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Controlling Of Transformer-less UPFC With Cascaded Multilevel Inverter

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Abstract:-- **:- The traditional UPFC that exists two back-to-back inverters bulky and more complicated zig-zag transformers for isolation and reaching high power/voltage rating. To overcome this difficulty, two zig-zag transformers are completely eliminated, in this place two cascaded multilevel inverter are proposed. The unique configuration and control of two CMI's as power flow controller lead to possible independently control active and reactive power over transmission line. The proposed configuration has unique features and several advantages over the traditional configuration such as reduction of cost, transformer-less, high efficiency, light weight, fast dynamic response and more reliability. A simulation model is built to represent the operating of proposed transformer less UPFC.**

Index Terms: AC Transmission system, Cascaded Multi-level inverter(CMI), FACTS, Unified Power Flow Controller(UPFC) .

INTRODUCTION:

A more no. of power flow control solutions are available such as series reactor or capacitor, phase shifting transformer, STATCOM, SSSC and UPFC. The UPFC combines the functions of several FACTS devices and is capable of realizing voltage regulation, impedance compensation and phase angle regulation. At same time, thus realizing separate control of active power P and reactive power Q transmitted over the line. As seen, general UPFC exists of two back-to-back voltage source inverters. Inverter1 is parallel while other Inverter 2 is series with the transmission line. Inverter1 and Inverter2 are coupled through a common dc-link.

A series voltage has been injected from Inverter2 at any angle w.r.t the line current, which provides complete flexibility and controllability of active and reactive power over the line. As a result, UPFC is more versatile and powerful FACT device. It can effectively suppress congestion and enhance capacity of the transmission line. The general UPFC has certain practical applications, which has succeeding features: 1) both inverters shares same dc link; 2) both inverters need to ex-change real power each other; 3) a transformer is to used an interface b/w the transmission line and inverters. The high-voltage, high-power inverters have to usage bulky and complexity of zig-zag transformers to reach their required VA rating and desired waveforms.

The two new UPFC structures are: 1) matrix converter-based UPFC and 2)distributed power-flow controller(DPFC). First one uses the matrix converter replaces dc capacitor with an ac capacitor. The DPFC utilize many distributed series inverter coupled to the line through single-turn transformers, and dc link is eliminated. In summary, both UPFC's is to still use the transformers, which surely cause problems affiliate with transformer. Moreover, this type based UPFC's are slow dynamic response by virtue of large time constant of magnetizing inductance over resistance.

A cascade multi-level inverter is the practical inverter topology to scope the high-voltage levels without use of transformers. A novel configuration of two CMI's is to eliminate transformers thoroughly, which results in major advantages over general UPFC such as reduction of weight, cost and size, high efficiency and reliability. This system provides quick dynamic response and it is well suited for fast and DPFC of wind and solar power transmission. The detailed simulation is carried out to determine the working principle of proposed a novel configuration.

II. NOVEL CONFIGURATION OF UPFC AND ITS WORKING PRINCIPLE

The proposed new UPFC has various features:

1)Each inverter has it's own dc capacitor and it supported to dc voltage;

2)There is no real power ex-change among two inverters, which is not connected any sources for real power to flow;

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3)Unlike the conventional back-to-back dc link coupling, there is no require of transformers in the new UPFC system.

4)The series inverter is connected in transmission line afterwards shunt inverter is connected

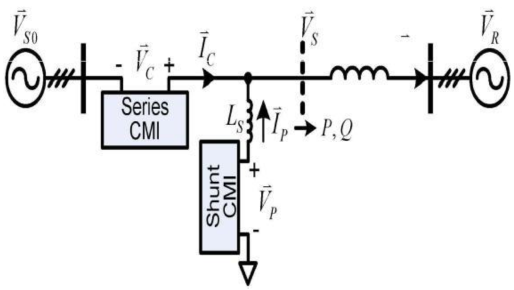

Fig.1 Novel configuration transformerless UPFC

The series CMI is controlled to set up a desired voltage V_C for attaining new sending end voltage V_S, which controls real and reactive power in the line. Concurrently, shunt CMI injects a current I_P to new sending bus form zero real power into both CMI's, i.e., to make the series and shunt CMI's current IP and IC are perpendicular to their voltages V_C and VS, respectively. Therefore, the both CMI's need to supply reactive power.

