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Power Flow Control and Analysis of Transformerless Upfc

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ABSTRACT: In this paper, operation and investigation for an enhanced transformer-less unified power flow controller (UPFC) is introduced. As is well-known, the generalized UPFC that consists of two back to back inverters requires bulky and often complicated zigzag transformers for isolation and reaching high power rating with desired voltage waveforms. To overcome this problem, a completely transformer-less UPFC **Dr. YERRA SREENIVASA RAO** based on innovative configuration of two cascade multilevel inverters (CMIs) has been proposed in [1]. The advantages of the enhanced UPFC incorporate, other than the upsides of transformer-less UPFC officially had, same usefulness of unique structure, no more equipment required, more adaptable operation and less converter rating. This paper presents rating examination and operation rule for this new transformer less UPFC.

INTRODUCTION:

The unified power flow controller (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) . 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. The resultant real power at the terminals of inverter-2 is provided or absorbed by inverter-1 through the common dc link. As a result, UPFC is the most versatile and powerful flexible ac transmission systems device. It can effectively reduce congestions and increase the capacity of existing transmission lines. This allows the overall system to operate at its theoretical maximum capacity. The basic control methods, transient analysis, and practical operation considerations for UPFC have been investigated . The conventional UPFC has been put into several practical applications 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. Moreover, the zigzag transformerbased 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 .

Recently, there are two new UPFC structures under investigation: 1) the matrix converter-based UPFC and 2) distributed power-flow controller (DPFC) derived from the conventional UPFC . The first one uses the matrix converter replacing the back-to-back inverter to eliminate the dc capacitor with ac capacitor on one side of the matrix converter. The DPFC employs many distributed series inverters coupled to the transmission line through single-turn transformers, and the common dc link between the shunt and series inverters is eliminated. The single-turn transformers lose one design freedom, thus making them even bulkier than a conventional transformer given a same VA rating. In summary, both UPFCs still have to use the transformers, which inevitably cause the same aforementioned problems associated with transformers (such as bulky, lossy, high cost, and slow in response).

LITERATURE SURVEY

N. G. Hingorani and L. Gyugyi,:

Electrical Engineering Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems The Flexible AC Transmission

System (FACTS)—a new technology based on power electronics—offers an opportunity to enhance controllability, stability, and power transfer capability of ac transmission systems. Pioneers in FACTS and leading world experts in power electronics applications, Narain G. Hingorani and Laszlo Gyugyi, have teamed together to bring you the definitive book on FACTS technology. Drs. Hingorani and Gyugyi present a practical approach to FACTS that will enable electrical engineers working in the power industry to understand the principles underlying this advanced system. Understanding FACTS will enhance your expertise in equipment specifications and engineering design, and will offer you an informed view of the future of power electronics in ac transmission systems. This comprehensive reference book provides in-depth discussions on: Power semiconductor devices Voltage-sourced and current-sourced converters Specific FACTS Controllers, including SVC, STATCOM, TCSC, SSSC, UPFC, IPFC plus voltage regulators, phase shifters, and special Controllers with a detailed comparison of their performance attributes Major FACTS applications in the U.S. Understanding FACTS is an authoritative resource that is essential reading for electrical engineers who want to stay on the cusp of the power electronics revolution.

L. Gyugyi, C. D. Schauder, S. L. Williams, T. R. Rietman, D. R. Torgerson, and A. Edris,

This paper shows that the unified power flow controller (UPFC) is able to control both the transmitted real power and, independently, the reactive power flows at the sending- and the receiving-end of the transmission line. The unique capabilities of the UPFC in multiple line compensation are integrated into a generalized power flow controller that is able to maintain prescribed, and independently controllable, real power and reactive power flow in the line. The paper describes the basic concepts of the proposed generalized P and Q controller and compares it to the more conventional, but related power flow controllers, such as the thyristor-controlled series capacitor and thyristor-controlled phase angle regulator. The paper also presents results of computer simulations showing the performance of the UPFC under different system conditions.

