Discuss and provide examples for the PWM process

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Abstract: This research introduces the Pulse Width Modulation (PWM) and the control method of PWM. We also discuss three common types of device using PWM and Control strategy of parallel PWM rectifier under unbalanced grid voltage.

1. Introduction

In the past, we used rheostat connected in series to change the amount of current flowing to the load. This method is not very efficient, because it will consume the energy. We know the equation of Joule heating ($\frac{dQ}{dt} = I^2R$), the current flowing to the rheostat will cause the heat, which we do not want to use in a circuit. Thus, we created a method in switch called pulse width modulation (PWM).

PWM is using digital output of microprocessor to control the analog circuit. It has been used for many fields, such as telecommunication, electronic design automation and power control.

PWM signal is a square wave, which can be produced by hardware and software. There are two common types for generating PWM signal. One is using triangular or sawtooth wave generators to produce high-frequency modulated waves, and through the comparator to produce PWM signal. The other is using internal integration PWM generator of Single Chip Microcomputer (SCM) to produce PWM signal, which is controlled by program.

An important concept in PWM is the duty cycle. Duty cycle is the ratio of power on hours to the total time during a pulse period. A higher duty cycle means higher power and a lower duty cycle means lower power. That is the scheme that we do to control the power (usually lower the power). When the switch is always on, the duty cycle is 100%, and for 50% duty cycle means the switch on time is same as the switch off time during one period, which means power in load will be the half of the primary.

Control strategy of parallel PWM rectifier under unbalanced grid voltage is the key technology to ensure its safe and stable operation. Traditional control algorithm has many problems, such as large amount of coordinate transformation, complex control structure, DC bus voltage fluctuation and network current distortion. In order to deal with above problems, a control strategy of parallel PWM rectifier based on stationary coordinate system is proposed in this paper. A mathematical model is built under unbalance voltage conditions. Basic principle of positive, negative and zero sequence circulating current suppression is given. DC voltage outer loop based on proportion integral resonant (PIR) controller and grid-side current inner loop based on proportion feedback resonant controller is proposed to eliminate DC bus voltage fluctuation and grid-side current harmonics. The overall control diagram of PWM rectifier parallel operation is given. The parameters of proportion feedback resonant controller are designed. Finally, simulation research is carried out with simulation software, and effectiveness of the proposed method is verified with simulation results.

