The Scope of Application of Power Decoupling Technology and Its Evolution

Yankai Zhang *

School of Intelligent Manufacturing and Control Engineering, Qilu Institute of Technology, Jinan, 250200, China

* Corresponding Author Email: zyk0309@qlit.edu.cn

Abstract. As energy consumption worldwide continues to escalate, the gap between energy supply and demand is becoming alarmingly evident. This disparity, combined with the mounting environmental threats impacting production and human existence, intensifies the energy challenges our nation confronts. At the heart of addressing these issues is the imperative to maximize energy efficiency. Within the realm of power electronics, the topic of power decoupling has emerged as a pivotal area of research. This paper delves into the application of power decoupling in power electronics, offering a comprehensive analysis of its characteristics and applicability. Tracing its evolutionary trajectory, the paper systematically explores the historical progression of power decoupling technology. It further segments the technology, elucidating its merits, limitations, and mechanisms for enhancement. By aggregating data, the study categorizes various inverters and contrasts their roles in the domain of power decoupling. Subsequently, the discourse distinguishes between active and reactive power decoupling, providing prevalent examples of the former. The paper concludes by affirming the trajectory of power decoupling towards increased cleanliness and efficiency. The emphasis on high-precision and high-efficiency apparatuses heralds the anticipated future direction of this field.

Keywords: Power decoupling technology; energy development; inverter.

1. Introduction

With the improvement of people's awareness of environmental protection and the promotion of energy transformation, China's energy structure has undergone certain changes. Clean energy, represented by wind, solar and water, has been more developed and utilized. At the same time, the rapid growth of energy consumption, the increasingly prominent contradiction between energy supply and demand, and the continuous threat of the environment to people's production and life have also increased China's energy challenges. As a result, China's energy development strategy has been newly adjusted: energy saving, the development of nuclear energy, the development of new energy and renewable energy. The key to our solution is the application of energy for maximum efficiency. In terms of power electronics, to improve circuit performance and efficiency and reduce power loss and interference caused by natural energy uncertainty, power decoupling technology with broad development prospects will be selected.

Due to the instantaneous power imbalance between the microinverter's AC and DC side of the microinverter, we need to take corresponding energy buffer devices to achieve power decoupling. Power decoupling technology is also becoming more mature and perfect under multiple conditions, such as time and external environmental interference. The literature often involves generators and inverters, such as combined with inverters, To meet the requirements of doubled frequency current suppression [1]. Another article is to solve the problem that the output power of the virtual synchronous generator (VSG) is coupled during line transmission, resulting in steady-state error, dynamic oscillation and even control failure of power control [2]. Of course, it also plays a pivotal role in energy represented by wind energy and solar energy. Although power decoupling technology has made some achievements, there is still room for improving circuit efficiency. In this paper, the scope of the application of power decoupling is analyzed and studied. The future development is planned and summarized from the technical classification, method improvement and the problems faced.

2. Basics of Power Decoupling

2.1. Application Reasons

Improve the performance and efficiency of the circuit: power decoupling isolates input power from output power by controlling components in the circuit and provides better matching between input and output. High technical content: unlike traditional large-capacity electrolytic capacitors, the new power decoupling circuit has a long life and small capacitance. The circuit can be effectively optimized, the performance and efficiency of the circuit can be improved, and the power loss can be reduced. Power decoupling is applicable in a wide range of applications and methods. It is mostly suitable for photovoltaic power grids, wind turbines, etc., with broad research prospects and high social attention.

2.2. The principle

Coupling is the bridge between two functional circuits that enables the transmission of signals and energy. Power decoupling is a circuit design technique that separates the power between the active components in a circuit and the load. The electrical parameters on the stator side and the rotation on the rotor side are put together, and the parameters of the straight shaft do not generate rotational torque, which is decoupling. The new single-phase inverter with boost and power decoupling functions is shown in Fig. 1, including a post-stage full-bridge circuit and a frontstage rotating buck-boost circuit. The circuit considers filtering high-frequency components in practical applications, connects a capacitor in parallel on the H-bridge input DC bus, and considers its partial power decoupling function to optimize the design together with the decoupling capacitor.

