

Transient Stability Improvement using UPFC-SMES in a Multi Machine Power System

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ABSTRACT

Unified Power Flow Controller (UPFC) is a Voltage sourced converter based Flexible A.C.Transmission (FACTS) controller which has a capability of simultaneously or selectively controlling all the parameters affecting transmission of power. With emphasis on harnessing renewable energy many energy storage technologies are being used. Superconducting magnetic energy storage (SMES) stores energy in magnetic form by means of a D.C. current circulating in a superconducting coil. To exchange power with SMES a power electronic interface is required. Feasibility of interfacing SMES to D.C. link of UPFC has been explored in this paper. A multimachine system with a long transmission line is compensated by UPFC-SMES .A DC-DC chopper modulates power of SMES so as to improve the transient stability of system. Complete simulation has been done using MATLAB/Simulink which shows improvement of first peak, damping of oscillations & improvement in critical clearing time.

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1. INTRODUCTION

The FACTS Controllers have been around Electrical Engineering domain for quite a few years now. Both variable impedance type and Voltage Sourced Converter (VSC) type devices have been explored intensively for addressing many power system issues such as increasing the capacity of transmission line to its thermal limits, improving power quality and transient stability. This has been possible primarily due stretching of stability margins by rapid control of parameters such as line voltage, phase angle, line impedance etc. Recent developments in power electronics have expedited the growth of FACTS controllers as the cost and size of the controllers is reducing rapidly. While on one hand the Variable impedance type FACTS controllers like SVC provide a simple configuration and low cost, on the other VSC devices are smaller in size and have better speed of response. [1]

In VSC based FACTS controllers a small capacitor acts a DC source and various converter topologies can be used to modulate this input to get appropriate output. Based on the topology and application; VSC based FACTS controllers can be identified as STATCOM, SSSC, UPFC and IPFC. STATCOM and SSSC are shunt and series devices respectively used which use a single VSC, generally of 48 pulse configuration to reduce harmonics in the output. UPFC and IPFC use two converters in Shunt-Series and Series-Series Configurations. The two converters have a common DC link. [2] The presence of this DC link presents an opportunity to integrate Energy storage. The primary aim of UPFC is to increase the power flow and control of it over a transmission line. The addition of energy storage provides a value addition in

terms of opportunity to harness distributed generation (DG), greater degree of freedom in control of power resulting in improved transient and steady state performance.

Many candidate energy storage systems (ESS) are available for integration with FACTS controllers namely Battery Energy Storage System (BESS), Superconducting Magnetic Energy Storage (SMES), Flywheels and Ultracapacitors. Selection of a particular ESS depends mainly on two things; one amount of power required and other the time for which this power is required. Other selection criteria may include speed of response, cost, interface switchgear required etc. BESS is characterized by good energy density; however its life is limited by number and rate of charge/discharge cycles. SMES has a very rapid response, good energy density and good power density. Requirement of cooling and size of SMES is the limiting factor. Ultracapacitors have very high power density and rapid response with good life. However, ultracapacitors have low energy density and are available in low voltage ratings. This requires series-parallel banks to be prepared for Multi-MW applications. [3]

In this work a multi machine power system is simulated with UPFC-SMES combination. The main objective of this work is to simulate performance of power system under severe fault conditions. Transient stability improvement is one of the main objectives for integration of UPFC with SMES. This paper is arranged as follows. Section 2 provides a detailed description of the system under consideration. Section 3 deals with detailed control scheme & modeling. Section 4 describes system simulation under various operating conditions. Section 5 concludes the findings followed by references in section 6.

2. RESEARCH METHOD

2.1. System Description

The system under consideration for study of impact of UPFC and SMES is shown in Figure 1 below.

