

Research Article

Analysis and control of UPFC for voltage compensation using ATP/EMTP

Panumat Sanpoung, Paisan Boonchiam and Boonyang Plangklang

Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, 39 Moo 1 Klong 6, Thanyaburi, Pathumthani 12110 Thailand.

*Author to whom correspondence should be addressed, email: saanneto@yahoo.com

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Abstract

This paper presents the analysis and control of a unified power flow compensator (UPFC) for voltage compensation using the Alternative Transients Program/Electromagnetic Transients Program (ATP/EMTP) software. One of the common power quality problems experienced in power systems is the voltage hanging, both amplitude and phase, especially voltage swell. To compensate the voltage sag on the load bus, the UPFC has been proposed by using pq-theory. The system parameters and controller gains are designed under the real power system conditions in Thailand. The simulation results show that the shunt and series part of UPFC can control the amplitude and phase of injection voltage and current on the load bus. These results demonstrate both the benefit and the performance of the proposed methodology which will enhance the performance of UPFC for voltage compensation.

Keywords: Unified power flow compensator, modelling, electric power systems, FACTS, UPQC, Thailand

Introduction

The power system is an interconnection of generating units to load centres through high voltage electric transmission lines and in general is mechanically controlled. It can be divided into three subsystems: generation, transmission and distribution subsystems. Until recently all three subsystems were under supervision of one body within a certain geographical area providing power at regulated rates. In order to provide cheaper electricity, the deregulation of power systems, which will be produced by separate generation, transmission and distribution companies, is already being implemented. At the same time, electric power demand continues to grow, while at the same time the building of new generating units and transmission circuits is becoming more difficult because of economic and environmental reasons. Therefore, power utilities are forced to rely on utilization of existing generating units and to load existing transmission lines close to their thermal limits. However, stability has to be

maintained at all times. Hence, in order to operate power systems effectively, without reduction in the system security and quality of supply, even in the case of contingency conditions such as loss of transmission lines and/or generating units, which occur frequently, and will most probably occur at a higher frequency under deregulation, new control strategies need to be implemented.

In the late 1980s the Electric Power Research Institute (EPRI) in the USA, introduced a new technology program known as Flexible AC Transmission System (FACTS) [1]. The main idea behind this program is to increase controllability and optimize the utilization of the existing power system capacities by replacing mechanical controllers with reliable and high speed power electronic devices. FACTS devices provide strategic benefits for developing transmission system management. FACTS devices can increase power transmission capacity of existing transmission lines. By introducing voltage source converters (VSC), new equipment adds to FACTS devices, providing them with special characteristics. The unified power flow controller (UPFC) is a perfect, new and important FACTS device, which has multi-usage compensations capability [2]. Using the converter technology series and shunt devices can be combined by interconnection of DC bus, which can control power system parameters such as terminal voltage, line impedance and phase angle.

UPFC is a generalized synchronous voltage source, represented at the fundamental frequency by voltage phasor V_{pq} with controllable magnitude V_{pq} ($0 \leq V_{pq} \leq V_{pqmax}$) and angle ρ ($0 \leq \rho \leq 2\pi$) [3-4], in series with transmission line, as illustrated for an elementary two-machine or two independent source with a transmission link intertie in Figure 1. In this functionally unrestricted operation, which clearly includes voltage and angle regulation, the synchronous voltage source generally exchanges bolt reactive and real power with the transmission system. Since a synchronous voltage source is able to generate only the reactive power exchanged, real power must be supplied to it, or absorbed from it, by suitable power supply or sink. In the UPFC arrangement the real power exchanged is provided by one of the end buses (e.g., the sending-end bus), as shown in Figure 1.

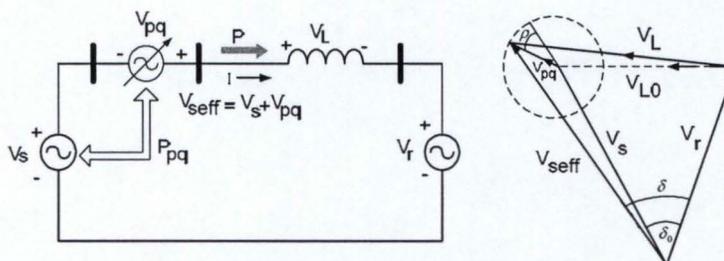


Figure 1. Equivalent circuit and phasor diagram of UPFC.