A. Rajabi-Ghahnavieh, M. Fotuhi-Firuzabad, M. Shahidehpour, and R. Feuillet,:

This paper discusses various aspects of unified power flow controller (UPFC) control modes and settings and evaluates their impacts on the power system reliability. UPFC is the most versatile flexible ac transmission system device ever applied to improve the power system operation and delivery. It can control various power system parameters, such as bus voltages and line flows. The impact of UPFC control modes and settings on the power system reliability has not been addressed sufficiently yet. A power injection model is used to represent UPFC and a comprehensive method is proposed to select the optimal UPFC control mode and settings. The proposed method applies the results of a contingency screening study to estimate the remedial action cost (RAC) associated with control modes and settings and finds the optimal control for improving the system reliability by solving a mixed-integer nonlinear optimization problem. The proposed method is applied to a test system in this paper and the UPFC performance is analyzed in detail.

H. Fujita, Y. Watanabe, and H. Akagi,

This paper presents a control scheme and comprehensive analysis for a unified power flow controller (UPFC) on the basis of theory, computer simulation and experiment. This developed theoretical analysis reveals that a conventional power feedback control scheme makes the UPFC induce power fluctuation in transient states. The conventional control scheme cannot attenuate the power fluctuation, and so the time constant of damping is independent of active and reactive power feedback gains integrated in its control circuit. This paper proposes an advanced control scheme which has the function of successfully damping out the power fluctuation. A UPFC rated at 10 kVA is designed and constructed, which is a combination of a series device consisting of three single-phase pulsewidth modulation (PWM) converters and a shunt device consisting of a three-phase diode rectifier. Although the dynamics of the shunt device are not included, it is possible to confirm and demonstrate the performance of the series device. Experimental results agree well with both analytical and simulated results and show viability and effectiveness of the proposed control scheme.

Ajami, A., Oskuee, M.R.J., Mokhberdoran, A., van den Bossche, A.:

In this study, a novel structure for cascade multilevel inverter is presented. The proposed inverter can generate all possible DC voltage levels with the value of positive and negative. The proposed structure results in reduction of switches number, relevant gate driver circuits and also the installation area and inverter cost. The suggested inverter can be used as symmetric and asymmetric structures. Comparing the peak inverse voltage and losses of the proposed inverter with conventional multilevel inverters show the superiority of the proposed converter. The operation and good performance of the proposed multilevel inverter have been verified by the simulation results of a single-phase nine-level symmetric and 17-level asymmetric multilevel inverter and experimental results of a nine-level and 17-level inverters. Simulation and experimental results confirmed the validity and effectiveness performance of the proposed inverter.

M. A. Sayed and T. Takeshita

This paper presents the line loss minimum condition in isolated substations and same substation multiple loop distribution systems by using the unified power flow controller (UPFC). In each case, the mathematical model is presented and the line loss minimum conditions are obtained based on the line parameters of the distribution feeders. Since multiple loop distribution system is fed from same substation, the line loss minimization can be achieved by compensating the summation of the line reactance voltage drop. In an isolated substation loop distribution system, the line loss minimization can be achieved by compensating the summation of the line reactance voltage drop in addition to the voltage difference of the substations. Realization of both cases can be achieved if the loop current is eliminated from the loop system. The series compensation technique applied by the UPFC is used to eliminate the loop current from the loop distribution system and hence minimize the total line loss. The effectiveness of the proposed control schemes of the UPFC have been verified experimentally.

OPERATION PRINCIPLE OF THE TRANSFORMERLESS UPFC

The conventional UPFC consists of two back-to-back connected voltage source inverters that share a common dc link, as shown in Fig. 1.

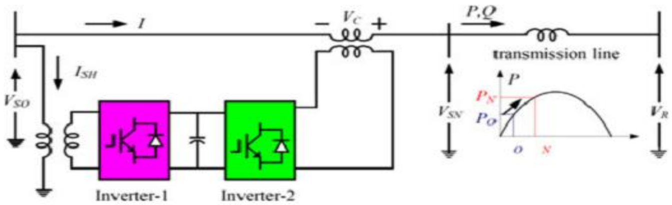

Fig. 1. Conventional UPFC.

