

Power Controllability of a Three-Phase Converter with an Unbalanced Ac Source

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Abstract- *This paper explains the power controllability of three phase converter with an unbalanced AC source by using fuzzy logic controller. Three-phase DC-AC power converters suffer from power oscillation and over current problems in case of unbalanced AC source voltage that can be caused by grid/generator faults. Existing solutions to handle these problems are properly selecting and controlling the positive and negative sequence currents. In this work a new series of control strategies which utilize the zero-sequence components are proposed to enhance the power control ability under this adverse condition. A fuzzy logic controller is rule based logic; it is having more advantages than other controllers. By using fuzzy logic controller we get required output. It is concluded that by introducing proper zero sequence current controls and corresponding circuit configurations, the power converter can enable more flexible control targets, achieving better performances in the delivered power and load current when suffering from unbalanced AC source.*

Index Terms— DC-AC converter, Unbalanced AC source, Control strategy, Fault tolerance, fuzzy logic controller.

I. INTRODUCTION

In many important applications for power electronics such as power generation, motor drives, power quality, etc., the three-phase DC-AC converters are important part as the backbone interface between DC and AC electrical systems [1],As shown in Fig.

1, a typical DC-AC voltage source converter is used to convert the energy between the DC bus and the three-phase AC sources, which could be the power grid, generation units or the electric machines depending on the applications [3]-[5].

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. It is becoming a need in many applications that the power converters should be reliable to withstand some faults or disturbances in order to ensure certain availability of the energy supply [6]-[13].

When the voltages become distorted and unbalanced under faults or disturbances, the unbalanced AC voltages have been proven to be a

great challenge for the control of DC-AC converters in order to keep them normally operating and connected to the AC sources [2], [14], [15]. Special control methods which can regulate both the positive and negative sequence currents have been introduced to handle these problems [2], [16]-[21]. However, the resulting performances by these control methods are not satisfactory: either distorted load currents or power oscillations will be introduced, and thereby not only the grid/generator but also the power converter will be further stressed.

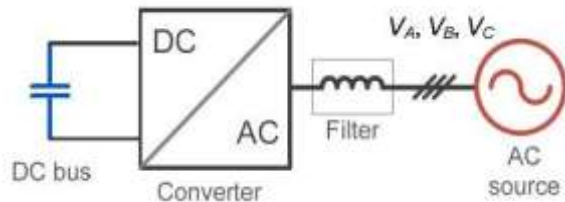


Fig. 1. A typical DC-AC converter application

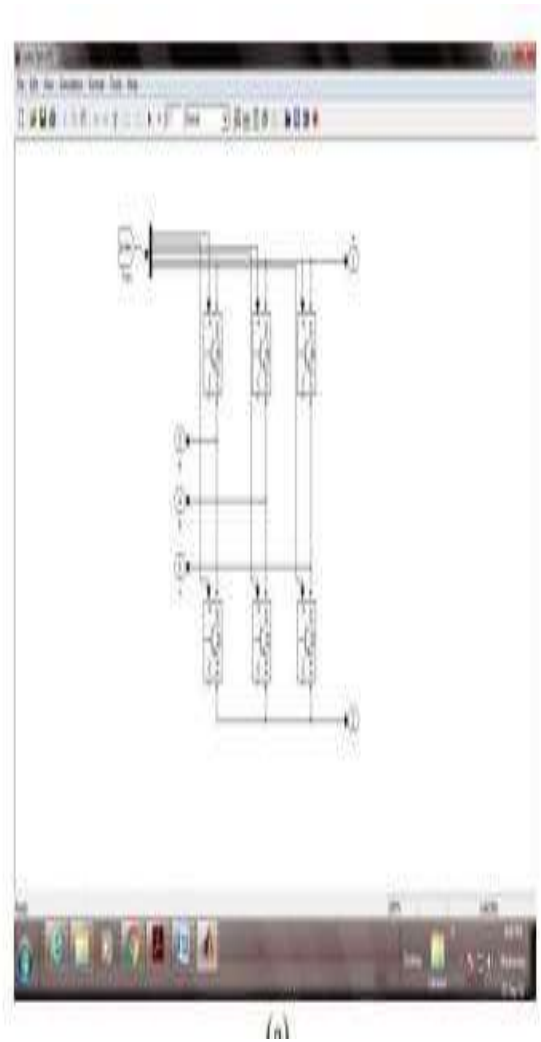
This paper targets to improve the power control limits of typical three-phase DC-AC converter system under unbalanced AC source (e.g. grid or generator with voltage dips). A new series of control strategies which utilizes the zero-sequence components are then proposed to enhance the power control ability under this adverse condition.