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2. Different duty cycle

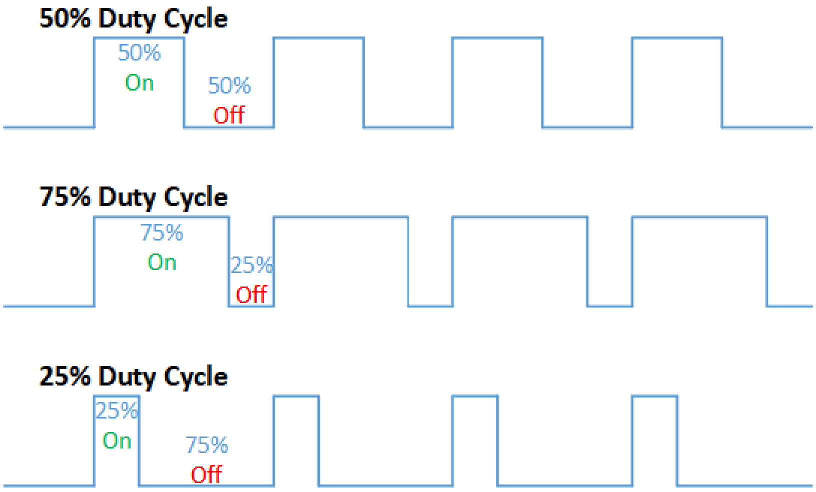


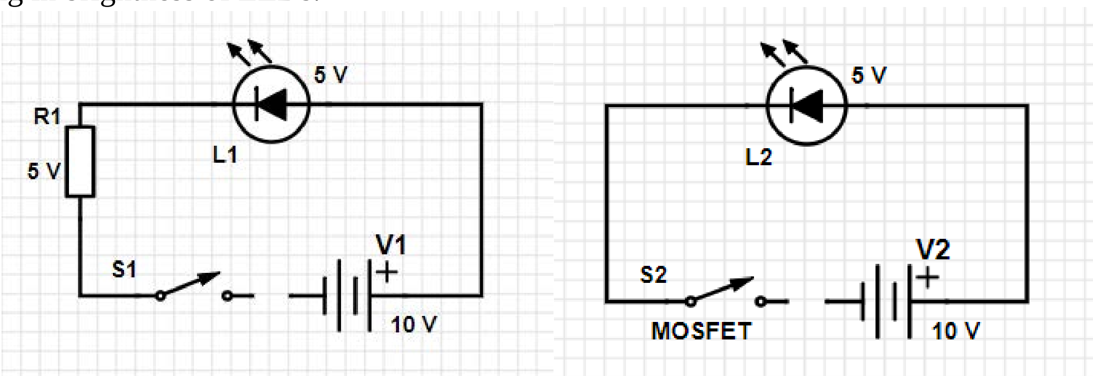
Figure 1. Pulse signal of different duty cycle[1]

After understanding the theory of PWM, we have found that there are many devices used by PWM method, such as light-emitting diode (LED), electric motors and PWM charge controller. We want to discuss how PWM used in these devices.

3. LED

PWM signal can be used as the control system for a LED. Many LEDs need the function of adjusting brightness of the light. To reduce the current flowing through the device can adjust the brightness of LED (Figure 2.a). But if the current below the rated current, it will cause several problems. The best way is used PWM controller (Figure 2.b).

The PWM signal is not directly used in control LED. It is used to control the switch, such as Metal-Oxide -Semiconductor Field Effect Transistor (MOSFET). The PWM signal controller adjust the duty cycle to change the output current and the brightness. As the frequency is very high, the changing speed of switch is very fast that human can not distinguish. What we can see is the changing in brightness of LEDs.



(a) (b)

Figure 2. (a) Using resistor to reduce current

(b) Using PWM controller with 50% duty cycle.

The PWM principle is can be formed by equation (duty cycle is 50%, voltage supply is 10V), the voltage cross the light is:

$$V = \frac{10V*T_{on}+0V*T_{off}}{T_{total}} = 10V*\frac{T_{on}}{T_{total}} = 10V*duty\ cycle = 5V$$

For large frequency, there is almost no voltage across the switch, which means no energy loss during switch.

4. Electric motors

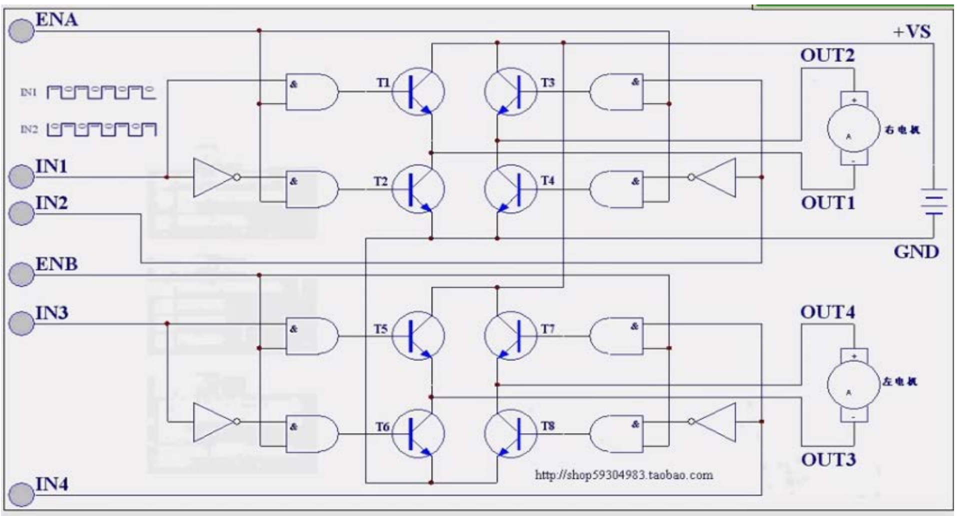
There are huge amount needs of electric motor, as it can play mechanical rotary motion.