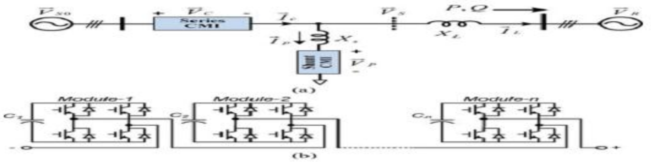

Fig. 2. New transformerless UFPC. (a) System configuration of transformerless UPFC. (b) One phase of the cascaded multilevel inverter.

BASIC FREQUENCY MODULATION FOR CMIS 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: • Fundamental frequency modulation (FFM) and • 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. The FFM has been investigated for many years, however, most studies focused on the FFM optimization with low number of modules (e.g. 4 to 5) and the steady-state THD minimization. In this paper, FFM will be designed with high number of modules. Specifically, switching angles will be optimized for all 10 series H-bridge modules and 20 shunt H-bridge modules to achieve extremely low THD. Furthermore, it will also demonstrate that CMIs with FFM can also achieve fast dynamic response, e.g. 8 ms. Fig. 4 shows the operation principle of traditional FFM, where phase a output voltage of an 11-level CMI is shown as an example. A stair-case voltage waveform, Va could be synthesized when each of five H-bridge modules generates a quasi-square wave, VH1, VH2, …, VH5. Each H-bridge has the identical dc-link voltage Vdc for the modular design consideration. Different approaches have been studied to decide the switching angles of H-bridge modules for selected harmonic elimination (SHE) or minimum THD. Due to the unique system configuration, the basic operation principle of the transformerless UPFC is quite different from conventional UPFC. Fig. 3 shows the phasor diagram of the transformerless UPFC, where V S0 and V R are the original sending-end and receiving-end voltage, respectively. Here V S0 is aligned with real axis, which means phase angle of V S0 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.

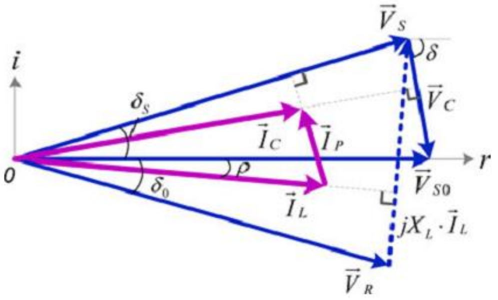

Fig. 3. Phasor diagram of the transformerless UPFC

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

$$P + jQ = \vec{V}_R \cdot \left(\frac{\vec{V}_{S0} - \vec{V}_C - \vec{V}_R}{jX_L} \right)^*$$
$$= \left(-\frac{V_{S0} V_R}{X_L} \sin\delta_0 + \frac{V_C V_R}{X_L} \sin(\delta_0 - \delta) \right)$$
$$+ j \left(\frac{V_{S0} V_R \cos\delta_0 - V_R^2}{X_L} - \frac{V_C V_R}{X_L} \cos(\delta_0 \right.$$

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

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

It means the series CMI current I C and the shunt CMI current I P 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

$$\vec{I}_P = I_P \angle \theta_{I_P}$$

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 calculation of injected current I P for shunt CMI from guarantee zero active power into both series and shunt CMIs

SIMULATION RESULTS:

