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Transformerless UPFC Using Multilevel Inverter

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***Abstract*— This paper proposes transformer-less Unified Power Flow Controller (UPFC) which can be able to control the parameters of the transmission line. It incorporates back to back inverter that requires large transformers for power flow injection. The transformers are somewhat bulky, very costly and introduce high losses due to magnetic properties of the material used for the erection of core. To conquer this difficulty, a totally transformer-less UPFC is proposed in this work. The proposed controller will reduce the cost and space when compared to the traditional UPFC. A multilevel configuration technique will be used to decrease the total harmonic content. The proposed configuration requires a separate dc source for every level. To reduce the switch count and to eliminate separate dc sources, this multilevel configuration can be further modified. This paper focuses on the performance of transformer-less UPFC involving Fundamental Frequency Modulation (FFM) for reducing the Total Harmonic Distortion (THD) and increasing the efficiency. The proposed UPFC is simulated as a result of using MATLAB Simulink.**

Keywords— ***Flexible AC Transmission Systems (FACTS), Unified Power Flow Controller (UPFC), Multilevel Inverter.***

I. Introduction

The FACTS controller is a power electronic controller that may be afford to control the parameters in transmission system [1-2].The FACTS controllers of concern here, the STATCOM has the capability to enhance/reduce the terminal voltage magnitude and, accordingly, to enhance/reduce power flow [4]. The SSSC manage power flow by varying the series reactance of the transmission line, while the UPFC can manage all these parameters simultaneously.

From the figure 1.1 Inverter 1 is attached in parallel with the transmission line, while Inverter 2 is linked in series with the transmission line [3]. The two inverters are connected back-to-back via a common dc-link. This deal enables real power flow in any direction involving the two inverters. UPFC can insert a voltage with changing magnitude and phase angle it can share real power with the transmission line. UPFC can control and transmit real power at its series connected output-end while separately given that reactive power to the transmission line at its shunt connected input-end [4-6].

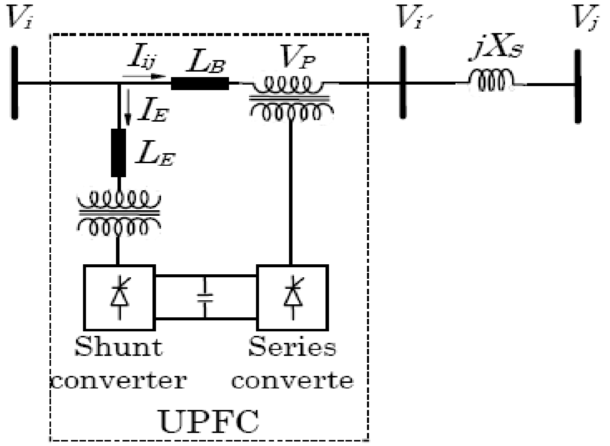

Fig 1.1 Conventional UPFC with back-to-back configuration

The most important advantages of Unified Power Flow Controller are,

- Greater flexibility in power network,
- Transient stability improvement,

The major applications of Unified Power Flow Controller are,

- Enhancement Voltage Profile
- Minimization Of Losses,
- Improving Micro Grid Voltage Profile,

II.DESIGN OF TRANSFORMERLESS UPFC

2.1 Description

Hence to reduce the transformer entirely, a new transformer-less UPFC can be proposed.The H-bridge inverters can be formed as two separate inverters that are like face to face configuration can solve the problems for Unified Power Flow Controller (UPFC) as shown in Fig 2.1.

The series cascaded multilevel inverter can be maintained to inject voltage in series with transmission line, that can be changed from low voltage to maximum voltage. The shunt connected CMI is mostly used to supply real power demand of series CMI that is derived from transmission line itself, it can maintain constant voltage [6]. The Transformer-less UPFC has significant advantages over the traditional UPFC such as increase efficiency, increases reliability, less cost, lossless and compact structure.

