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Fuzzy Based Three-Phase Converter for Compensating Harmonics and Reactive Power under Ac Voltage Source



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Abstract:

Analyzing of the controllability and the performance of the power electronics converter under an adverse ac source, a severe unbalanced ac voltage were proposed in this project. A typically used three-phase three-wire two-level voltage source dc–ac converter is chosen and basically designed. In this project, a new series of control strategies which utilize the zero-sequence components are proposed to enhance the power control ability under this adverse condition. In order to overcome the disadvantage of the active power oscillation under the unbalanced ac source, a Zero-Sequence Current Control Technique was proposed. The capability to control the reactive power is also a critical performance for the converter under the unbalanced ac source, the proposed two control methods are also tested by MATLAB/Simulink under the conditions to deliver the inductive/capacitive reactive power.

1. INTRODUCTION:

In many important applications for power electronics such as renewable energy generation, motor drives, power quality, and microgrid, etc., the three-phase dc–ac converters are critical components as the power flow interface of dc and ac electrical systems. Since the power electronics are getting so widely used and becoming essential in the energy conversion technology, the failures or shutting down of these backbone dc–ac converters may result in serious problems and cost.

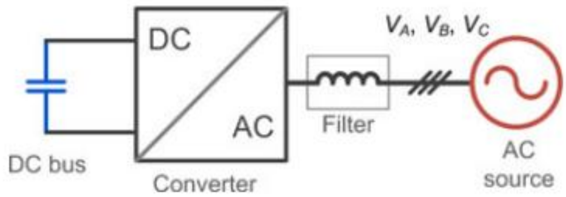

Fig. 1.Typical dc–ac power converter application

The sudden disconnection of the power converter may cause significant impacts on the grid stability and also on the high cost for maintenance/repair. As a result, transmission system operators (TSOs) in different countries have been issuing strict requirements for the wind turbine behavior under grid faults.

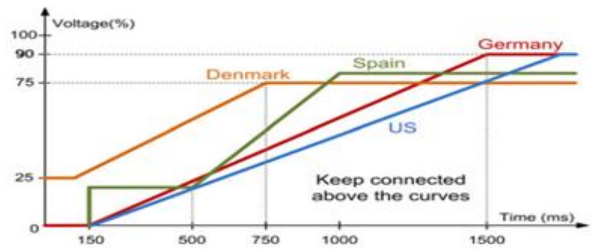

Fig. 2 Grid codes of wind turbines under the grid voltage dip by different countries.

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When the ac source shown in Fig. 1 becomes distorted under faults or disturbances, the unbalanced ac voltages have been proven to be one of the greatest challenges for the control ofthe dc–ac converter in order to keep them normally operatingand connected to the ac source.

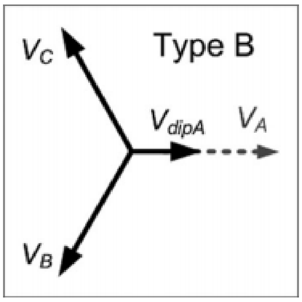

Fig. 3.Phasor diagram definitions for the voltage dips in the ac source of Fig. 1

VA , VB , and VC means the voltage of three phases in the ac source.

DC–AC CONVERTER INVERETER:

The main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable. According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled ac output is a voltage waveform.

Basic Designs:

In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.

Output Waveforms:

The switch in the simple inverter described above, when not coupled to an output transformer, produces a square voltage waveform due to its simple off and on nature as opposed to the sinusoidal waveform that is the usual waveform of an AC power supply.

MODELING OF PROPOSED THEORY LIMITS OF A TYPICAL THREE-WIRE CONVERTER SYSTEM:

In order to analyze the controllability and the performance ofthe power electronics converter under an adverse ac source, asevere unbalanced ac voltage is first defined as a case study inthis paper.

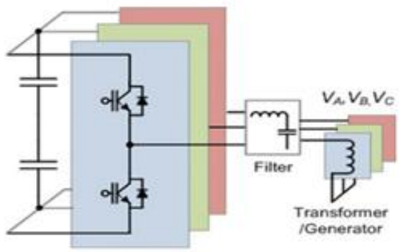

Fig. 4. Typical three-phase three-wire 2L-voltage source converter

TABLE I: CONVERTER PARAMETERS OF THE CASE STUDY

Rated output active power P_o	10 MW
DC bus voltage V_{dc}	5.6 kV DC
*Rated primary side voltage V_p	3.3 kV rms
Rated line-to-line grid voltage V_g	20 kV rms
Rated load current I_{load}	1.75 kA rms
Carrier frequency f_c	750 Hz
Filter inductance L_f	1.1 mH (0.25 p.u.)

*Line-to-line voltage in the primary windings of transformer.