The active and reactive power P & Q over the line with transformer less UPFC can be equated as

$$P + jQ = V_R\left(\frac{V_{S0} - V_C - V_R}{jX_L}\right)^*$$
$$= \left(-\frac{V_{S0}V_R}{X_L}\sin\delta_0 + \frac{V_C V_R}{X_L}\sin(\delta_0 - \delta)\right)$$
$$+ j\left(\frac{V_{S0}V_R\cos\delta_0 - V_R^2}{X_L} - \frac{V_C V_R}{X_L}\cos(\delta_0 - \delta)\right) \quad ......(1)$$

where symbol * represents the conjugate of a complex number; δ0 is phase angle of receiving end voltage V_R; δ is the phase angle of series CMI injected voltage V_C; X_L is the equivalent line impedance of transmission line.

First, the series CMI voltage V_C is injected according to transmission line real or reactive power command, then

$$\vec{V}_C = V_C < \delta$$
$$= \frac{X_L}{V_R}\sqrt{P_C^{\ 2} + Q_C^{\ 2}} < \left(\delta_0 - \arctan\left(\frac{P_C}{Q_C}\right)\right) \quad ......(2)$$

Next, The shunt CMI injects current I_P to decouple the series CMI current I_C from the line current I_L. Therefore, zero real power ex-change to the two series and shunt CMI's can be achieved, making it possible to apply the CMI with floating capacitors to the proposed transformerless UPFC.
Output of shunt CMI current can be determined as

$$\vec{I}_P = I_P < \theta \quad ......(3)$$

In summary, the operation of UPFC has followed by two critical steps are: 1) calculation of injected series CMI voltage V_C according to power command over the line expressed in eq.(2) and 2) calculation of injected shunt CMI current I_P from eq.(3) to guaranty zero real power into both CMIs.

1) FFM and 2) carrier-based high-frequency pulse width modulation(PWM). Compared to carrier-based high frequency PWM, FFM has lower switching losses, making it attractive for transmission-level UPFC and other high-voltage high-power applications. Furthermore, it will also
demonstrate that CMIs with FFM can achieve fast Dynamic response, i.e., ≤10 ms.
Compared to carrier-based high-frequency PWM scheme, the CMIs with FFM have the following features:
1) FFM has low switching losses, thus higher efficiency;
2) With high number of H-bridge modules, output voltage could be nearer to sinusoidal and extremely low THD could be achieved without any extra filters;
3) FFM can also obtain fast dynamic response, e.g., <10\ ms

b) UPFC Controlling Capabilities

As seen, the operation of UPFC from the viewpoint of traditional power transmission based on reactive shunt-compensation, series-compensation and phase shifting, the UPFC can execute all these functions and their meet multiple control objective by adding the injected voltage

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Vc phase angle and amplitude to sending end voltage Vs. The UPFC power-flow control functions are
i) phase shifting;
ii)line impedance compensation.

i) Phase shifting: Transmission angle regulator (phase shifting) is an UPFC function to achieve desired phase shift(retard or advance) without change in magnitude. In practical, the normal phase shifters, the ac system does not
have to supply reactive power the phase shifting process demands. Hence, it is internally generated by UPFC converter.
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°.
ii) Line impedance compensation: UPFC function of line impedance compensation is differ from the phase shifting. The voltage Vc is injected in quadrature with line current IL.
This is similar to, however more general than the controlled series capacitive and inductive line compensation. This injected compensated voltage can be kept constant, independent of line current IL variation. Where, voltage across series compensation varies with line current IL.
In this section has three operating points with line impedance compensation (a) caseB1: original line impedance without compensation about to 0.5p.u., (b) case B2: equivalent line impedance after compensation about to 1 p.u., and (c) case B3: equivalent line impedance after compensation is equal to infinity. For case B1 (same as case A3), system without compensation has 0.5 p.u. voltage between $V_S = V_R$ (corresponding to 30° voltage difference). With the line impedance equal to 0.31 H (0.5 p.u.).

IV. SIMULATION RESULTS

The transformerless UPFC system with proposed modulation and control algorithm, a 4160-V test setup has been implemented in Matlab simulink and the equivalent receiving-end voltage VR has same amplitude as original sending-end voltage VS 0 , but 30° phase lagging. This 30° phase lagging is introduced by transformer 2 with Y/Δ configuration (Y/Δ, 480 V/4160 V).