II. CONVERTER SYSTEM WITH THE ZERO SEQUENCE CURRENT PATH

As can be finished up, in the typical three-stage three-wire converter structure, four control flexibilities for the load current appear to be insufficient to accomplish attractive exhibitions under the uneven air conditioning source. (Regardless of what mixes of control targets are utilized, either

huge power swaying or overburden/mutilated current will be displayed.) Therefore, more present control flexibilities are required so as to enhance the control execution under the unequal air conditioning source conditions. Another arrangement of the converter structure are appeared as demonstrated as the four-wire framework in Fig. 9(a) and the six-wire framework in Fig. 9(b). Contrasted with the three-wire converter structure, these sorts of converters present the zero-sequence current path, which may empower additional present control flexibilities to accomplish better power control exhibitions. It is noticed that in the framework associated application, the zero- sequence current isn't infused into the

matrix yet caught in the ordinarily utilized d-Y transformer.



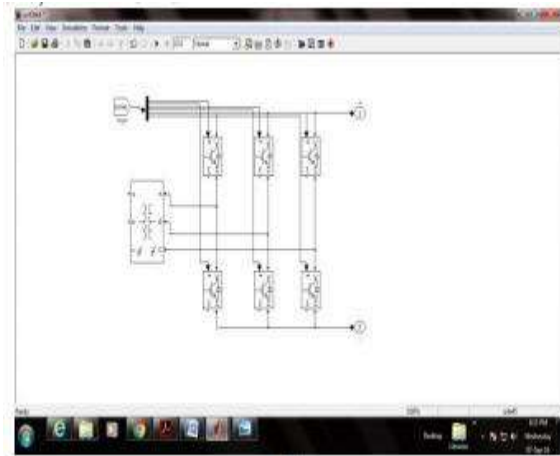


Fig.4. Converter structure with the zero-sequence current path. (a) Four-wire system. (b) Six-wire system

By operating the voltage of the ac source (1) and the current controlled by the power converter(2), the instantaneous generated real power p , the imaginary power q in the $\alpha\beta$ coordinate, and the real power p_0 in the zero coordinate can be calculated as

$$\begin{bmatrix} p \\ q \\ p_0 \end{bmatrix} = \begin{bmatrix} v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta \\ v_\alpha \cdot i_\beta - v_\beta \cdot i_\alpha \\ v_0 \cdot i_0 \end{bmatrix} \quad (2)$$

$$= \begin{bmatrix} \bar{P} + P_{c2} \cdot \cos(2\omega t) + P_{s2} \cdot \sin(2\omega t) \\ \bar{Q} + Q_{c2} \cdot \cos(2\omega t) + Q_{s2} \cdot \sin(2\omega t) \\ \bar{P}_0 + P_{0c2} \cdot \cos(2\omega t) + P_{0s2} \cdot \sin(2\omega t) \end{bmatrix}$$

