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# Analysis of an improved three-phase voltage source converter with high-performance operation under unbalanced conditions

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**Abstract.** The power system is rapidly transforming into a new large-scale distributed power generation model using renewable energy. Grid-connected converters, particularly voltage control compensators like STATCOM, will be crucial to the functioning of this new situation. Voltage source converter (VSC) is one of the most commonly used topologies in grid connection converters. As a distributed power-generating device, VSCs can be utilized as a means of connecting sustainable energy sources to the power grid. The three-phase voltage source currents or voltage ripples may appear in the DC chain. This study examines the enhanced three-phase VSC, pinpoints the factors that contribute to the great performance of VSCs, and looks at future trends in three-phase VSCs. VSC is a power electronic device capable of converting DC voltages to three-phase AC voltages and is commonly used in areas such as grid connection, reactive power compensation and harmonic suppression. In practical applications, various types of grid or load disturbances pose hidden dangers to the normal operation of the VSC. Due to the presence of unbalanced grids and loads, significant double frequency.

**Keywords:** power system, three phase, voltage source converter, unbalanced condition.

## 1. Introduction

VSC is a power electronic device that converts electrical energy from one source to another, for example, from AC to DC or from DC to AC. It is an inverter or rectifier consisting of switching devices (e.g., IGBTs) and filters that enable fast control of the output voltage or current. At the same time, he has the advantages of high efficiency, flexibility and controllability and has been widely used in DC power transmission, power electronic transformers and electric vehicle charging piles. It can improve the stability, reliability and power quality of the system while also reducing the losses and costs of the system. However, in practice, various types of grid or load disturbances and faults pose significant challenges to the proper operation of VSCs [1,2]. Due to unbalanced grids and loads, significant dual-frequency currents or voltage ripples can occur in the DC chain [3-5]. These can cause the system to suffer damage as it reduces the efficiency of the PV panels, causes the cells to overheat and shortens the

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life of the fuel cells. Therefore, VSCs need to be operated at high performance under unbalanced conditions, and advanced control algorithms are needed, such as space vector modulation (SVM), to achieve minimum distortion and maximum power transfer under unbalanced conditions [6]. However, control strategies for voltage source inverters must be optimized for unbalance conditions, e.g., dynamic current balancing control can balance the load current under power imbalance conditions [7]. At the same time, high-quality inductors and capacitors are necessary to reduce current harmonics and voltage swings in an imbalanced situation. This paper presents an analysis of existing modified three-phase VSCs to derive the reasons for the high performance of VSCs.

## 2. Improvement analysis

This paper presents an analysis of existing modified three-phase VSCs to derive the reasons for the high performance of VSCs.

### 2.1. *An improved topology*

Improved topology circuit and working principle there is currently an enhanced three-phase VSC topology for obtaining high-performance operation in an imbalanced environment [8]. This architecture includes a conductive route to enable the passage of harmonic currents in an imbalanced system, thus ensuring sinusoidally symmetrical grid currents and ripple-free DC link currents/voltages. This conductive path is able to function as a standard-mode route to restrict components of the converter's high-frequency current. This can be used to lower leakage currents in photovoltaic systems without transformers or get rid of high-frequency circulating currents across many parallel converters. Due to the simplicity with which the additional conductive line may be inserted onto the printed circuit board of the power stage, this architecture differs from previous hardware solutions in that it does not raise system cost or size. Unlike the conventional three-phase VSC topology structure, an improved topology structure as shown in Figure 1 adds a line connecting the negative pole of the DC voltage source at the intersection of three AC capacitors. The red line in Figure 1 shows that the enhancement may have a substantial impact on the quality of the AC grid current or load voltage as well as the performance of the power supply. A balanced and sinusoidal distribution of the AC output current (or voltage) is possible at the same time. Such improvements make it easier for this topology structure to be integrated into circuit boards without increasing system size and cost.