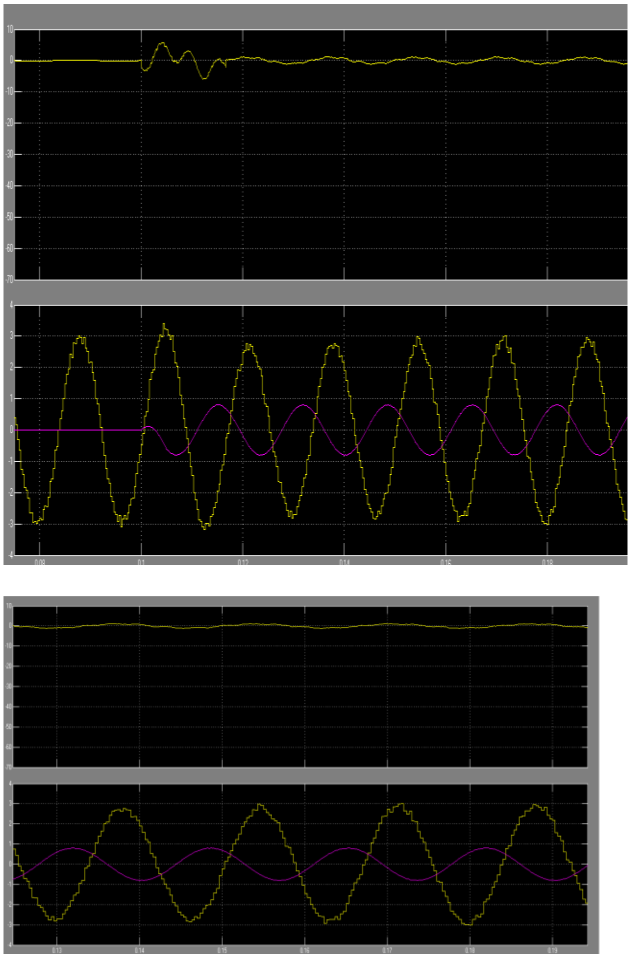

Fig. 14. Experimental waveforms of UPFC operating from case A1 to case A2 (phase shifting 30° to 15°): (a) shunt CMI line voltage VP ab , shunt CMI phase current IP a , and line current ILa , and (b) the zoomed in waveforms.

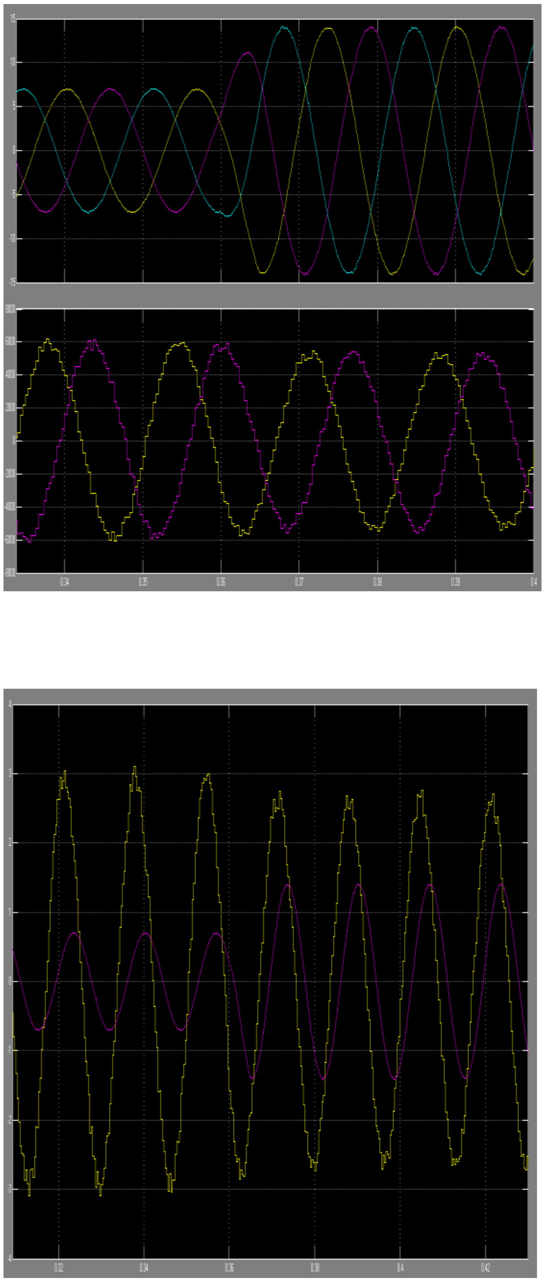

Fig. 15. Experimental waveforms of UPFC operating from case A2 to case A3 (phase shifting 15° to 0°): (a) shunt CMI phase voltage VP a , VP b and line current ILa , ILb , ILc , and (b) line current ILa and shunt CMI line voltage VP ab .