Then, the instantaneous three-phase real power $p_{3\Phi}$ and the imaginary power $q_{3\Phi}$ of the converter can be written as

$$\begin{bmatrix} p_{3\Phi} \\ q_{3\Phi} \end{bmatrix} = \begin{bmatrix} p + p_0 \\ q \end{bmatrix} = \begin{bmatrix} \bar{P} + \bar{P}_0 \\ \bar{Q} \end{bmatrix} + \begin{bmatrix} P_{c2} + P_{0c2} \\ Q_{c2} \end{bmatrix} \cos(2\omega t) + \begin{bmatrix} P_{s2} + P_{0s2} \\ Q_{s2} \end{bmatrix} \sin$$

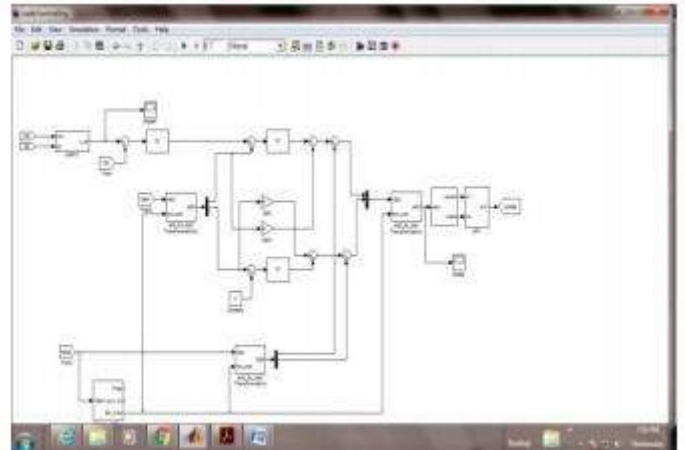


Fig.5. Control structure for the converter system with the zero-sequence current

A potential control structure is proposed in which an extra control loop is introduced to enable the controllability of the zero-sequence current. After introducing the regulated zero-sequence current, the three-phase current generated by the converter can be written as

$$I_C = I^+ + I^- + I^0 \quad (1)$$

It is noted that the voltage and the current in zero sequence only contribute to the real power $p_{3\Phi}$ of the converter. Each part of (2) can be calculated as

$$\begin{aligned} \bar{P} &= \frac{3}{2}(v_d^+ \cdot i_d^+ + v_q^+ \cdot i_q^+ + v_d^- \cdot i_d^- + v_q^- \cdot i_q^-) \\ P_{c2} &= \frac{3}{2}(v_d^+ \cdot i_d^+ + v_q^+ \cdot i_q^+ + v_d^- \cdot i_d^- + v_q^- \cdot i_q^-) \\ P_{s2} &= \frac{3}{2}(v_q^- \cdot i_d^+ - v_d^- \cdot i_q^+ - v_q^+ \cdot i_d^- + v_d^+ \cdot i_q^-) \\ \bar{Q} &= \frac{3}{2}(v_q^+ \cdot i_d^+ - v_d^+ \cdot i_q^+ + v_q^- \cdot i_d^- - v_d^- \cdot i_q^-) \\ Q_{c2} &= \frac{3}{2}(v_q^- \cdot i_d^+ - v_d^- \cdot i_q^+ + v_q^+ \cdot i_d^- - v_d^+ \cdot i_q^-) \\ Q_{s2} &= \frac{3}{2}(-v_d^- \cdot i_d^+ - v_q^- \cdot i_q^+ + v_d^+ \cdot i_d^- + v_q^+ \cdot i_q^-) \\ \bar{P}_0 &= \frac{3}{2}(v_{Re}^0 \cdot i_{Re}^0 + v_{Im}^0 \cdot i_{Im}^0) \\ P_{0c2} &= \frac{3}{2}(v_{Re}^0 \cdot i_{Re}^0 - v_{Im}^0 \cdot i_{Im}^0) \\ P_{0s2} &= \frac{3}{2}(-v_{Im}^0 \cdot i_{Re}^0 - v_{Re}^0 \cdot i_{Im}^0) \end{aligned}$$

