A MODULATION AND CONTROL OF A NEW TRANSFORMERLESS UPFC USING FUZZY LOGIC CONTROLLER

1VADLA VENKATESHAM, 2A. NARASIMHA RAO
1M.Tech, Vidya Jyothi Institute of Technology (Autonomous), Affiliated to JNTU Hyderabad, Telangana, India.
2Associate Professor, Vidya Jyothi Institute of Technology (Autonomous), Affiliated to JNTU Hyderabad, Telangana, India.

ABSTRACT: Now a day’s FACTS devices are used to control the flow of power, to increase the transmission capacity and to improve the stability of the power system. One of the most commonly used FACTS devices is Unified Power Flow Controller (UPFC), modulation and control method for the new transformerless unified power flow controller (UPFC) is proposed in this paper. To overcome this problem, a transformerless UPFC based on an innovative configuration of two cascade multilevel inverters has been proposed. The conventional UPFC may contents of two back-to-back connected inverters which needed bulky and often complicated zigzag transformers for isolation and reaching high power rating with desired voltage waveforms. The new UPFC offers various merits over the traditional technology, such as light weight, transformerless, low cost, high efficiency and also fast dynamic response. From this, the capacity of UPFC is observed by using different control mechanisms based on fuzzy logic controllers (FLC) in this study. UPFC on controlling the flow of power and the effectiveness of controllers on the performance of UPFC is used to simulate UPFC model and to create the FLC.

Keywords: FACTS, Fuzzy Logic Controller, UPFC

INTRODUCTION

The unified power flowcontroller (UPFC) is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (i.e., voltage magnitude, impedance, and phase angle) [1]–[3]. The conventional UPFC has been put into several practical applications [11]–[13], which has the following features: 1) both inverters share the same dc link; 2) both inverters need to exchange real power with each other and the transmission line; 3) a transformer must be used as an interface between the transmission line and each inverter. In addition, any utility-scale UPFC requires two high-voltage, high-power (from several MVA to hundreds of MVA) inverters.

This high-voltage, high-power inverters have to use bulky and complicated zigzag transformers to reach their required VA ratings and desired voltage waveforms. The zigzag transformers are: 1) very expensive (30–40% of total system cost); 2) lossy (50% of the total power losses); 3) bulky (40% of system real estate area and 90% of the system weight); and 4) prone to failure [14].

Moreover, the zigzag transformer-based UPFCs are still too slow in dynamic response due to large time constant of magnetizing inductance over resistance and pose control challenges because of transformer saturation, magnetizing current, and voltage surge [5]. Recently, there are two new UPFC structures under investigation: 1) the matrix converter-based UPFC [6]–[8] and 2) distributed power-flow controller (DPFC) derived from the conventional UPFC [9].

The conventional UPFC consists of two back-to-back connected voltage source inverters that share a common dc link, as shown in Fig. 1. The injected series voltage from inverter-2 can be at any angle with respect to the line current, which provides complete flexibility and controllability to control both active and reactive power flows over the transmission line.

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line; while the other is shunt CMI, which is connected in parallel to the sending end after series CMI.

Each CMI is composed of a series of cascaded H-bridge modules as shown in Fig. 2(b). The transformerless UPFC has significant advantages over the traditional UPFC such as highly modular structure, light weight, high efficiency, high reliability, low cost, and a fast dynamic response.

![Fig. 2. New transformerless UFPC. (a) System configuration of transformerless UPFC. (b) One phase of the cascaded multilevel inverter.](image)

Table I
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
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<td>System power rating</td>
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<tr>
<td>$V_{so}$</td>
<td>13.8 kV</td>
</tr>
<tr>
<td>Max series CMI current, $I_{C}$</td>
<td>42 A</td>
</tr>
<tr>
<td>Max shunt CMI current, $I_{D}$</td>
<td>42 A</td>
</tr>
<tr>
<td>$V_{dc}$ (Shunt)</td>
<td>600 V</td>
</tr>
<tr>
<td>$V_{dc}$ (Series)</td>
<td>600 V</td>
</tr>
<tr>
<td>H-bridge dc capacitance</td>
<td>2350 μF</td>
</tr>
<tr>
<td>No. of H-bridges per phase (Shunt)</td>
<td>20</td>
</tr>
<tr>
<td>No. of H-bridges per phase (Series)</td>
<td>10</td>
</tr>
</tbody>
</table>

Nevertheless, there are still challenges for the modulation and control of this new UPFC: 1) UPFC power flow control, such as voltage regulation, line impedance compensation, phase shifting or simultaneous control of voltage, impedance, and phase angle, thus achieving independently control both the active and reactive power flow in the line; 2) dc capacitor voltage balance control for H-bridges of both series and shunt CMIs; 3) modulation of the CMI for low total harmonic distortion (THD) of output voltage and low switching loss; 4) fast system dynamic response.