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A. Elimination of the Negative-Sequence Current:

In most of the grid integration applications, there are strict grid codes to regulate the behavior of the grid connected converters. The negative-sequence current which always results in the unbalanced load current may be unacceptable from the point view of a TSO [13]. Therefore, extra two control targets which to eliminate the negative-sequence current can be added as

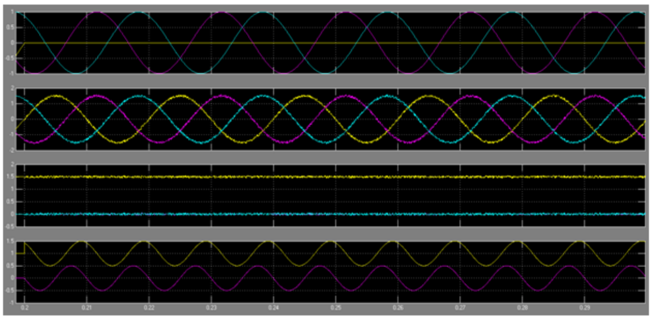
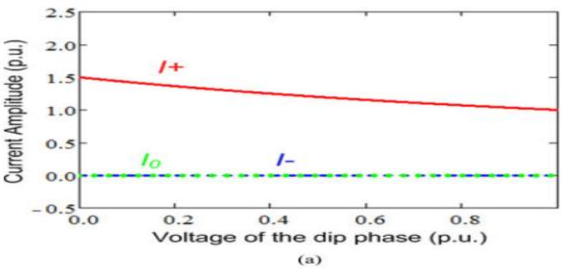


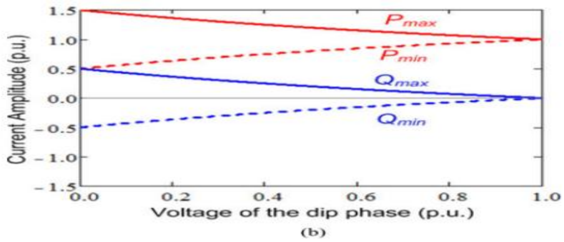
Fig. 5. Simulation of the converter with no negative-sequence current control(three-phase three-wire converter, Pref = 1 p.u., Qref = 0 p.u., Id − = 0 p.u.,Iq− = 0 p.u., VA = 0 p.u., I+, I−, and I0 means the amplitude of the currentin the positive, negative, and zero sequences, respectively)

B. Elimination of the Active Power Oscillation:

In order to overcome the disadvantage of the active poweroscillation under the unbalanced ac source, another two extracontrol targets which aim to cancel the oscillation items in theinstantaneous active power can be used to replace (11) as

$$P_{3\emptyset c2} = P_{c2} = 0$$
$$P_{3\emptyset s2} = P_{s2} = 0 \qquad (14)$$





When applying the current references in (15), the corresponding source voltage, load current, sequence current, and the instantaneous power delivered by the converter are shown in Fig. 7

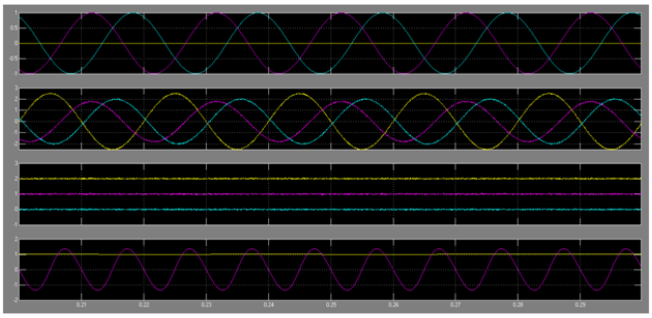


Fig. 7. Simulation of the converter control with no active power oscillation(three-phase three-wire converter, Pref = 1 p.u., Qref = 0 p.u., Ps2 = 0 p.u.,Pc2 = 0 p.u., VA = 0 p.u. I+, I−, and I0 means the amplitude of the currentin the positive, negative, and zero sequences, respectively.

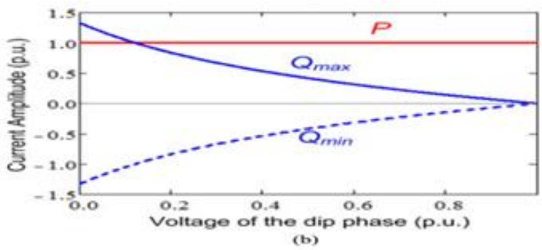


Fig. 8. Profile of converter control with no active power oscillation (threephase three-wire converter, Pref = 1 p.u., Qref = 0 p.u., Ps2 = 0 p.u., Pc2 =0 p.u.). (a) Sequence current amplitude versus VA . (I+, I-, and I0 means the amplitude of the current in the positive, negative, and zero sequences, respectively).(b) P and Q range versus VA.

