A Review Paper on Modulation and Control of Transformerless UPFC

Sonali N. Tarle[1] Prof. Aranke Vivek Raghunath[2]
[1]ME Student [2]Assistant Professor
[1,2]Matoshri Education Society's Matoshri College of Engineering & Research Center, Nasik, India

Abstract— A modulation and control method for the new transformerless unified power flow controller (UPFC) is proposed in this paper. To overcome this problem, a completely transformerless UPFC based on an innovative configuration of two cascade multilevel inverters has been proposed. The conventional 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. The new UPFC offers several advantages over the traditional technology, such as transformerless, light weight, high efficiency, low cost and fast dynamic response. This paper focuses on the modulation and control for this new transformerless UPFC, including optimized fundamental frequency modulation for low total harmonic distortion and high efficiency, independent active and reactive power control over the transmission line, dc-link voltage balance control, etc. By using the simulation results we can analyze the both the steady-state and dynamic-response results.

Key words: Control of Transformerless UPFC, UPFC

I. 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) [1]–[3]. The conventional UPFC consists of two back-to-back connected voltage source inverters that share a common dc link, as shown in Fig. 1.

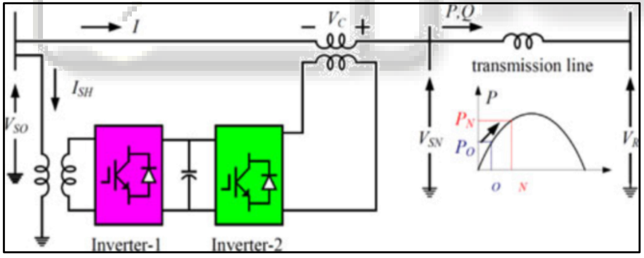


Fig. 1: Conventional UPFC.

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 in [4]–[10]. 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.

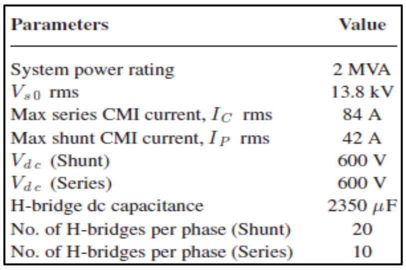
This paper presents the modulation and control for the new transformerless UPFC to address aforementioned challenges. Recently, there are two new UPFC structures under investigation: 1) the matrix converter-based UPFC and 2) distributed power-flow controller (DPFC) derived from the conventional UPFC.

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).

The cascade multilevel inverter (CMI) is the only practical inverter technology to reach high-voltage levels without the use of transformers, a large number of semiconductor devices (diodes), or a large number of capacitors. However, the CMI could not be directly used in the conventional UPFC, because the conventional UPFC requires two inverters connected back-to-back to deal with active power exchange. To address this problem, a UPFC with two face-to-face connected CMIs was developed in [27] to eliminate the zigzag transformers that are needed in the conventional multipulse inverter-based UPFC. However, it still required an isolation transformer.

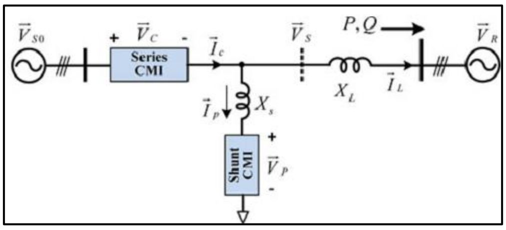
To eliminate the transformer completely, a new transformerless UPFC based on an innovative configuration of two CMIs has been proposed in [28]. The system configuration is shown in Fig. 2(a) and main system parameters for a 13.8-kV/2-MVAprototype (target system) is shown in Table 1.



Parameters	Value
System power rating	2 MVA
V_{s0} rms	13.8 kV
Max series CMI current, I_C rms	84 A
Max shunt CMI current, I_P rms	42 A
V_{dc} (Shunt)	600 V
V_{dc} (Series)	600 V
H-bridge dc capacitance	2350 μF
No. of H-bridges per phase (Shunt)	20
No. of H-bridges per phase (Series)	10

Table 1: Main System Parameters For 13.8-Kv

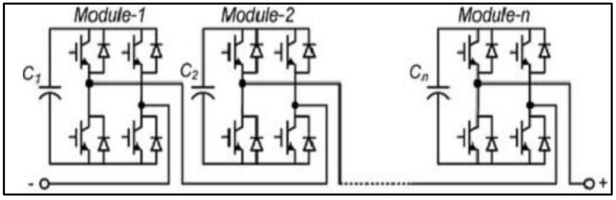
As shown in Fig. 2(a), the transformerless UPFC consists of two CMIs, one is series CMI, which is directly connected in series with the transmission line; while the other is shunt CMI, which is connected in parallel to the sending end after series CMI.