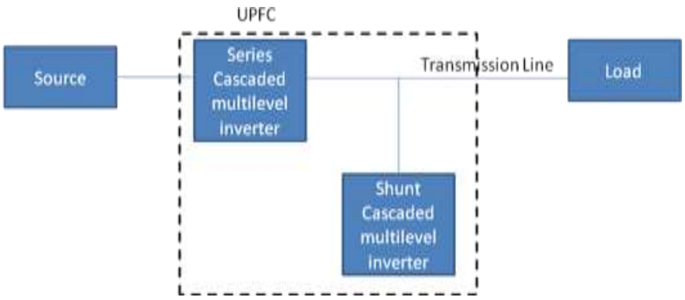

Fig 2.1 Block Diagram Of Transformer-less UPFC.

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The cascaded H-bridge multi level inverter is to utilize capacitors and switches and requires less number of components in every level as illustrated in Fig 2.2. This topology comprises of series of power transformation cells can be essentially scaled [7-9]. The mix of capacitors and switches pair combined is called an H-bridge and gives the dissimilar input DC voltage for each H-bridge. It comprises of H-bridge cells and each cell can give the three unique voltages like zero, positive DC and negative DC voltages [8]. The cost and weight of the inverter are lesser than those of the two inverters.

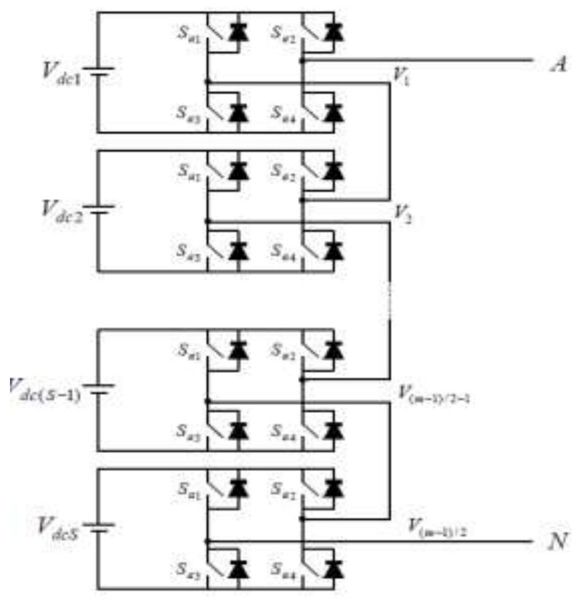

Fig 2.2 Single-Phase Arrangement of an n-Level Cascaded Inverter

2.2 Operating Principle

1) Unlike the conventional back-to-back dc link coupling, the transformer-less UPFC requires no transformer, then it can achieve low cost, light weight, compact, increases efficiency and reliability.
2) The shunt inverter is connected after the series inverter, that is entirely vary from the traditional UPFC[9].
3) The new UPFC utilizes modular CMIs and their inherent redundancy provides greater flexibility and higher reliability.

From the fig 2.3 the transmitted active power (P) and reactive power (Q) over the line with the transformer-less UPFC can be given as,

$$P + jQ = \vec{V_R} \cdot \left(\frac{\vec{V_{S0}} - \vec{V_C} - \vec{V_R}}{jX_L}\right)^* \tag{1}$$

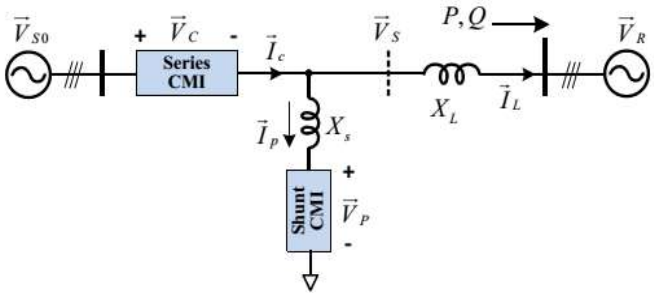

Fig 2.3 System Design of Transformer-Less UPFC

$$P + jQ = \left(-\frac{V_{S0}V_R}{X}\sin\delta + \frac{V_C V_R}{X}\sin(\delta_0 - \delta)\right) + j\left(\frac{V_{S0}V_R\cos\delta_0 - V_R^{\,2}}{X} - \frac{V_C V_R}{X}\cos(\delta_0 - \delta)\right) \tag{2}$$

