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AN UNBALANCED AC SOURCE THREE-PHASE CONVERTER POWER CONTROLLABILITY USING FUZZY LOGIC CONTROLLER

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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], [2]. 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.

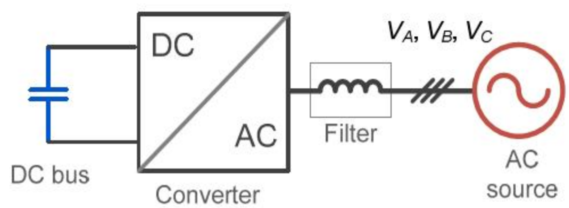


Fig. 1. A typical DC-AC converter application

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. LIMITS OF TYPICAL THREE-WIRE CONVERTER SYSTEM

In order to analyze the control ability and performance of power converter under adverse AC source condition, a distorted source voltage is first defined as a case study in this paper.

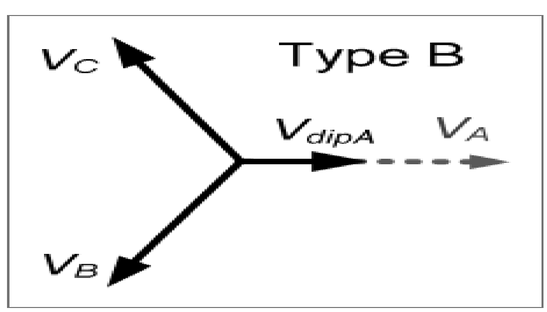


Fig. 2. Phasor diagram definitions for the voltage dips in the AC source of Fig. 1. VA, VB, VC means the voltage of three phases in the AC source

As shown in Fig. 2, the phasor diagram of the three phase distorted voltage are indicated, it is assumed that the type B fault happens in the AC source with significant voltage dip on phase A. Also there are many other types of voltage faults which are defined as type A-F in [22].

According to [2], [19], any distorted three-phase voltage can be expressed by the sum of components in positive sequence, negative sequence and zero sequence. For simplicity of analysis only the components with fundamental frequency are considered in this paper, however it is also possible to extend the analysis to higher order harmonics. The distorted three-phase AC source voltage in Fig. 2 can be represented by:

$$V_s = V^+ + V^- + V^0 = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = v^+ \begin{bmatrix} \sin(\omega t + \varphi^+) \\ \sin(\omega t - 120^\circ + \varphi^+) \\ \sin(\omega t + 120^\circ + \varphi^+) \end{bmatrix} + v^- \begin{bmatrix} \sin(\omega t + \varphi^-) \\ \sin(\omega t + 120^\circ + \varphi^-) \\ \sin(\omega t - 120^\circ + \varphi^-) \end{bmatrix} + v^0 \begin{bmatrix} \sin(\omega t + \varphi^0) \\ \sin(\omega t + \varphi^0) \\ \sin(\omega t + \varphi^0) \end{bmatrix} \quad (1)$$

Where V+, V- and V0 are the voltage amplitude in positive, negative and zero sequence respectively. And φ+, φ- and φ0 represent the initial phase angles in positive sequence, negative sequence and zero sequence respectively. The predefined single phase voltage dip as indicated in Fig. 2 should contain voltage components in all the three sequences [2], [11].

A typical used three-phase three-wire two-level voltage source DC-AC converter is chosen and basically designed, as shown in Fig. 3 and Table I, where the converter configuration and the parameters are indicated respectively. It is noted that the three-phase AC source is represented here by three windings with a common neutral point, which can be the windings of electric machine or transformer.

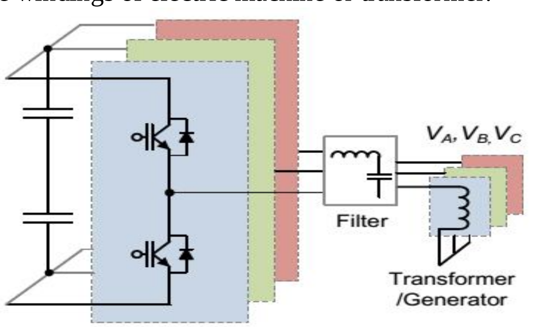


Fig. 3. Typical three-phase three-wire 2L VSC.

TABLE I: converter parameters for 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.)