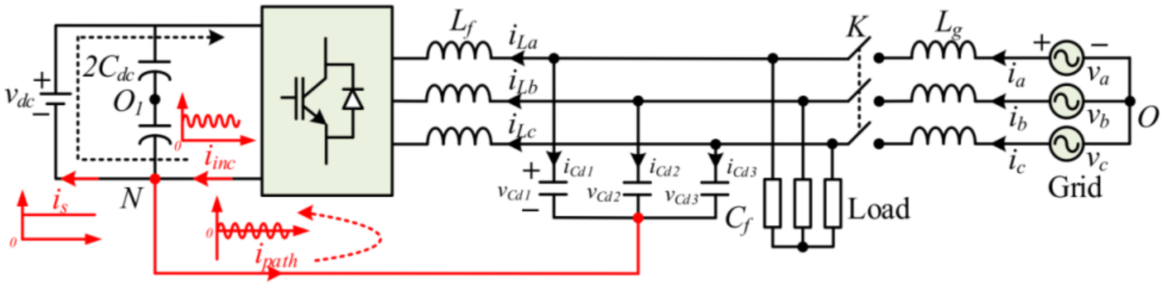

**Figure 1.** The enhanced three-phase VSC in an imbalanced three-phase situations.

The improved topology structure proposed in Figure 2 can restrict the common-mode current components at high frequencies.in the additional path through circuit characteristics without additional control. Therefore this section mainly discusses control methods for eliminating dual-frequency harmonic currents in DC sources. The revised topology structure's control block diagram is seen in the figure and is made up of two sections: a ripple control loop and a control loop for current and voltage with the balanced operation. In order to control the output power, the former primarily creates balanced sinusoidal currents (or voltages).

It also restricts components of low order in the extra conduction route with respect to the ripple control loop. This may be accomplished by indirectly eliminating the DC source current's ripple, in accordance with Kirchhoff's current law. To do this in the control loop, the reference value is set to zero, and source current serves as feedback. To achieve accurate tracking at a specific frequency when the system is experiencing unequal or asymmetrical conditions, a resonant controller should integrate the anticipated current error based on the common-mode voltage formulation. This compensates for the unbalanced conditions and minimizes tracking error. Moreover, resonant controller output is unaffected by the presence of DC components in the feedback signal since resonant controllers have zero gain for DC signals. In order to fulfil control goals, the resonant controller's output increases the voltage reference value from the balanced control loop. This improves control accuracy of the output voltage and compensates for any unbalanced conditions. Of course, when three phases are balanced, the system may function properly and be unaffected by the ripple power control circuit.

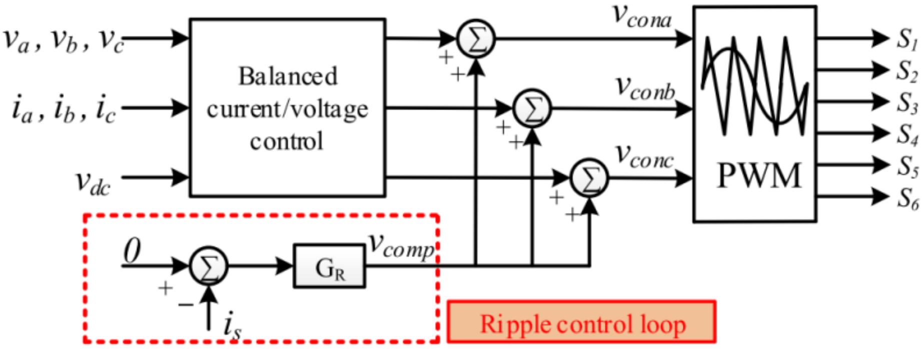

**Figure 2.** The enhanced topology's control system.

### 2.2. *Model predictive control of STATCOM*

A technique for controlling the AC-side current of a VSC using finite-set model predictive control (FS-MPC) is available for use as a static reactive power compensator (STATCOM) [9]. This method can control the output current of VSC to generate the necessary reactive power to regulate grid voltage under balanced and unbalanced load conditions. This technique as proposed in Figure 3 is simple to use, and it has been tested through simulation using the MATLAB/SIMULINK programme. For time-domain simulation, a three-phase, three-wire grid model was created in order to assess the viability of the FS-MPC architecture for VSC. IGBT and diode built-in variants with a 100kHz switching frequency are used in the MATLAB/SIMULINK model of this VSC. In order to manage grid voltage, this VSC, which utilizes current mode control with FS-MPC as its foundation, establishes the VSC as STATCOM. In this instance, the VSC supplies the grid with reactive power to control system voltage. The amount of reactive power needed for regulation can be calculated from voltage changes. As reference values for FS-MPC currents, equivalent currents can be calculated after reactive power has been determined.