1) From case A1 to case A2 (Phase shifting 30° to 15°) there is already 30° phase difference between the original sending-end voltage $\vec{V}_{S0}$ and receiving-end voltage $\vec{V}_R$. For case A1, $\vec{V}_S = \vec{V}_R$. This section UPFC is used to compensate voltage difference caused by transformer 30° phase shift. Therefore, the resulting line current in this case is almost zero. While for case A2, new sending-end voltage $\vec{V}_S$ is shifted from $\vec{V}_{S0}$ by 15°.

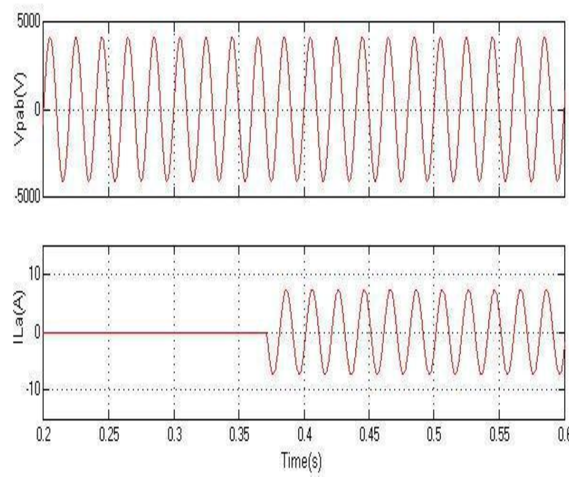

Fig.2 UPFC operating from case A1 to case A2 shunt CMI line voltage V_{Pab}, shunt CMI line current I_{La}.

This result about 7.3A of line current. Fig.2 shows the current smoothly and quickly raised from 0 to 7.3A, while operating point is changed from case A1 to A2.

2) Similarly, case A2 to case A3(phase shifting 15° to 0°), the shunt CMI phase voltage and line current are shown in Fig.3

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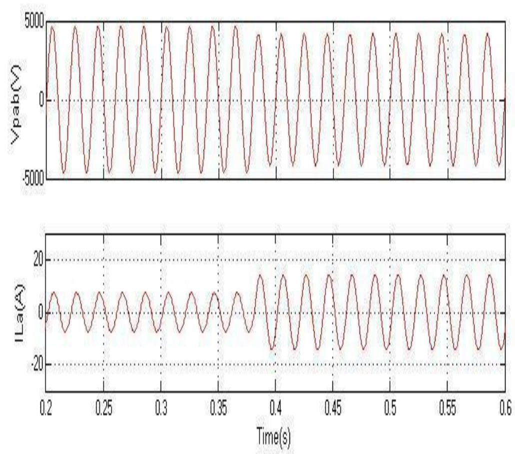

For case A3, the phase shifting is 0°, it indicating a system without compensation. Therefore $\vec{V}_S$ is equal to $\vec{V}_{S0}$ and phase angle between $\vec{V}_S$ and $\vec{V}_R$ is 30°.This resulting current in this section is 14.5A.

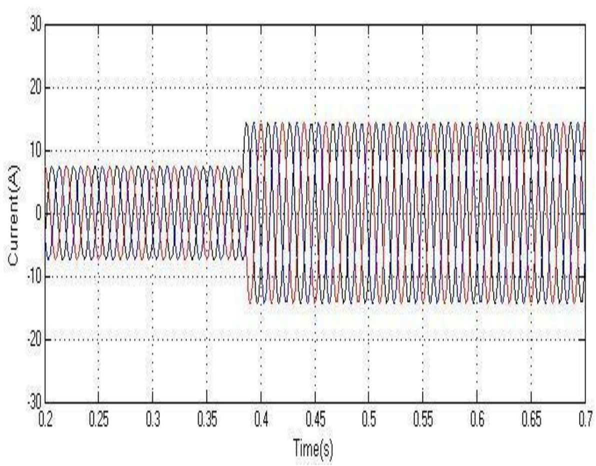

Fig.4 UPFC operating from case A2 to case A3, line current I_{La}, I_{Lb}, I_{Lc}

The operating point changing from case A2 to A3,then current amplitude would changes from 7.3A to 14.5A.Fig.3 shows shunt CMI line voltage V_{Pab} and line current ILa. Fig.5 shows, the UPFC has achieved fast dynamic response about 8 ms. This performance is better for transmission power flow control.