OPERATION PRINCIPLE OF THE TRANSFORMERLESS UPFC

Fig. 3 shows the phasor diagram of the transformerless UPFC, where $V_{so}$ and $V_{r}$ are the original sending-end and receiving-end voltage, respectively.

![Fig. 3. Phasor diagram of the transformerless UPFC](image)

Here, $V_{so}$ is aligned with real axis, which means phase angle of $V_{so}$ is zero. The series CMI is controlled to generate a desired voltage $V_{c}$ for obtaining the new sending-end voltage $V_{s}$, which in turn, controls active and reactive power flows over the transmission line.

The detailed operating principle of the transformerless UPFC can be formulated as follows. With referring to Figs. 2 and 3, the transmitted active power $P$ and reactive power $Q$ over the line with the transformer-less UPFC can be expressed as

$$
\begin{align*}
P + jQ &= \bar{V}_{r} \cdot \frac{(\bar{V}_{so} - \bar{V}_{r})}{jX_L} = \left( \frac{V_{so}V_{r}}{X_L} \sin \delta_0 + \frac{V_{so}V_{r} \sin (\delta_0 - \delta)}{X_L} \right) + j \left( \frac{V_{so}V_{r} \cos (\delta - \delta)}{X_L} \right) \\
\end{align*}
$$

where symbol * represents the conjugate of a complex number; $\delta_0$ is the phase angle of the receiving-end voltage $V_{r}$; $\delta$ is the phase angle of the series CMI injected voltage $V_{c}$; $X_L$ is the equivalent transmission line impedance. The original active and reactive powers $P_0$ and $Q_0$ with the uncompensated system (without the UPFC, or $V_{c} = 0$) are

$$
\begin{align*}
P_0 &= -\frac{V_{so}V_{r}}{X_L} \sin \delta_0 \\
Q_0 &= \frac{V_{so}V_{r} \cos (\delta_0 - \delta)}{X_L} \\
\end{align*}
$$

The net differences between the original (without the UPFC) powers expressed in (2) and the new (with the UPFC) powers in (1) are the controllable active and reactive powers, $PC$ and $QC$ by the transformerless UPFC, which can be expressed as

$$
\begin{align*}
P_C &= \frac{V_{so}V_{r}}{X_L} \sin (\delta_0 - \delta) \\
Q_C &= -\frac{V_{so}V_{r} \cos (\delta_0 - \delta)}{X_L} \\
\end{align*}
$$

Therefore, we can rewrite (1) as
\[ P + jQ = \left( \frac{-V_{S_0}Y_{Sr}}{X_L} \sin \delta_0 / P_0 + \frac{V_{C}Y_{Cr}}{X_L} \sin(\delta_0 - \delta) / P_0 \right) + j \left( \frac{V_{S_0}Y_{Sr} \cos \delta_0 - V_{C}Y_{Cr} \cos(\delta_0 - \delta)}{X_L} / Q_0 - \frac{V_{C}Y_{Cr} \cos \delta_0}{X_L} / Q_0 \right) \]  

(4)

Because both amplitude VC and phase angle \( \delta \) of the UPFC injected voltage VC can be any values as commanded, the new UPFC provides a full controllable range of \((-VC VR/XL , +VC VR/XL\) ) for both active and reactive powers, PC and QC, which are advantageously independent of the original sending-end voltage and phase angle \( \delta_0 \).

