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Design and Simulation Research on Energy Consumption of Electric Vehicle Charging Stations

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Abstract

Development of automobile industry has made a significant contribution to the liquidity needs of people's lives, but it also brings some major issue such as global warming, air pollution, depletion of oil resources and so on. Electric vehicles are able to replace conventional cars, they are clean vehicle, which is important to solve the current problem. Centralized and efficient safe and reliable charging station become one of the key aspects for the promotion of electric vehicles, which is the energy indispensable service infrastructure after the large-scale industrialization of electric vehicles. To design high degree of automation, reliable, efficient energy-saving, easy to use maintenance management system plays an important role in the construction of the charging station. Modern computer technology, communication technology, control technology and information management technology just provides us an effective way to solve this problem. In this letter, the overall energy efficiency of the charging station is designed.

***Keywords**: electric vehicle, charging station, design and simlation study.*

1. Introduction

Since the 1990 s, the electric car research began to be taken seriously. After years of research and development, functional prototype testing and demonstration applications, China's electric car technology has become mature. To meet the requirements of the development of electric vehicles, the national grid in the "Twelve five" period preliminary built smart grid operators charge for power plants and service network. China has become the world's largest electric vehicle charging equipment country [1-4].

Electric cars and the rapid increase in the number of charge and discharge facilities, will also introduce some new problems [5-8]. As the electric car charging and discharging rapidly increase in the number of facilities, energy facilities constructed network of electric vehicle charging and discharging will be enormous. EV charging load in time and space has a certain randomness may cause power grid peak load increasing, which require new grid capacity, some of the transmission and distribution network will not carry its energy needs.Harmonic generation in electric vehicle charging equipment will also have an impact on the quality of the local power grid [9]. For more scientific and rational layout of electric vehicle charging and discharging facilities, and the electric vehicle charging and discharging facilities construction will not affect the normal operation of power grids, it is necessary to have an in-depth research on energy management.

Based on this, the overall energy efficiency of the charging station will be researched. It can be divided into two levels, the first level of is the equivalent model of charging function, which based on a typical charging characteristic curve of lithium-ion battery to establish energy model, and simulate the own loss of each element in the practical work under different load conditions. The second level is energy efficiency model of the charging station, which based on the type of charger, charging station power mode of

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consumption structure and configuration to simulate the charging system of energy consumption [10]. Simulation can be used MATLAB and PSCAD software to modeling.

2. The Key Element Modeling of Simulation Model

The energy efficiency simulation of charging stations should be able to begin from the bottom components of the charging station, and establishes energy efficient models of transformers, power lines, power factor correction and reactive power compensation device, charger and lithium-ion battery. The modeling power electronic devices mainly involves capacitors, inductance and power switching devices.