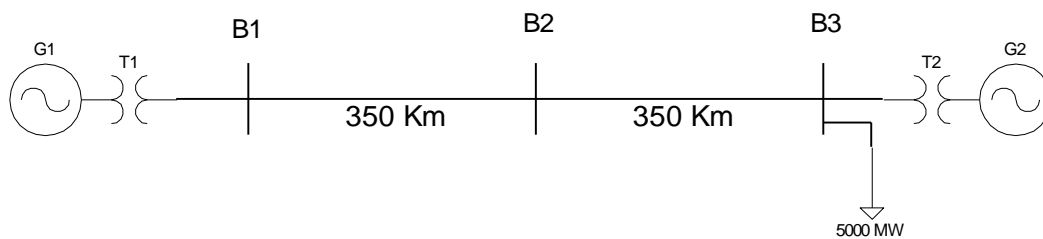


Figure 1. Two Machine System under study

Machine G1 is connected to a load center through 500kV, 700km transmission line. Load center is modeled by 5000 MW resistive load which is also fed by a nearby generation of 5000 MW by machine M2 [4]. A Phasor model of the above system in MATLAB simulink has been used for the study purpose. The phasor solution method is mainly used to study electromechanical oscillations of power systems consisting of large generators and motors. The system has been initialized for the transmission line to carry 950 MW which is close to its surge impedance loading. It has been well established that in order to get proper segmentation of transmission line the best location of a FACTS controller is the mid point of transmission system. In this study a UPFC is connected at bus B2. In absence of energy storage interface the DC Link capacitor of UPFC has very little storage capability. Even though UPFC can inject real power component of power through its series converter, but the energy is essentially drawn from the shunt converter. Integration with ESS not only helps in storage of any available renewable but also improved transient performance. Many previous studies have been carried out which have explored combination of FACTS controllers with ESS. A UPFC-SMES combination has been explored in [5]; however there is no clear mention of system size and parameters and system conditions. Comprehensive modeling of UPFC-SMES has been discussed in [6]; however the focus is on power flow control and load flow studies. Power Swings Damping Improvement by Control of UPFC and has been carried out in [7]; but impact of UPFC without SMES is not compared with UPFC-SMES. Many other studies have explored UPFC-SMES & FACTS-SMES combination but mostly with single machine infinite bus system [8-11]. In this paper a multi machine system has been modeled in totality and impact of UPFC, UPFC-SMES has been investigated under severe fault conditions.

2.2. UPFC-SMES system

The schematic of UPFC-SMES used in this study is illustrated in figure 2 below. The UPFC-SMES combination is placed at bus B2. It is well established fact that the best location of shunt FACTS controller is mid point of the transmission system. Shunt part of the UPFC i.e. STATCOM operation is achieved by combination of VSC 1 and shunt transformer T1. SSSC operation is achieved by VSC2 and series transformer T2. A common DC link is provided by capacitor C which gives reference voltage for controllable reactive power to be exchanged with the transmission\ system. While STATCOM independently exchanges

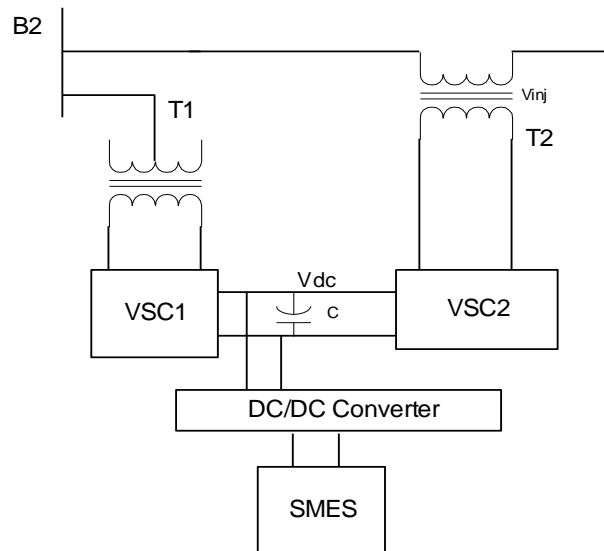


Figure 2. Schematic of UPFC-SMES

Reactive power at bus B2, SSSC injects voltage in series with transmission line. In case of UPFC the series injected voltage can be at any angle with respect to line current by virtue of real power supplied by STATCOM via D.C. link. DC link of the UPFC is connected to SMES via a DC/DC converter. DC/DC converter helps not only in controlling the power exchange but also helps in optimizing the size of SMES.