Because there are only three-wires and a common neutral point in the windings of AC source, the currents flowing in the three phases don't contain zero sequence components. As a result the three-phase load current controlled by the converter can be written as:

$$I_C = I^+ + I^- \quad (2)$$

With the voltage of AC source in (1) and current controlled by converter in (2), the instantaneous real power p and imaginary power q in αβ coordinate, as well as the real power p0 in the zero coordinate can be calculated as:

$$\begin{bmatrix} p \\ q \\ p_0 \end{bmatrix} = \begin{bmatrix} v_\alpha . i_\alpha + v_\beta i_\beta \\ v_\alpha . i_\beta - v_\alpha i_\beta \\ v_0 . 0 \end{bmatrix} = \begin{bmatrix} \bar{P} + P_{C2}.\cos(2\omega t) + P_{S2}\sin(2\omega t) \\ \bar{Q} + Q_{C2}.\cos(2\omega t) + Q_{S2}\sin(2\omega t) \\ 0 \end{bmatrix} \quad (3)$$

Then the instantaneous three phase real power p3Φand imaginary power q3Φ of the AC source/converter can be written as:

$$\begin{bmatrix} p_{3\varphi} \\ q_{3\varphi} \end{bmatrix} = \begin{bmatrix} \bar{P} \\ \bar{Q} \end{bmatrix} + \begin{bmatrix} P_{c2} \\ Q_{c2} \end{bmatrix} \cos(2\omega t) + \begin{bmatrix} P_{s2} \\ Q_{s2} \end{bmatrix} \sin(2\omega t) \quad (4)$$

Where P and Q is the average part of the real and imaginary power, Pc2, Ps2 and Qc2, Qs2 are the oscillation parts, which can be calculated as:

$$\bar{P} = \frac{3}{2}(V_d^+ . i_d^+ + v_d^- . i_d^-) \quad (5a)$$

$$P_{c2} = \frac{3}{2}(V_d^- . i_d^+ + v_d^+ . i_d^-) \quad (5b)$$

$$P_{s2} = \frac{3}{2}(-V_d^- . i_q^+ + v_d^+ . i_q^-) \quad (5c)$$

$$\bar{Q} = \frac{3}{2}(-V_d^+ . i_q^+ - v_d^- . i_q^-) \quad (6a)$$

$$Q_{c2} = \frac{3}{2}(-V_d^- . i_q^+ - v_d^+ . i_q^-) \quad (6b)$$

$$Q_{s2} = \frac{3}{2}(-V_d^- . i_d^+ + v_d^+ . i_d^-) \quad (6c)$$

It can be seen from (5) and (6) that if the AC source voltage is decided, then the converter has four controllable freedoms (id+, iq+, id-and iq-) to regulate the current flowing in the AC source. That also means: four control targets/functions can be established. Normally the three-phase average active and reactive powers delivered by the converter are two basic requirements for a given application, then two basic control functions have to first be settled as:

$$\overline{P_{3\emptyset}} = \overline{P} = P_{ref} \quad (7a)$$

$$\overline{Q_{3\emptyset}} = \overline{Q} = Q_{ref} \quad (7b)$$

Different applications may have different requirements for the average power. For the power generation application, the active power reference Pref is set as negative, meanwhile large amount of reactive power Qref may be needed in order to help the grid recover from voltage dips [12], [13]. As for the electric machine application, the Pref is set as negative for generator mode and positive for motor mode, there may be no or a few reactive power Qref requirements for magnetizing.

While in most power quality applications e.g. STACOM, Pref is normally set to be very small to provide low converter loss, and a large amount of Qref is normally required.

A. Elimination of 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 unbalanced load current may be unacceptable from the point view of Transmission System Operator (TSO) [13]. Therefore, extra two control targets which aim to eliminate the negative sequence current can be added as:

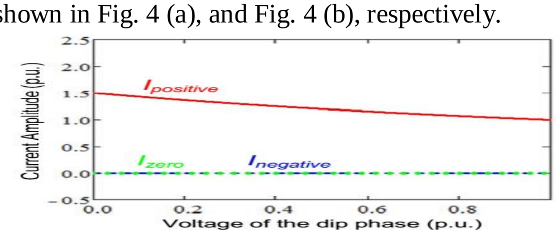
$$i_d^- = 0 \text{ and } i_q^- = 0 \quad (8)$$

Translating the control targets in (8) and (9), all the controllable current components can be calculated as:

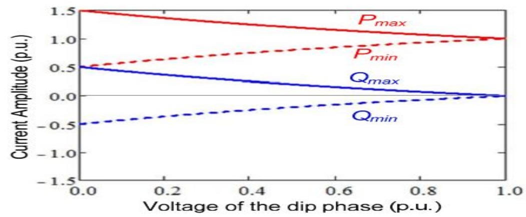
$$i_d^+ = \frac{2}{3} \cdot \frac{p_{ref}}{v_d^+ - v_d^-} \text{ and } i_d^- = 0 \quad (9a)$$

$$i_q^+ = -\frac{2}{3} \cdot \frac{Q_{ref}}{v_d^+} \text{ and } i_q^- = 0 \quad (9b)$$

The current amplitude in different sequences and the delivered active/reactive power with relation to the voltage amplitude of the dipping phase VAare shown in Fig. 4 (a), and Fig. 4 (b), respectively.



