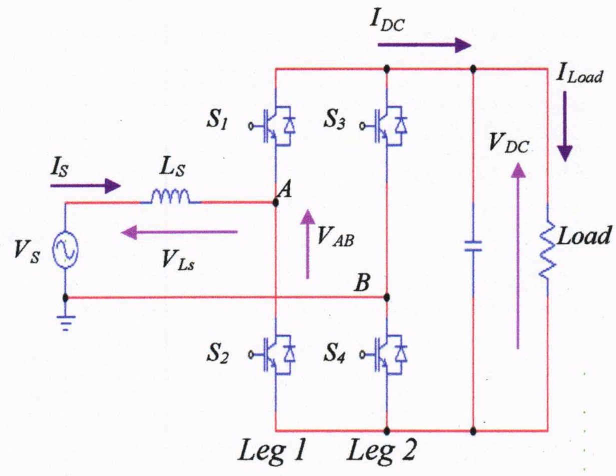

Figure 1 PWM Rectifier

As shown in Figure 1, V_{AB} is the fundamental voltage and input for the converter. S_1 and S_2 should not be switch ON together at a same time, while S_3 and S_4 should not be switch ON together at a same time to avoid short circuit. *Leg 1* and *leg 2* are independent of each other, so the switching sequence between *leg 1* and *leg 2* can be made separately.

$$V_S = V_{AB} + L_S \frac{dI_S}{dt}$$

I_S has to be in phase with V_S for the converter to have unity power factor as shown in Figure 2. I_S flows through inductor, L_S and will have a drop across it, which is $L_S\omega I_S$, this drop is perpendicular with V_S and I_S. V_{AB} is the resultant vector summation.

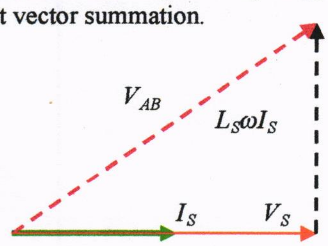

Figure 2 Phasor Diagram

The variation of I_S depends on the load connected across V_{DC}. So V_{AB} is controlled such that for any load connected or load changes, the output power has to be match drawn from the input source while I_S and V_S has to be in phase to maintain unity power factor.

Switching Sequence

The condition of switching sequence during PWM sine-triangle comparison is as below:

Sine > Triangle: S_1 ON, S_2 OFF
Sine < Triangle: S_2 ON, S_1 OFF
Sine > Triangle: S_4 ON, S_3 OFF
Sine < Triangle: S_3 ON, S_4 OFF

S_1 and S_2 comparison uses the same triangle while a different triangle is use for S_3 and S_4 comparison. Triangle for S_1 and S_2 is 180° phase shifted with triangle for S_3 and S_4.

Control Loops

There are two control-loops in proposed converter i.e. current control-loop and voltage control-loop. There is a faster inner current control-loop and slower outer voltage control-loop. The output dc voltage is controlled by matching the input power from the converter to the output power demand from the load, while maintaining unity power factor at all the loads.. The outer voltage loop is working with dc quantities and the inner current loop is working with sinusoidal quantities. The reference sine wave for the inner current control-loop is derived from the input mains. The block schematic of current and voltage control-loops are shown in Figure 3 and 4. Unity Modulus method is used in designing the control-loops to find the parameters of current control-loop and voltage control-loop.