In energy, we are changing different types of energies by using electric motor as a middle part. Especially in the renewable energy, we use electric motor to transduce kinetic energy into magnetic energy and then produce electric energy during Eolic system and Low Head Hydroelectric system. With the PWM method, we can control the speed and direction of an electric motor. (Figure 3)

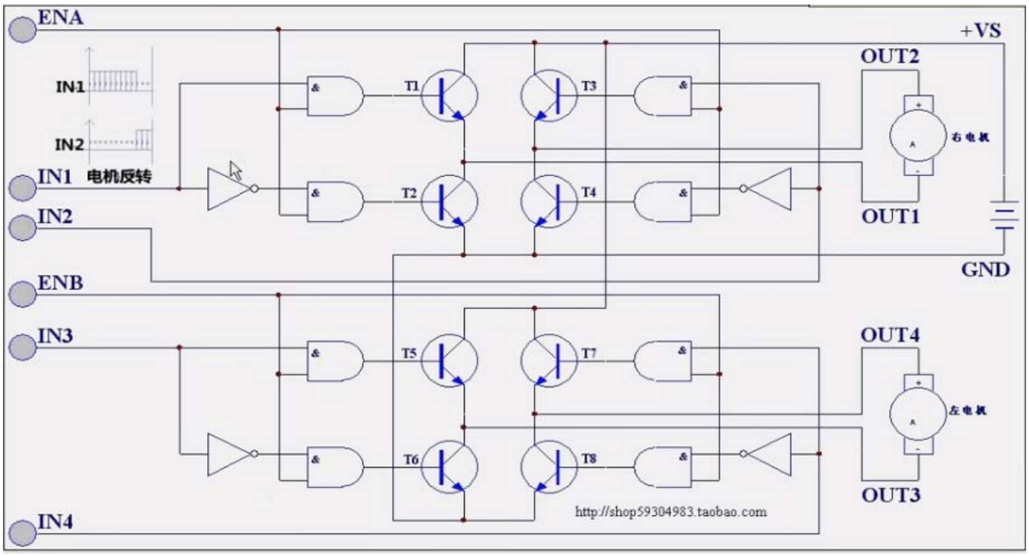
We using two PWM signal to control one electric motor. The two input power signals must be opposite in On-Off time. Because it will stop electric motor by no voltage difference between point A and B.

For controlling the direction of electric motor, we need to change the duty cycle of IN1 and IN2. If the duty cycle of IN1 is larger than IN2, the voltage of point A is larger than that of point B during one period. Thus, the electric motor will rotate anticlockwise. (Figure 3b) One the contrary, if the duty cycle of IN1 is smaller than that of IN2, the voltage of point B is larger than that of point A. The electric motor will rotate clockwise. (Figure 3c) However, when the duty cycle of IN1 is equal to the duty cycle of IN2 (50%), which means the electric motor will stop.

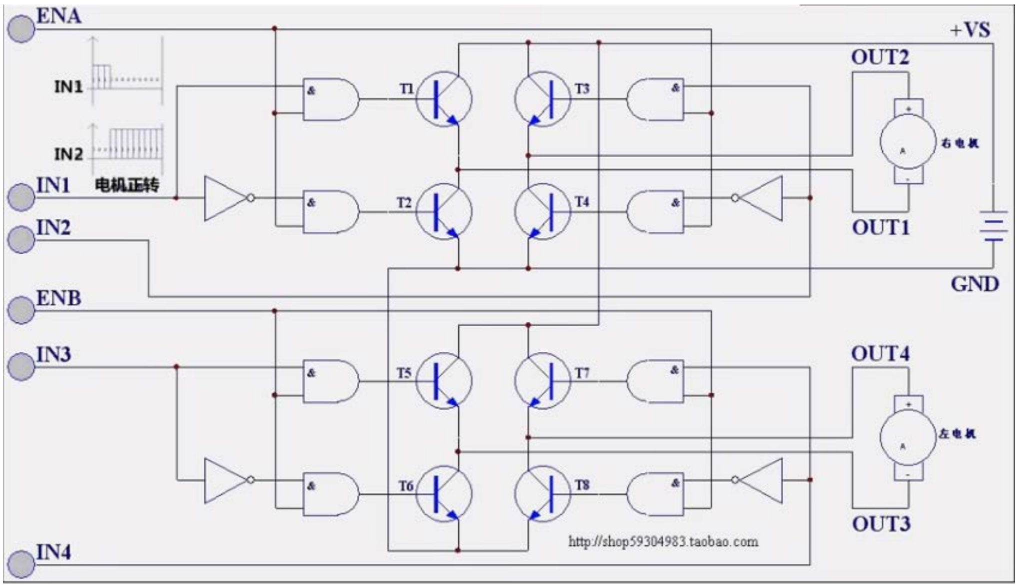
For controlling the speed of electric motor, we also need to change the duty cycle of IN1 and IN2. The larger the difference of duty cycle between IN1 and IN2, the larger the voltage difference between point A and B. The higher the voltage difference crosses through the electric motor, the faster the motor rotates.



