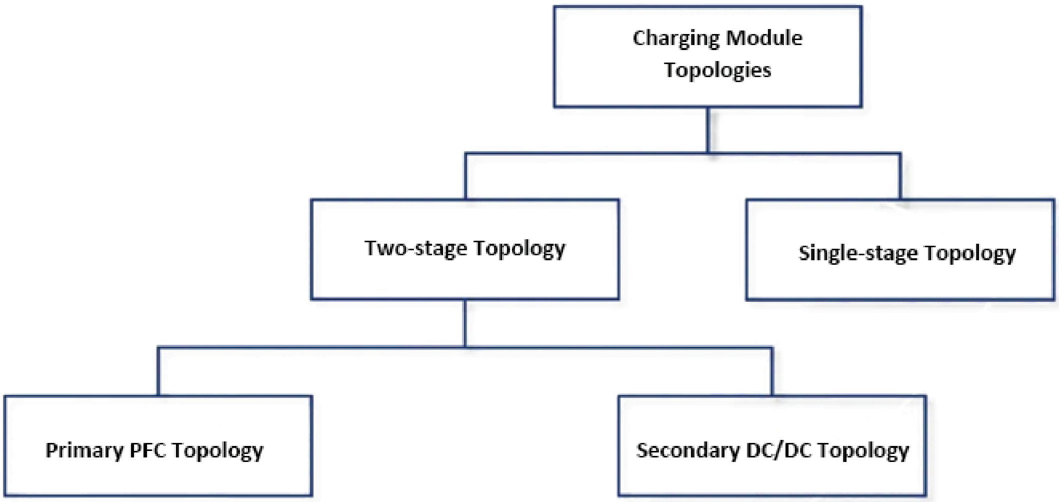
XY Power | A Brief Analysis of Mainstream Charging Module Topologies

As key components in the DC charging stations, the charging module not only facilitates the conversion of electrical energy from AC to DC but also enables circuit control to ensure circuit stability. The performance of the charging modules greatly determines the output power, efficiency, system reliability, and safety of the DC charging stations.

The topology of the charging module determines the circuit structure and configuration of the modules, and it is significant for enhancing the performance and efficiency of charging stations. Currently, charging module topologies are mainly classified into Single-stage and Two-stage topologies, with the Two-stage Topology further divided into Primary PFC Topology and Secondary DC-DC Topology. Today, XY Power will provide a brief analysis of the topologies of mainstream modules on the market, making it easier for you to understand the charging modules better.