3. SYSTEM MODELING

In this work modeling and simulation has been done using MATLAB Simulink. As the objective of this work is evaluating impact of UPFC-SMES on transient stability, it is not necessary to consider fast oscillations due to interaction of RLC elements and distributed parameter lines. This is best possible by using Phasor modeling method. In the phasor method, the network's differential equations are replaced by a set of algebraic equations. The state-space model of the network is replaced by a transfer function evaluated at the fundamental frequency. The phasor simulation method reduces the simulation time drastically. As this study involves complete non-linear modeling of two generators, transmission lines, UPFC, SMES and other components like power system stabilizer, loads etc. it is pertinent to use the phasor model for rapid and accurate assessment of stability.

3.1. UPFC Modeling and control system

Figure 3 shows the control system of Series part of the UPFC. The shunt converter control scheme is not reproduced here as it is same as the control scheme of STATCOM. The voltage at shunt converter terminals and common DC link voltage is controlled by this scheme. The series part control is slightly different than SSSC. Here the two degrees of freedom are used to control active and reactive power. PQ measurement block calculates active and reactive power values based on the current in the line and voltage at two ends of UPFC. UPFC controls active and reactive power based on the references P_{ref} and Q_{ref} . P_{ref} and Q_{ref} can be derived for different objectives such as power flow control, oscillations damping etc. In this work UPFC is being utilized not only for power flow control but also improvement in transient stability. Power supplied or absorbed by SMES is added to the power calculated by PQ measurement block. The modeling and control of SMES is discussed in next section.

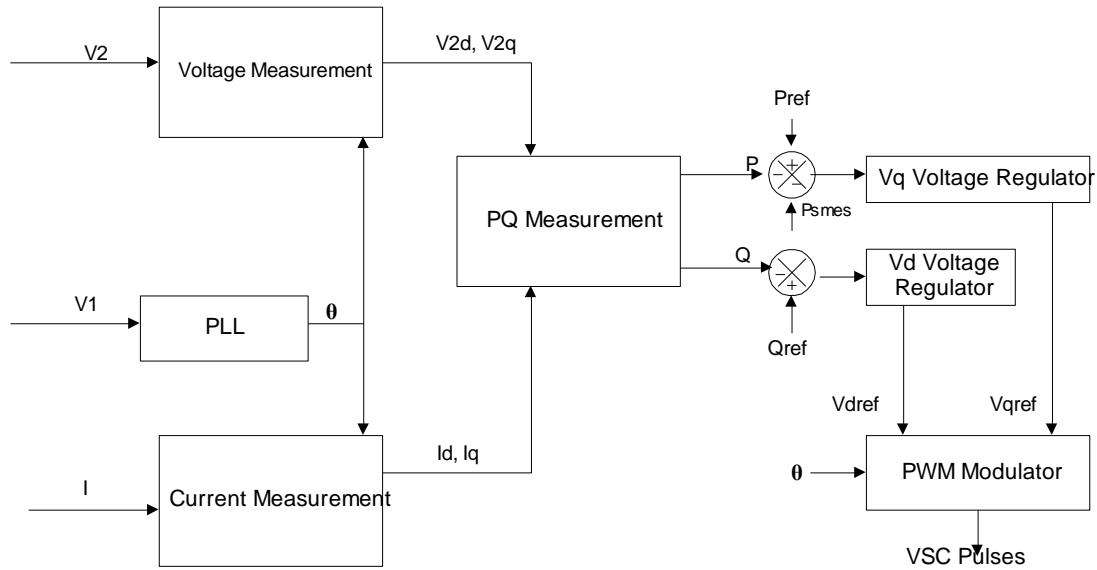


Figure 3. Control Scheme of Series part of UPFC

3.2. Modeling of SMES & DC-DC interface

Many models of SMES have been reported in literature [12-13]. However a comprehensive study of modeling of SMES has been carried out by EPRI [14]. A SMES device stores energy in the magnetic field. Magnetic field is created by a dc current flowing in superconducting wire in a large magnet. Energy stored in the inductor is related to current through coil by following expression

$$E_{smes} = \frac{1}{2} L_{smes} I_{smes}^2 \tag{1}$$

wherein

- E_{smes} = Energy stored in SMES
- L_{smes} = Inductance of SMES coil
- I_{smes} = Current through SMES coil

As the phasor model of UPFC is being used in this paper, it was necessary to create an appropriate model of SMES which could demonstrate the effect of SMES in an efficient manner. Also as depicted in Fig. 2 a DC-DC chopper interface is required between DC link of UPFC and the SMES. Both these objectives have been achieved by creating a subsystem using basic Simulink mathematical modeling. Fig. 4 below shows the schematic of DC-DC chopper used for simulation in this paper.