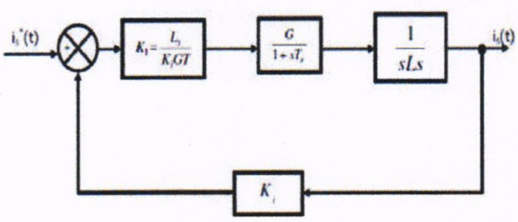

Figure 3 Current Control Loop

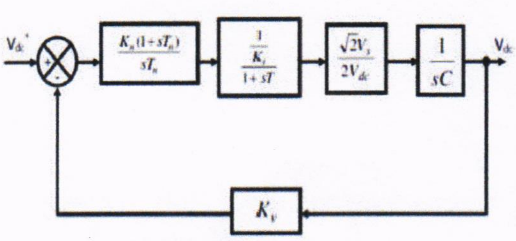

Figure 4 Voltage Control Loop

Simulation Results

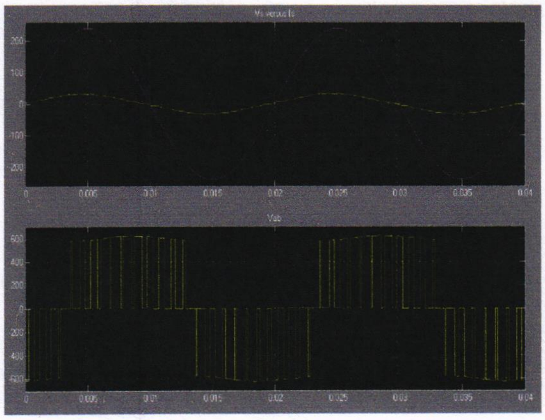

Figure 5 Top: Supply voltage, V_S (magenta) and supply current, I_S (yellow); Bottom: Input voltage for the converter, V_{AB}

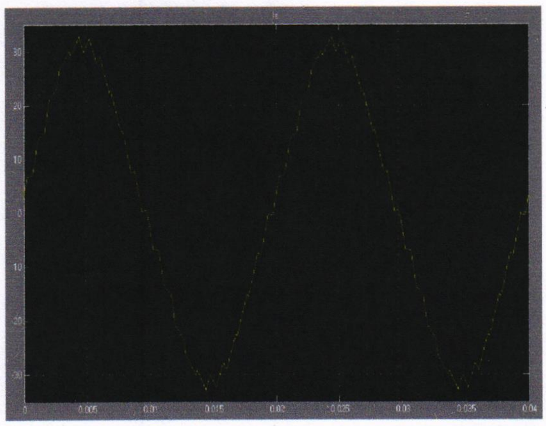

Figure 6 Close view of a supply current, I_S

On top of Figure 5 it shows that the supply voltage, V_S and supply current, I_S are in phase and it is expected to have nearly unity power factor. On bottom of Figure 33, shows the controllable input voltage V_{AB}. By sight visual, it has the pulses form but the average value of those pulses will give a sinusoidal form of discrete format. The close view of supply current, I_S as shown in Figure 6 is highly sinusoidal and it is expected to have low total harmonics distortion.

Figure 7 shows that output voltage, V_{DC} is around 600V and output current, I_{DC} is around 6A, this is matched with the design value. The close view of maximum output voltage, V_{DC} in Figure 8 shows that the ripple is approximately 40V at around average value of 600V while the designed value is 30V. Figure 9 shows that the converter is giving the same amount of power transferred when there is a sudden change in load demand.

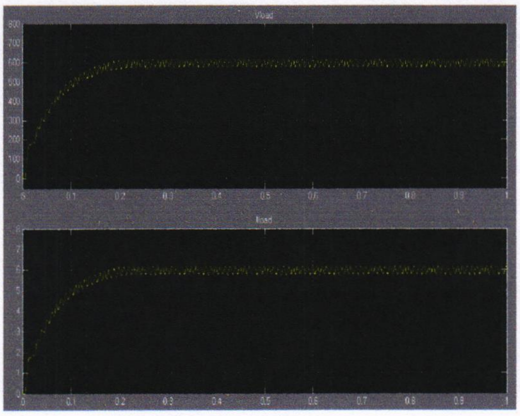

Figure 7 Top: Maximum load voltage, V_{Load}; Bottom: Maximum load current, I_{Load}

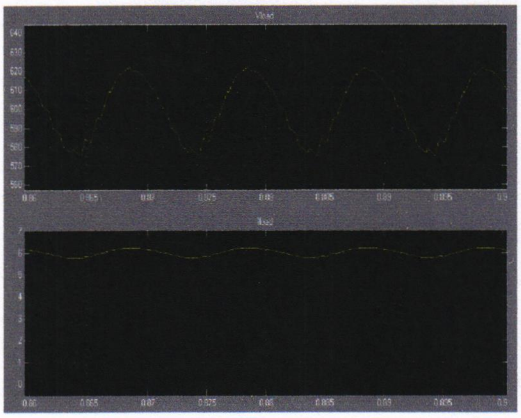

Figure 8 Top: Ripple of maximum load voltage; Bottom: Ripple of maximum load current

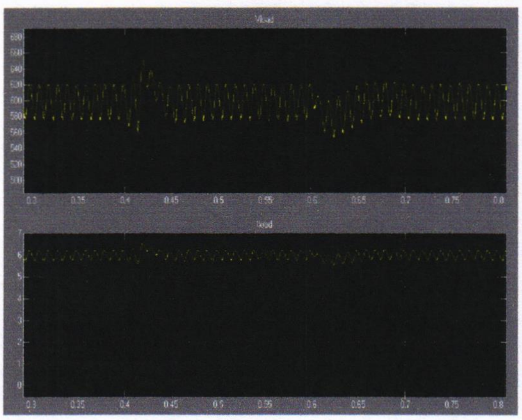

Figure 9 Load voltage and load current response due to 50% step load change (decrease and increase)