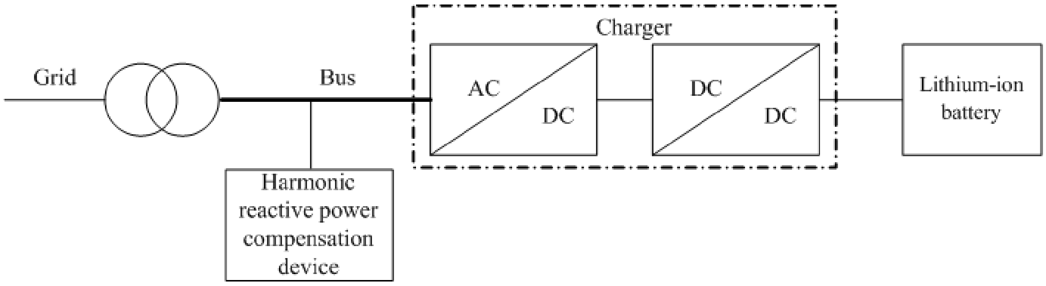


Figure 1. Bottom Components of Charging Station

Charging pile provides alternating current power supply for the electric vehicles with car charger. It has many characteristics, such as smaller power, smaller area, and flexible stationing. It can be installed in the parking lot, shopping plaza, and other existing location which is convenient for electric car to be parked. Charging station, which takes a large area, can take a variety of ways for electric car to be powered. There are quick charge, slow charge and change the battery. At the same time when it charged, it can be able to monitor the conditions of the charger, power battery and battery replacement equipment. A charging station is composed of many sets of charger and charging pile. The charger adopts rectifying installation charge for storage battery of electric vehicle. It has large power, wide range of the output current and voltage, so it can meet the demand of different types of electric vehicles [4]. Otherwise, a charging pile uses AC charge for the charge of electric car. A converter stations provide users services of changing the battery and battery maintenance services. The battery removal and installation equipment is the main equipment for a converter station. It has many characteristics of the specialized operation, short battery replacement time (usually 5-10 minutes), smaller occupied area than charging station and easy stationing on a large scale in the city. As we all known, the AC charging piles are the most common charging infrastructures with the biggest energy change. It also the charging and discharging equipment which combined the most close with the technology research and application of intelligent building integrated energy efficiency management. Also the charging station and converter station can be considered to be composed of every charging pile (charger). This article mainly uses charging stations for a particular study.

(1) Transformer

Transformer losses generally include no-load loss and load loss. Transformer Efficiency reflects the operating characteristics of the transformer, and expressed by efficiency curve.

(2) Power line

Power line loss is related with line length, the load current and line impedance.

(3) Battery

As the lithium-ion battery has a large advantage in energy density, power density, cycle life, *etc*., it has been widely used in electric vehicles. Lithium ion batteries generally use the first constant current and constant voltage method, which starts with the pre-given constant current, when the voltage reaches a certain value, then charge with constant voltage.

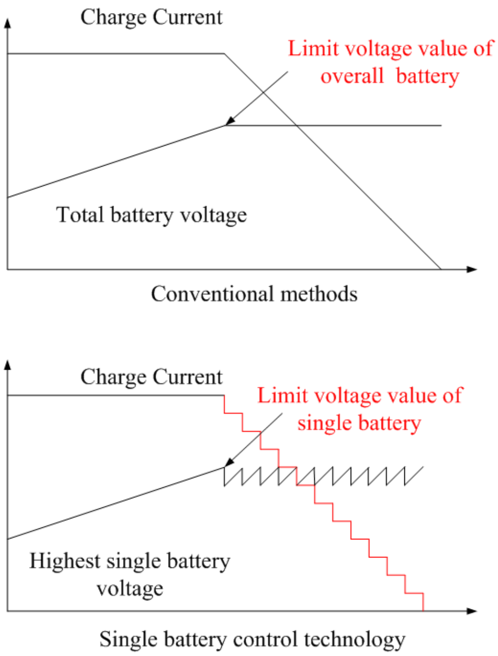


Figure 2. The Charging Voltage-Current Characteristic Curve of Lithium-ion Battery

(4) Capacitors

The capacitance of the "ideal" is different of the capacitors in practice, "real" capacitor due to its packaging, materials, *etc*., will have an inductance and a resistor of additional features, which must be add additional "parasitic" elements or "non-ideal" performance to characterize its performance in the form of a resistance element and an inductive element, non-linear and dielectric storage performance.

(5) Inductance

Inductance L model is equivalent to their own values and series resistance ESR.