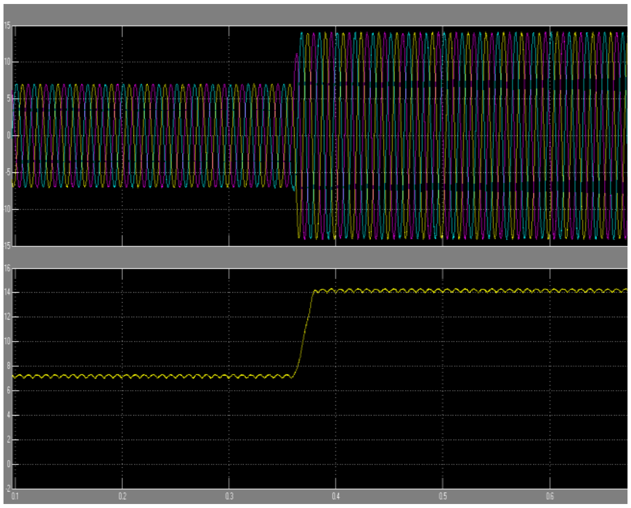

Fig. 16. Measured dynamic response with operating point changing from case A2 to case A3 (phase shifting 15° to 0°).

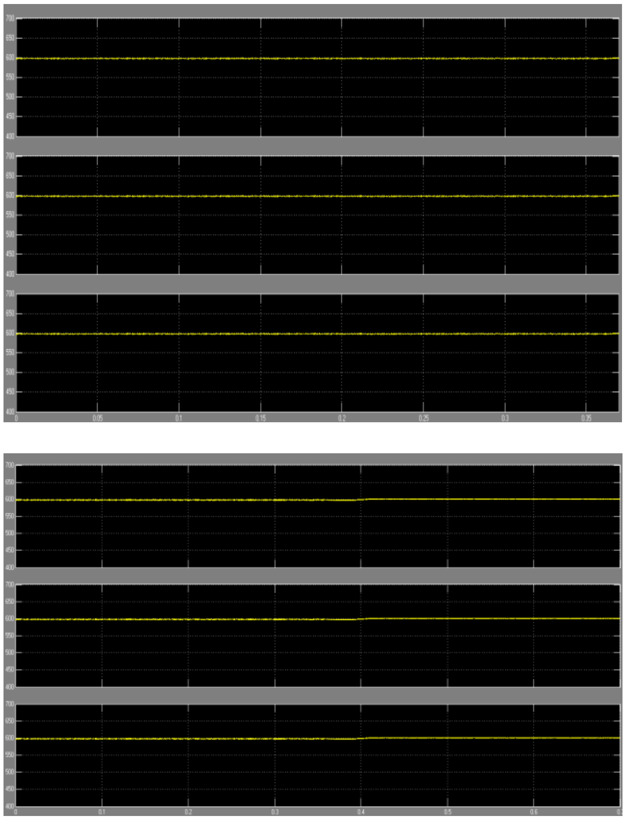

Fig. 17. Experimental results of dc capacitor voltage of series and shunt CMIs, from case A2 to case A3 (phase shifting 15° to 0°): (a) dc capacitor voltage of series CMI and (b) dc capacitor voltage of shunt CMI.

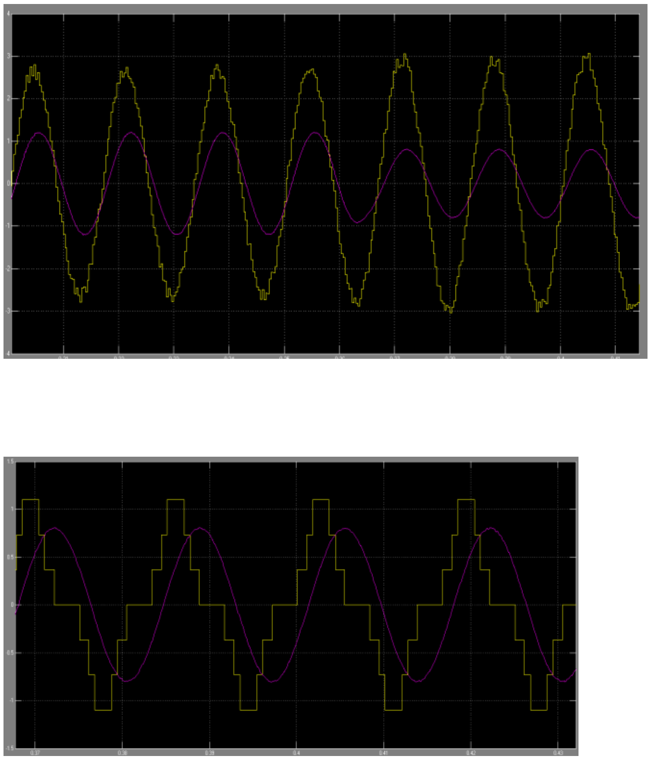

Fig. 19. Experimental waveforms of UPFC operating from case B1 to case B2 (line impedance from original 0.5 p.u. without compensation to 1 p.u. after compensation): (a) line current ILa and shunt CMI line voltage VP ab , (b) line current ILa and series CMI phase voltage VC a