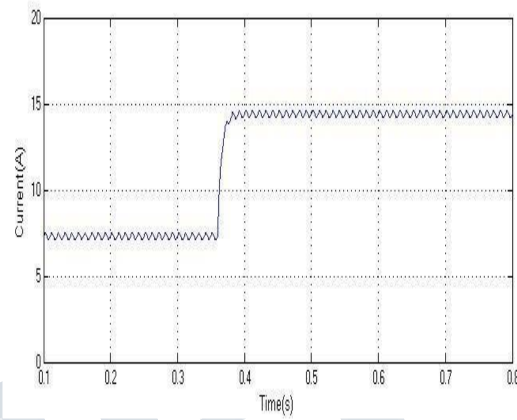

Fig.5 Measured dynamic response with changing operating point from case A2 to case A3.

3) UPFC operation from case B1 to case B2, where the line impedance changed from 0.5p.u (without compensation) to 1p.u after compensation. Shunt CMI phase voltage V_{Pa} and V_{Pb} and line current I_{La} I_{Lb} I_{Lc}, as shown in fig. then the line current smoothly changed from 14.5A to 7.3A due to doubled line impedance.

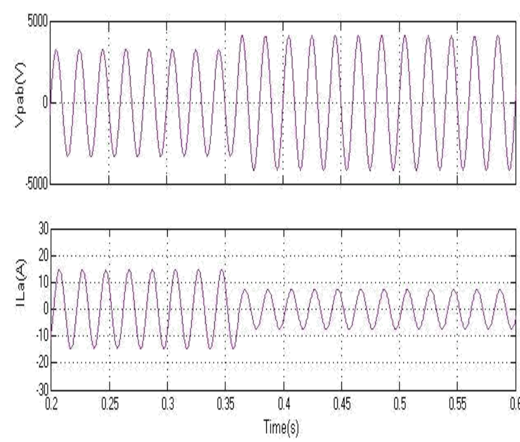

Fig.6 UPFC operating from case B1 to B2, shunt CMI voltage V_{Pab} and line current I_{La}.

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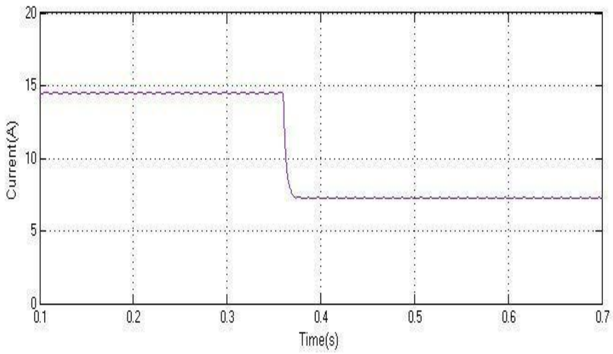

Fig.7 Measured dynamic response with changing operating point from case B1 to case B2.

And series CMI injected voltage V_{Ca} and line current I_{La} are shown in fig. In this waveform we can see the I_{La} is lagging V_{Ca} by 90o, i.e., series CMIs acts as inductors. Dynamic response measured with operating point changing from case B1 to case B2 is about 8 ms (response time).

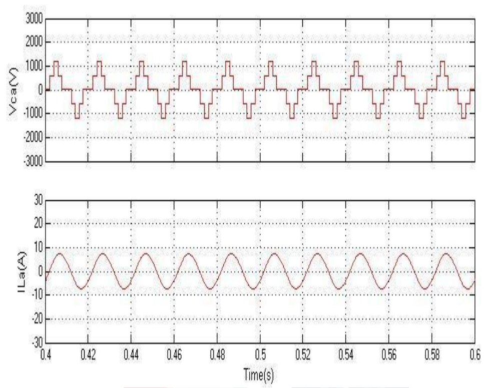

Fig.7 UPFC operating from case B1 to case B2 series CMI phase voltage V_{Ca} and line current I_{La}.

CONCLUSION

In summary, the cascaded multi-level inverter has: i)it can eliminate the bulky transformers; ii)generates almost sinusoidal waveform and iii) fast dynamic response. The controlling of new transformer less UPFC has successive improvements: 1)extremely lower switching losses and greater efficiency of CMI by using FFM technique; 2)entire UPFC functions are achieved and 3)quick dynamic response of the system. The operation and performance of new transformerless UPFC have been analyzed by simulink model. This new controlling structure can be installed wherever in the grid to optimize/enhance the energy transmission, suppresses the transmission congestion and to scope for enabling the huge renewable energy sources.

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