2.3. Application Illustration

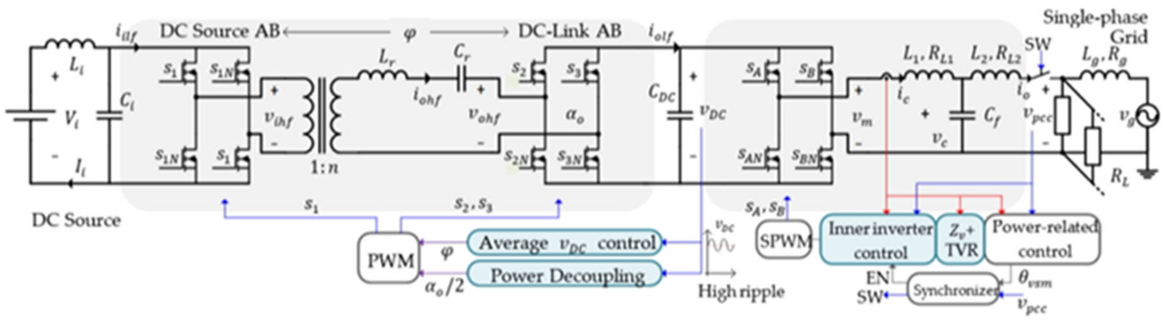

Fig. 1 Two-stage DC-AC charger structure and control overview [3]

The analyzed two-stage DC-AC structure and the overall control overview are depicted in Fig. 2. The two-stage DC-AC converter is composed of a VSI (DC-AC stage) cascaded with a DABSR (DC-DC stage) converter, considering a high LFR in the DC-link [3]. It can be seen from the figure that power decoupling technology plays a crucial role.

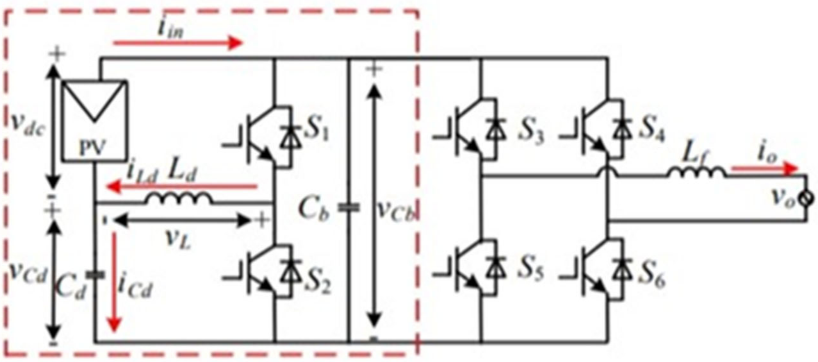

Fig. 2 New single-phase inverter with boost decoupling [4]

The new single-phase inverter with boost and power decoupling functions is shown in the figure, including a post-stage full-bridge circuit and a frontstage rotating buck-boost circuit. The circuit considers filtering high-frequency components in practical applications, connects a capacitor in parallel on the H-bridge input DC bus, and considers its partial power decoupling function to optimize the design together with the decoupling capacitor.

2.4. Evolved Scope of Application

Much of the literature on power decoupling is from 2018 to 2022. There has been an increase during the pandemic. In the past ten years, the article's keywords revolve around sag control, virtual synchronous generator, active power decoupling, microgrid, virtual impedance, inverter, photovoltaic power generation, wind power generation, etc. In the past three years, the proportion of photovoltaic literature has risen with the emergence and application of new energy. The above changes show that the publication of power decoupling literature is greatly affected by the external environment, and at the same time, on the basis of power equipment, more and more rely on clean new energy.