(a)



(b)



(c)

Figure 3. (a) the scheme structure of PWM signal in electric motor,

(b) The anticlockwise of electric motor (the duty cycle of IN1 is larger than IN2),

(c) The clockwise of electric motor (the duty cycle of IN1 is smaller than IN2)

5. Pulse Width Modulation Charge Controller (PWMCC)

The charge controller is an electrical device used to avoid overcharging and discharging in batteries of a Photovoltaic (PV) system. As the voltage push the current from high voltage to low voltage. The voltage of PV panels is usually larger than that of batteries, thus we can charge the battery. But if we overcharging the battery, it may cause water electrolysis in lead-acid battery (LAB), which can produce hydrogen and get exploded. For a PWMCC, it will curtail the excess voltage of PV solar cells produced for protecting batteries. The method is changing the duty cycle of switch just like what we do for brightness of LEDs. This method is not very efficient as it will curtail the power, but it can be improved by plus a DC-DC converter. This type charge controller is not better than maximum power point tracking charge controller (MPPTCC), but it is cheaper than MPPTCC. Thus, it is very commonly used in PV system. (Figure 4)

6. The control of parallel PWM rectifier in the case of unbalanced voltage

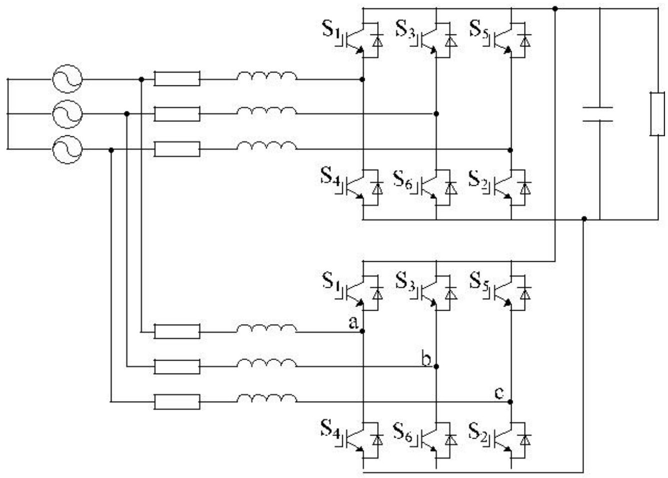


Figure 4. Topology structure of parallel PWM rectifier

The topology of parallel PWM rectifier is shown in Figure 4. In Figure 4, L1 and R1 are the filter inductance and equivalent series resistance of rectifier 1; L2 and R2 are the filter inductance and equivalent series resistance of rectifier 2; C is the filter capacitance of DC bus; RL is the load resistance; uabc is the three-phase grid voltage.

Single-module voltage source PWM rectifier has the advantages of bi-directional energy flow, flexible and adjustable power factor, low harmonic current on grid side, controllable voltage on DC side, and has been widely used in distributed grid-connected power generation system, uninterruptible power supply, active power filter, flexible DC transmission and other fields. However, due to the limitations of IGBT devices, it is difficult to apply in low voltage and high current situations. Therefore, two or more modules are usually used in parallel to increase the system capacity.