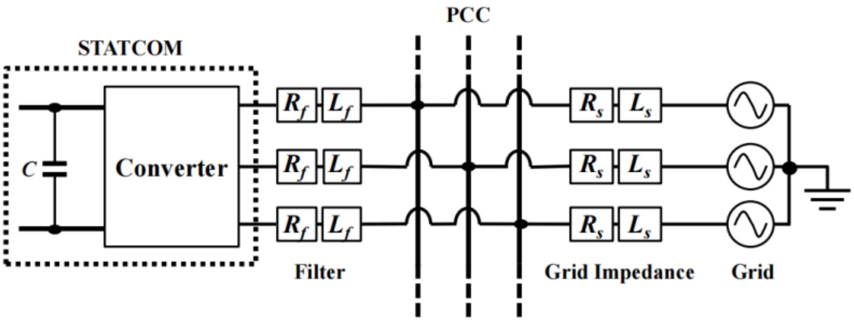

**Figure 3.** A VSC in STATCOM configuration.

The graphic in Figure 4 displays the grid voltage variations that were taken into account throughout this simulation. The voltage changes to 0.95 p.u. during time interval t = 0.10 s. The voltage changes to 1.05 p.u. during time interval t = 0.30 s. When voltage variations occur, external control establishes the necessary reference current to produce reactive power capable of bringing voltage back to within one p.u. After then, the reference current is tracked by the FS-MPC-based internal control loop. Take note of how the reactive power signal has caused the STATCOM current to phase change (reactive power is generated when the voltage is low and is dissipated when the voltage rises).

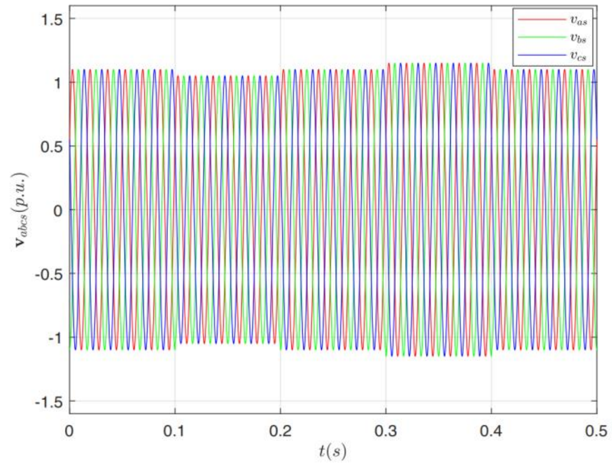

**Figure 4.** This simulation considering the changes in grid voltage $V_{abcs}$ (t).

### 2.3. *VOFC method*

There is now a novel control approach that develops and implements VFOC for front-end VSC by adopting the power estimating theory used in Voltage Oriented Control (VOC) and Virtual Flux Direct Power Control (VFDPC) [10]. With this control strategy, fewer sensors are needed, and AC voltage supply sensors are not necessary. This strategy makes use of feedforward and d-q decoupling components to enhance front-end VSC performance in the presence of load and supply voltage fluctuations. VFOC-based control can be utilized in an AC-DC converter to achieve an output voltage with adjustable DC, unity power factor at a fixed switching frequency, and line currents with minimal harmonic distortion. This control technique's originality is in its new approach, VFOC, which can adjust active power factor in three-phase grid-connected converter systems without estimating or monitoring AC voltage supply signals' phase angles. In order to enhance the performance of the VSC at the input side under load changes and voltage fluctuations and to increase system resilience against parameter changes, nonlinear loads harmonic interference, and other uncertainties [11], d-q decoupling and feedforward components are used. It responds quickly, tracks accurately, is stable, and is resilient in both steady-state and dynamic situations.

## 3. Future prospects

The analysis of the above three improved three-phase VSCs shows the importance of the VSC in the overall power system and the challenges it will face in the future, such as the quality of power delivery. To cope with these problems in the future, and with the development of artificial intelligence, the VSC will become even more intelligent. The VSC can perform adaptive control through the iterative updating of intelligent algorithms, automatically adjusting to the grid's load under unbalanced conditions. It will also be able to network with other devices through IoT technology, enabling more efficient power transmission and pre-distribution. Secondly, the VSC will be simpler and smaller in the future, making installing and maintaining the equipment easier. In a future where energy efficiency and environmental protection are promoted, environmental protection is a major trend. To make power systems more energy efficient and environmentally friendly, they need to be adapted to the environment's needs through more efficient control algorithms and device materials. For the future development of VSCs, intelligence, simplicity and environmental protection are essential for the sustainable development of future power systems.

## 4. Conclusion

This article explains VSC and discusses its difficulties in real-world settings. Advanced control algorithms, premium inductors, and capacitors are required to provide high-performance operating under imbalanced situations. This study of improved three-phase VSCs leads to the conclusion that the improved topology structure of these converters, which adds a conductive path to guarantee ripple-free DC link current/voltage and sinusoidal symmetrical AC grid current while restricting components for high-frequency current in the converter, is what allows VSCs to operate at high performance levels. Second, under balanced or unbalanced load situations, finite set model predictive control (FS-MPC) may adjust VSC output current to produce the required reactive power for controlling grid voltage. Lastly, VFOC uses d-q decoupling feedforward components to improve front-end VSC performance under load disturbances or supply voltage disturbances while reducing sensor count and avoiding the need of AC voltage supply sensors. Consequently, intelligent, straightforward, and environmentally friendly VSCs are trends for future development based on study of enhanced three-phase VSCs.

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