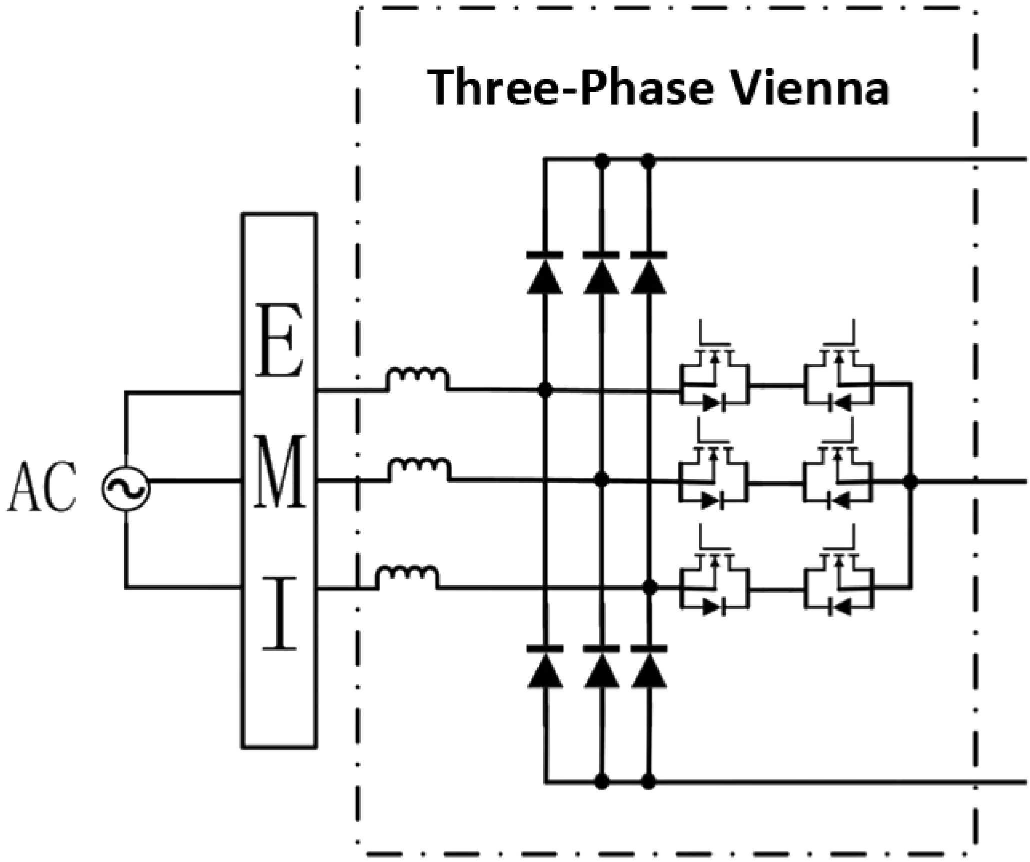
1. Primary PFC Topology

With the continuous development of power electronics technology and the increasing emphasis on energy efficiency, environmental protection, and low-carbon initiatives, research on high-efficiency, low-energy circuit topologies have made significant progress. AC/DC converters are widely used in daily life and industrial production, but the power conversion process inevitably generates harmonics, which can pollute the power grid. Therefore, topologies that are efficient, high power factor, and low harmonic have attracted widespread attention.

To achieve low harmonics and high power factor AC/DC conversion, the front-end PFC topology (Power Factor Correction, PFC) has emerged. In charging modules, commonly used forms include the three-phase Vienna PFC topology and the three-phase six-switch PFC topology.

1.1 Three-Phase Vienna PFC Topology

The Three-Phase Vienna PFC Topology is one of the most widely used topologies at present, extensively employed in charging modules and high-power switch-mode power supplies. At a power level of 30 kW, it can achieve an efficiency of over 98.6%. Compared to the standard three-phase BOOST PFC, it can reduce the voltage stress on power MOSFETs, lower switching losses, increase switching frequency to enhance the volume of magnetic components, and offer other advantages.



The Three-Phase Vienna PFC Topology also possesses the following advantages at the application level:

▷ The topology is relatively stable, with no direct bridge arm phenomenon. (Direct bridge arm: caused when both IGBTs of a bridge arm are turned on simultaneously, which may result from electromagnetic interference, controller malfunctions, or the failure of one IGBT in the bridge arm while the other IGBT operates normally.)

▷ Low voltage stress on switching devices (half-bus voltage); higher stability of IGBTs.

▷ Low switching device losses.

▷ Small inductance value.

▷ Low ripple current.

▷ Low common-mode interference.