where sign * represents the complex conjugate; δ_0 is the phase angle of the receiving-end voltage.
The original active and reactive powers, P_0 and Q_0 with the uncompensated system are,

$$\begin{cases} P_0 = -\dfrac{V_{S0}V_R}{X_L}\sin\delta_0 \\ Q_0 = \dfrac{V_{S0}V_R}{X_L}\cos\delta_0 - V_R^{\,2} \end{cases} \tag{3}$$

The controllable active and reactive powers, P_c and Q_c by the transformer-less UPFC, which can be given as,

$$\begin{cases} P_C = \dfrac{V_C V_R}{X_L}(\sin\delta_0 - \delta) \\ Q_C = -\dfrac{V_C V_R}{X_L}\cos(\delta_0 - \delta) \end{cases} \tag{4}$$

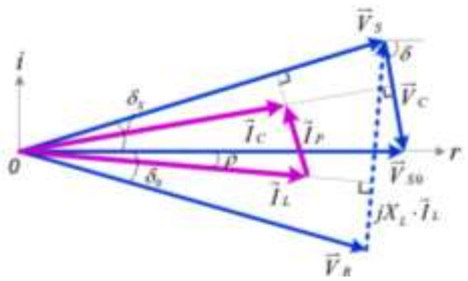

Fig 2.4 Phasor diagram of the transformer-less UPFC

List of Symbols

$\vec{V_C}$	Injected voltage
$\vec{I_P}$	Injected current
$\vec{V_{S0}}$	Sending-end voltage
$\vec{V_R}$	Receiving-end voltage
$\overrightarrow{V_{C0}^{*}}$	Voltage reference for series CMI
$\overrightarrow{I_{P0}^{*}}$	Current reference for shunt CMI
V_0	rms value of output phase voltage
α	Switching angle

Firstly, the series CMI voltage is injected according to transmission line active and reactive power command, which can be calculated from (3)

$$V_c = V_c\angle\delta = \frac{X_L}{V_c}\sqrt{P_c{}^2 + Q_c{}^2\left(\angle\delta_o - arc\tan(\frac{P_c}{Q_c})\right)} \qquad (5)$$

From the fig 2.4 once the series CMI inject voltage is decided by (5), the new sending-end voltage and the transmission line current will be determined consequently [10].

$$\vec{V_s} = V_s\angle\delta_s = \vec{V}_{so} - \vec{V_c} \qquad (6)$$

Where,

$$\begin{cases} V_s = \sqrt{(V_{so} - V_c\cos\delta)^2} + \sqrt{(V_c\sin\delta)^2} \\ \delta_s = arc\tan\left(\dfrac{-V_c\sin\delta}{V_{so} - V_c\cos\delta}\right) \end{cases}$$

And $\vec{I}_L = I\angle\rho$ (7)

$$\rho = arc\tan\left(\frac{V_{so} - V_c\cos\delta - V_R\cos\delta_o}{V_c\sin\delta + V_R\sin\delta_o}\right)$$

In such a way, zero active power exchange to both series and shunt CMIs may be achieved, make it feasible to submit the CMI with floating capacitors of the proposed transformer-less UPFC. Therefore, we have

$$P_{se} = \vec{V_c}\cdot\vec{I}_c = 0$$
$$P_{sh} = \vec{V_s}\cdot\vec{I}_p = 0 \qquad (8)$$

III.CASCADED MULTILEVEL INVERTER TOPOLOGY

3.1 Methodology

The proposed work, only cascaded multilevel inverter is performed without the presence of transformers. The notice here is interfacing a individual DC power source with a cascade multilevel inverter wherever the additional DC sources are capacitors as shown in Fig 3.1. Presently, each stage have cascaded multilevel inverter needs n quantity of DC sources for 2n+1 levels.

