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TRANSIENT STABILITY ENHANCEMENT USING MULTILEVEL INVERTER BASED UPFC

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Abstract: Power flow control is important in power systems and recently becomes more urgent because of the deregulation. This paper presents a novel configuration of unified power flow controller and performance of UPFC intended for installation on transmission line. When no UPFC is installed, any interruption in the line due to fault reduces the active power flow through the line. Installing the UPFC makes it possible to control an amount of active power flow through the line. Simulations were carried out using Matlab to validate the performance of UPFC.

INTRODUCTION

The power transfer capability of long transmission line is usually limited by large signal stability. Economic factors, such as high cost of long lines and revenue from the delivery of additional power, give strong incentives to explore all economically and technically feasible means of raising the stability limit. On the other hand, the development of effective ways to use transmission systems at their maximal thermal and dielectric capability has caught much research attention in recent years. Fast progression in the field of power electronics has great influence on the power industry. One direct outcome of its influence is the concept of Flexible AC Transmission System (FACTS), which improves stability to increase usable power transmission capacity to its thermal limit. In principle, the FACTS devices could provide fast control of active and reactive power through a transmission line. The family of FACTS devices includes the Static Var Compensators(SVCs), Static Synchronous Compensator(STATCOM), Thyristors Controlled Series Compensators(TCSCs), the Static Synchronous Series Compensators(SSSCs), and the Unified Power Flow Controller. The UPFC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC [1]. The UPFC can provide simultaneous control of all basic power system parameters, viz., transmission voltage, impedance and phase angle. This paper first briefly describes the function of the UPFC as well as its conventional configuration, and then proposes a new configuration. Simulation of the new configuration will be presented.

CONVENTIONAL CONFIGURATION OF UPFC

As it can be seen, the conventional UPFC configuration consists of two voltage source inverters. Inverter 1 is in parallel with the transmission line, while Inverter 2 in series with the transmission line. The two inverters are connected back-to-back through a common dc-link. This arrangement enables real power flow in either direction between the two inverters. Inverter 2 provides the main function of UPFC by injecting an ac voltage $\vec{V}_c$ through a series connected transformer. $\vec{V}_c$ has controllable magnitude $V_c(0 \le V_c \le V_{c\max})$ and phase angle $\delta(0 \le \delta \le 360^0)$ and can be considered as synchronous ac voltage source. Because the transmission line current flows through this voltage source, the Inverter 2 needs to exchange active and reactive power with the transmission line through the transformer. The needed reactive power can be generated independently by itself. The active power exchange is actually provided or absorbed by Inverter 1 through the common dc link.

Thus the basic function of the Inverter 1 is to supply or absorb the real power demanded by Inverter 2 at the common dc link. Besides this, Inverter 1 also can generate or absorb reactive power independently. Fig.2 is a vector diagram of Fig.1, illustrating the principle of UPFC. It can be seen, when $\vec{V}_c$ is added to the system, the equivalent sending end voltage changes from $\vec{V}_{so}$ to $\vec{V}s$, the angle difference between the sending end and the receiving end voltages changes from θ to θ', the active and reactive power transmitted from the sending end to the receiving end over a transmission line changes from