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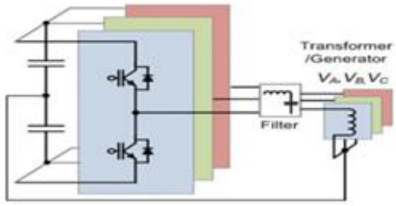
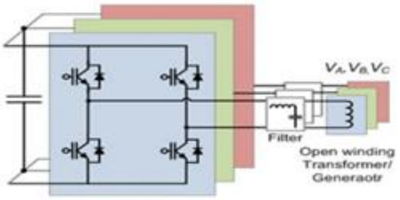
5.2 CONVERTER SYSTEM WITH THE ZERO-SEQUENCECURRENT PATH:

As can be concluded, in the typical three-phase three-wire converter structure, four control freedoms for the load current seem to be not enough to achieve satisfactory performances under the unbalanced ac source (No matter what combinations of control targets are used, either significant power oscillation or overloaded/distorted current will be presented.) Therefore, more current control freedoms are needed in order to improve the control performance under the unbalanced ac source conditions.



(a)



(b)

Fig. 9.Converter structure with the zero-sequence current path (a) Four-wiresystem. (b) Six-wire system.

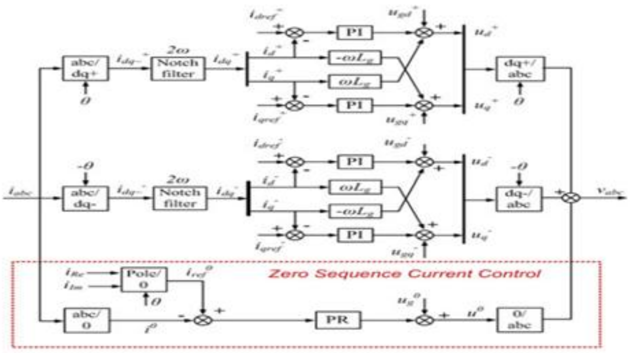


Fig. 10. Control structure for the converter system with the zero-sequencecurrent.

A. Elimination of Both the Active and Reactive Power Oscillation.

Because of more current control freedoms, the power converters with the zero-sequence current path can not only eliminate the oscillation in the active power, but also cancel the oscillation in the reactive power at the same time. This control targets can be written as

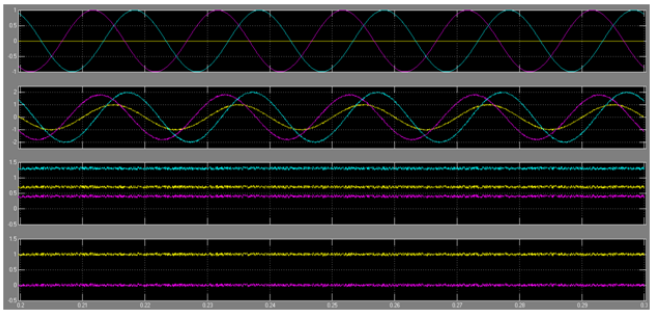
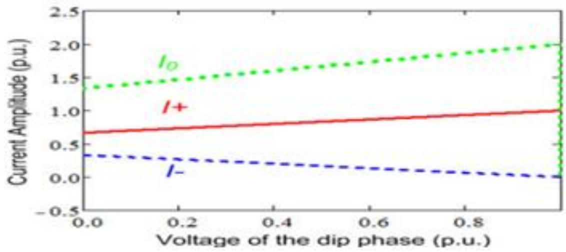


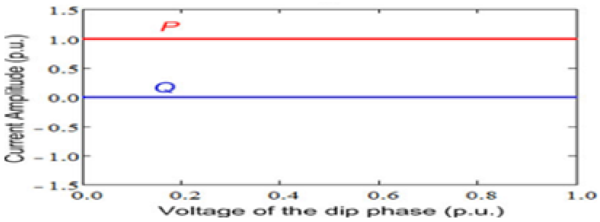
Fig. 11. Simulation of converter control with no active and reactive poweroscillation (three-phase converter with the zero-sequence path, Pref = 1 p.u.,Qref = 0 p.u., Ps2 = 0 p.u., Pc2 = 0 p.u., Qs2 = 0 p.u., Qc2 = 0 p.u., VA =0 p.u.).