Then, matrix equation as

$$\begin{bmatrix} P + P_0 \\ P_{c2} + P_{0c2} \\ P_{s2} + P_{0s2} \\ \bar{Q} \\ Q_{c2} \\ Q_{s2} \end{bmatrix} = \frac{3}{2} \begin{bmatrix} v_d^+ & v_q^+ & v_d^- & v_q^- & v_{Re}^0 & v_{Im}^0 \\ v_d^- & v_q^- & v_d^+ & v_q^+ & v_{Re}^0 & -v_{Im}^0 \\ v_q^- & -v_d^- & -v_q^+ & v_d^+ & -v_{Im}^0 & -v_{Re}^0 \\ v_q^+ & -v_d^+ & v_q^- & -v_d^- & 0 & 0 \\ v_q^- & -v_d^- & v_q^+ & -v_d^+ & 0 & 0 \\ -v_q^+ & -v_q^- & v_d^+ & v_d^- & 0 & 0 \end{bmatrix} \begin{bmatrix} i_d^+ \\ i_q^+ \\ i_d^- \\ i_q^- \\ i_{Re}^0 \\ i_{Im}^0 \end{bmatrix}$$

It is noted that unlike the traditional approach in which the zero sequence components are normally minimized, the zero sequence voltage and the current here look like single-phase AC components running at the same fundamental frequency. As a result, the zero-sequence voltage/current can be represented by vectors in a synchronous reference frame in the zero sequence as

$$\mathbf{V}_0 = v_{Re}^0 + v_{Im}^0 j \tag{4}$$

$$\mathbf{I}_0 = i_{Re}^0 + i_{Im}^0 j \tag{5}$$

as So, for the converter system with the zero-sequence current path, there are four control freedoms left to achieve two more control targets than the traditional three-wire system, this also means extended controllability and better performance under the unbalanced ac source.

III. ELIMINATION OF BOTH THE ACTIVE AND REACTIVE POWER OSCILLATION

Because of more current control freedoms, the power converter 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

$$\begin{aligned} Q_{s2} &= 0 \\ P_{3\phi c2} &= P_{c2} + P_{0c2} = 0 \\ P_{3\phi s2} &= P_{s2} + P_{0s2} = 0 \end{aligned}$$

where the real part and imaginary part can be represented as follows:

$$v_{Re}^0 = V^0 \cos(\varphi^0) \tag{6}$$

It can be seen that if the three-phase ac source voltage is decided, then the converter has six controllable freedoms ($i^+ d$, $i^+ q$, $i^- d$, $i^- q$, $i_0 Re$, and $i_0 Im$) to regulate the current flowing in the ac source. That means: six control targets/functions can be established by the converter having the zero-sequence current path. Similarly, the three-phase average active and reactive power delivered by the converter are two basic requirements for a given application, then, two control functions need to be first settled

The power oscillation caused by the zero-sequence current P_{0c2} and P_{0s2} are used to compensate the power oscillation caused by the positive- and negative-sequence currents P_{c2} and P_{s2} .

$$\begin{bmatrix} i_d^+ \\ i_q^+ \\ i_d^- \\ i_q^- \\ i_{Re}^0 \\ i_{Im}^0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} v_d^+ & v_q^+ & v_d^- & v_q^- & v_{Re}^0 & v_{Im}^0 \\ v_d^- & v_q^- & v_d^+ & v_q^+ & v_{Re}^0 & -v_{Im}^0 \\ v_q^- & -v_d^- & -v_q^+ & v_d^+ & -v_{Im}^0 & -v_{Re}^0 \\ v_q^+ & -v_d^+ & v_q^- & -v_d^- & 0 & 0 \\ v_q^- & -v_d^- & v_q^+ & -v_d^+ & 0 & 0 \\ -v_d^- & -v_q^- & v_d^+ & v_q^+ & 0 & 0 \end{bmatrix}^{-1} \begin{bmatrix} P_{ref} \\ 0 \\ 0 \\ Q_{ref} \\ 0 \\ 0 \end{bmatrix}$$

