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A review on Unified Power Flow Controller as a Power Flow Controller FACTS device in power system

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Abstract— This paper introduces a power flow controller FACTS device called UNIFIED POWER FLOW CONTROLLER (UPFC). In this paper the basic construction, operating principle and operating modes are explained. UPFC can control both real and reactive power independently at the sending end and receiving end of the transmission line.

Keyword—FACTS, Power Flow control, Unified Power Flow Control (UPFC), Power System.

I. INTRODUCTION

with the increment of load, power utilities are finding the ways to maximize the utilization of the existing transmission system. Continuous and fast improvement of electronic devices has made Flexible AC Transmission system (FACTS) [1] devices a promising concept for power system development. With proper use of FACTS technology, power flow along the transmission line can be more flexibly controlled as the name suggests.

Among many FACTS controllers, UPFC is discussed in detail. UPFC an advanced power system device which can help to control both, voltage magnitude and active and reactive power simultaneously.

UPFC was proposed for real time and dynamic compensation [2] of AC transmission systems, providing the necessary functional flexibility required to solve many of the problems facing the utility industries.

Unified Power Flow Controller consists of two switching converters [1], which in the implementations are voltage sourced inverter using gate turn off (GTO) thyristor valves. (refer fig. 1)

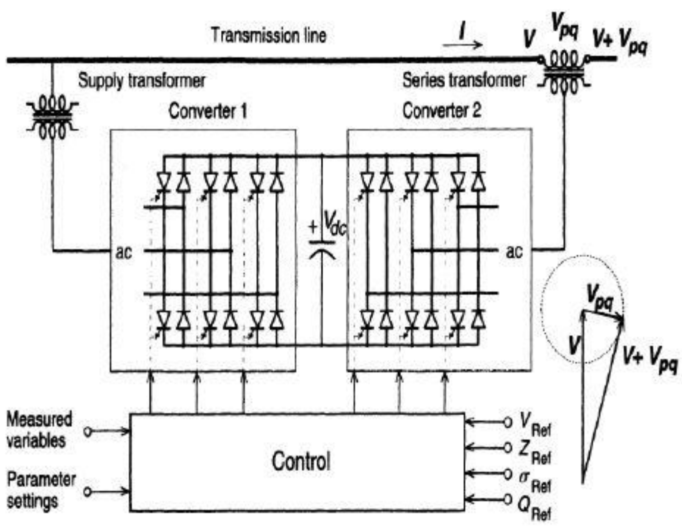

Fig. 1 : Basic circuit arrangement of UPFC

These inverters, labelled "Inverter 1" and "Inverter 2" in the figure, are operated from a common dc link provided by a dc storage capacitor. This arrangement functions as an ideal acto ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminal.

Inverter 2 provides the main function of the UPFC by injecting an ac voltage V_{pq} with controllable magnitude V_{pq} $(0 \leq V_{pq} \leq V_{pq\max})$ and phase angle ρ $(0 \leq \rho \leq 360^\circ)$, at the power frequency, in series with line via an insertion transformer. This injected voltage *can* be considered essentially as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal (i.e., at the terminal of the insertion transformer) is converted by the inverter into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter.

The basic function of Inverter 1 is to supply or absorb real power demanded by Inverter 2 at the common dc link. This dc link power is converted back to ac and coupled to the transmission line via shunt connected transformer. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed "direct" path for the real power negotiated by the action of series voltage injection through Inverters 1 and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by Inverter 2 and therefore it does not flow through the line. Thus, Inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by Inverter 2. This means that there is no continuous reactive power flow through the UPFC.

When viewed the operation of the UPFC, it can perform the functions of reactive shunt compensation, series compensation and phase shifting simultaneously; thereby can meet multiple control objectives by adding the injected voltage Vpq, with appropriate amplitude and phase angle, to the terminal voltage, $V_{0.}$

II. BASIC OPERATING MODES FOR THE UPFC

A. Shunt Inverter

The shunt inverter is operated in such a way as to draw a controlled current from the line. One component of this current is automatically determined by the requirement to balance the real power of the series inverter. The remaining current component is reactive and can be set to any desired reference level (inductive or capacitive) within the capability of the inverter. The reactive compensation control modes of the shunt inverter are very similar to those commonly employed on conventional static var compensators.

a) *VAR Control Mode:* In var control mode the reference input is an inductive or capacitive var request. The shunt inverter control translates the var reference into a corresponding shunt current request and adjusts the gating of the inverter to establish the desired current.
b) *Automatic voltage control mode* . In voltage control mode, the shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value, with a defined droop characteristic.