In current practical implementation, the UPFC consists of two voltage source converters, as illustrated in Figure 2. These back-to-back converters operate from a common dc link provided by a dc storage capacitor. This arrangement functions as an ideal ac-to-ac power converter in which the real power can freely flow in either direction between the ac terminal of the two converters and each converter can independently generate (or absorb) reactive power at its own ac output terminal.

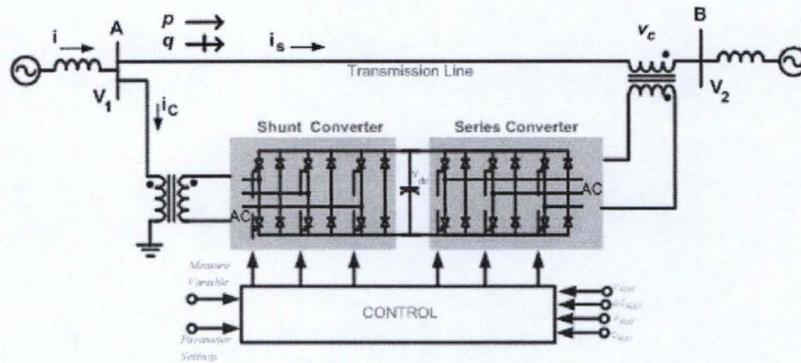


Figure 2. Basic scheme of UPFC.

Instantaneous Current Compensation

Akagi *et al* [3], proposed a theory based on instantaneous values in three-phase power systems, with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms known as Instantaneous Power Theory or Active-Reactive (p-q) Theory which consists of an algebraic transformation (Clarke transformation) of three-phase voltages in *a-b-c* coordinates to α - β -0 coordinates, followed by the calculation of the p-q theory instantaneous power components:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

In three phase, three wire systems, there is no zero sequence component. If v_0 and i_0 are neglected, instantaneous voltage (v), and current phasor (i) can be defined from their corresponding α and β components as follows:

$$v = v_{\alpha} + jv_{\beta} \tag{3}$$

$$i = i_{\alpha} + ji_{\beta} \tag{4}$$

From (3) and (4), instantaneous complex power can be defined as the product of the instantaneous voltage phasor and complex conjugate of instantaneous current phasor given in (5)

$$S = VI^* = (v_{\alpha} + ji_{\beta})(v_{\alpha} + ji_{\beta}) = p + jq \tag{5}$$

where

$$p = v_{\alpha} \cdot i_{\alpha} + v_{\beta} \cdot i_{\beta} \quad \text{Instantaneous active Power} \tag{6}$$

$$q = v_{\alpha} \cdot i_{\beta} - v_{\beta} \cdot i_{\alpha} \quad \text{Instantaneous reactive Power} \tag{7}$$

The instantaneous complex power is useful. It can be applied for transient or steady-state analysis. The following equation is a compact form for the instantaneous real and reactive power definition and its inversion:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{\alpha} & v_{\beta} \\ -v_{\beta} & v_{\alpha} \end{bmatrix} \begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} = \frac{1}{v_{\alpha}^2 + v_{\beta}^2} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{9}$$

$$p = \bar{p} + \tilde{p} \tag{10}$$

$$q = \bar{q} + \tilde{q} \tag{11}$$

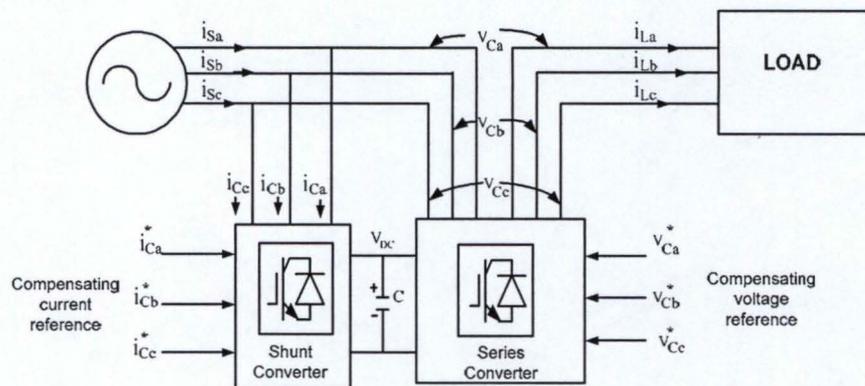


Figure 3. Concept of shunt current and voltage compensation.