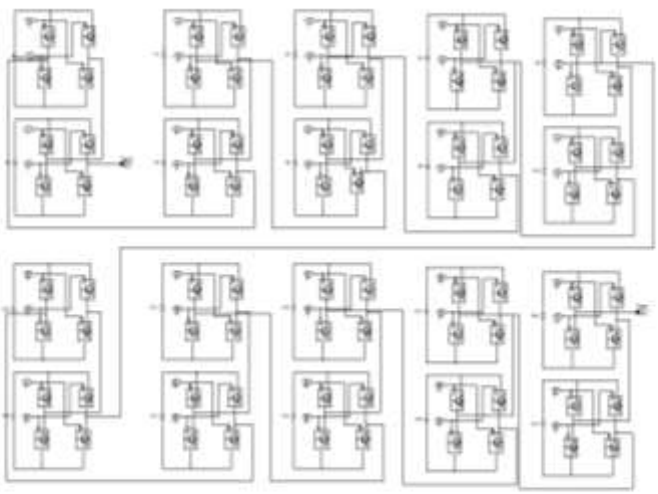

Fig 3.1 Topology of Cascaded Multilevel Generation

3.2 Calculation of Switching Angles

A stair-case voltage waveform, V a could be synthesized when each of five H-bridge cells produces a quasi-square wave, V_{H1}, V_{H2}, …, V_{H5}. However, these paper mostly focused on low number (not more than 5) of H-bridge modules [11]. In this paper, switches angles will be optimized for minimum THD with the high quantity of H-bridge modules for the transformer-less UPFC.

The Fourier series extension of the CMI output voltage can be given as,

$$V(wt) = \sum_{n=1}^{\infty} V\cdot\sin(nwt) \quad ,$$

$$V_{an} = \begin{cases} \dfrac{4}{n\pi}\displaystyle\sum_{k=1}^{s} V_{dc}\cos(n\propto_k) \end{cases} \qquad (9)$$

where n is harmonic number, s is the total quantity of H-bridge modules, and α_k represents the switching angles for the k^{th} H-bridge module Therefore, all triplen harmonics will be ignored for voltage THD calculation, which then can BE given as

$$THD = \frac{1}{V_{a1}}\sqrt{\sum_{n=5,7,11..}^{\infty} V_{an}{}^2} \qquad (10)$$

Basically, equation (10) gives an objective utility to be minimized, with the subsequent two constrains,

$$0 < \alpha_1 < \alpha_2 < \alpha_3 \dots . < \alpha_5 < \frac{\pi}{2} \qquad (11)$$

And harmonics,

$$V_{a1} = \begin{cases} \dfrac{4}{\pi}\displaystyle\sum_{k=1}^{s} V_{dc}\cos(\alpha_k) \end{cases} \qquad (12)$$

In the first fundamental cycle, the optimized ten switching angles are distributed to ten H-bridge modules in a special sequence. After one cycle, the switching angles for the H-bridge modules will be swapped as illustrated in Fig. 3.2. If we take a appear at the switching angles for all of the ten modules, it would be in an order of $\alpha 1$, $\alpha 10$, $\alpha 2$, $\alpha 9$, $\alpha 3$, $\alpha 8$, $\alpha 4$, $\alpha 7$, $\alpha 5$, $\alpha 6$, $\alpha 1$, . . .for the successive fundamental cycles. Since smaller switching angle (corresponding to larger duty cycle) of an H-bridge module results in more capacitor charge [12].