(6) Power Devices

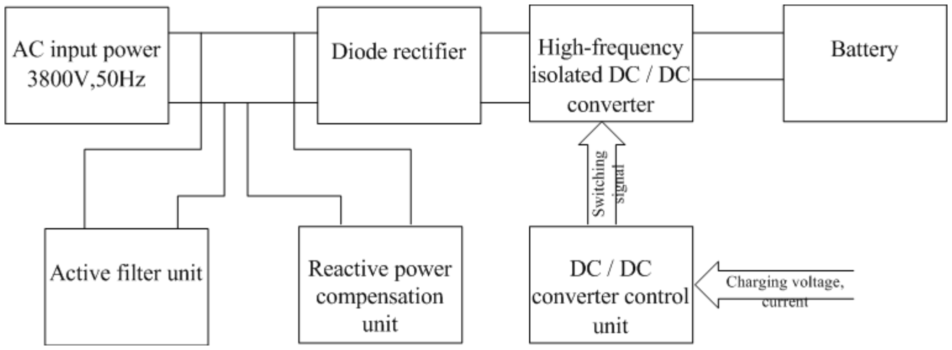
Power device loss mainly contain conduction loss, turn-on loss and turn-off loss. Conduction loss power devices affected load current, and switching losses are associated with the device switching speed, device capability driver, switching current, switching voltage and switching frequency. By in-depth study of the device switching characteristics and the mechanism of loss, establishing loss model in different working state is of great significance for the charging machine to select the optimal device and circuit topology.

3. Simulation of Charging Station

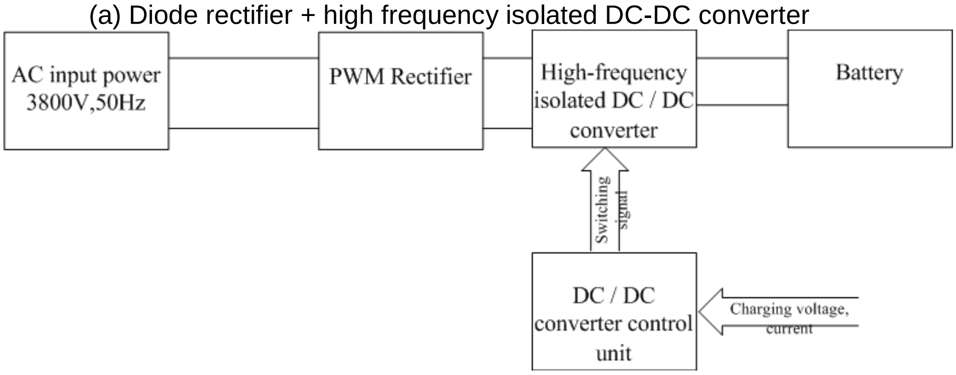
3.1 The Main Circuit Topology of Charger

(1) Research of charger Topology

The differences of charging machine topology constitute, key components and control methods will directly affect the charger power factor, harmonic current content, efficiency and other parameters. And as the main electrical equipment of charging station charger, its level of energy efficiency is important for the energy efficiency of the whole charging station. Currently, the most two widely used typical topology are charger diode rectifier + high frequency isolated DC-DC converter and PWM Rectifier + high frequency isolated DC-DC converter (as shown in Figure 3). As the diode rectifier charger generates great harmonics during the charging process to pollute the grid, it must increase the effective harmonics and reactive power compensation device.



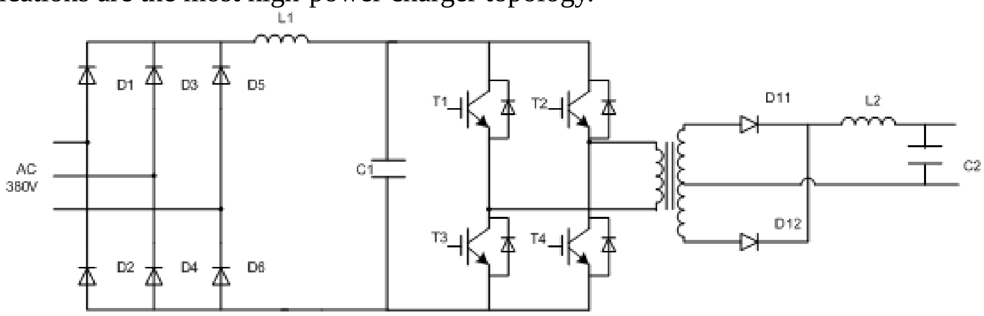
(a) Diode rectifier + high frequency isolated DC-DC converter