3. Introduction to Power Decoupling Technology

3.1. Classification of Power Decoupling

At present, it is known that power decoupling technologies can be roughly divided into four categories: coordinate transformation decoupling, feed-forward compensation, optimization control, and virtual impedance decoupling [5]. Coordinate transformation decoupling is achieved by introducing virtual power or voltage and frequency, but the output power is still coupled due to small work angle constraints [5]. The article is based on the overall adjustment of the four parameters of the plane coordinate transformation of the inverse solution plane of the common point position [6]. The pathological method matrix may occur due to the dimensional problem, so the generation mechanism of pathology is analyzed, and the solution parameters are decoupled by the center of gravity transformation of the original point [6]. The feed-forward compensation decoupling algorithm eliminates the coupling by introducing feed-forward compensation by the relative gain method, but only in the quasi-steady-state model. It is widely used in agriculture and forestry with torque current, permanent magnets, inverters, etc. The literature decouples three main variables in the greenhouse system by studying the application of a feed-forward compensation algorithm in the three-dimensional system [7]. It also establishes the mathematical model of the greenhouse system [7]. And then conducts simulation research and verifies the efficiency and stability of the feed-forward compensation algorithm applied to the simulation system by comparing it with the simulation results [7].

Optimized control decoupling is proposed, a decoupling control method based on objective function diagonalization. There are few literatures involving optimal control, and here the author has selected a more representative one. There is literature on grid-connected speed control of hydraulic storage wind turbines under wind speed and synchronous generator load changes. A new grid-connected speed control method is proposed - decoupling generalized prediction optimization control method. Under the given constraints, it seeks a control system to achieve the maximum or minimum control of the given controlled system performance indicators [8]. Power decoupling control is widely used, and virtual impedance decoupling is mature. Adding a virtual inductor to the control system makes the output impedance of the system inductive and reduces the power coupling between the two. In addition, there are some special circuit topologies and control methods. The main ones are the active filtering (APF) method, decoupling circuit series connection method, single-stage flyback inverter conversion method, multi-stage inverter decoupling method, three-port decoupling method and so on [9]. Series decoupling circuit control is easier to implement independently. However, all the power output of the PV module will pass through the decoupling circuit, increasing the losses and the voltage and current capability of the switching tube. Therefore, it can be solved by optimizing the circuit structure, improving the transformer efficiency or optimizing the load organization.

3.2. Power Decoupling Applications

3.2.1 combination of power decoupling and inverter

The inverter mentioned above has the function of converting DC to AC. Inverters are divided into single-phase inverters, three-phase inverters, and multiple inverters. The number of phases output can be divided into single-phase inverter, three-phase inverter and multi-phase inverter. Inverter and power decoupling are also often inseparable, such as synchronous and photovoltaic microinverters. Different types of inverters combined with power decoupling technology will produce different effects. The literature uses decoupling control of active power based on pulse energy modulation to deliver second-order ripple power to a film capacitor for power decoupling [10]. Another article is a feed-forward decoupling control method that introduces a series of virtual impedance in the voltage loop and increases the active instructions of the current loop [11].

3.2.2 Applications for active power decoupling

Taking single-phase inverters as an example, the existing literature mainly includes passive and active power decoupling [12]. Passive power decoupling is to absorb secondary ripple with the resonance of the inductor and capacitor, but the resonant voltage is uncontrollable, and the adjustment range is limited by the DC bus, which requires the use of large-capacity device energy storage components; In addition, the resonant loop has a single filtering frequency and poor frequency adaptability. Electrolytic capacitors' large size and short life greatly reduce single-phase inverters' service life and reliability. To reduce the evaporation of the electrolyte of the liquid, a double-layer sealing system can be used to improve the tightness and thus extend the service life. When selecting, pay attention to leaving a margin in voltage and capacity, which can extend a certain life. Active power decoupling is a circuit design technique that separates the power between the active components (such as transistors, amplifiers, etc.) in a circuit and the load. This technology isolates input power from output power by controlling components in the circuit and can provide better matching between input and output. A circuit that implements active power decoupling typically consists of three parts: a power amplifier, a power isolator, and a load.