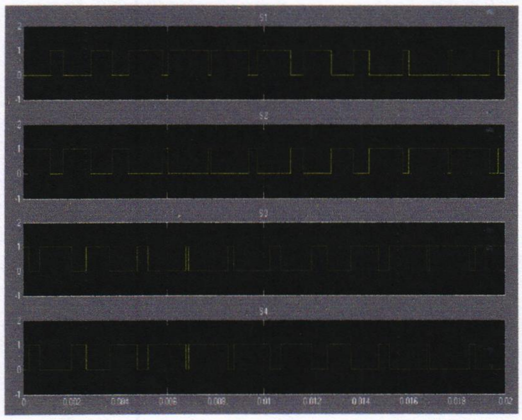

Figure 10 Switching pulse signal for one sinusoidal cycle

Figure 10 shows the switching pulse sequence to fire the IGBT switches, it is shown that switches pair of a same leg is not turn ON at a same time to avoid short circuit.

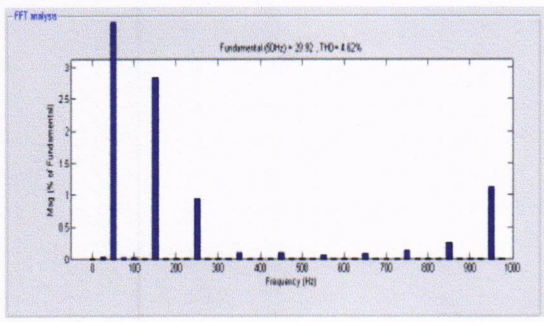

Figure 11 Total harmonic distortions of purely resistive load

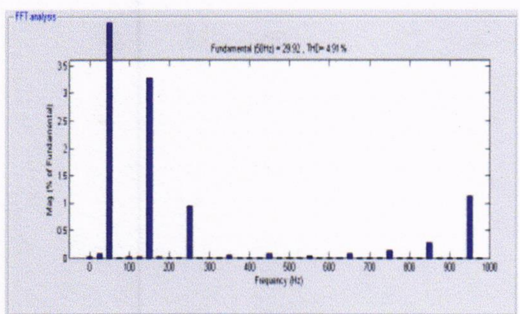

Figure 12 Total harmonic distortions with resistive and inductive load

Figure 11 shows the total harmonic distortion is 4.62% for purely resistive load with R value of 100Ω while Figure 12 shows the total harmonic distortion is 4.91% for resistive and inductive load with R value of 100Ω and L value of 2000mH. If we see in both figures, the harmonics at f_C (550Hz) and its sidebands of $f_C \pm 2f_M$ and $f_C \pm 4f_M$ are highly suppressed. The expected next higher harmonics to be happened is at the sidebands of $2f_C \pm f_M$, $2f_C \pm 3f_M$ and so on, it is shown that the harmonics at $2f_C - 3f_M$ (850Hz) and $2f_C - 5f_M$ (950Hz) are still exist but their effect is not that critical that is the THD still below 5% (IEEE Regulation) for both load condition.

Conclusion

We knew the square wave generated by using only one triangle signal during the sine-triangle PWM comparison content odd harmonics. By adding one more triangle signal into the sine-triangle PWM comparison with 180° phase shift with respect to each other, the odd harmonics content can be suppressed. The average value of the generated square wave is in sinusoidal discrete format and the resultant magnitude of the square wave has the magnitude of two times the fundamental magnitude of single triangle of sine-triangle PWM comparison and is proportional with the modulation index. With proper arrangement of switching sequence, this square wave can be use to give command to the IGBT switches so that the output voltage can be control while at the same time the harmonics content of input current can be reduced. The controller for the converter can be designed start with inner loop (current control loop) and then the outer loop (voltage control loop). The current controller parameters are designed to have the first order lag response through the modification of standard proportional controller. The voltage controller parameters are derived through a method called unity modulus or the magnitude optimum method and the system is designed with under damped control condition. So far we only compared the calculation with the simulation result which proves to be true. The future works that still need to be done is to design the circuit for the PI controller and P controller so that the practical measurement can be compared with the simulation results.

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