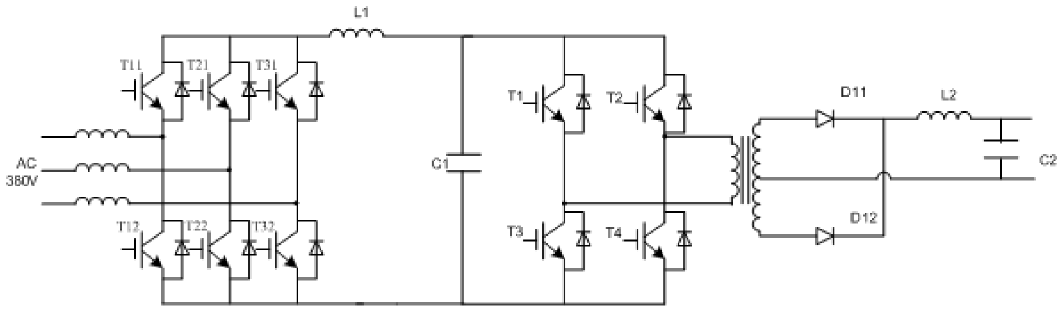
(b) PWM Rectifier + High frequency isolated DC-DC converter

Figure 3. Two Typical Topology Charger

Due to the high power level required, the high-frequency isolated DC / DC converter is generally chosen a full-bridge mode. Main circuit structure and control method of the most hard-switching PWM converter is simple, making it the most mature technology, applications are the most high-power charger topology.



(a) Diode rectifier charger



(b) PWM rectifier charger

Figure 4. Two Typical Isolation Charger Main Circuit

(2) The MATLAB will be used to establish various topology of charging machine, and analyze the charging machine efficiency of different topology. Due to the battery charging characteristics, in a complete charge cycle, typical curves of charger output current and output voltage is the charger output power curve. In which the $U_{0\max}$ and $I_{0\max}$ is the basic parameters determined on the type and power battery charger charging characteristics.

In addition, as the power battery charging time is much long, when studying the impact on the grid of charger harmonic, in the modulation period it can be considered that charger output current and output voltage is constant, and therefore it can select an approximate resistance to simulate equivalent input impedance of the high frequency power conversion circuit. Thus in the entire charging process, it can be used a non-linear variation of the equivalent resistor instead of high frequency power conversion circuits. The curve fitting method will be used to establish charger output model, and deduce the equivalent impedance model of high-frequency power converter, which can obtained charger simplified model of different methods of rectifying.

3.2 The Simulation of Charging Station Topology

Based on the energy efficiency model of charger, it will use PSCAD simulation software to establish various topology model of energy efficiency.

(1) AC power supply + diode / PWM Rectifier charger topology.

According to transmission lines, turn off impedance of power devices, access number of charging machine and supply operation mode of charger AC power, the overall energy efficiency of the charging station factors will be analyzed, and charging station overall energy efficiency of two different configurations (diode rectifier charger + APF and PWM Rectifier charger) are comprehensive compared.

(2) DC power + PWM Rectifier + non-isolated DC/DC charger topology.

In DC power supply model, the AC transmission line is fed to the rectifying means, after rectification, a DC transmission line is delivered to non-isolated DC/DC charger. By setting the AC transmission lines and HVDC circuit length, the two cases of rectifier placed in transformer substation or charging station can be simulated, and the overall energy efficiency of the charging station by AC power supply of PWM rectifier charger and DC power supply concentrated PWM Rectifier is analyzed and compared.

4. Design of Charging Station Energy Consumption

4.1 The Control Strategy Design of Charging Station

Energy efficiency model of charging stations is established based on the energy efficiency model of charging machine. When more than one charge unit make up into charging station, every charging machine of different switching methods directly affect the efficiency of charging station. Switching of different ways, such as at the same time put more than one charger, charger into intervals or flexible control each charging station charging effect on the energy efficiency of the machine investment of time, *etc*., have far-reaching significance for determining the control strategy of charging stations.