In order to facilitate the analytical solution, assuming that the d-axis or the real axis in the synchronous reference frame is allied with the voltage vectors in each of the sequence positive, negative, and zero), then

all of the controllable current components with the zero-sequence current path can be solved by

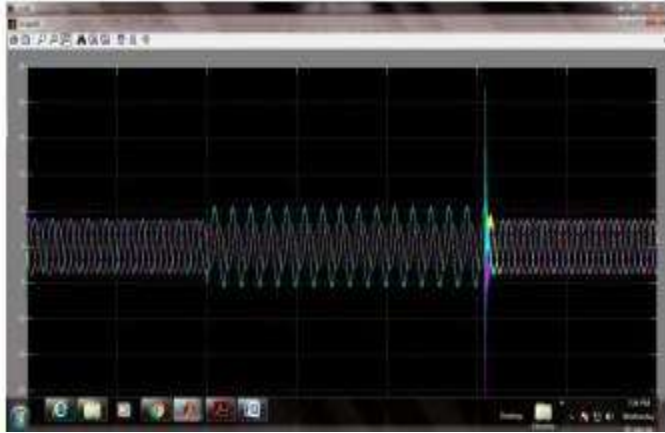


Fig.6. Simulation of converter control with no active and reactive power oscillation (three-phase converter with the zero-sequence path, Pref = 1 p.u., Qref = 0 p.u., Ps2 = 0 p.u., Pc 2 = 0 p.u., Qs2 = 0 p.u., Qc 2 = 0 p.u., VA = 0 p.u.). A. Elimination of

It is noted that the converter has to deliver constant positive- and zero-sequence currents in order to achieve this control strategy under different dips of the source voltage. The oscillation of the reactive power is maintained in a much smaller range (up to 0.3 p.u.) compared to that in the three wire system (up to 1.3 p.u.) in Fig9(b). The zero-sequence current is controlled as zero when the voltage dip is at 1.0 p.u

IV.EXPERIMENTAL RESULTS

The control results by different converter structures and control strategies are

Fig.7. Profile of converter control with no active power oscillation and no negative sequence (three-phase converter with the zero-sequence current path, Pref = 1 p.u., Qref = 0 p.u., Ps2 = 0 p.u., Pc 2 = 0 p.u., id-

the Active Power Oscillation and the Negative-Sequence Current

And each of the current components can be calculated as

$$\begin{bmatrix} i_d^+ \\ i_q^+ \\ i_{Re}^0 \\ i_{Im}^0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} v_d^+ & v_q^+ & v_{Re}^0 & v_{Im}^0 \\ v_d^- & v_q^- & v_{Re}^0 & -v_{Im}^0 \\ v_q^- & -v_d^- & -v_{Im}^0 & -v_{Re}^0 \\ v_q^+ & -v_d^+ & 0 & 0 \end{bmatrix}^{-1} \begin{bmatrix} P_{ref} \\ 0 \\ 0 \\ Q_{ref} \end{bmatrix}$$

In order to facilitate the analytical solution, assuming that the d-axis or the real axis in the synchronous reference frame is allied with the voltage vectors in each of the sequence, then all of the controllable current components with the zero sequence current path can be solved as

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 amplitude of the phase A voltage in the programmable ac source is adjusted to 0.1 p.u. (22 Vrms) in order to establish an adverse unbalanced condition.