(a) Sequence current amplitude vs. VA.



(b) P and Q ocillation range vs. VA.

Fig. 4. Profile of converter control with no negative sequence current (three phase three-wire converter, Pref=1 p.u., Qref=0 p.u., Id-=0 p.u., Iq-=0 p.u.)

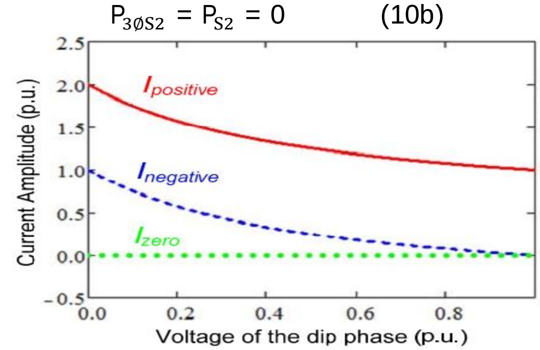
It is noted that only positive sequence current are generated by the converter, and there is up to ±0.5 p.u. oscillations both in the active and reactive power when VA dips to zero. The significant fluctuation of active power would result in the voltage fluctuation of the DC bus [16]-[19], compromising not only the THD but also the reliability performances of the converter according to [23].

B. Elimination of active power oscillation

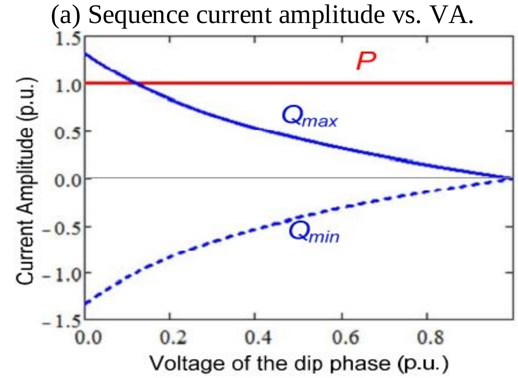
In order to overcome the disadvantage of the active power 1.3oscillation under unbalanced AC source, another two extra control targets which aim to cancel the oscillation items in the instantaneous active power can be used to replace (9) as:

$$P_{3\emptyset c2} = P_{C2} = 0 \quad (10a)$$

$$P_{3\emptyset S2} = P_{S2} = 0 \quad (10b)$$



(a) Sequence current amplitude vs. VA.



(b) P and Q range vs. VA.

Fig. 5. Profile of 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.)

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Translating the control targets in (8) and (11), all the controllable current components of the converter can be calculated as:

$$i_d^+ = \frac{2}{3}.\frac{P_{ref}.v_d^+}{M} \text{ and } i_d^- = -\frac{2}{3}.\frac{P_{ref}.v_d^-}{M} \quad (11a)$$

$$i_q^+ = 0 \text{ and } i_q^- = 0 \quad (11b)$$

The current amplitude in the different sequences, as well as the delivered active/reactive power with relation to the voltage amplitude on dipping phase is shown in Fig.5. (a) and Fig.5. (b) respectively. It is noted that the converter has to deliver both positive and negative sequence current to achieve this control strategy, and up to ±1.3 p.u. oscillation in the reactive power is generated when VA dips to zero.

Another three possible control strategies which can eliminate the oscillation of reactive power as shown in (14), or reduce the oscillations of both active and reactive power as shown in (15) and (16), are also possible for the three-phase three-wire converter under unbalanced AC source:

$$Q_{C2} = 0 \text{ and } Q_{S2} = 0 \quad (12)$$

$$P_{C2} = 0 \; and \; Q_{S2} = 0 \quad (13)$$

$$P_{S2} = 0 \text{ and } Q_{C2} = 0 \quad (14)$$

III. CONVERTER SYSTEM WITH ZERO-SEQUENCE CURRENT PATH

As can be seen, in the typical three-phase three-wire converter structure, four control freedoms for load current seem not to be enough to achieve satisfactory performances under unbalanced AC source (either significantly power oscillation or over-loaded and unbalanced current will be presented). Another series of converter structure is shown in Fig. 6 (a) and Fig. 6 (b), with the control method in Fig. 7. It is noted that in the grid connected application, the zero sequence current is not injected into the grid but trapped in the typically used d-Y transformer.