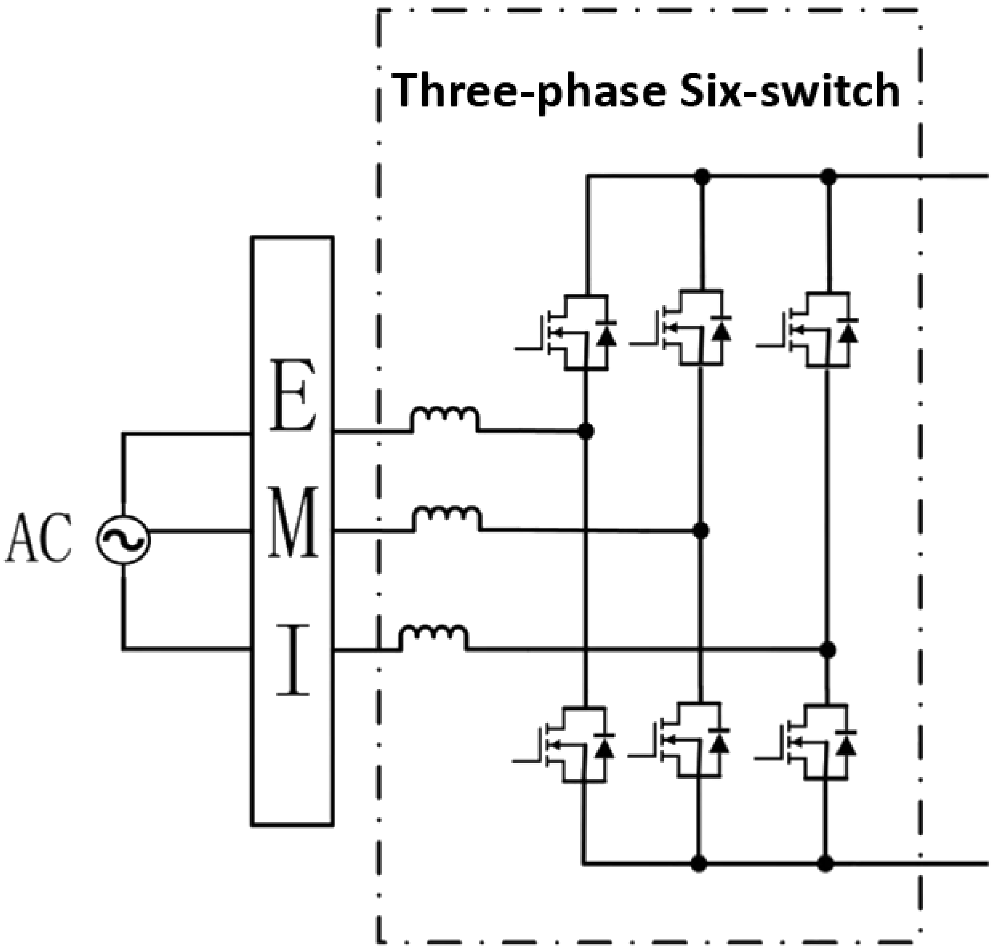
▷ Cost-effective.

▷ Simple drive and control.

However, the Three-Phase Vienna PFC Topology also faces challenges in practical applications, such as a high number of components (diodes and IGBTs), which is not conducive to achieving high power density. Additionally, it supports unidirectional energy flow only and cannot meet the requirements of bidirectional energy applications like Vehicle-to-Grid (V2G) systems.

1.2 Three-Phase Six-Switch PFC Topology

Compared to the Vienna Topology, the Three-Phase Six-Switch PFC Topology features a relatively simple circuit topology, making it easier to control. Its main characteristic is the convenient bidirectional control of high-power flow, allowing for the achievement of a high power factor with reasonable efficiency. As a result, it is widely used in various bidirectional power control applications.



In practical applications, the Three-Phase Six-Switch PFC Topology has the following advantages and disadvantages:

Advantages:

▷ Operates in four quadrants, suitable for bidirectional applications.

▷ Requires fewer components, making it easier to reduce losses by incorporating strategies like DPWM and TCM.

▷ Mature control algorithms.

Disadvantages:

▷ High voltage stress on switching devices (using SiC MOSFETs).

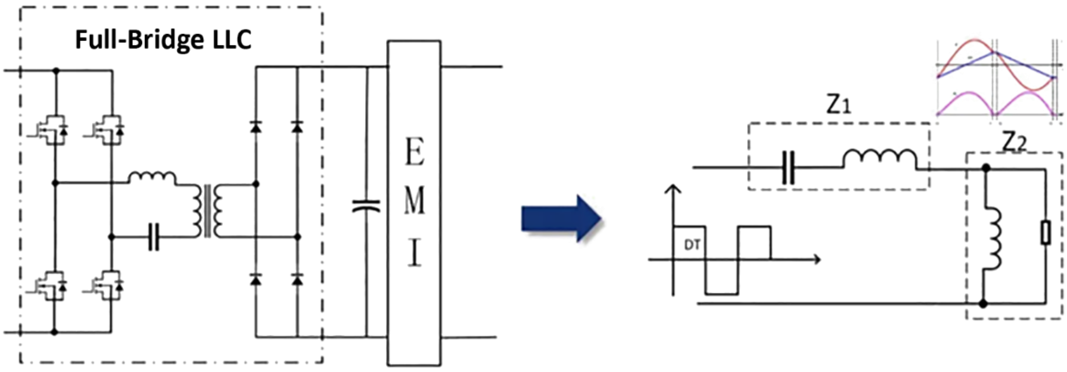
▷ Relatively poor Total Harmonic Distortion of Input Current (THDI).
▷ Risk of direct conduction for the two series-connected switching devices in each bridge arm, requiring high reliability in power drive control.
▷ Multiple drive paths (high demand on DSP drive resources when implementing interleaved parallel operation).
▷ High cost.