The WTHD achieves the minimum current THD for inductive should be changed to

$$WTHD = \frac{1}{V_{a1}}\sqrt{\sum_{n=5,7,11..}^{\infty}\left(\frac{V_{an}}{n}\right)^2} \qquad (13)$$

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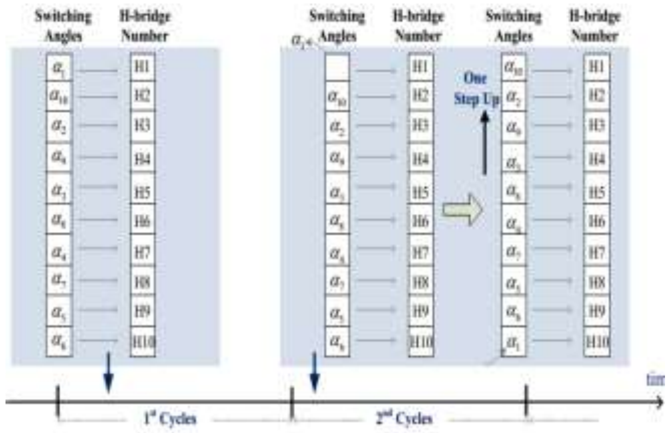

Fig 3.2 Lookup table for pulse swapping

IV.SIMULATION RESULTS

In order to corroborate the performance of the proposed transformer less UPFC controller an MATLAB/Simulink model for a UPFC arrangement with Fundamental Frequency Modulation and control scheme has been executed with a source system of 480 - 4160 V test setup gets developed.

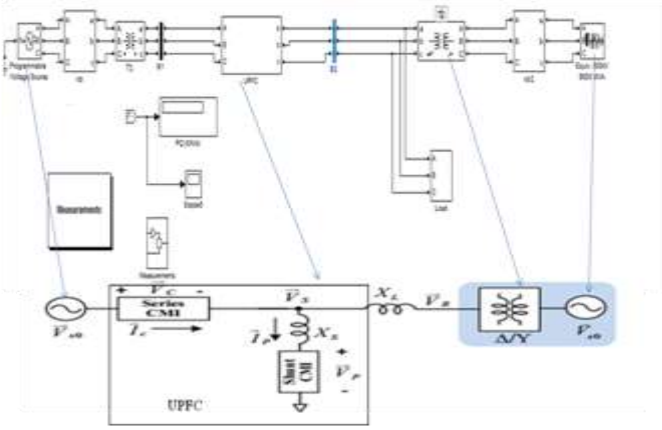

Fig 4.1 Proposed System for the Transformer-Less UPFC with Cascaded Multilevel Inverter.

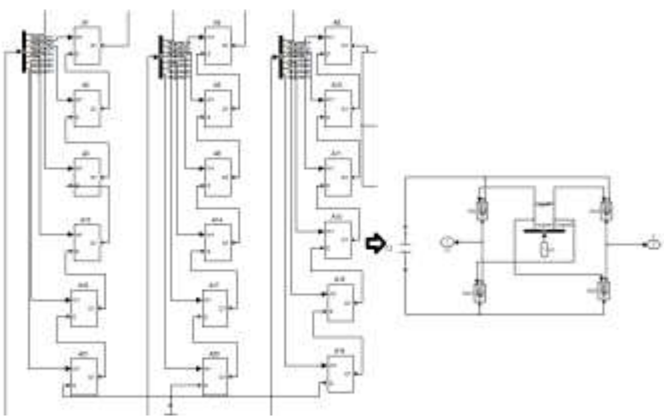

Fig 4.2 Proposed multilevel topology structure that contains a single dc source, with a H bridges cascaded shares a single dc source with a balanced capacitor voltages.