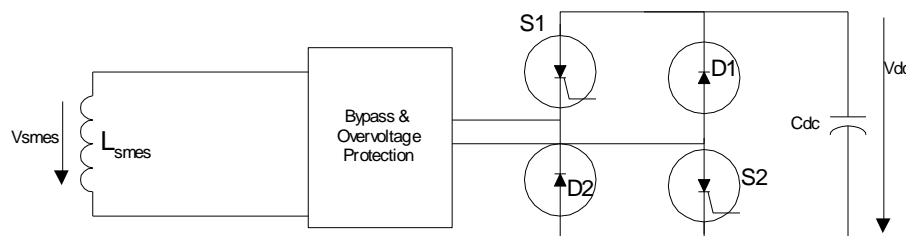


Figure 4. DC-DC Chopper interface with SMES

As per figure 4 SMES inductor coil is interfaced to DC link of UPFC through protection circuit and DC-DC converter. Switches S1 & S2 are turned on and off in accordance to a duty cycle d which controls the waveform of V_{smes} across the SMES coil. DC component of V_{smes} is related to voltage V_{dc} of UPFC dc link capacitor by following expression

$$V_{smes} = (1-2d) V_{dc} \quad (2)$$

Average value of the coil current I_{smes} is expressed in terms V_{smes} and coil inductance L_{smes} as follows

$$\frac{dI_{smes}}{dt} = -\frac{V_{smes}}{L_{smes}} \quad (3)$$

According to (3) following three modes of operations can be defined for SMES

- when $d=0.5$ then $\frac{dI_{smes}}{dt} = 0$ there is no net energy transfer and SMES is in standby mode.
- when $d>0.5$ then $\frac{dI_{smes}}{dt} < 0$ energy is transferred out of coil and SMES is in discharge mode.
- when $d<0.5$ then $\frac{dI_{smes}}{dt} > 0$ energy is transferred into coil and SMES is in charge mode.

In the UPFC phasor model of MATLAB D.C. link voltage signal is available. Utilizing this signal and referring (1) through (3) we can write

$$I_{smes} = \frac{-1}{L_{smes}} \int V_{smes} \quad (4)$$

And

$$P_{smes} = V_{smes} * I_{smes} \quad (5)$$

Now considering equations (1) through (5) and using Simulink the model of SMES interfaced with DC-DC converter is prepared. P_{smes} as calculated in (5) is fed as an additional signal as shown in fig. 3.

Duty cycle ratio d of the DC-DC chopper can be controlled in accordance to various requirements. In this work the main objective is damping of power system oscillations. While doing the simulation it is assumed that SMES is initially charged with some energy. As and when there is a transient event like a severe fault, energy stored in the SMES is either pumped into power system or absorbed from power system in antipathy to power system oscillations.

4. SYSTEM SIMULATION AND RESULTS

In order to observe the efficacy of the UPFC-SMES combination on transient performance of the system a severe fault (3Phase to ground) is carried out at bus B1 and response of rotor angle difference between machines 1 & 2 is observed. The given system is stable under steady state conditions. Under light faults like L-G fault the system returns to stability without need of UPFC or SMES Figure 5. Conventional power system stabilizer is effective enough to handle this situation. When there is a severe fault the system is unstable without UPFC-SMES Fig. 6. With addition of UPFC alone, the rotor angle oscillations die out and the system returns to stability Fig.7. With integration of SMES to UPFC the oscillations die out faster and transient response is improved Fig. Also the critical clearing angle is improved with addition of SMES figure 8.