In summary, (1)–(4) indicate that the new transformerless UPFC has the same functionality as the conventional UPFC. First, the series CMI voltage \( V_C \) is injected according to transmission line active/reactive power command, which can be calculated from (3)

\[ \bar{V}_C = V_C \angle \delta = \frac{X_L}{V_R} \sqrt{P_C^2 + Q_C^2} \angle (\delta_0 - \arctan \left( \frac{P_C}{Q_C} \right)) \]  

(5)

Once the series CMI injected voltage \( V_C \) is decided by (5), the new sending-end voltage \( V_S \) and the transmission line current will be decided accordingly

\[ \bar{V}_S = V_S \angle \delta_S = \bar{V}_{S0} - \bar{V}_C \]  

(6)

Where

\[ V_S = \sqrt{(V_{S0} - V_C \cos \delta)^2 + (V_C \sin \delta)^2} \]

\[ \delta_S = \arctan \left( \frac{-V_C \sin \delta}{V_{S0} - V_C \cos \delta} \right) \]  

(7)

Next, the shunt CMI injects current IP to decouple the series CMI current IC from the line current IL. In such a way, zero active power exchange to both series and shunt CMIs can be achieved, making it possible to apply the CMI with floating capacitors to the proposed transformerless UPFC. Therefore, we have

\[ \begin{align*}
I_{se} &= \bar{V}_C \angle \delta_C = 0 \\
I_{sh} &= \bar{V}_S \angle \delta_S = 0
\end{align*} \]  

(8)

It means the series CMI current IC and the shunt CMI current IP need to be perpendicular to their voltages \( V_C \) and \( V_S \), respectively, as illustrated in Fig. 3. With the geometrical relationship of the voltages and currents in Fig. 3, the shunt CMI output current can be calculated as

\[ I_P = I_p \angle \theta_P \]  

(9)

Where

\[ \begin{align*}
I_P &= I_L \left( \frac{\cos(\rho - \rho_S)}{\tan(\rho - \rho_S)} - \sin(\rho - \rho_S) \right) \\
\theta_P &= 90^\circ + \delta_S
\end{align*} \]  

(10)

In summary, there are two critical steps for the operation of UPFC: 1) calculation of injected voltage \( V_C \) for series CMI according to active/reactive power command over the transmission line expressed in (5), and 2) calculation of injected current IP for shunt CMI from (10) and (11) to guarantee zero active power into both series and shunt CMIs.

**FUNDAMENTAL FREQUENCY MODULATION (FFM) FOR CMI**

Before embarking on development of UPFC control, the modulation strategy for CMIs is introduced first. In general, the modulation for CMIs can be classed into two main categories: 1) FFM and 2) carrier-based high-frequency pulse width modulation (PWM). Compared to the carrier-based high-frequency PWM, the FFM has much lower switching loss, making it attractive for the transmission-level UPFC and other high-voltage high-power applications.

**Optimization Of Switching Angles For Minimum THD**

Fig. 4 shows the operation principle of traditional FFM, where phase a output voltage of an 11-level CMI is shown as an example.

![Fig. 4. Operation principle of FFM.](image-url)

The Fourier series expansion of the CMI output voltage shown in Fig. 4 is

\[ V_{an}(\omega t) = \sum_{n=1}^{s} V_{an} \sin(\pi nt), \]

\[ V_{an} = \frac{1}{n \pi} \sum_{k=1}^{s} V_{an} \cos(\pi nk), \text{ for odd } n \]

\[ 0, \text{ for even } n \]  

(11)

where \( n \) is harmonic number, \( s \) is the total number of H-bridge modules, and \( \alpha_k \) represents the switching angle for the \( k \)th H-bridge module. Therefore, all triplen harmonics will be ignored for voltage THD calculation which then can be expressed as

\[ THD = \frac{1}{V_{an}} \sqrt{\sum_{n=5,7,11,\ldots}^{s} V_{an}^2} \]  

(12)

Basically, (13) gives an objective function to be minimized, with the following two constraints:

\[ 0 < \alpha_1 < \alpha_2 < \alpha_3 \ldots \ldots < \alpha_s < \frac{\pi}{2} \]  

(13)

And

\[ V_{an} = \frac{1}{\pi} \sum_{k=1}^{s} V_{dc} \cos(\alpha_k) \]  

(14)

The corresponding results have been shown in Fig. 5.
In addition, an alternative optimization of FFM could be the “minimum weighted total harmonics distortion (WTHD).” The WTHD achieves the minimum current THD for inductive loads (i.e., directly optimized for best power quality), which is preferred for application where current distortion is of interest. In such a case, the objective function in (13) should be changed to

$$WTHD = \frac{1}{V_{\text{in}}} \sum_{n=5.7,11,13,17} (V_{\text{in}}/n)^2$$

(15)

As shown in Table I, for the 13.8-kV/2-MVA system, the number of H-bridges for shunt CMI is ten and the number of H-bridges for series CMI is 20.