B. Series Inverter

The series inverter controls the magnitude and angle of the I - voltage injected in series with the line. This voltage injection is always intended to influence the flow of power on the line, but the actual value of the injected voltage can be determined in several different ways. These include:

a) *Direct Voltage Injection Mode.* The series inverter simply generates a voltage vector with magnitude and phase angle requested by reference input
b) *Phase angle shifter emulation mode* the series inverter injects the appropriate voltage so that the voltage V, is phase shifted relative to the voltage VI by an angle specified by reference input.
c) *Line Impedance Emulation Mode.* The series injected voltage is controlled in proportion to the line current so that the series insertion transformer appears as an impedance when viewed from the line.
d) *Automatic Power Flow Control Mode* The UPFC has the unique capability of independently controlling both the real power flow. P, on a transmission line and the reactive power Q, at a specified point. The transmission line containing the UPFC thus appears to the rest of the power system as a high impedance power source or sink.

C. Stand Alone Mode

Depending on the requirements of a particular installation, switchgear can be provided that will allow either of the two inverters to operate independently of the other by isconnecting their common dc terminals and splitting the capacitor bank. In this case, the shunt inverter operates as a stand-alone STATCOM, and the series inverter as a SSSC.

III. UPFC EQUIVALENT CIRCUITS

Two UPFC models are presented here. They are the voltage source-based model [6] and the model due to Nabavi-Niaki and Iravani [5]. These models are used as the basis of the UPFC-OPF formulation.

3.1 Voltage source – based model

The UPFC equivalent circuit shown in fig.2 [5,6] is used to derive a very flexible OPF-UPFC model [4]. The only restriction with this model is that the UPFC converter valves are taken to be lossless; Active power losses being negligible is a reasonable assumption. In this situation, the active power supplied to the shunt converter Re{V_{VR} I_{VR}*} satisfies the active power demanded by the series converter Re{VCR IR^*}.

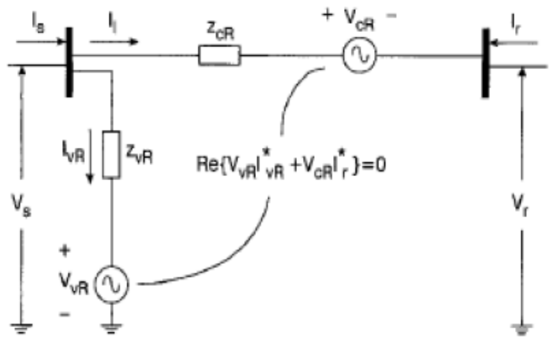

Fig. 2 : Equivalent source of UPFC voltage source-based model

The circuit is made up of two ideal voltage sources representing the fundamental Fourier series component of the switched voltage waveforms at the AC converter terminals. The series and shunt transformers' impedance, ZCR and ZVR, are included in this model.

The ideal voltage sources are

$V_{VR} = V_{VR} (\cos \theta_{VR} + j \sin \theta_{VR})$

$V_{CR} = V_{CR} (\cos \theta_{CR} + j \sin \theta_{CR})$

Where V_{VR} and θ_{VR} are the controllable magnitude ($V_{VRmin} \leq V_{VR} \leq V_{VRmax}$) and angle ($0 \leq \theta_{VR} \leq 2\pi$) of the ideal voltage source representing shunt converter. The magnitude VCR and angle θ CR of the ideal voltage source representing the series converter are controlled between limits ($V_{CRmin} \leq V_{CR} \leq V_{CRmax}$) and ($0 \leq \theta_{CR} \leq 2\pi$) respectively.

Load flows and OPF algorithms using this UPFC model are very flexible, since the UPFC can be set to control active and reactive powers and voltage magnitude simultaneously.

3.2 Nabavi-Niaki and Iravani model

Fig.3 shows equivalent circuit representation of UPFC connected between nodes s and r, in terms of load flow terminology. This equivalent circuit is due to Nabavi-Niaki and Iravani[5].