(1) Charging control strategy

Charging machines generally include two basic way of a constant current output and constant voltage output, the control system must be able to provide the charger constant current control of output current and constant voltage control of the output voltage respectively. Principle charger dual-loop control block diagram is shown in Figure 5.

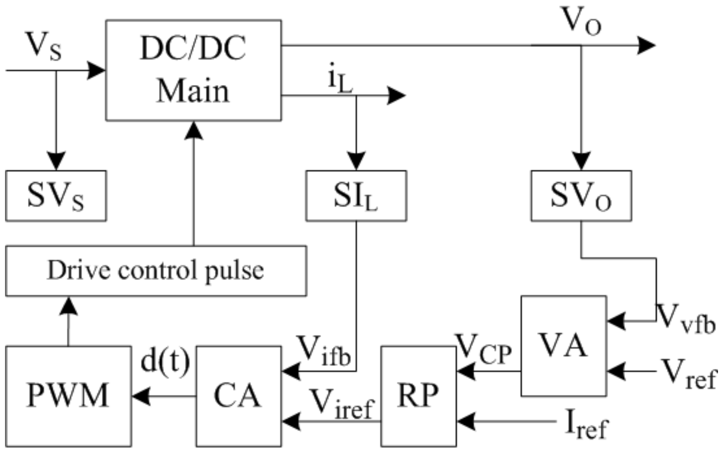


Figure 5. Double-Loop Control Schematic of Charger

In Figure 6, i_L and V_O respectively express the current of output filtering inductance and the voltage of output filtering capacitor, SI_L and SV_O representing the sampling part of output filter inductance current and output filter capacitor voltage. V_A is a voltage controller, which take comparison with the output voltage feedback signal V_{fb} and the reference signal V_{ref} , after adjusted by the PI controller, generates an error voltage signal V_{CP}. After the output current reference of signal I_{ref} and the error voltage of signal V_{CP} disposed by the reference signal processing circuit RP process, a unified current reference signal V_{iref} is formed. When the charger stands in the constant current output state, the output voltage is out of control, the characteristic curve of battery charging determines that the change of voltage is monotonically increasing, it is usually to set the output voltage of the reference signal to the maximum allowed battery charge voltage, at this time the output voltage of the controller will be in the forward saturation. And when the charger stands in constant voltage output state, the output current is out of controlled, the characteristic curve of battery charging determines the current trend is monotonically decreasing, it is usually to set the output current of the reference signal to the acceptance of the maximum charge of allowed current. Thus, the reference signal processing circuit RP is actually a minimum value of operation circuit. C_A is the current controller, which compared with the current feedback signal I_{fb} of output filter inductance and the reference signal, after the PI regulator, which generates the duty cycle signal d(t), and also generates a PWM signal by the PWM module, then IGBT working condition is controlled by the drive pulse signal generated of driving circuit.