Control Strategy for UPFC

A UPFC controller can be designed using only the concept learned from the p-q theory and concept of instantaneous aggregate voltage [4]. The function control block diagram of this UPFC controller is illustrated in Figure 4 for the UPFC shunt converter and Figure 5 for the UPFC series converter.

The instantaneous aggregate value is a corresponding value between instantaneous aggregate value in phase mode and in $\alpha\beta$ variables, that is:

$$v_{\Sigma} = \sqrt{v_a^2 + v_b^2 + v_c^2} = \sqrt{v_{\alpha}^2 + v_{\beta}^2 + v_0^2}$$

The compensating current on the $\alpha\beta$ axes are determined as

$$\begin{bmatrix} i_{C\alpha}^* \\ i_{C\beta}^* \end{bmatrix} = \frac{I}{v_{\alpha}^2 + v_{\beta}^2} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} p_l \\ q_l \end{bmatrix} \tag{12}$$

The inverse transformation gives the instantaneous references

$$\begin{bmatrix} i_{Ca}^* \\ i_{Cb}^* \\ i_{Cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1 & \frac{\sqrt{3}}{2} \\ 1 & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{C\alpha}^* \\ i_{C\beta}^* \end{bmatrix} \tag{13}$$

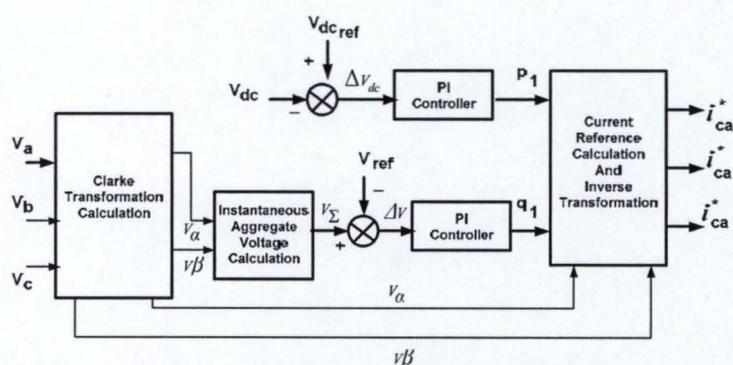


Figure 4. Control block of shunt current compensation.

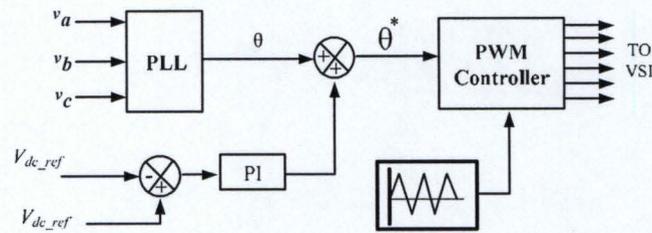


Figure 5. Control Block of Series Converter.

Simulation Results

Computer simulation has become an indispensable part of the power electronics design process [5]. Unified Power Quality Conditioner, or UPQC is a complex power electronics device and the analysis of its behaviour, which leads to improved understanding, would be very difficult without computer simulation. The overall design process can be shortened through the use of computer simulation, since it is usually easier to study the influence of a parameter on the system behaviour in simulation, as compared to accomplishing the same in the laboratory on a hardware prototype. A UPQC simulation model has been created in EMTP to investigate/calculate the prototype UPQC circuit waveforms, the dynamic and steady-state performance, and voltage and current ratings. Three typical case studies have been simulated and the results are presented below. Table 1 provides information on the test system and UPFC using the Provincial Electricity Authority (PEA) system in Thailand.