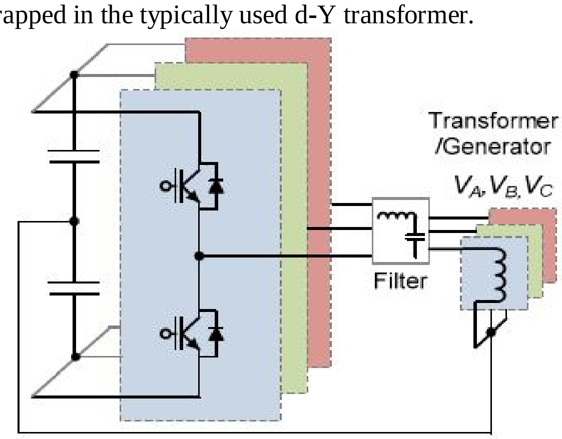


Fig. 6. Converter structure with zero sequence current path(a)Four-wire system

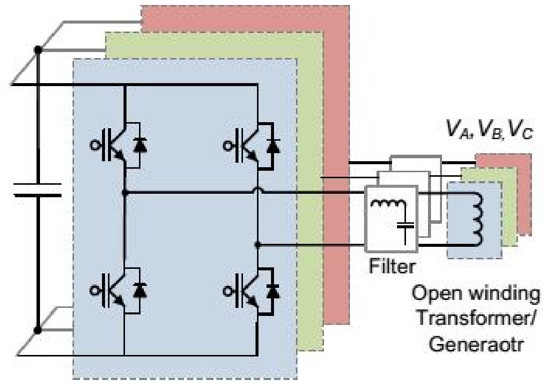


Fig. 6. Converter structure with zero sequence current path. (b) Six-wire system

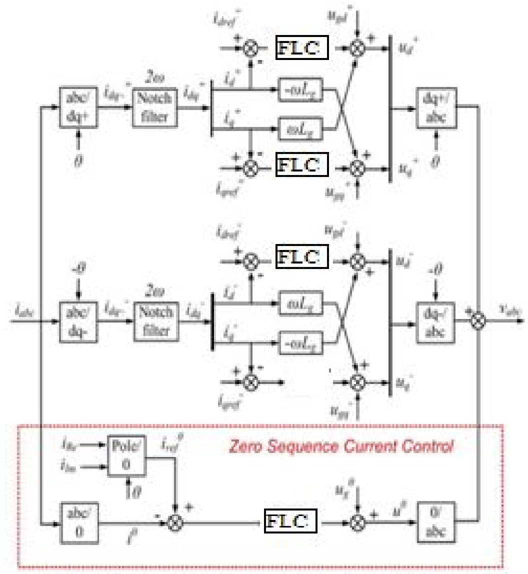


Fig. 7. Control structure for converter system with zero sequence current

With the zero sequence current, the three-phase current generated by the converter can be written as [27]-[19]:

$$I_c = I^+ + I^- + I^0 \quad (15)$$

By operating the voltage of AC source (1) and current controlled by power converter (17), the instantaneous generated real power p, imaginary power q in the αβ coordinate and the real power p0in the zero coordinate can be calculated as:

$$\begin{bmatrix} p \\ q \\ p_0 \end{bmatrix} = \begin{bmatrix} v_\alpha.i_\alpha + v_\beta i_\beta \\ v_\alpha.i_\beta - v_\alpha i_\beta \\ v_0.0 \end{bmatrix} = \begin{bmatrix} \bar{P} + P_{C2}.\cos(2\omega t) + P_{S2}\sin(2\omega t) \\ \bar{Q} + Q_{C2}.\cos(2\omega t) + Q_{S2}\sin(2\omega t) \\ \bar{P_0} + P_{0C2}.\cos(2\omega t) + P_{0S2}.\sin(2\omega t) \end{bmatrix} \quad (16)$$

Then the instantaneous three-phase real power p3Φand imaginary power q3Φof the converter can be written as:

$$\begin{bmatrix} p_{3\varphi} \\ q_{3\varphi} \end{bmatrix} = \begin{bmatrix} P + P_0 \\ q \end{bmatrix} = \begin{bmatrix} \overline{P} + \overline{P}_0 \\ \overline{Q} \end{bmatrix} + \begin{bmatrix} P_{C2} + P_{0C2} \\ Q_{C2} \end{bmatrix} \cos(2\omega t) + \begin{bmatrix} P_{s2} + P_{0s2} \\ Q_{s2} \end{bmatrix} \sin(2\omega t) \quad (17)$$

