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Investigation of performance of UPFC without DC link capacitor

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Abstract

This paper presents an analysis of the dynamic operation of unified power flow controller without DC link capacitor. In this scheme of UPFC the shunt converter present in the static synchronous compensator is operated as a current source rectifier, which maintains a fixed DC voltage and DC current on the DC link without capacitor. The capacitor in the DC link is replaced by an AC filter on the line side with a very small value to reduce higher order harmonics. The voltage source inverter present in the series compensator is operated with space vector modulation technique. The proposed scheme is fully validated through digital simulation. The simulated results show that the DC link voltage is maintained constant without DC link capacitor; STATCOM provides good voltage regulation and static synchronous series compensator influences power flow over the transmission line. Transient responses of single machine infinite bus power system have also been presented.

Keywords: Current source rectifier; Flexible AC transmission systems; Pulse width modulation; Space vector modulation; Unified power flow controller

1. Introduction

In recent years, it has become more difficult to construct new generation facilities and transmission lines due to energy and environment problems. Hence it is advisable to enhance the power transfer capability of the existing transmission lines instead of constructing new one. Recently, flexible AC transmission system (FACTS) devices have revived more attention in transmission system operations as they can be utilized to alter power system parameters in order to control power flows and stabilize the system, in addition to the fact that the FACTS devices have the capability of increasing transmission capabilities to the required level [1,2]. The advantages of these FACTS devices are rapid response and enhanced flexibility. Some of the main FACTS Controllers are Static var compensator (SVC), thyristor controlled series capacitor (TCSC), static synchronous compensator (STATCOM), static synchronous series compensator (SSSC) and unified power flow controller (UPFC).

The UPFC, which has been recognized as one of the best featured FACTS devices [3–5], is capable of providing simultaneous active and reactive power flow control, as well as voltage magnitude control. The UPFC is a combination of static synchronous compensator and static synchronous series compensator which are connected via a common DC link, to allow bi-directional flow of real power between series output terminals of SSSC and the shunt terminals of the STATCOM, and is allowed to provide concurrent real and reactive power compensation. These two devices are two voltage source inverters (VSI), operated from a common DC link provided by a DC storage capacitor. Ratings of this DC link capacitor bank may have a significant impact on the cost and physical size of the UPFC. The capacitor is sized for a specified ripple voltage, typically 10% of the nominal voltage. The main drawback with this DC link capacitor is its design for maintaining the desired ripple [6]. Also this capacitor has shorter life when compared to AC capacitor of same rating. This limits the life and reliability of the voltage source inverter [7]. Hence in this work an effort has been taken to remove the DC link capacitor in the UPFC without affecting its performances. In general, elimination of DC link capacitor results in too much of ripple in the DC link voltage and current distortions in the AC side. To overcome such problems three capacitors of much smaller rating and lower cost are used in the line side. Also the voltage source inverter, which is present in the STATCOM, is operated as a current source rectifier (CSR) with suitable pulse width modulation (PWM) technique. The

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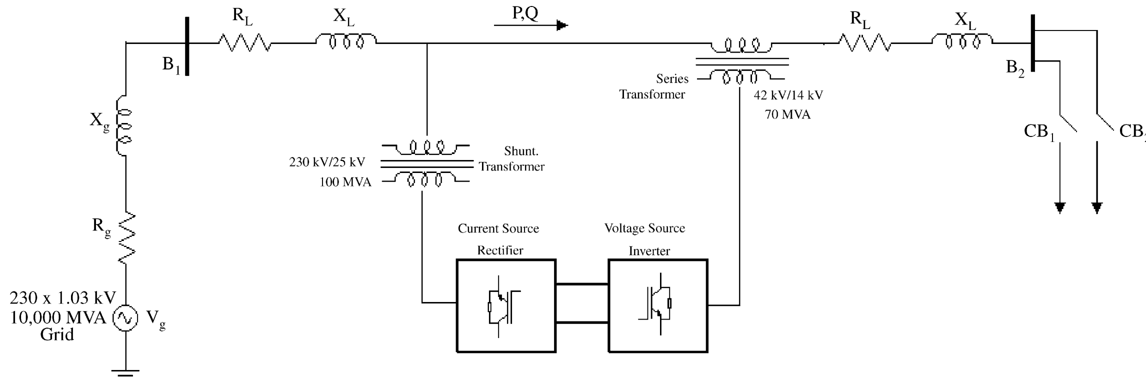