![Fig. 5. Minimum THD versus number of H-bridge modules](image)

1) FFM has much lower switching loss, thus higher efficiency;
2) with high number of H-bridge modules, output voltage could be very close to sinusoidal, and extremely low THD (e.g., 0.85%) could be achieved without any extra filters;
3) it is notable that FFM does not actually mean slow dynamic response. With high-frequency sampling, FFM can also achieve fast dynamic response, e.g., <10 ms, which will be discussed and experimentally verified in the next section.

**Analysis Of Capacitor Charge Of H-Bridges**

Capacitor charge of H-bridges will be studied based on two layers: 1) first layer is overall capacitor charge, meaning the total capacitor charge of all H-bridges of any one of three phases; 2) the other layer is individual capacitor charge, meaning the capacitor charge of each H-bridge. The overall active power flow of this phase from ac side into dc capacitors can be expressed as

$$P_a = V_o I_o \cos(\theta)$$

(16)

where $V_o$ and $I_o$ are rms values of CMI output phase voltage and current, respectively, and $\theta$ is the phase angle between output voltage and current. However, if the phase angle $\theta$ is smaller than 90°, denoted as $(90° - \Delta\theta)$, the overall dc capacitor voltage could be balanced if

$$P_a = V_o I_o \cos(90° - \Delta\theta) = V_o I_o \sin(\Delta\theta) = P_{\text{loss}}$$

(17)

where $P_{\text{loss}}$ is the total power loss of switching devices and capacitors of one phase. On the other side, with the shifted phase angle $\Delta\theta$, the individual capacitor charge for kth H-bridge, $C_k$ over one fundamental period is

$$C_k = \frac{1}{\omega} \int_{0}^{2\pi} I_0 \cos(\theta) \sin(\Delta\theta) d\theta = \frac{1}{\omega} \sqrt{2} I_0 \cos(\alpha_k) \sin(\Delta\theta)$$

(18)

where $\alpha_k$ is the duty cycle of the kth H-bridge. In (19), the entire modules in the same phase will have same load current $I_0$ and phase angle shift $\Delta\theta$. (19) indicates the quite different individual capacitor charge due to the unequal duty cycles of H-bridge modules. Fig. 7 illustrates the capacitor charges of 20 shunt H-bridges with corresponding switching angles given in Table II.

![Fig. 6. FFM with total 20 H-bridges. (a)Output voltage and current (41 levels) and (b) output voltage of each H-bridge.](image)

![Fig. 7. Capacitor charge of 20 H-bridge modules with FFM.](image)
POWER FLOW AND DC-LINK VOLTAGE CONTROL OF TRANSFORMERLESS UPFC

Dynamic Models of UPFC System

In order to design the vector-oriented control for the proposed transformerless UPFC with considering both steady-state and dynamic performance, the dynamic models are necessary. The models are based on synchronous (dq) reference frame. The phase angle of original sending-end voltage $V_{s0}$ is obtained from a digital phase-locked loop, which is used for abc to dq transformation. The dynamic models for the whole system shown in Fig. 2(a) will be divided into several parts. First, we can get the dynamic model from the new sending-end bus to receiving-end bus

$$
\begin{align*}
V_{sd} &= R_Li_{ld} + L_L\frac{di_{ld}}{dt} - \omega L_Li_{ld} + V_{rd} \\
V_{sq} &= R_Li_{ld} + L_L\frac{di_{ld}}{dt} - \omega L_Li_{ld} + V_{rq}
\end{align*}
$$

(19)

Since the new sending-end voltage $V_s$ is equal to original sending-end voltage $V_{s0}$ minus series CMI injected voltage $V_c$, thus we have

$$
\begin{align*}
V_c &= V_{sd} \\
V_{sq} &= V_{rq}
\end{align*}
$$

(20)

Furthermore, the model from the new sending-end to shunt CMI is

$$
\begin{align*}
V_{sd} &= R_Si_{pd} + L_S\frac{di_{pd}}{dt} - \omega L_Si_{pd} + V_{p0} \\
V_{sq} &= R_Si_{pd} + L_S\frac{di_{pd}}{dt} - \omega L_Si_{pd} + V_{pq}
\end{align*}
$$

(21)

Power Flow And Overall DC Voltage Control

Fig. 8(a) shows the overall control system, which is divided into three stages, i.e., stage I to stage III