It is noted that the voltage and current in zero sequence only contribute to the real power p3Φof the converter. Each part of (19) can be calculated as:

$$\overline{P} = \frac{3}{2}(V_d^+ . i_d^+ + v_d^- . i_d^-) \quad (18a)$$

$$P_{c2} = \frac{3}{2}(V_d^- . i_d^+ + v_d^+ . i_d^-) \quad (18b)$$

$$P_{s2} = \frac{3}{2}(-V_d^- . i_q^+ + v_d^+ . i_q^-) \quad (18c)$$

$$\overline{Q} = \frac{3}{2}(-V_d^+ . i_q^+ - v_d^- . i_q^-) \quad (19a)$$

$$Q_{c2} = \frac{3}{2}(-V_d^- . i_q^+ - v_d^+ . i_q^-) \quad (19b)$$

$$Q_{s2} = \frac{3}{2}(-V_d^- . i_d^+ + v_d^+ . i_d^-) \quad (19c)$$

$$\overline{P}_0 = \frac{3}{2}(v_{Re}^0 . i_{Re}^0) \quad (20a)$$

$$\overline{P_{0c2}} = \frac{3}{2}(v_{Re}^0 . i_{Re}^0) \quad (20b)$$

$$\overline{P_{0s2}} = \frac{3}{2}(-v_{Re}^0 . i_{Im}^0) \quad (20c)$$

Where the zero sequence voltage and current are more like a single phase AC component at fundamental frequency. They can be represented by the real part and imaginary part as:

$$v_{Re}^0 = V^0 \cos(\varphi^0) = V^0 \quad (21a)$$

$$v_{Im}^0 = V^0 \sin(\varphi^0) = 0 \quad (21b)$$

$$i_{Re}^0 = I^0 \cos(\delta^0) \quad (21c)$$

$$i_{Im}^0 = I^0 \sin(\delta^0) \quad (21d)$$

It can be seen from (20)-(22) that if the three-phase AC source voltage is decided, then the converter has six controllable freedoms (id+, iq+, id-, iq-, iRe0 and iIm0) to regulate the current flowing in AC source. That means: six control targets/functions can be established by the converter using the zero sequence current paths. Normally 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 as:

$$\overline{P_{3\varphi}} = \overline{P} + \overline{P}_0 = P_{ref} \quad (22a)$$

$$\overline{Q_{3\varphi}} = \overline{Q} = Q_{ref} \quad (22b)$$

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

A. Elimination of both active and reactive power oscillation.

Because of more current control freedoms, the power converter with zero sequence current paths 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:

$$P_{3\varphi C2} = P_{C2} + P_{0C2} = 0 \text{ and } Q_{c2} = 0 \quad (23a)$$

$$P_{3\varphi S2} = P_{S2} + P_{0s2} = 0 \text{ and } Q_{s2} = 0 \quad (23b)$$

Translating the control targets in (24) and (25), all the controllable current components of the converter with zero sequence current paths can be calculated as:

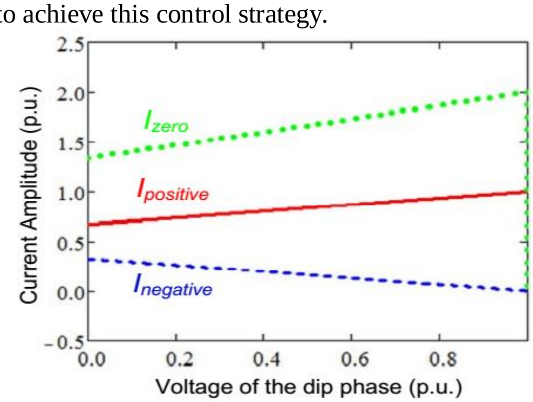
$$i_d^+ = \frac{2}{3} . \frac{P_{ref}}{(v_d^+ - v_d^-).\left(1 - \frac{v_d^-}{v_d^+}\right)} \text{ and } i_d^- = \frac{v_d^-}{v_d^+} . i_d^+ \quad (24a)$$

$$i_q^+ = \frac{2}{3} . \frac{Q_{ref}}{(-v_d^+) + (v_d^-)^2 / v_d^+} \text{ and } i_q^- = -\frac{v_d^-}{v_d^+} . i_q^+ \quad (24b)$$

$$i_{Re}^0 = \frac{2}{3} . \frac{P_{ref} - \overline{P}}{v_{Re}^0} \quad (25a)$$

$$i_{Im}^0 = \frac{v_d^+ . i_q^- - v_d^- . i_q^+}{v_{Re}^0} \quad (25b)$$

The current amplitude in different sequences, as well as the delivered active/reactive power with relation to the voltage amplitude on the dipping phase is shown in Fig. 8 (a) and Fig. 8 (b) respectively. It is noted that the converter has to deliver positive, negative and zero sequence currents to achieve this control strategy.