The power decoupling circuit and corresponding decoupling control method mainly realize it. The basic idea of the existing types of active power decoupling circuits is to use active circuits to transfer ripple power from the DC link to additional decoupled energy storage elements (usually capacitors) and maximize the use of energy storage elements by controlling the power processed by the decoupled energy storage elements as much as possible to fluctuate over a large range. There is literature that talks about harmonic-free detection APF. The reason is that the generated DC voltage is too small, and low-value film capacitors are often used instead of electrolytic capacitors [13]. Due to its characteristics of no polarity, high insulation impedance and wide frequency response, the reliability and power density of the inverter system are greatly improved. However, its active power decoupling circuit control is a semi-open-loop control, the decoupling operating current is in discontinuous mode, and the decoupling accuracy requires inductor parameters and a high switching frequency [13]. Based on the background of photovoltaic grid-connected inverters, the literature uses key component inverters to improve the compensation performance of reactive power by changing the phase angle and amplitude of the inverter [13].

In terms of active power decoupling control strategies, the existing research can be roughly divided into four categories according to the control ideas: control based on power balance, control based on harmonic suppression, control based on virtual impedance and control based on automatic power decoupling. Power balance refers to the balance of input and output power. The impedance of the circuit can be calculated according to the formula $Z=R+jX$. If $X>0$ is in the impedance of the entire circuit, the circuit is inductive; If $X<0$, the circuit is capacitive. 2. It is already known that the phase angle of the voltage phasors in the circuit is $\varphi 1$, and the phase angle of the current phasors is $\varphi 2$. If $\varphi 1-\varphi 2>0$, the circuit is inductive; the opposite is capacitive.

4. Conclusion

In view of the new adjustment of our energy development strategy: greater emphasis on energy conservation, the development of nuclear energy, and the development of new and renewable energy sources. The power decoupling technology has also been continuously improved and perfected. Scientists continue to study and rectify problems such as the coupling phenomenon between active and reactive power and the power dissipation of decoupling capacitors to reduce system efficiency. And more around active power decoupling, virtual synchronous generators and more technical electronic devices to solve difficult and high-precision problems. Such as solving active power filters, virtual synchronous machine power steady-state deviation, dynamic oscillation, etc. To cope with the rapid growth of energy consumption, the contradiction between energy supply and demand has become increasingly prominent. This paper analyzes the characteristics and scope of the application of power decoupling technology, which provides a clearer and more reliable development direction for the future of power decoupling technology.

Based on the references to power decoupling techniques, this paper summarizes the scope of application and evolution trend of power decoupling. The evolution law of power decoupling is introduced, its types are divided in detail, and its advantages and disadvantages and intervention improvement mechanism are expounded. With the development of science and technology, the use of clean energy power and power decoupling technology will be applied to more fields to solve high-precision problems, more efficient, safer and more reliable to contribute to energy utilization, national security and environmental protection, and provide a broader platform for talent training.

There are still some issues faced by people in this field at the current stage: i) Active and reactive power is also often coupled. Under the operating conditions of large power angles that is easy to occur in weak power grids and high impedance ratio of the route during power transmission, the active and reactive power of the virtual synchronous machine is seriously coupled, which may cause VSG power steady-state deviation, dynamic oscillation, and even system instability in severe cases. The VSG power coupling mechanism is currently analyzed using a dynamic relative gain array. ii) Sometimes, the power dissipation of the decoupling capacitor reduces system efficiency. iii) In the series decoupling circuit, all the power output of the photovoltaic module will pass through the decoupling circuit, which will increase the loss and affect the voltage and current capability of the switching tube.

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