(a)

Fig. 2: New transformerless UFPC. (a) System configuration of transformerless UPFC.

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.



(b)

Fig. 2: New transformerless UFPC. (b) One phase of the cascaded multilevel inverter.

The basic operation principle, operation range, and required VA rating for series and shunt CMIs have been presented.

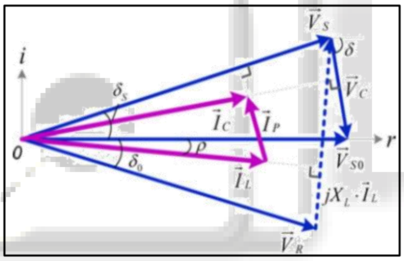


Fig. 3: Phasor diagram of the transformerless UPFC

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 flowin 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.

II. RELATED WORK

[1]L. Gyugyi, et.al proposes 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 proposes the performance of the UPFC under different system conditions by using simulation results.

[2]A. Rajabi-Ghahnavieh, proposes 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. By using the simulation results we can analyze the proposed method.

[3]H. Fujita, et.al proposes 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 pulse width 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. In this paper we can analyze both analytical and simulated results and show viability and effectiveness of the proposed control scheme.

[4]M. A. Sayed et.al proposes 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 by using simulation results.

[5]H. Fujita, et.al proposes a transient analysis of a unified power flow controller (UPFC), and design of capacitance of the DC-link capacitor. Active power flowing out of the series device in transient states is theoretically discussed to derive what amount of electric energy the DC link capacitor absorbs or releases through the series device. As a result, it is clarified that the active power flowing out of the series device is stored in the line inductance as magnetic energy during transient states. Design of capacitance of the DC-link capacitor is also presented in this paper, based on the theoretical analysis.

[6]H. Fujita, et.al proposes a dynamic control and performance of a unified power flow controller (UPFC) intended for installation on a transmission system consisting of two sets of three-phase transmission lines in parallel. When no UPFC is installed, interruption of either three-phase line due to a fault reduces an active power flow to half, because the line impedance becomes double before the interruption. Installing the UPFC makes it possible to control an amount of active power flowing through the transmission system.

[7]L. Liu, et.al proposes a real, reactive power, and voltage balance of the unified power-flow control (UPFC) system is analyzed. Two important results related to UPFC control are shown in this paper. First, the shunt converter provides all of the required reactive power during the power-flow changes if the UPFC bus voltage is constant. Second, the UPFC bus voltage can be controlled both from the sending side and from the receiving side. Based on the analysis, a novel coordination controller is proposed for the UPFC. The basic control strategy is such that the shunt converter controls the transmission-line reactive power flow and the dc-link voltage. The series converter controls the transmission-line real power flow and the UPFC bus voltage. The real/reactive power coordination controllers in the UPFC control system can obtain good performance both during transient and stable conditions. By using simulation results we can verify the effectiveness of the proposed control strategy.

[8]S. Kanna, et.al proposes a new real and reactive power coordination controller for a unified power flow controller (UPFC). The basic control for the UPFC is such that the series converter of the UPFC controls the transmission line real/reactive power flow and the shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the real power demand of the series converter is supplied by the shunt converter of the UPFC. The need for reactive power coordination controller for UPFC arises from the fact that excessive bus voltage (the bus to which the shunt converter is connected) excursions occur during reactive power transfers. A new reactive power coordination controller has been designed to limit excessive voltage excursions during reactive power transfers. Simulation results have been presented to show the improvement in the performance of the UPFC control with the proposed real power and reactive power coordination controller.

[9]C. D. Schauder, et.al proposes the UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission systems. It offers major potential advantages for the static and dynamic operation of transmission lines, but it brings with it major design challenges, both in the power electronics and from the perspective of the power system. As the UPFC transitions from concept to full-scale power system implementation, the control and protection of this sophisticated equipment are of primary concern.

III. CONCLUSION

A modulation and control method for the transformerless UPFC is proposed in this paper, which has the following features: 1) FFM of the CMI for extremely low THD of output voltage, low switching loss and high efficiency; 2) All UPFC functions, such as voltage regulation, line impedance compensation, phase shifting or simultaneous control of voltage, impedance, and phase angle, thus achieving independent active and reactive power flow control over the transmission line; 3) Dc capacitor voltage balancing control for both series and shunt CMIs; 4) Fast dynamic response (<10 ms). The transformerless UPFC with proposed modulation and control can be installed anywhere in the grid to maximize/optimize energy transmission over the existing grids, reduce transmission congestion and enable high penetration of renewable energy sources.

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