B. Elimination of the Active Power Oscillation and the Negative-Sequence Current.

Another promising control strategy for the converter using the zero-sequence current path is to eliminate the active power oscillation, and meanwhile cancel the negative-sequence current. The extra two control targets besides (26) can be written



(a)



(b)

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Fig. 12. Profile of converter control with no active and reactive power oscillation (three-phase converter with the zero sequence path, Pref = 1 p.u., Qref =0 p.u., Ps2 = 0 p.u., Pc2 = 0 p.u., Qs2 = 0 p.u., Qc2 = 0 p.u.). (a) Sequencecurrent amplitude versus VA . (I+, I−, and I0 means the amplitude of the currentin the positive, negative, and zero sequences, respectively). (b) P and Q Combing (26), (36), and (37), the matrix equation of (26) canbe degraded as

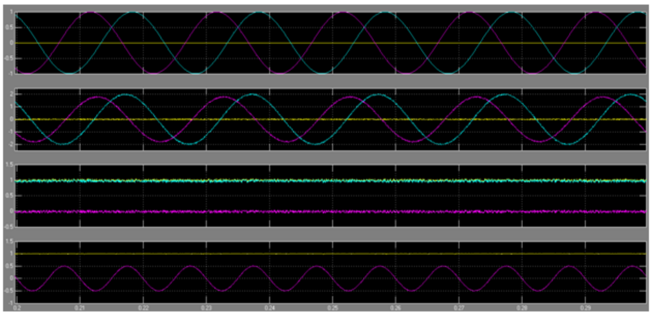
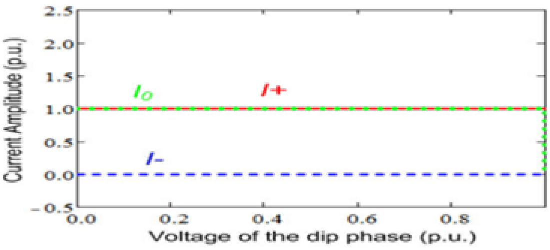
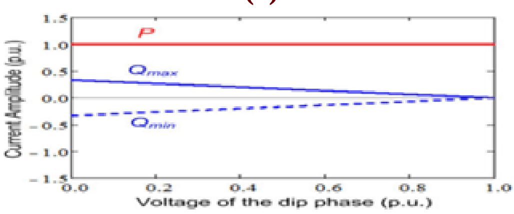


Fig. 13. Simulation of converter control with no active power oscillation andno negative sequence (three-phase converter with the zero-sequence currentpath, Pref = 1 p.u., Qref = 0 p.u., Ps2 = 0 p.u., Pc2 = 0 p.u., id − = 0 p.u.,iq − = 0 p.u., VA = 0 p.u. I+, I-, and I0 means the amplitude of the current inthe positive, negative, and zero sequences, respectively).



(a)



(b)

Fig. 14. Profile of converter control with no active power oscillation and nonegative sequence (three-phase converter with the zero-sequence current path,Pref = 1 p.u., Qref = 0 p.u., Ps2 = 0 p.u., Pc2 = 0 p.u., id − = 0 p.u., iq − =0 p.u.). (a) Sequence current amplitude versus VA . (b) P and Q rangesversusVA

6 .SIMULATION RESULTS:

The control results by different converter structures and control strategies are validated on a downscale dc–ac converter. As shown in Fig. 15, the circuit configurations and setup photo are both illustrated. A three-phase two-level converter with corresponding LCL filter is used to interconnect two dc voltage sources and a programmable three-phase ac voltage source. The detail parameters of the experimental setup are shown in Table III. It is noted that the converter is controlled to operate at the inverter mode, where the active power is flowing from the dc source to the ac source.

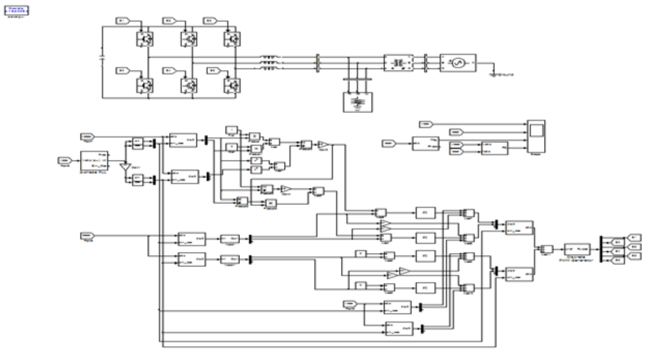


Fig.15. Configurations of the simulation setup Circuit topology

CONCLUSION:

In a typical three-phase three-wire converter structure, there are four current control freedoms, and it may be not enough to achieve satisfactory performances under the unbalanced ac source, because either significantly the oscillated power or the over loaded current will be presented. In the three-phase converter structure with the zero sequence current path, there are six current control freedoms. The extra two control freedoms coming from the zero sequence current can be utilized to extend the controllability of the converter and improve the control performance under the unbalanced ac source.

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By the proposed control strategies, it is possible to totally cancel the oscillation in both the active and the reactive power, or reduced the oscillation amplitude in the reactive power. Meanwhile, the current amplitude of the faulty phase is significantly relieved without further increasing the current amplitude in the normal phases. The advantage and features of the proposed controls can be still maintained under various conditions when delivering the reactive power. The analysis and proposed control methods are well agreed by experimental validations.

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