$$P = \frac{V_{SO}V_R \sin\theta}{X} \tag{1}$$

$$Q = -\frac{(V_R \cos\theta - V_{SO})V_{SO}}{X} \tag{2}$$

$$P' = \frac{V_S V_R \sin\theta'}{X} \tag{3}$$

$$Q' = -\frac{(V_R \cos\theta' - V_S)V_S}{X} \tag{4}$$

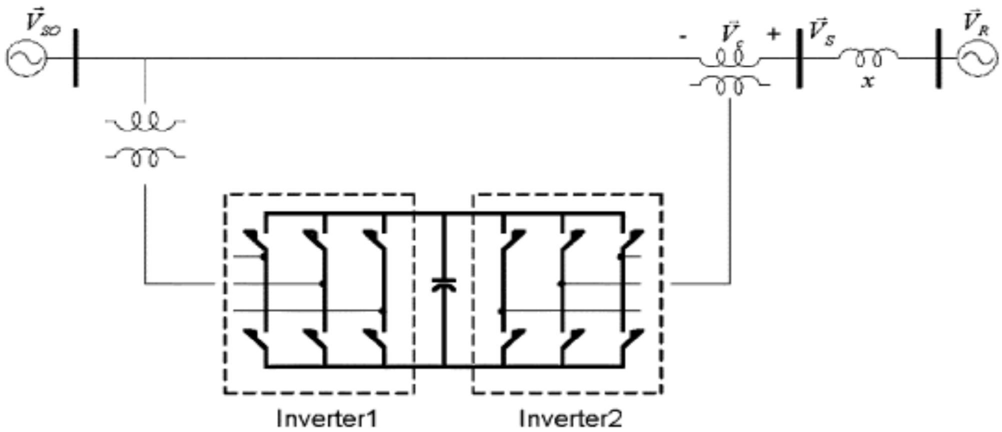

Fig.1. Conventional configuration of UPFC

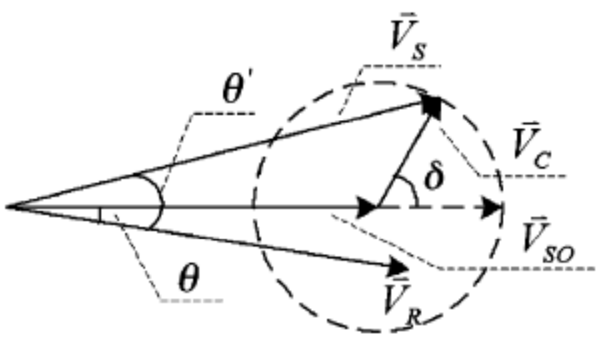

Fig.2. Basic UPFC control function

Thus the power transmitted over the transmission line is controlled to a desired value. In the equation above, V_{SO} is the amplitude of $\vec{V}_{so}$, V_S is the amplitude of $\vec{V}s$, V_R is the amplitude of $\vec{V}_R$ and X is the line impedance.

From the analysis above, the features of the conventional configuration can be concluded as: a) both inverters share the same dc link; b) both inverters need to exchange active power with each other and the transmission line; c) a transformer must be used as an interface between of the transmission line and each inverter.

NOVEL CONFIGURATION OF UPFC

The proposed new UPFC configuration is shown in Fig.3. It can be seen that in the configuration:

1) Each inverter has its own dc capacitor to support its dc voltage;
2) There would be no active power exchange among the two inverters and the line because the two inverters use separated dc capacitors, which are not connected to any sources for active power to flow;
3) Unlike the conventional back to back dc link coupling, the two inverters are coupled face-to-face on the ac sides instead.

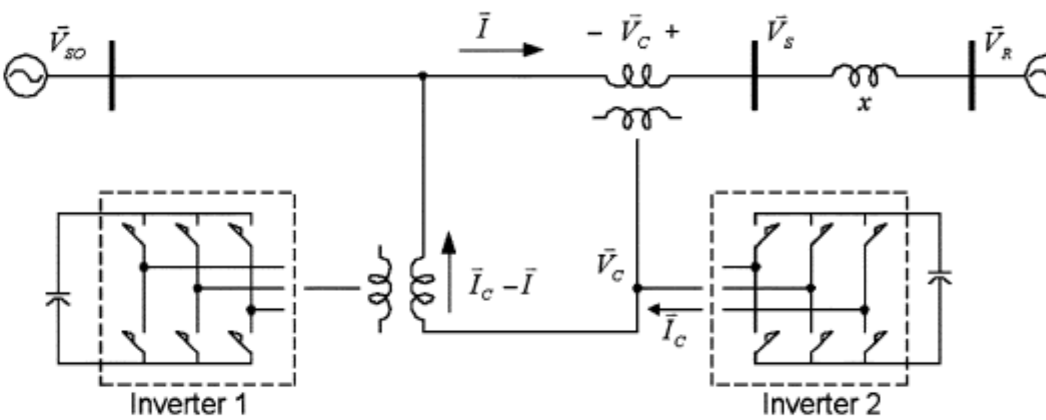

Fig.3. New configuration of UPFC

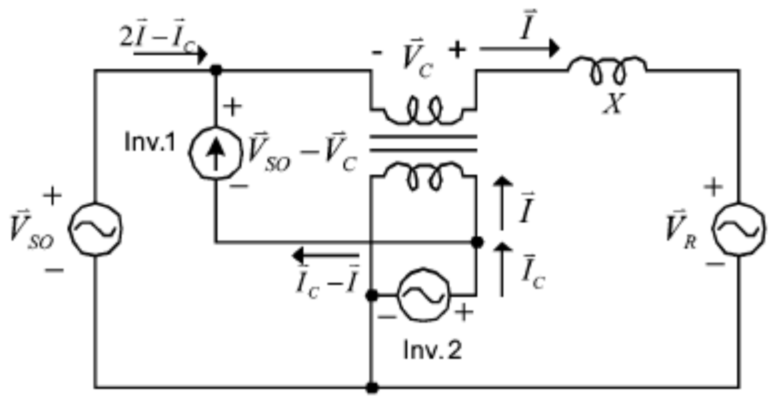

Fig.4. Equivalent circuit of UPFC

Like in the conventional configuration, Inverter 2 in this unique configuration is controlled to generate the desired $\vec{V}_c$ to control the active and reactive power flow, thus acting as a controlled voltage source.