2. Secondary DC-DC Topologies

In recent years, driven by the increasing demand in applications like "light storage charging" and microgrids, the need for isolation functions in charging modules and enhanced control over current and voltage has led to a growing adoption of secondary DC-DC topologies. Commonly used secondary DC-DC topologies in charging modules today include: Full-Bridge LLC, Three-Phase LLC, and Phase-Shifted Full-Bridge.

2.1 Full-Bridge LLC Topology

The Full-Bridge LLC circuit consists of an inductor (L), a capacitor (C), and a transformer (L). An AC square wave voltage or current is applied across the resonant network, generating high-frequency resonance. The resonant voltage or current, after rectification and filtering, is converted into DC voltage or current, thereby achieving DC-DC conversion. This topology is known for reducing switching losses, improving efficiency, high power density, and suitability for high-power applications.



Advantages:

- Soft turn-on for the MOSFETs on the left side of the resonance point, soft turn-off for the output diodes.
- Provides both step-up and step-down voltage functionality.
- Low switching losses.

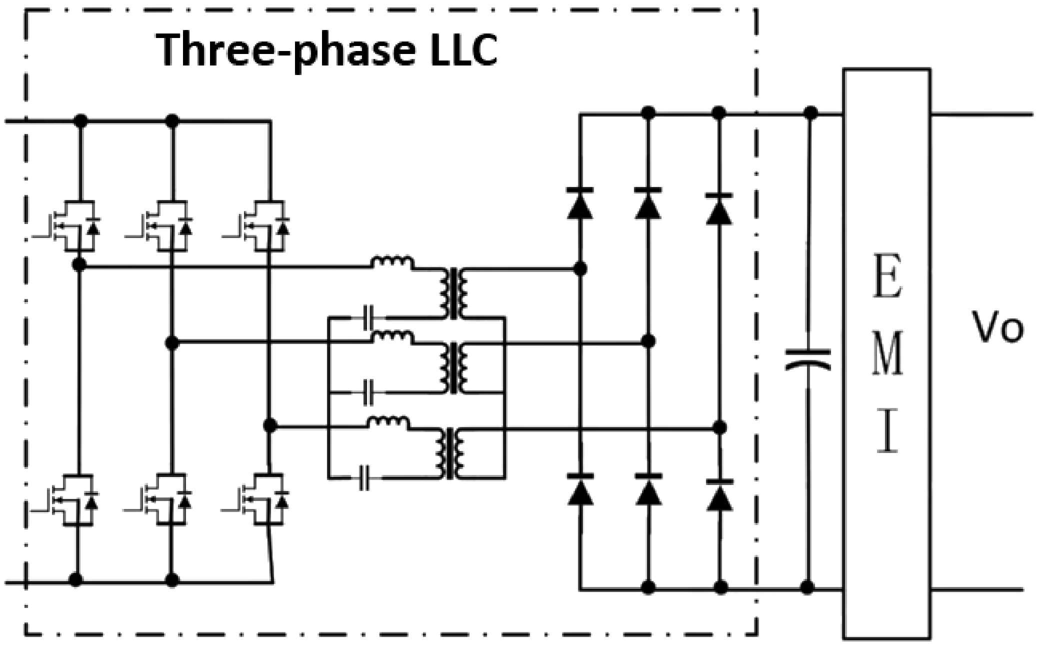
Disadvantages:

- Non-monotonic gain with wide bandwidth.
- Higher losses in the primary side MOSFETs and output rectifier diodes on the right side of

the resonance point.
- Higher excitation current on the primary side as the output voltage increases (leading to reactive power losses).
- Asymmetrical bidirectional gain, not conducive to Vehicle-to-Grid (V2G) functionality.