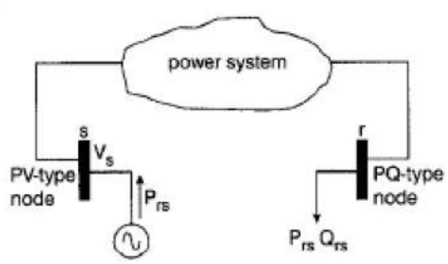

Fig. 3 : Nabavi-Niaki and Iravani model of UPFC

If the UPFC (converter valves and transformers) is assumed to be lossless, the UPFC can be modelled by transforming node s into a PV node and node r into a PQ-type node. This is a simple representation of the UPFC, but it will only work if nodal voltage magnitude at node s, active power flowing from nodes r to s and reactive power injected at node r, has to be controlled This model is not applicable if the limits of UPFC are violated.

IV. UPFC POWER FLOW EQUATIONS

The two UPFC models discussed above are implemented in the OPF algorithm. The active and reactive power loads at the PQ node requires no special attention within the OPF algorithm. The voltage source-based model is more flexible, and in the rest of the section voltage-source based model equations as required by the OPF algorithm are derived. Based on equivalent circuit shown in Fig.4, the following active and reactive power equations are written:

At node s:

$P_S = V^2{}_S G_{SS}$

$+ V_S Vr(G_{Sr} \cos(\theta_S - \theta_r) + B_{Sr} \sin(\theta_S - \theta_r))$

$+V_S V_{CR} (G_{Sr}.\cos(\theta_S - \theta_{CR}) +B_{Sr}.\sin(\theta_S - \theta_{CR}))$

$+V_S V_{VR} (G_{SR}.\cos(\theta_S - \theta_{VR}) +B_{SR}.\sin(\theta_S - \theta_{VR}))$

$QS = -V^2{}_S B_{SS}$

$+ V_S V_r (G_{Sr} \sin (\theta_S - \theta_r) - B_{Sr} \cos (\theta_S - \theta_r))$

$+V_S V_{CR} (G_{Sr}.\sin (\theta_S - \theta_{CR}) - B_{Sr}.\cos (\theta_S - \theta_{CR}))$

$+V_S V_{VR}(G_{SR} \sin(\theta_S - \theta_{VR}) - B_{SR} \cos(\theta_S - \theta_{VR}))$

At node r:

$P_r = V^2 rGrr$

$+ V_S V_r (G_{rs} \cos (\theta_r - \theta_s) + B_{rs} \sin (\theta_r - \theta_s))$

$+ V_r V_{CR} (G_{rr}.\cos (\theta_r - \theta_{CR})+B_{rr} \sin (\theta_r - \theta_{CR}))$

$Qr= -V^2 rB_{rr}$

$+ V_S V_r (G_{rs} \sin (\theta_r - \theta_s) - B_{rs} \cos (\theta_r - \theta_s))$

$+V_r V_{CR} (G_{rr} \sin (\theta_r - \theta_{CR}) - B_{rr} \cos (\theta_r - \theta_{CR}))$

Series converter:

$P_{CR}= V^2{}_{CR} G_{rr}$
$+V_{CR} V_s (G_{rs} \cos (\theta_{CR} - \theta_s) + B_{sr} \sin (\theta_{CR} - \theta_s))$
$+V_{CR} V_r (G_{rr} \cos (\theta_{CR} - \theta_r) + B_{rr} \sin (\theta_{CR} - \theta_r))$

$Q_{CR}= -V^2 CR2B_{rr}$
$+ V_{CR} V_s (G_{sr} \sin (\theta_{CR} - \theta_s) – B_{sr} \cos (\theta_{CR} - \theta_s))$
$+ V_{CR} V_s (G_{rr} \sin (\theta_{CR} - \theta_s) - B_{rr} \cos (\theta_{CR} - \theta_r))$

Shunt converter:

$P_{vR}=-V^2_{vR}G_{vr}$
$+V_{vR}V_s\,(G_{vR}.\cos(\theta_{vR}-\theta_s)+B_{vR}\sin(\theta_{vR}-\theta_s))$

$Q_{vR}=V^2_{vR}B_{vR}+V_{vR}V_s\,(G_{vR}.\sin(\theta_{vR}-\theta_s)–B_{vR}.\cos(\theta_{vR}-\theta_s))$

Assuming a loss less converter operation, the UPFC neither absorbs nor injects active power with respect to the AC system. In this situation, the active power supplied to the shunt converter, PvR, must satisfy the active power demanded by the series converter, PCR. Hence, $P_{vR}+P_{CR}=0$.

V. CONCLUSION

In this paper the basic of UPFC is discussed. Also the basic operation modes of UPFC like Shunt inverter, Series inverter, and stand alone mode are introduced. Also an easy model used for Optimal Power Flow study is derived and UPFC power flow equations are derived. The presented model is very flexible.

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