= 0 p.u., $i_{q^-} = 0$ p.u.). (a) Sequence current amplitude versus VA . (b) P and Q ranges versus VA

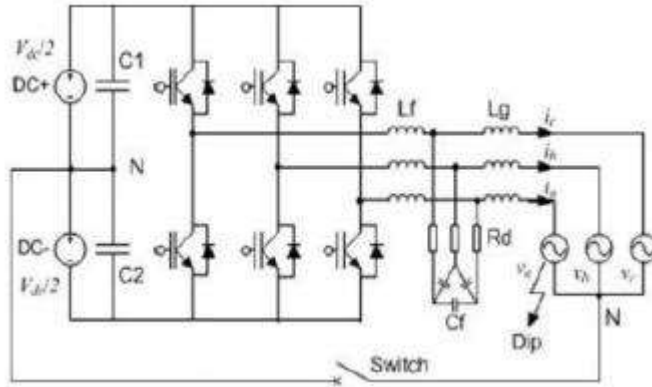


Fig.8. Configurations of the experimental setup. (a) Circuit topology

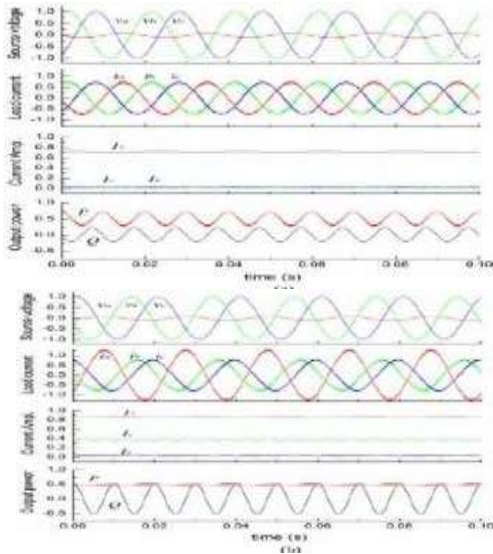
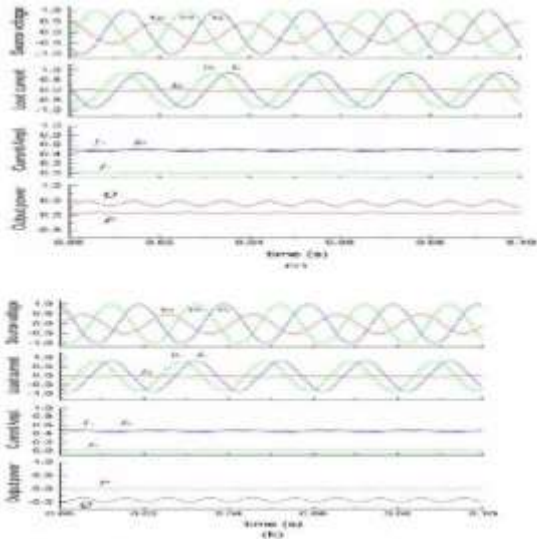


Fig.9. Experimental control performance of the converter in Fig. 15(a) with only three wires (units are nominalized by parameters, reference given: $P_{ref} = 0.5$ p.u., $Q_{ref} = 0$ p.u., ac source condition: amplitude of the phase voltage $V_A = 0.1$ p.u., $V_B = V_C = 1$ p.u.). (a) No negative-sequence current control (b) No P oscillation control.



V.CONCLUSION:

In a regular three-stage three-wire converter structure, there are four current control flexibilities, and it might be insufficient to accomplish tasteful exhibitions under the unequal air conditioning source, in light of the fact that either altogether the wavered control or the over-burden current will be introduced. In the three-stage converter structure with the zero grouping current way, there are six current control opportunities. The additional two control opportunities originating from the zero grouping current can be used to expand the controllability of the converter and enhance the control execution under the uneven air conditioning source. By the proposed control techniques, it is conceivable to thoroughly cross out the swaying in both the dynamic and the responsive control, or diminished the swaying sufficiency in the receptive control. Then, the present adequacy of the flawed stage is altogether

assuaged without additionally expanding the current abundance in the ordinary stages. The favorable position and highlights of the proposed controls can be as yet kept up under different conditions while conveying the receptive power. The examination what's more, proposed control strategies are very much concurred by trial approvals.

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