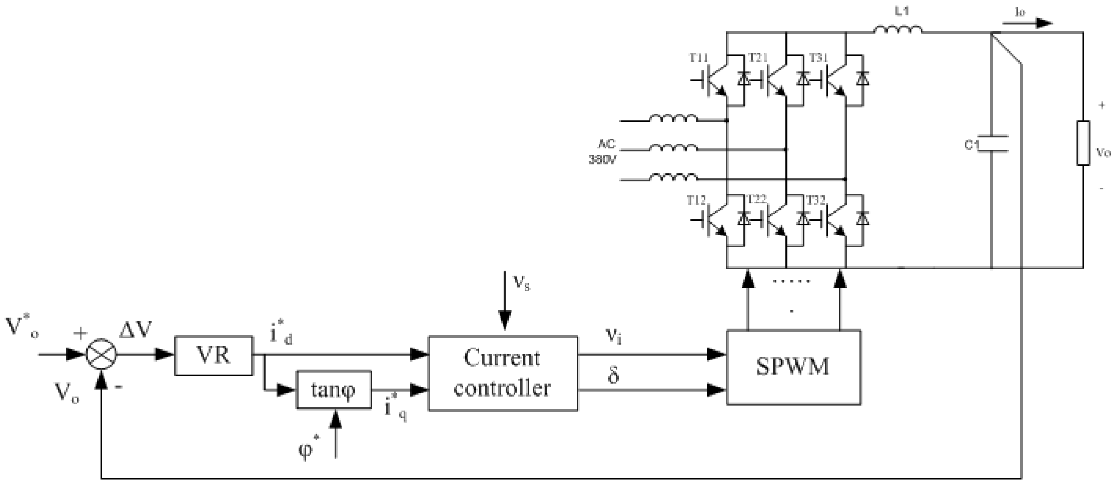


Figure 6. Rectifier Control Schematic of PWM

When the charger works in constant current output state, dual-loop control of the voltage outer limiting maximum output voltage, the dual-loop control is actually equivalent to the current single-loop control. But when the charger operates in constant voltage output, double-loop work achieves the regulation of current inner and outer voltage, so that the system has the advantages of current control technology.

The current controller uses an average current control methods. In order to reflect the average current value of the output of the controller filter inductance, a current signal low-pass filter is needed to eliminate high frequency components of filter inductance current.

(2) Control strategy of PWM rectifier

In order to ensure a stable DC voltage, PWM rectifier commonly used voltage feedback loop control. The control system detects the actual value V_o and compared with the instruction value V^*_o, and take the voltage error ΔV into voltage error regulator VR of PI, PI regulator output is taken as the current command value i^*_d, then depending on the required power factor angle φ, getting reactive current command i^*_q, the AC voltage instruction vi of PWM rectifier and phase angle δ are calculated, SPWM waveform controller produces six switch on-off signals of the device. When the AC voltage and DC load change, either the voltage closed-loop control ensures the DC output voltage constant, and can ensure PWM rectifier power factor is 1.

4.2 Key Performance Indicators of Charging Station Simulation Model

A total of three type's integrated charger of large medium and small are designed, and large, medium and small charging stations are constituted by different number of the three types of charging units.

Table 1. The Number of Different Types of Charging Stations Charger

	Small charger	Medium charger	Large charger
Large charging station	8	4	2
Medium charging station	8	4	0
Small charging station	4	0	0

Table 2. Integrated Charging Machine Parameters and Performance Requirements

	Small charger	Medium charger	Large charger
Input voltage	380V, 50Hz	380V, 50Hz	380V, 50Hz
Output voltage range	300V~500V	200V~400V	150V~350V
Output current range	100A	200A	400A

(1) Power factor compensation

When the output power is 50% to 100% of rated power, the power factor is not less than 0.95.

(2) Harmonic current requirements

Harmonic currents generated by content charger should not exceed GB / T 19826-2003 limits specified in 5.4.2.2

(3) Battery type: Lithium-ion batteries

(4) Charger performance requirements

Output current steady flow accuracy: ± 1%

Output voltage regulation accuracy: ± 0.5%

Ripple factor: RMS output ripple factor should not exceed ± 0.5%, the ripple crest factor shall not exceed ± 1%

4.3 The Design of Charging Stations Reactive Power Compensation and Harmonic Suppression

Diode rectifier charger generates great harmonic during the charging process, causing pollution to the power grid by charging stations, which affects other users of public low-voltage power transformers. When the harmonic voltage and harmonic current charger not meet the requirements, it can be used to increase the number of pulses, add centralized compensation device (passive and active filters) to suppress harmonics. By energy efficiency simulation of charging station, analysis the influence factors of the compensation capacity, the compensation capacity are obtained. The PWM rectifier charger by the rational control technology can control the AC voltage input current distortion small sinusoidal current, the power factor is close to 1, the system does not need additional harmonics and reactive power compensation device.