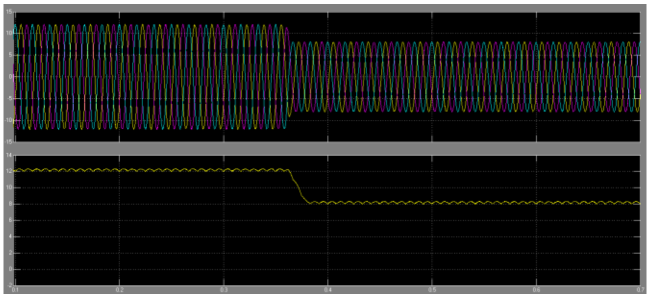

Fig. 20. Measured dynamic response with operating point changing from case B1 to case B2 (line impedance from original 0.5 p.u. without compensation to 1 p.u. after compensation)

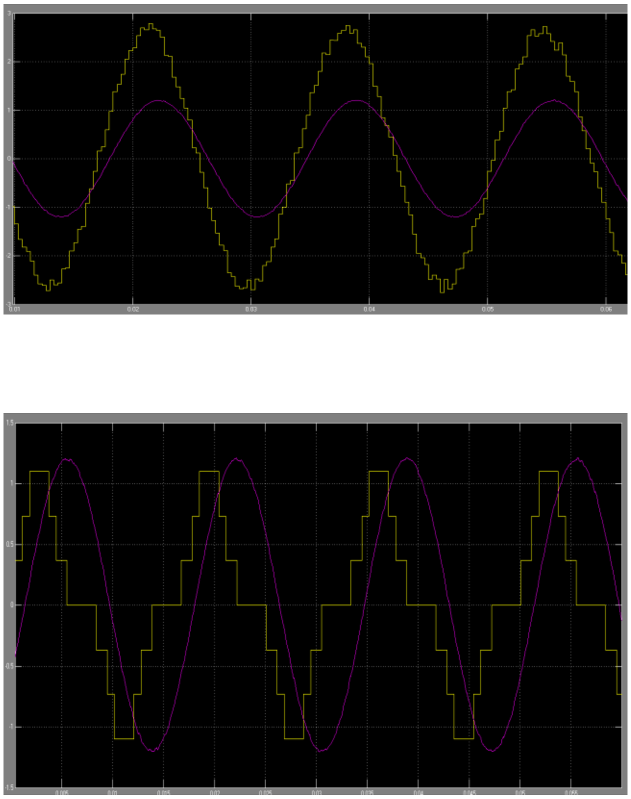

Fig. 22. Experimental waveforms of UPFC operation case C1: P = 0.25, Q = 0: (a) line current ILa and shunt CMI line voltage VP ab , and (b) line current ILa and series CMI phase voltage VC a

CONCLUSION This paper shows the operation and investigation for an enhanced transformer-less UPFC. The steady state and element demonstrate have been produced and essential operation rule has been broke down. Moreover, its converter rating has been contrasted and unique transformer-less UPFC. The enhanced transformer-less UPFC has the accompanying components: 1) same equipment prerequisite and more control flexibility; 2) diminished shunt current rating and lessened aggregate converter rating contrasted with unique transformer-less UPFC 3)able to accomplish autonomous dynamic and receptive power stream control over the transmission line. Because of the adaptable execution, the enhanced transformer-less UPFC can be introduced anyplace in the system to augment/upgrade vitality transmission over the current networks and lessen transmission blockage. The MATLAB Simulation check at 13.8 kV/2 MVA models is left for future work. The transformer-less UPFC with proposed regulation and control can be introduced anyplace in the network to expand/streamline vitality transmission over the current lattices, decrease transmission blockage and empower high infiltration of renewable vitality sources.

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