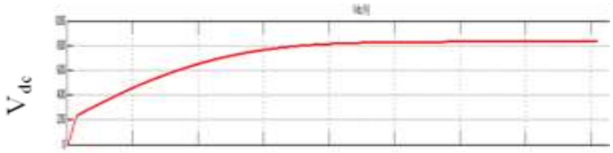

Fig 4.3 V_{dc} stabilization of the proposed UPFC

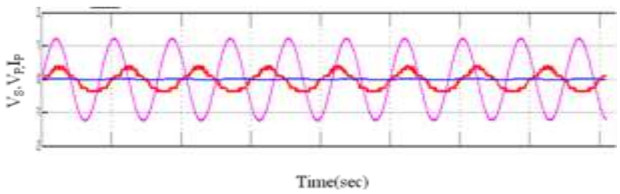

Fig 4.4 Angle deviation and correction wave pattern at 30^o

TABLE I
SPECIFICATIONS OF THE PROPOSED MULTILEVEL INVERTER BASED UPFC

PARAMETERS	**VALUES**
Grid voltage *Vg*	480 V
Rated frequency	60 Hz
Sampling frequency	2.5 kHz
V_{dc} of each shunt H-bridge	600 V
V_{dc} of each series H-bridge	600 V
No.of shunt H-bridges/ phase	6
No.of series H-bridges /phase	3
Transformer 1 (Δ/Δ)	480 V/ 4160 V, 75 kVA
Transformer 2 (Y/Δ)	480 V/ 4160 V, 75 kVA
Rated line current	10A

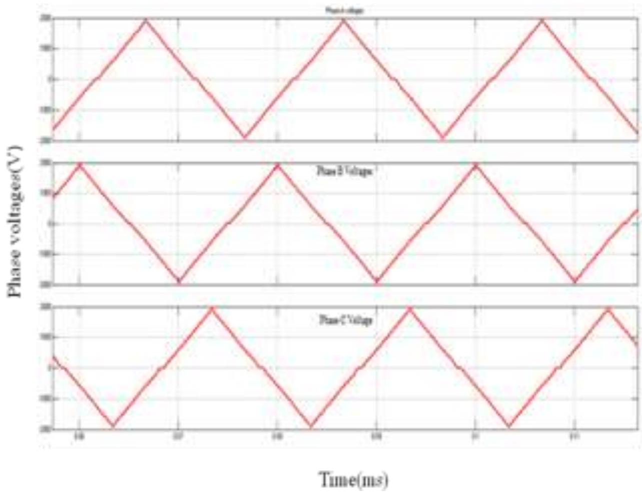

Fig 4.5 Proposed multilevel inverter output under 20 step mode

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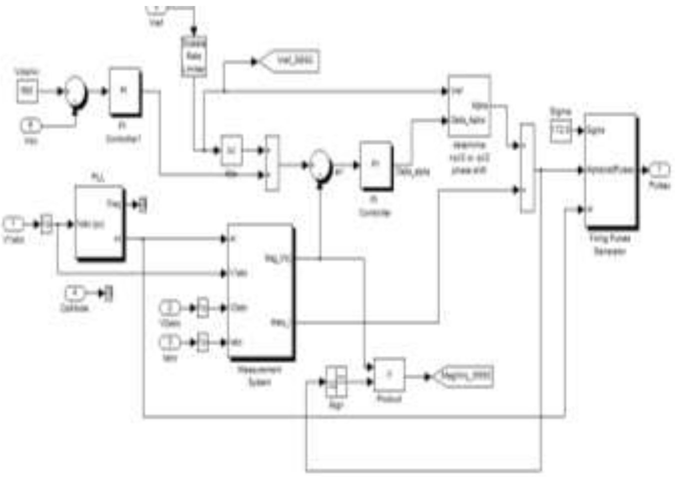