Inverter 1, the parallel inverter, rather than supplying or absorbing active power for Inverter 2, injects a current to the line to guarantee that active power flowing into both of the inverters be zero.

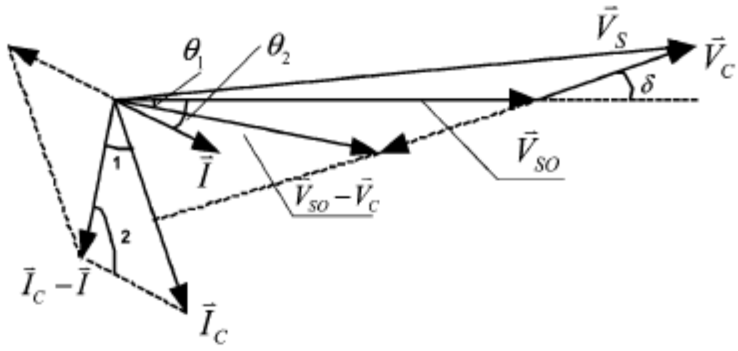

Fig.5. Relationship between $\vec{V}_c$ and $\vec{I}_C$

Fig.4 is the equivalent circuit of the new configuration. Based on the analysis above and Fig.4, it can be seen that Inverter 1 should be controlled to make Inverter 2 current, $\vec{I}_C$ and inverter 1 current, $(\vec{I}_C-\vec{I})$, perpendicular to their generated voltages, $\vec{V}_c$ and $(\vec{V}_{SO}-\vec{V}_C)$, respectively. $\vec{I}_C$ receiving end line current.

In summary, the command for Inverter 2 is the desired voltage $\vec{V}_c$. The command for Inverter 1 is $(\vec{I}_C-\vec{I})$. $\vec{V}_c$ can be easily calculated by the power demand of the system. After $\vec{V}_c$ is given, $(\vec{I}_C-\vec{I})$ also can be found by the following analysis.

Given that the phase angle of the $\vec{V}_c$ is δ, the phase angle of $\vec{I}_C$ should be

$$\angle\vec{I}_C=\delta\pm 90^\circ \tag{5}$$

for the active power flowing into inverter 2 to be zero.

Based on the analysis above and Fig.5, the vector diagram of the new configuration, the equation of the active power flowing into Inverter 1 can be written as

$$\begin{aligned} P_1 &= (\vec{V}_{SO}-\vec{V}_C).(\vec{I}_C-\vec{I}) \\ &= V_{SO}I_C\cos(\delta\pm 90^\circ)+V_C I\cos(\delta-\theta_2)-V_{SO}I\cos\theta_2=0. \end{aligned} \tag{6}$$

From (6), the amplitude of $\vec{I}_C$ could be found as

$$I_C=\frac{V_{SO}I\cos\theta_2-V_C I\cos(\delta-\theta_2)}{V_{SO}\cos(\delta\pm 90^\circ)} \tag{7}$$

Combine (5) and (6), we have

$$I_C=\frac{V_{SO}I\cos\theta_2-V_C I\cos(\delta-\theta_2)}{V_{SO}\cos(\delta\pm 90^\circ)}\angle\delta\pm 90^\circ \tag{8}$$

After $\vec{I}_C$ is decided, $(\vec{I}_C-\vec{I})$ is also found because the receiving end line current, $\vec{I}$, is a result of the commanded power flow and can be detected by current sensor.

SIMULATION AND RESULTS

A transmission line of a simple power system with parameters as given in Table 1 is considered. UPFC is placed in series with the transmission line at the sending end. The considered contingency is a Line – Ground fault to the transmission line. The fault time in simulation is considered between t=1.0 and 1.05 s. The fault is cleared in 1.05 sec with operation of transmission line reclosure.

Table 1.System Parameters

Line to line voltage	230[kV]
Frequency	50 [Hz]
Transmission rating	100 [MVA]
Length of the transmission line	300 [Km]
Resistance of the line	42[μΩ/m]
Inductive reactance of the line	400[μΩ/m]
Capacitive reactance of the line	230[μΩ/m]