Stage I: the calculation from $P*$/$Q*$ $\tan I*P0$. As mentioned before, the $V* C0$ is the voltage reference for series CMI, which is generated according to the transmission line power command as given in (5), while $I*P0$ is the current reference for shunt CMI, which is used to keep zero active power for both CMIs as given in (10), (11). Note that instead of calculating $V* C0$ directly from (5), an alternative way is shown in Fig. 8(b). Here, the line current reference $I* Ld/I*$ $Lq$ is calculated out of the $P*/Q*$ reference, then the $d$- and $q$-axis components of series voltage $V_{cd}$, $V* C0q$ are calculated according to (23), where the dynamic model of (20) is included.

Stage II: overall dc-link voltage regulation. With the $V* C0$ and $I* P0$ given in stage I, the dc-link voltage cannot be maintained due to the following three main reasons: 1) the CMIs always have a power loss, 2) the calculation error caused by the parameter deviations, 3) the error between reference and actual output. In order to control dc-link voltage with better robustness, two variables $\Delta V_C$ and $\Delta I_P$ were introduced for the independent dc-link voltage regulation of series CMI and shunt CMI, respectively, as shown in Fig. 8(a).

Fig. 8. Control system for transformerless UPFC (b) detailed calculation from $P*/Q*$ to $V* C0$ and $I* P0$, and (c) current closed-loop control for shunt CMI. Stage III: voltage and current generation for series and shunt CMI. While for shunt CMI, decoupling feedback current control is used to control output current to follow the reference current $I* P$, as shown in Fig. 8(c).

Individual DC Control And Phase Balance Control

Usually, the dc capacitor voltage balance control for CMIs adopts hierarchical control structure, e.g., an outer control loop and an inner control loop.

Fig. 10. Three-phase separated overall dc voltage control for series CMI, considering capacitor-voltage unbalance between the three phases.

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.

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.

**TABLE III: Fuzzy Rules**

<table>
<thead>
<tr>
<th>Change Error</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
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<td>NM</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
</tr>
</tbody>
</table>

**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 value of input error and change in error are normalized by an input scaling factor. 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

$$E(k) = \frac{P_{ph}(k)-P_{ph}(k-1)}{V_{ph}(k)-V_{ph}(k-1)}$$  \hspace{1cm} (23)

$$CE(k) = E(k) - E(k-1)$$  \hspace{1cm} (24)

**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.

**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. To achieve this, the membership functions of FC are: error, change in error and output. The set of FC rules are derived from

$$u = \{\alpha E + (1-\alpha)*C\}$$  \hspace{1cm} (25)

**SIMULATION RESULTS**

To validate the functionality of the transformerless UPFC system with proposed modulation and control algorithm.

**UPFC Operation - Phase Shifting**

Three operating points with different shifted phases are considered as shown in Fig. 13(a) case A1: 30°, (b) case A2: 15°, and (c) case A3: 0°. All three phase shifting cases (case A1 to case A3) have been tested and corresponding test results are shown in Figs. 14–17.

**Fig. 13. UPFC operating points with different phase shifting:** (a) case A1: 30°, (b) case A2: 15°, and (c) case A3: 0°.
Some discussions about the test results are given as follows:

1) Fig. 14 shows the simulation waveforms of UPFC operating from case A1 to case A2 (Phase shifting 30° to 15°). In addition, Fig. 14 also shows that the current smoothly and quickly raised from zero to 7 A, when the operating point is changed from case A1 to A2.

![Fig. 14. Simulation waveforms of UPFC operating from case A1 to case A2 (phase shifting 30° to 15°): (a) shunt CMI line voltage VP_ab, shunt CMI phase current IP_a, and line current ILa, and (b) the zoomed in waveforms](image)

2) Similarly, the simulation waveforms of UPFC operating from case A2 to case A3 (Phase shifting 15° to 0°) are shown in Fig. 15.

![Fig. 15. Simulation waveforms of UPFC operating from case A2 to case A3 (phase shifting 15° to 0°): (a) shunt CMI phase voltage VP_a, VP_b, and line current ILa, ILb, ILc, and (b) line current ILa and shunt CMI line voltage VP_ab.](image)

3) Fig. 16 shows the measured dynamic response with operating point changing from case A2 to case A3, where the current amplitude would change from 7 to 14 A.