Fig 4.6 Implementation of the control system

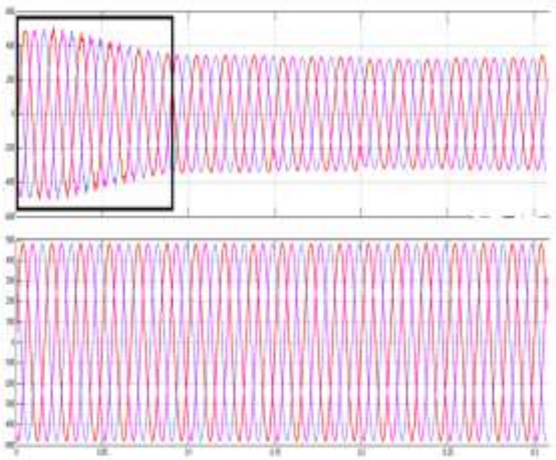

Fig 4.7 Voltage balancing of the proposed scheme

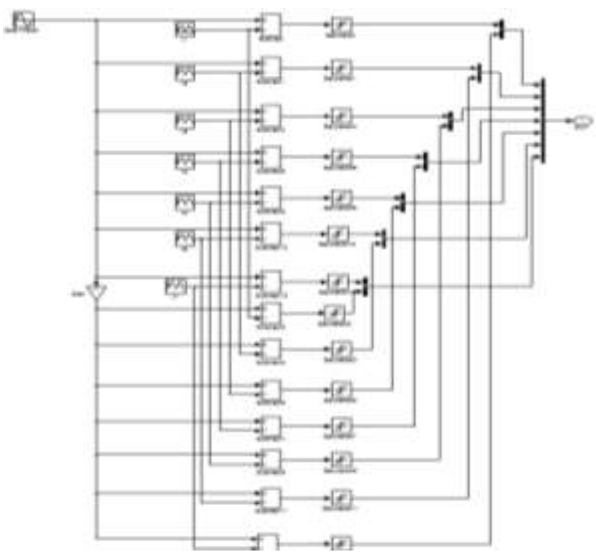

Fig 4.8 Implementation of the Fundamental Frequency Modulation Scheme

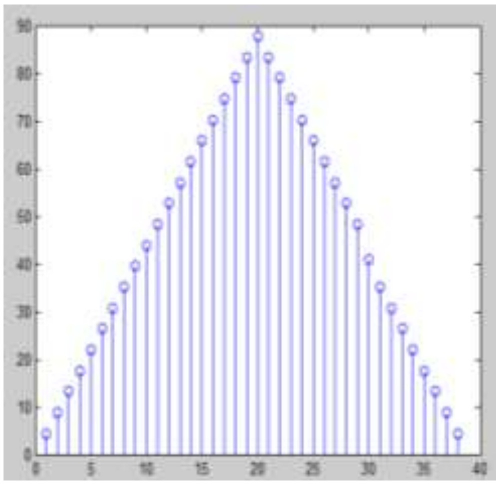

Fig 4.9 Calculated triggering angles of the Proposed Methodology.

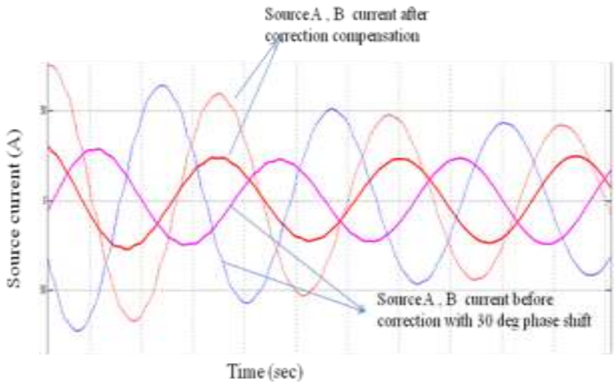

Fig 4.10 Angle deviation and angle corrected patterns of UPFC

V. CONCLUSION

This paper presented a transformer-less UPFC using multilevel inverter to reduce the cost and space when compared to the traditional UPFC. From the simulation results, it is found that, the proposed UPFC has the ability to control real and reactive power flow, can reduce the total harmonic content and the phase shifting with simultaneous control of voltage. Also, it can reduce the switching losses via the Fundamental Frequency Modulation (FFM).

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