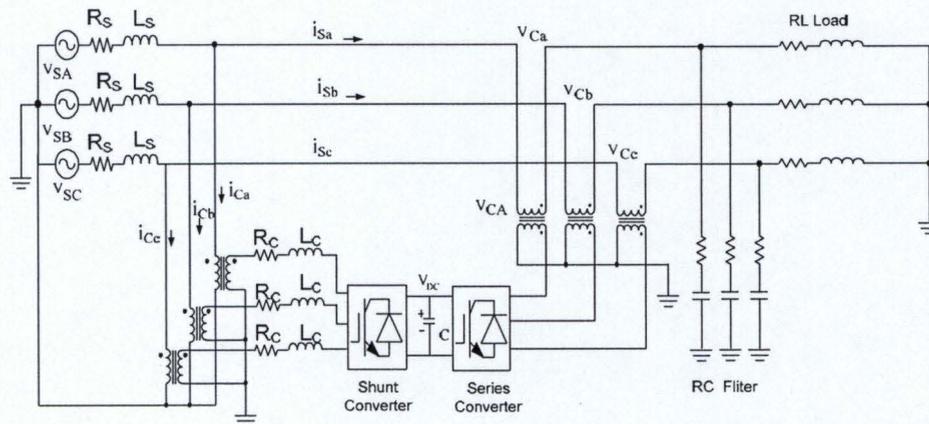


Figure 6. A UPFC compensating AC load.

Table 1. Parameters of Test System.

Parameter	Value
Voltage supply	1 p.u. 50 Hz
DC Link	300 μ F
DC voltage reference	$V_{DC_REF} = 2.5$
Interface coupling	$L_C = 3$ mH, $R_C = 0.1$ Ω
AC Load	$L_C = 100$ mH, $R_C = 30$ Ω

Figure 7 illustrates the simulation of three phase fault case of terminal voltage in the power transmission system. It can be seen that the percentage of voltage sag is approximately 30% with the time in the ranges of 0.4-0.6 s. When the UPFC was included into the power transmission system, the load voltage was fulfilled in the ranges of times, as shown in Figure 8. In addition, the UPFC can produce the compensating voltage to the load, resulting in the terminal voltage being improved to the load voltage, as can be seen in Figure 9. Figure 10 presents the voltage which was produced by the UPFC inserted to bus, while the voltage sag is within the time ranges of 0.4-0.6 s. (Figure 11), the UPFC supplied reactive power provides constant bus voltage and meanwhile, the real power is still constant.

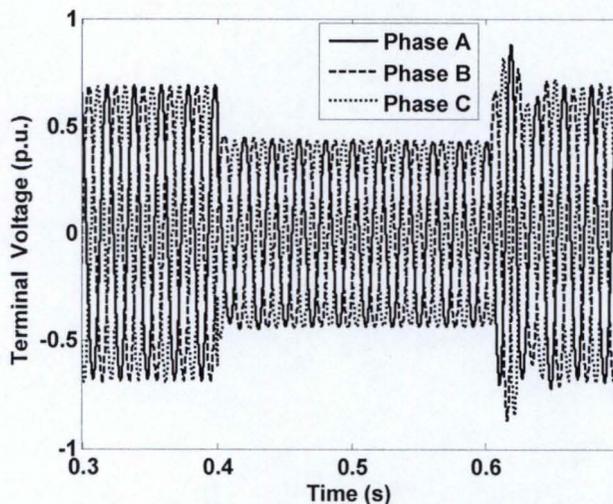


Figure 7. Supply Voltage.

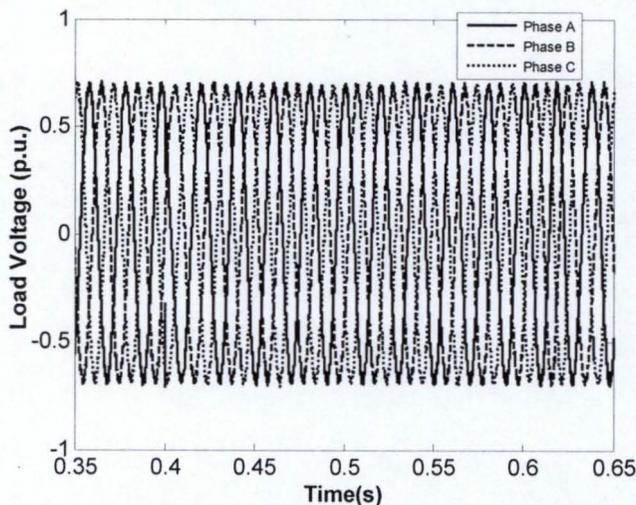


Figure 8. Load Voltage.