(a) Sequence current amplitude vs. VA.

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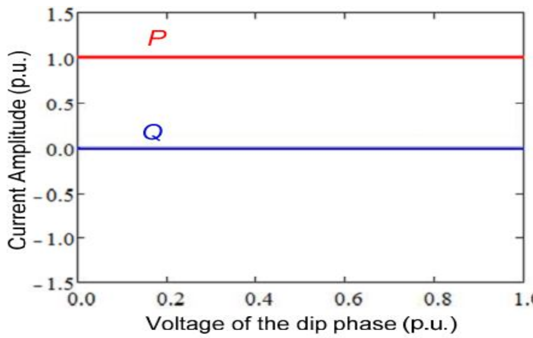


(b) P and Q ranges vs. VA.

Fig. 8. Profile of converter control with no active and reactive power oscillation (three phase converter with 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.)

B. Elimination of active power oscillation and negative sequence current.

Another promising control strategy for the converter using zero sequence current path is to eliminate the active power oscillation and negative sequence current at the same time, the extra four control targets besides (24) can be written as:

$$P_{3\varphi C2} = P_{C2} + P_{0C2} = 0 \text{ and } i_d^- = 0 \quad (26a)$$

$$P_{3\varphi S2} = P_{S2} + P_{0s2} = 0 \text{ and } i_q^- = 0 \quad (26b)$$

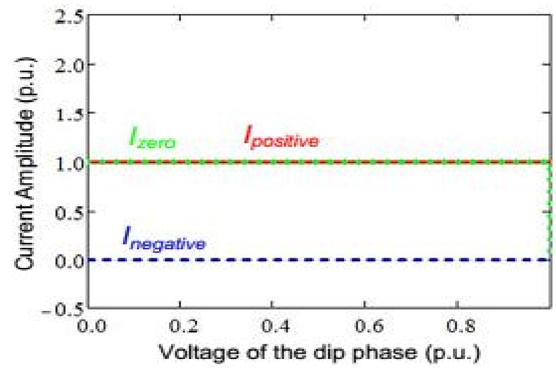
Translating the control targets in (24) and (28), all the controllable current components of the converter with zero sequence current path can be calculated as:

$$i_d^+ = \frac{2}{3} \cdot \frac{P_{ref}}{(v_d^+ - v_d^-)} \text{ and } i_d^- = 0 \quad (27a)$$

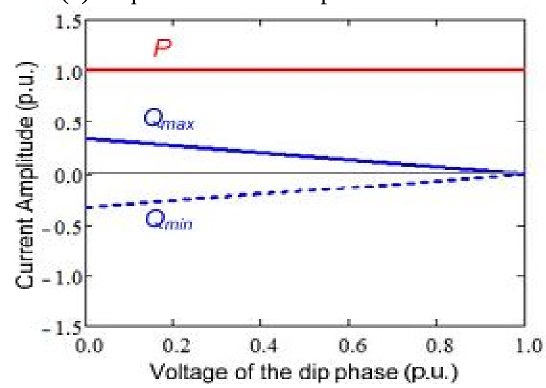
$$i_q^+ = \frac{2}{3} \cdot \frac{Q_{ref}}{-v_d^+} \text{ and } i_q^- = 0 \quad (27b)$$

$$i_{Re}^0 = \frac{-v_d^- \cdot i_d^+}{v_{Re}^0} \text{ and } i_{Im}^0 = 0 \quad (28)$$

The current amplitude in the different sequences, as well as the delivered active/reactive power with relation to the voltage on the dipping phase are shown in Fig. 9 (a) and Fig. 9 (b) respectively. 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 source voltage. The oscillation of 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 Fig. 5 (b).



(a) Sequence current amplitude vs. VA.



(b) P and Q ranges vs. VA.

Fig. 9. Profile of converter control with no active power oscillation and no negative sequence (three phase converter with 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.)

The converter stresses for the active/reactive power oscillations and the current amplitude in the faulty/normal phases are compared in Table II, where different control strategies and converter structures are indicated respectively. It can be seen that by introducing the converter structures and controls with zero sequence current path, the power oscillations under unbalanced AC source are significantly reduced, meanwhile the current amplitude in the normal phases are not further stressed, and the current stress in the faulty phases are significantly relieved.