Fig. 1. SMIB system with the proposed scheme of UPFC.

objectives of this rectifier are to maintain a fixed DC voltage on the DC link without DC link capacitor and to regulate the bus voltage. This CSR is connected in shunt with the transmission line through a coupling transformer. To reduce the distortions present in the DC link current, AC capacitor of very small value is used in the line side. The voltage source inverter present in the SSSC side is controlled by space vector modulation (SVM) technique to enable the inverter to generate synchronous AC voltage of controllable magnitude and phase angle with reduced harmonics. This inverter is connected in series with the transmission line through a series insertion transformer.

2. Power system with the proposed scheme of UPFC

The single machine infinite bus (SMIB) power system considered in [8] is used for verifying the performance of proposed scheme of UPFC is shown in Fig. 1. The feeding network is represented by a Thevenin's equivalent circuit at bus B1 where the voltage source is a 230 kV × 1.03 kV with a short circuit power level of 10,000 MVA and an $X/R = 8$. The UPFC is placed between two sections B1 and B2 of the transmission line as shown in Fig. 1. The complete system parameters are given in Table 1. The STATCOM model in the UPFC is connected in shunt with the transmission line using a step-down transformer having leakage reactance X_T and a three-phase IGBT based current source rectifier. The AC voltage difference across this transformer leakage reactance produces reactive power exchange between the STATCOM and the power system at the point of interface. The voltage can be regulated to improve the voltage profile of the interconnected power system. Thus, the main function of STATCOM is to regulate key bus voltage magnitude by dynamically absorbing or generating reactive power to the AC grid network.

The SSSC, which is a part of UPFC, is a power electronic-based synchronous voltage source that generates three-phase AC voltages of controllable magnitude and phase angle. This voltage injected in series with the transmission line is almost in quadrature with the transmission line current and hence emulates an equivalent inductive or capacitive reactance in series with the transmission line. A small part of this injected voltage is in phase with the transmission line current supplying the required losses in the inverter bridge and coupling transformer [5].

Table 1
Power system parameters

Three-phase AC source	
Rated voltage	230 kV × 1.03 kV
Frequency	50 Hz
SC level	10,000 MVA
Base voltage	230 kV
X/*R*	8
Transmission line	
Resistance per unit length	0.01755 Ω/km
Inductance per unit length	0.8737 mH/km
Capacitance per unit length	13.33 nF/km
Line length	180 km
Shunt transformer	
Nominal power	100 MVA
Frequency	50 Hz
Primary voltage	230 kV
Secondary voltage	25 kV
Magnetization resistance	500 p.u.
Magnetization reactance	500 p.u.
DC link	
DC voltage	42 kV
Series transformer	
Rated voltage	42 kV/14 kV
Rated power	70 MVA
Magnetization resistance	200 p.u.
Magnetization reactance	800 p.u.
IGBT switches	
Internal resistance	0.001 Ω
Snubber resistance	0.1 MΩ
Snubber capacitance	Infinite

The scheme of AC–DC–AC conversion without DC link capacitor is shown in Fig. 2. Here the filter components R, L_f and C_f present at the input side of the current source rectifier have a significant role in maintaining the DC link current constant and reducing the distortions at the transformer and CSR interface. The switching functions of the current source rectifier and voltage source inverter are adjusted to maintain the average DC side voltage and current constant [9].

It is assumed that the AC input voltages to the current source rectifier after the step-down shunt transformer are the three-