2.2 Three-Phase LLC Topology

The Three-Phase LLC Topology is a circuit structure commonly used in power converters, consisting of a three-phase bridge rectifier and an LLC resonant converter. It is characterized by high efficiency, low electromagnetic interference, and low losses.



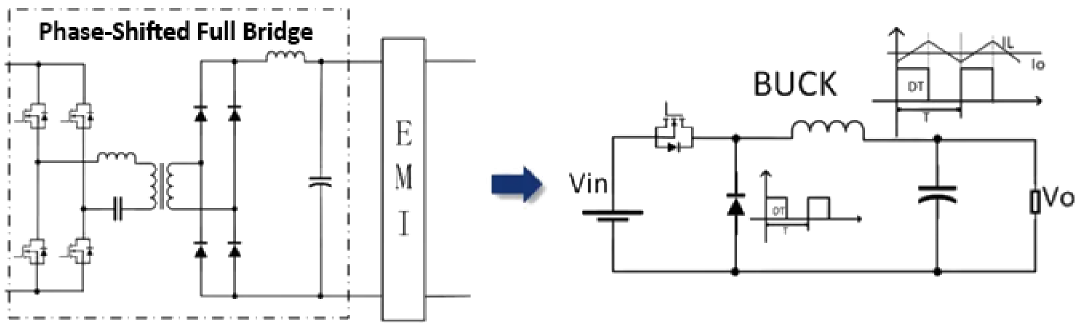
Advantages:
- Soft turn-on for the MOSFETs on the left side of the resonance point, soft turn-off for the output diodes.
- Provides both step-up and step-down voltage functionality.
- Low switching losses.
- Low input-output ripple.
- Lower current in the primary side MOSFETs, resulting in reduced conduction losses.

Disadvantages:
- Non-monotonic gain with wide bandwidth.
- Higher losses in the primary side MOSFETs and output rectifier diodes on the right side of the resonance point.
- Higher excitation current on the primary side as the output voltage increases (leading to reactive power losses).

- Higher number of power devices (switching devices and magnetic components), leading to higher costs.

2.3 Phase-Shifted Full-Bridge Topology

The Phase-Shifted Full-Bridge Topology is a common switch-mode power circuit topology used as a transformer structure, known for its wide input voltage range, adjustable output power, and high efficiency. It finds wide applications in the field of power electronics.



Advantages:

- Buck-type voltage regulation with a wide voltage regulation range.
- Soft switching can be achieved.
- More suitable for bidirectional applications.

Disadvantages:

- Secondary-side duty cycle loss.
- Difficult to achieve soft switching on the high-side bridges at light loads.
- Only offers step-down functionality.
- Higher switching losses.

3. Single-Stage Topologies

Single-stage topologies refer to topologies where internal components undergo only one level of power conversion. As a novel form, single-stage topologies are gradually being applied in the charging industry. Common single-stage topologies include: Single-Stage SWISS, Single-Stage RMC, and Single-Stage EN5.

Single-Stage SWISS Topology

The Single-Stage SWISS topology is a single-stage three-phase Buck-type PWM rectifier known for high efficiency and compact size.

Single-Stage RMC Topology

The Reduced Matrix Converter (RMC) consists of a three-phase input LC filter, three-phase/single-phase matrix conversion unit, high-frequency transformer, full-bridge rectifier unit, and output LC filter. It is characterized by a low number of conversion stages and high power density.

Single-Stage EN5 Topology

The Single-Stage EN5 topology employs single-stage AC-DC power conversion technology, completing the process of converting AC to DC through a 1-stage topology circuit, representing a novel topology technology.

Charging modules, as products of power electronics technology, require a certain level of technical expertise. Both the technical platform and the research and development personnel need to have accumulated technical knowledge. Through iterative development, reliable, efficient, and stable high-quality products can be provided to customers.

With over 25 years of industry technical experience, XY Power focuses on product technical accumulation, having accumulated experience from hundreds of checklists. While ensuring product stability and reliability, the company adheres to customer-centric principles, continuously introducing product technologies and solutions to enhance product quality and simplify operations.

In the future, XY Power hopes to collaborate with partners to launch even more competitive products, facilitating the healthy and rapid development of the charging industry.