Table II. Converter stress comparison by different control strategies (values are represented in p.u.,Pref=1 p.u., Qref=0 p.u., VA=0 p.u.).

Converter stress	Typical 3-wire		Zero-sequence	
	Control A	Control B	Control A	Control B
Active power osc. P_{osc}	0.5	0	0	0
Reactive power osc. Q_{osc}	0.5	1.3	0	0.3
Current in faulty phase I_{fault}	1.5	3	1	0
Current in normal phase I_{norm}	1.5	2	2	2

IV. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

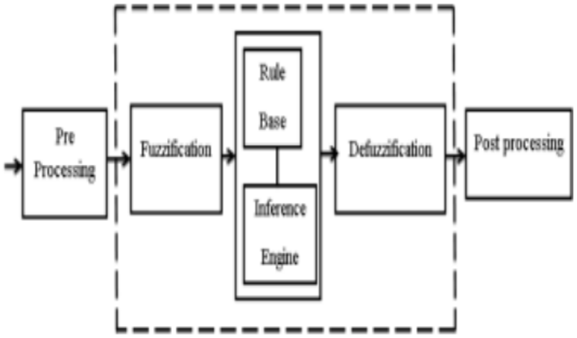


Fig.10.Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership CE(k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

TABLE III: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \qquad (29)$$

$$CE(k) = E(k) - E(k-1) \qquad (30)$$

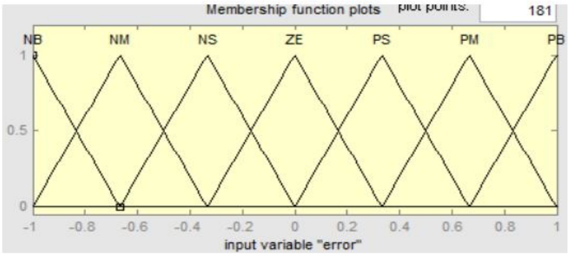


Fig.11.Membership functions

Inference Method: Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

Defuzzification: As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u = -[\alpha E + (1-\alpha) * C] \qquad (31)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable.

A large value of error E indicates that given system is not in the balanced state.

If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible.

One the other hand, small value of the error E indicates that the system is near to balanced state.