![Fig. 16. Measured dynamic response with operating point changing from case A2 to case A3 (phase shifting 15° to 0°).](image)

4) Fig. 17 shows the simulation results of dc capacitor voltage of both series and shunt CMIs when operating from case A2 to case A3, where top three waveforms correspond to average dc voltage of each phase, and bottom one corresponds to average dc voltage of all three phases.

![Fig. 17. Simulation results of dc capacitor voltage of series and shunt CMIs, from case A2 to case A3 (phase shifting 15° to 0°): (a) dc capacitor voltage of series CMI and (b) dc capacitor voltage of shunt CMI.](image)

**UPFC Operation - Line Impedance Compensation**

Fig. 18 shows three operation points with line impedance compensation, (a) caseB1: original line impedance without compensation is equal to 0.5 p.u., (b) case B2: equivalent line impedance after compensation is equal to 1 p.u., and (c) case B3: equivalent line impedance after compensation is equal to infinity.
Fig. 18. UPFC operating points with line impedance compensation: (a) case B1: original line impedance without compensation = 0.5 p.u., (b) case B2: equivalent line impedance after compensation = 1 p.u., and (c) case B3: equivalent line impedance after compensation = \( \alpha \).

Fig. 19. Simulation waveforms of UPFC operating from case B1 to case B2 (line impedance from original 0.5 p.u. without compensation to 1 p.u. after compensation): (a) line current ILa and shunt CMI line voltage VP ab, (b) line current ILa and series CMI phase voltage VCa.

Fig. 20. Measured dynamic response with operating point changing from case B1 to case B2 (line impedance from original 0.5 p.u. without compensation to 1 p.u. after compensation).

**UPFC Operation - Independent P/Q Control**

The blue curve in Fig. 21(a) shows the transmittable active power P and receiving-end reactive power Q versus receiving-end voltage phase angle \( \delta_0 \) in the uncompensated system, where original sending-end voltage is oriented to 0°.

Fig. 21. Independent P/Q control: (a) control region of the attainable active power P and receiving-end reactive power Q with series CMI voltage = 0.517 p.u. and \( \delta_0 = -30^\circ \), (b) case C1: P = 0.25, Q = 0.

Fig. 22 shows the corresponding experimental waveforms, (a) line current ILa and shunt CMI line voltage VP ab, and (b) line current ILa and series CMI phase voltage VCa.

Fig. 22. Simulation waveforms of UPFC operation case C1: P = 0.25, Q = 0: (a) line current ILa and shunt CMI line voltage VP ab, and (b) line current ILa and series CMI phase voltage VCa.

**CONCLUSION**

According to this paper present a modulation and control technique for the transformer much less UPFC, which has the subsequent features: All UPFC functions, together with voltage law, line impedance reimbursement, segment transferring or simultaneous manipulate of voltage, impedance, and...
section attitude, thus attaining unbiased energetic and reactive electricity drift manage over the transmission line; FFM of the CMI for extremely low THD of output voltage, low switching loss and excessive performance; Dc capacitor voltage balancing manipulate for both collection and shunt CMLs; Fast dynamic reaction (<10 ms). The fuzzy controller is that the nice applicable for the human choice-making mechanism, imparting the operation of AN electronic system with alternatives of professionals. The FLC incorporates of 3 parts: fuzzification, interference engine and defuzzification. The transformerless UPFC with proposed modulation and manipulate may be mounted everywhere in the grid to maximise/optimize electricity transmission over the prevailing grids, reduce transmission congestion and enable high penetration of renewable electricity resources.

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VADLA VENKATESHAM
Completed B.TECH in Electrical & Electronics Engineering in 2015 from Sri Indu Institute of Engineering and Technology affiliated to JNTU Hyderabad and Pursuing M.Tech from Vidya Jyothi Institute of Technology (Autonomous), Affiliated to JNTU Hyderabad, Telangana, India. Area of interest includes Electrical Power Systems.
E-mail id: venkatchinna2094@gmail.com

A. NARASIMHA RAO
Associate Professor, Dept of EEE, Vidya Jyothi Institute of Technology, Aziznagar Gate, Hyderabad, Telangana, India. He had his M.tech with specialization of Power system from University college of Engineering, OU in 1982. And Graduated in BE Electrical, University College of Engineering, OU in 1976. He is having 16 years of experience in teaching. His Research Area include Power systems, Electrical circuits, Micro processors and controllers and Digital Electronics.
E-mail id: anraw@yahoo.com