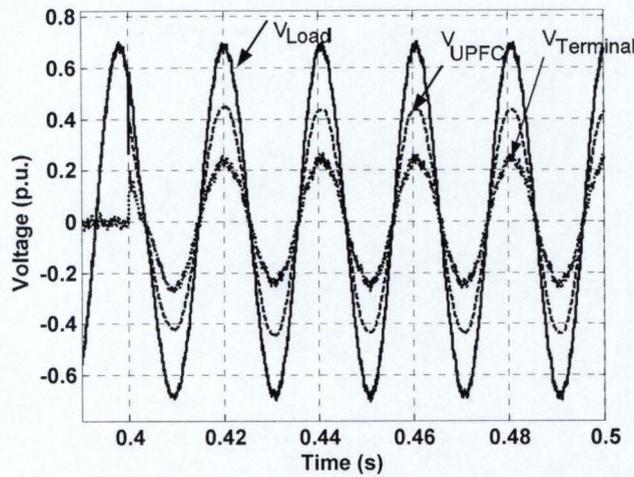


Figure 9. Terminal Voltage, UPFC Voltage and Load Voltage.

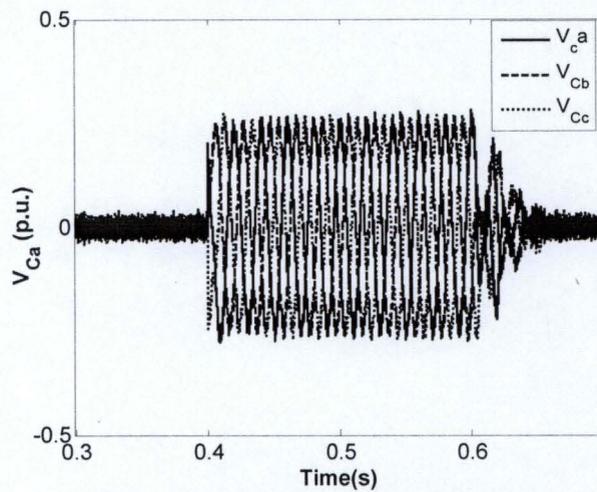


Figure 10. Injection Voltage of UPFC.

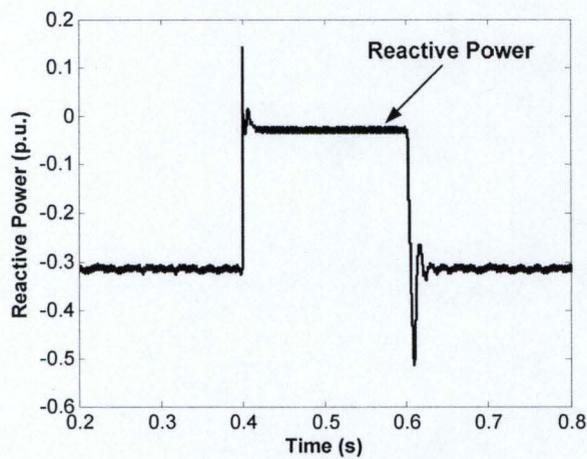


Figure 11. Reactive Power.

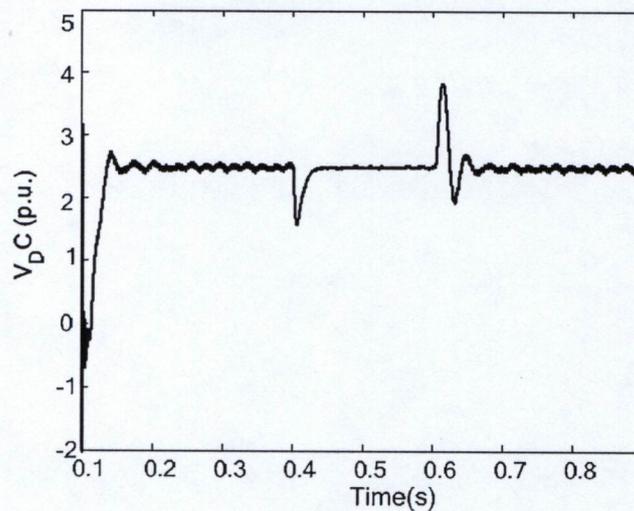


Figure 12. Real Power.

Conclusion

The unified power flow controller (UPFC) was used to improve the problem of voltage sag in the transmission power system. The UPFC shunt converter supplied reactive power into the controller bus for regulated voltage bus. In this study, the results showed that the UPFC can operate and compensate voltage at bus controller rapidly and efficiently.

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