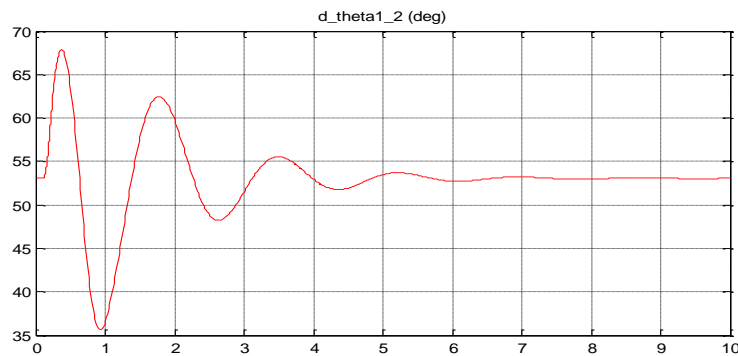


Figure 5. Plot of rotor angle difference for a L-G fault at Bus B1

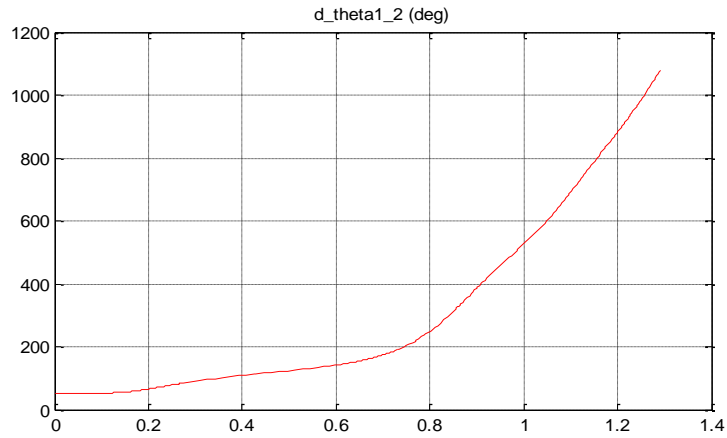


Figure 6. Plot of rotor angle difference for a 3phase-Ground fault at Bus B1 without UPFC

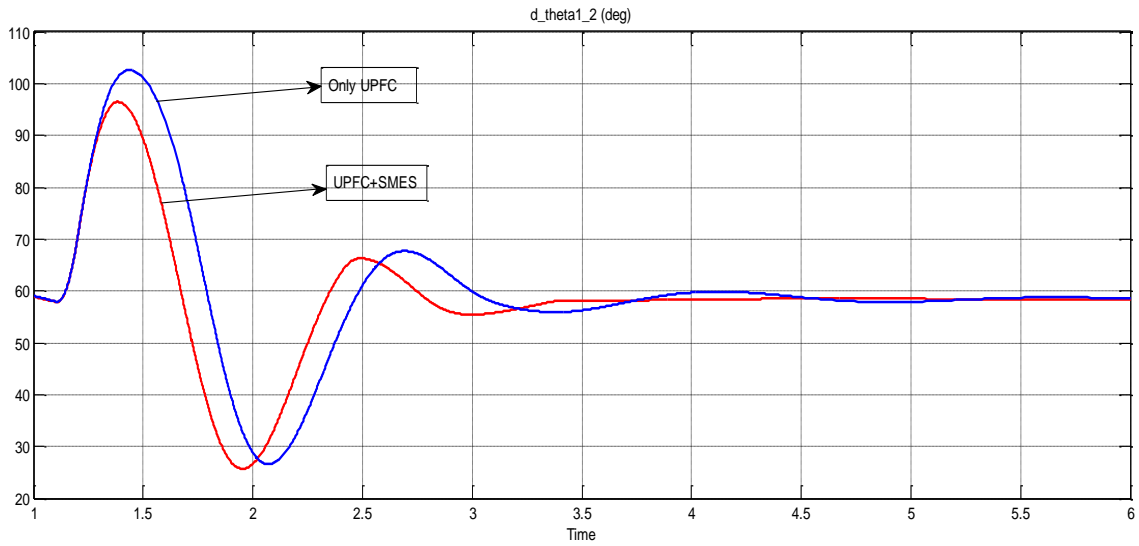


Figure 7. Plot of rotor angle difference for a 3phase-Ground fault at Bus B1 with UPFC-SMES