Although the parallel operation of the modules solves the problem of IGBT switching device limitation, the hardware parameters of different modules can not be completely consistent, and the controllers of different modules can not be fully synchronized. Therefore, the key technical problem of parallel PWM rectifiers is the current suppression problem. At present, a variety of solution have been proposed for that circulate current suppression problem of parallel PWM rectifiers, Methods of eliminating circulation are generally divided into hardware and software methods: 1) In the hardware mode, the zero-sequence path can be blocked by adding an isolation transformer on the AC side to restrain the circulating current[6]. However, the addition of an isolation transformer will lead to the oversize of the equipment, which is not suitable for the development trend of miniaturization and lightweight of power electronic equipment. References propose an integrated coupling inductor method to restrain the circulating current. 2) According to the different modulation strategies of PWM rectifier control system, the software methods can be divided into: ① Space vector pulse width modulation (SVPWM) improvement method; ② Based on sine-wave pulse width modulation (SPWM) control strategy and multi-carrier modulation strategy[. The former is to reduce the circulation by adjusting the zero-vector action time in SVPWM modulation, while the latter is to reduce the circulation by injecting zero-sequence control output components into the sinusoidal modulation signal or by adopting carrier phase-shifted modulation strategy.

In the practical operation of shunt PWM rectifiers, short circuit faults, especially asymmetric short circuit faults, will lead to three-phase unbalance of grid voltage, which will lead to DC bus voltage fluctuations, current distortion imbalance and other problems, at the same time, will also cause negative sequence circulation. Reference adopts the closed-loop control of positive and negative sequence current in synchronous coordinate system, and injects the modulated signal into the output of zero sequence current controller to suppress the circulating current. Reference assumes that the DC side is connected to the DC voltage source, the positive and negative sequence current control in the synchronous coordinate system is also adopted, and the zero sequence current is suppressed by the improved SVPWM modulation method.

As can be seen from that above analysis, At present, there is little research on parallel control strategy of PWM rectifier under the condition of unbalanced voltage in power system, Moreover, the current proposed methods are all controlled in synchronous coordinate system, there are some problems, such as too large coordinate conversion operation, the need for voltage and current positive and negative sequence extraction module and synchronous phase-locked loop module, large control delay, not considering DC load and so on. For the above analysis, This paper presents a parallel control method of PWM rectifier based on static coordinates, A mathematical model of static coordinate system is establish under that condition of unbalance of electric network, The influence of voltage imbalance on circulating current is analyzed, the suppression principles of zero-sequence, positive-sequence and negative-sequence circulating current are given, and the control strategy of adding resonant controller to forward channel and feedback channel to suppress DC voltage fluctuation and current harmonics is put forward. Finally, the system simulation model is built and the simulation research is carried out.

7. Discussion and Conclusion

Pulse width modulation help us to solve the problem that energy dissipated as heat, when we use resistor to adjust the current. For changing the duty cycle of PWM signal, we can do not only for switch, but also transfer the data information in telecommunication. There are so many devices used for PWM.

Aiming at the problems of traditional algorithm, such as large computation, complex control structure, DC voltage fluctuation and current distortion, the control strategy of parallel PWM rectifier based on static coordinate system is proposed in this paper. The proposed control strategy has the advantages of low computation cost, no need of current positive and negative sequence extraction module and synchronous phase-locked loop module, and the current extraction method using MCCF can reduce the control delay. The proposed control strategy uses PIR controller to realize zero steady-state error regulation of DC voltage in the outer loop of DC voltage, and controls its fluctuation component to be zero, while PFR controller is used in the inner loop of power grid current to reduce the low harmonic component of current. At the same time, compared with the traditional algorithm, the proposed algorithm can effectively suppress negative sequence circulation, and further reduce zero sequence circulation, improve power quality. In the case of sudden change of load, the proposed algorithm can stabilize the DC voltage and current rapidly in the case of normal or unbalanced voltage, and has the advantages of fast dynamic response and small impact on DC voltage.

Reference

[1] Thewrightstuff, *Examples of 50%, 75%, and 25% Duty Cycles.* 19 September 2018.