V. SIMULATION RESULTS

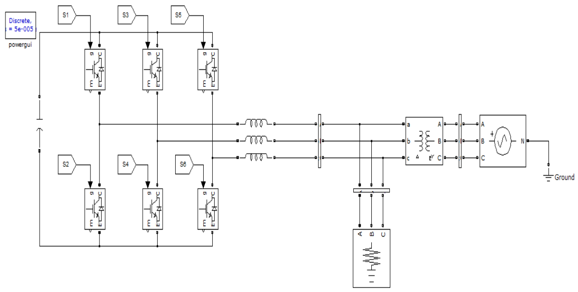


Fig.12. Matlab model of proposed system

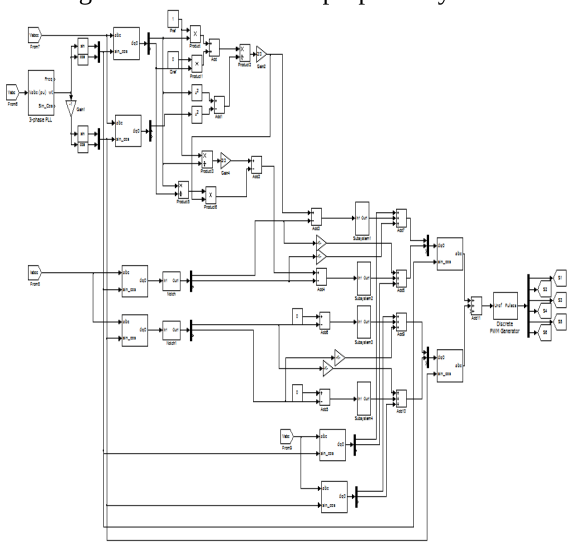


Fig.13. Matlab model for control strategy

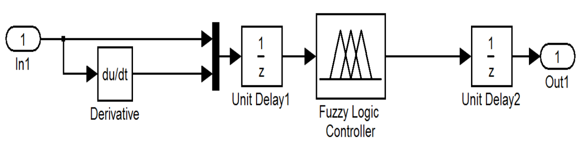


Fig.14. Matlab model for fuzzy logic controller

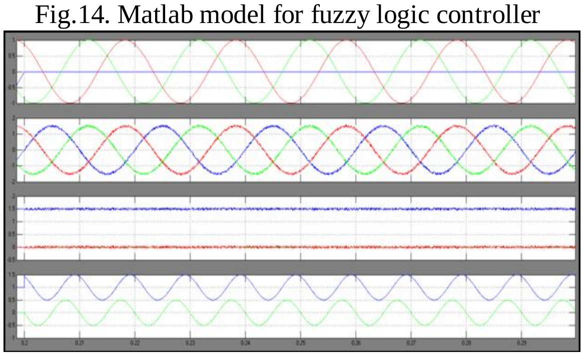


Fig. 15. Simulation of the converter with no negative-sequence current control (three-phase three-wire converter, Pref =1 p.u., Qref =0 p.u., Id−=0 p.u., Iq−=0 p.u., VA=0 p.u., I+, I−,and I0 means the amplitude of the current in the positive, negative, and zero sequences, respectively).

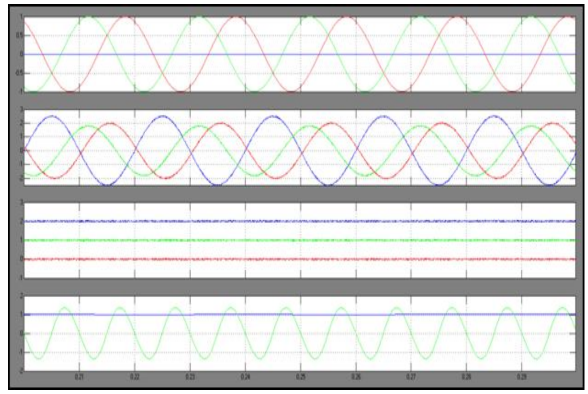


Fig. 16. Simulation of the converter control with no active power oscillation (three-phase three-wire converter, Pref =1 p.u.,Qref =0 p.u.,Ps2 =0 p.u., Pc2 =0 p.u.,VA=0p.u.I+, I−,andI0 means the amplitude of the current in the positive, negative, and zero sequences, respectively.

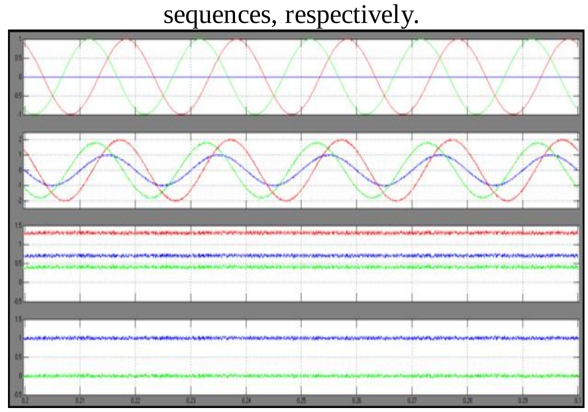


Fig. 17. Simulation of converter control with no active and reactive power oscillation (three-phase converter with the zero-sequence path,Pref =1 p.u., Qref =0 p.u.,Ps2 =0 p.u.,Pc2 =0 p.u.,Qs2 =0 p.u.,Qc2 =0 p.u.,VA=0 p.u.)

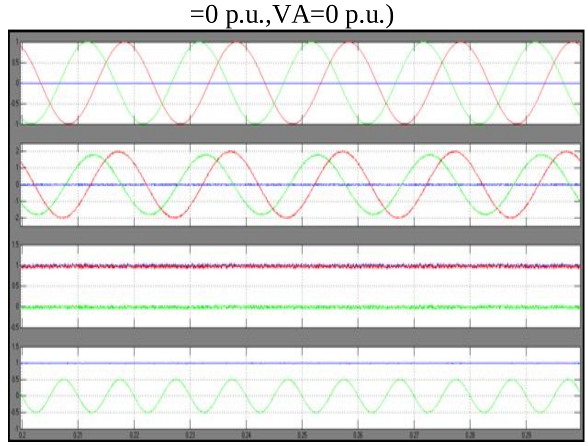


Fig. 18. Simulation of converter control with no active power oscillation and no negative sequence (three-phase converter with the zero-sequence current path, Pref =1 p.u., Qref =0 p.u.,Ps2 =0 p.u.,Pc2 =0 p.u., id−=0 p.u., iq−=0 p.u., VA=0p.u.I+,I-,andI0

means the amplitude of the current in the positive, negative, and zero sequences, respectively).

VI. CONCLUSION

This paper explained about the power controllability of three phase converter with an unbalanced Ac source along with the usage of fuzzy logic controller for controlling purpose. 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 unbalanced AC source because either significantly oscillated power or over-loaded current will be presented. 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 unbalanced AC source. 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. Here we are using fuzzy logic controller instead of using other controller. The simulation was done by using MATLAB/Simulink software.

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