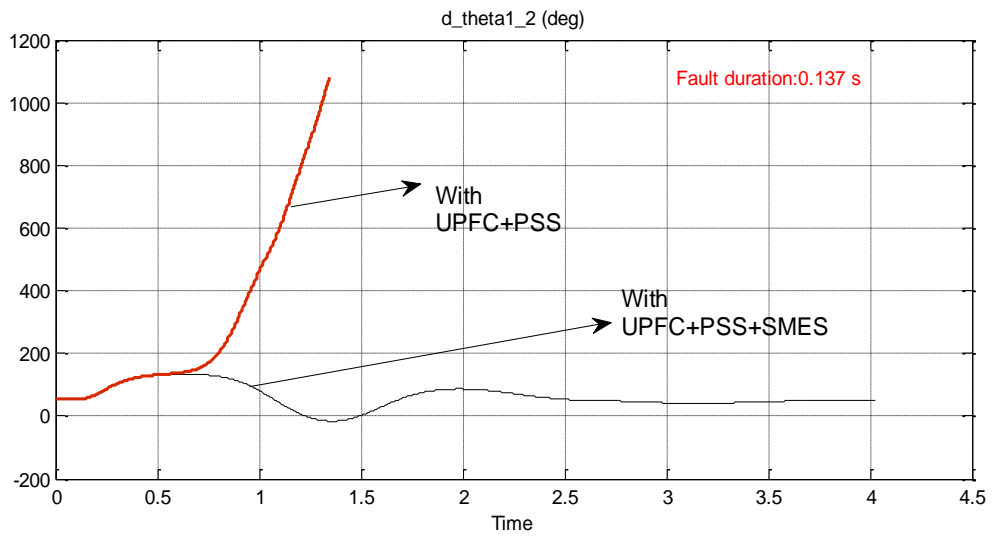


Figure 8. Improvement of Critical Clearing Time with UPFC-SMES

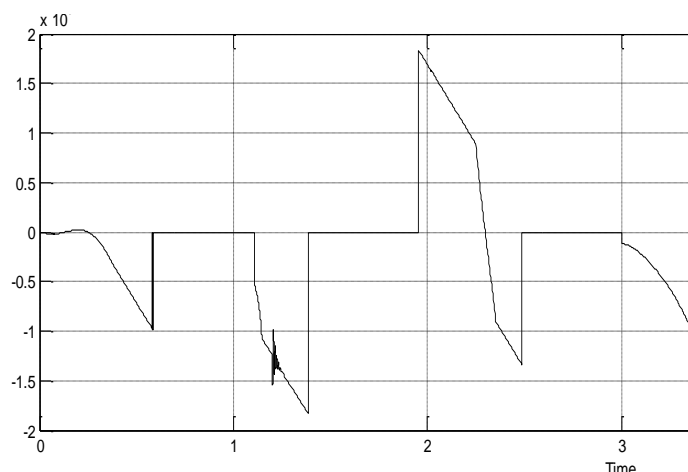


Figure 9. Response of SMES Power in antipathy to power oscillations

For figures 5 through 7 above the fault duration is of 0.1 seconds on a 60 Hz frequency. For seeing improvement in critical clearing time fault duration is extended to 0.137 seconds as shown in figure 8. Figure 9 demonstrates the modulation of SMES power in antipathy to the power system oscillations.

5. CONCLUSION

UPFC integrated with SMES in a multimachine system has been explored. By controlling the duty cycle ratio of the DC-DC chopper SMES power is modulated in antipathy of power system oscillations. It is found that the UPFC improves power system transient performance. Integration of SMES with UPFC improves the oscillation damping, reduces first peak significantly and also improves the critical clearing time in case of a severe fault.

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Er. Kantilal Joshi secured his B.E. degree in Electrical Engineering and M.Tech degree in Integrated Power Systems in the year 1999 & 2006 respectively from Rashtrasanta Tukadoji Maharaj Nagpur University and is currently pursuing his PhD He has been awarded two gold medals for his performance in M.Tech examination by the university. His research interests include FACTS, Energy storage and Power systems. He has 14 years of Teaching & Research experience and has published more than 20 papers. He is a Senior Member of IEEE and Life member of ISTE and CSI. He has to his credit two textbooks and grants worth Rs. 10 Lakhs.



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