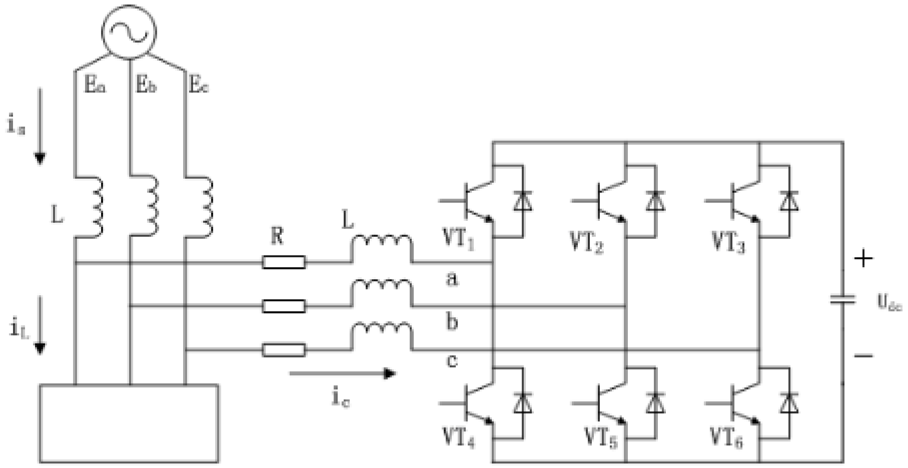


Figure 7. AFP Main Circuit

Active power filter produces an equal with harmonics and reactive power compensation, and phase opposite compensation current, and injected into the grid, which can obtain the required power factor sinusoidal current, in order to achieve active filtering and reactive power compensation.

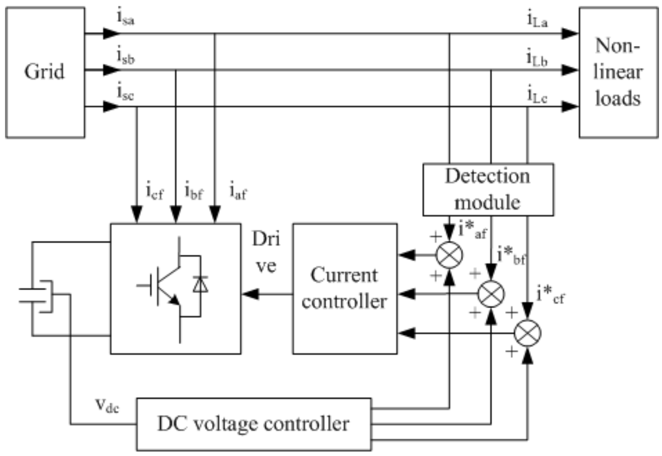


Figure 8. The Schematic of Reactive Power Compensation and Harmonic Control

The i_{sa}, i_{sb}, i_{sc} are grid current, and i_{La}, i_{Lb}, i_{Lc} are the load side of the current. Real-time network-side detection module detects the load current harmonics and reactive current, and reverse polarity as the current instruction i^*_{af}, i^*_{bf}, i^*_{cf} of APF, and ultimately controlled by the current controller of the APF current i_{af}, i_{bf}, i_{cf}, thereby compensate grid current harmonic and reactive power. Control system consists of a voltage loop, current loop bicyclic structure, the voltage loop is used to stabilize the DC voltage, current loop on the one hand compensates harmonics and reactive current, on the other hand to compensate the voltage corresponding to the active current loop output.

5. Conclusion

Electric vehicle charging and discharging facilities is a complex electrical system, there are many factors to affect its energy consumption. In this letter, we understand the electric vehicle charging and discharging structure, the facility subsystem, gather some information necessary parameters, and try to understand the characteristics of each part. The volatility factors of electric vehicle charging and discharging energy facilities are analyzed to make the necessary and reasonable simplification. According to the causality relationship of assumptions and the inherent rule, the energy simulation model of electric car is draw.

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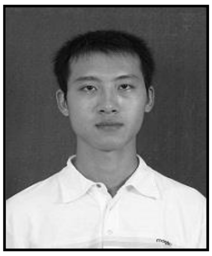

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