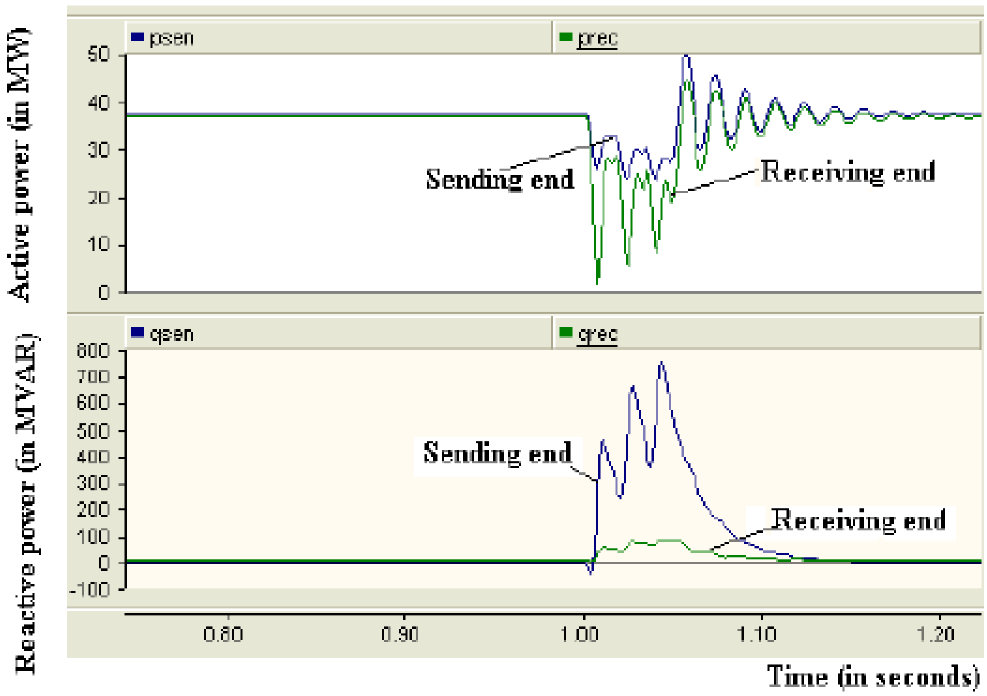

Fig.6. Variation of active power and reactive power in sending and receiving end

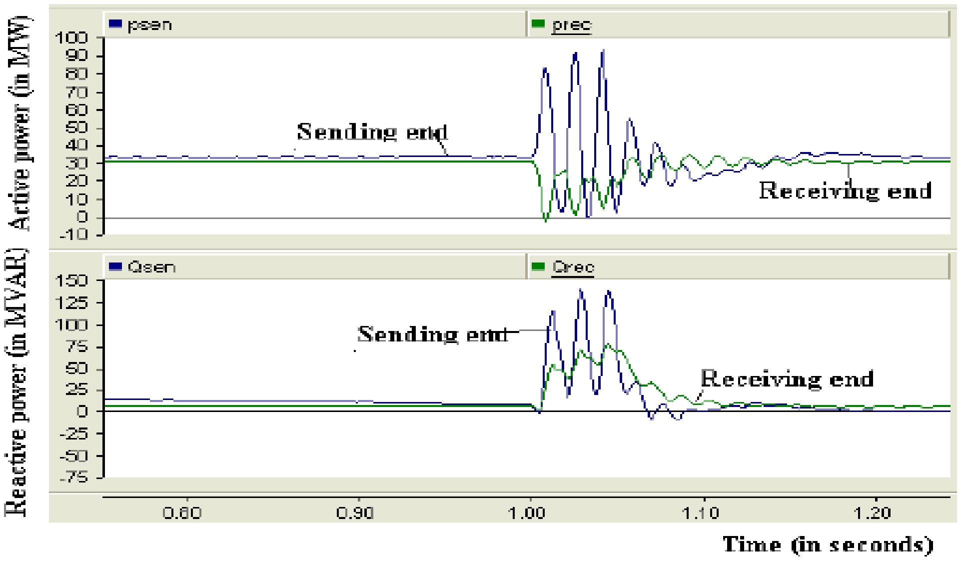

Fig.7. Variation of active power and reactive power in sending and receiving end

Fig.6. shows the response when the UPFC is not employed. This curve indicates that the system is unstable, with both the electrical power lines and voltage being sent into undamped oscillation.

Fig.7, the simulation results are shown for the same fault duration, but the system is equipped by a UPFC. It is clear that the series compensation effectively damps the power-flow oscillation on the transmission line.

CONCLUSION

The performance and impact of UPFC on the power system behavior is investigated under fault conditions. The investigation is carried out by performing the simulation in Matlab power system Block-set. The simulation result shows that the UPFC significantly improves the system performance by way of maintaining the power flows when fault occurs. By modulating the active and reactive powers, it is possible to bring a vast improvement in the first swing transient stability. Overall it can be concluded that, with the inclusion of UPFC the whole system performance is notably enhanced even under the fault condition.

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