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Dynamic control modeling and simulation of a UPFC–SMES compensator in power systems

Saravanan Kandasamy [a,*], Anita Rajapalan [b]

[a] Department of Electrical and Electronics Engineering, Paavai College of Engineering, Namakkal, Tamil Nadu, India
[b] Department of Electrical and Electronics Engineering, IRTT, Erode, Tamil Nadu, India

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Abstract Flexible AC Transmission Systems (FACTS) is granting a new group of advanced power electronic devices emerging for the enhancement of the power system performance. Unified Power Flow Controller (UPFC) is a recent version of FACTS devices for power system applications. The back-up energy supply system incorporated with UPFC is providing a complete control of real and reactive power at the same time and hence is competent to improve the performance of an electrical power system. In this article, backup energy supply units such as superconducting magnetic energy storage (SMES) are integrated with UPFC. In addition, comparative exploration of UPFC–battery, UPFC–UC and UPFC–SMES performance is evaluated through the vibrant simulation by using MATLAB/Simulink software.

1. Introduction

The FACTS technology improves the performance of an electrical network with the organization of real and reactive power control. Particularly, FACTS components are responsible for power quality problems such as voltage flicker, power loss and transient stability problems. These problems can be mitigated by sufficient power flow control. The main responsibility of power flow controllers is compensating line voltage and load support. UPFC has attained the classic recognition of the numerous FACTS devices. UPFC embraces with two FACTS devices through DC link capacitor, and it is capable of performing series compensation, voltage and phase angle control simultaneously, guide to the control of real and reactive power [1–4]. DC link capacitor energy storage is unable to supply controllable active power for an extensive duration due to its inadequate energy storage [5,6]. This DC link capacitor cannot compensate converter losses for the period of large transients [7]. Though the DC link capacitor energy storage is limited to a definite value, the backup energy storage systems have been introduced to store more energy. This backup energy storage system is used to improve the dynamic performance of power systems.

Energy storage systems (ESS) will be classified according to their applications such as short term responses and long term responses. Flywheels, superconducting coils and capacitor technologies correspond to short term response. These

* Corresponding author. Tel.: +91 9003742853.
E-mail addresses: saravanan.me07@gmail.com (S. Kandasamy), anitha_irtt@yahoo.co.in (A. Rajapalan).
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Nomenclature

V_i, V_j	voltage of *i*th and *j*th bus	V_{dcref}	UPFC dc-bus reference voltage
δ_i, δ_j	phase angle of voltages V_i and V_j	P_{lref}, Q_{lref}	active and reactive power reference in line
V_l	transmission line voltage	I_{ESS}	current through energy storage system
δ_l	phase angle of V_l	V_{ESS}	voltage accurse energy storage system
V_{inv}	UPFC inverter voltage	P_S, Q_S	active and reactive power at sending end
V_{dc}	UPFC dc-bus voltage	P_R, Q_R	active and reactive power at receiving end

technologies are able to absorb and supply energy for a short duration (few seconds to minutes) with high power density. In general, it is used to improve power quality and voltage stability. ESS such as batteries, fuel cells and compressed air belongs to long term response; they can provide potential to act in response for long time periods (few minutes to hours). These devices perform power systems applications such as power grid management, energy management and frequency regulation [8].

A Battery energy storage system (BESS) typically has high energy density; however, it has a limited life cycle, discharge rates and high temperature at functional environment. A UC energy storage system classically has rapid responses, high power density and extended life cycle [9]. SMES unit has the rewards of rapid responses, minimum energy loss during the conversion, high energy density and high efficiency evaluated with other backup energy storage systems. ESS with the FACTS integrated system operates as the best solution for improving the power quality [10–15].

This research article discusses the comparative investigation of UPFC–battery, UPFC–UC and UPFC–SMES using MATLAB/Simulink software. The main intention of this work is to control a UPFC with energy storage devices under three phase fault conditions for the power system stability enrichment. This research article is ordered as follows. Section 2 contains system description dealing with the operation of UPFC, ESS and chopper. Section 3 explains control strategy for UPFC–battery/UC/SMES integrated systems in detail. The simulation results are demonstrated in Section 4. Finally integrated system is concluded with Section 5.

2. System description

The system model of UPFC integrated with energy storage systems is shown in Fig. 1. In this model UPFC with energy storage systems is connected to the long transmission line. System model contains four main components such as UPFC, ESS, DC–DC chopper and controller. An ESS (Battery/UC/SMES) is allied to the UPFC through DC–DC chopper interface. However, UPFC–ESS integrated systems proffer a better dynamic performance than a standalone UPFC. The rapid and autonomous control of both real and reactive power of UPFC -ESS system formulates it as the ultimate aspirant for several applications in the electrical power systems.

2.1. UPFC operation

An UPFC circuit consists of a boosting transformer, excitation transformer, two voltage source converters (VSC1 and VSC2) and a DC link capacitor. VSC1 (Shunt converter) is connected to a transmission line in parallel through boosting transformer and VSC2 (Series converter) coupled with excitation transformer in the transmission power network. These VSC1 and VSC2 converters are coupled with each other with a common DC link capacitor. This DC bus permits the bidirectional flow of real power between terminals of SSSC and STATCOM. Shunt and series converters independently exchange reactive power with transmission power line. The VSC1 is primarily used for providing real power demand of the series converter through common DC link terminals. It can generate or absorb reactive power at its AC terminal, which is autonomous of the active power transfer to (or from) the DC terminal. The series connected inverter injects a voltage by means of controllable magnitude and phase angle in series with transmission line, thus providing real and reactive power to the transmission line. The combined version of real and reactive power provides the total complex power of the line. Real power can be calculated by line current in phase with injected voltage and reactive power is calculated by line current quadrature phase with injected voltage. The complex power of line will be expressed as (1),

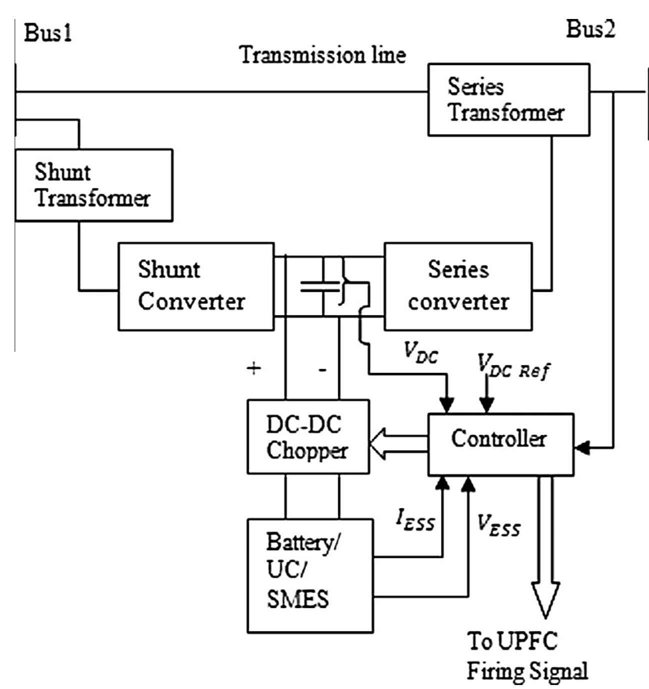

Figure 1 System model.