Simulation of Supercapacitor Energy Storage System with Bi DC-DC converters

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ABSTRACT--FACTS devices are extensively employed to enhance power system quality and security. They are capable of exchanging limited real power even though they have real and reactive power exchanging capability with power system. The main reason for the limited ability to exchange real power is not considering energy storage device. In FACTS devices STATCOMs are most commonly employed because of many advantages. STATCOMs coupling with Energy Storage Devices (ESD) like batteries, Supercapacitor, flywheels, semiconductor magnetic energy storage (SMES) were initiated to increase real power exchanging capability with the power system. Because of slow chemical reaction batteries the power discharging capability is limited. Present trend is to employ energy storage for short term to improve dynamic stability. Supercapacitor ESD will help in the dynamic stability and quality with STATCOMs. Even though they have less energy storing capability power exchanging capability is large when comparison with batteries. In this paper design of energy storage system with Supercapacitor is discussed and coupling with bi dc/dc converters with controlled strategies. To control the SCESS system a peak current mode controller is used. SCESS system is constructed in MATLAB simulink and results with Supercapacitor and without Supercapacitor are discussed in this paper.

Keywords: SCESS, STATCOM, FACTS, Energy storage

1. INTRODUCTION

FACTS devices are employed to improve power system quality and security. FACTS device can exchange reactive power on their own with the system, but the real power exchanging capability is less because energy storage devices like Supercapacitor and battery are absent. Energy storage devices like batteries coupled with STATCOM will improve power system stability and quality. Because of slow chemical reaction of batteries, the power discharging capability is limited. Present trend is to employ energy storage for short term to improve dynamic stability. Supercapacitor ESD will help in the dynamic stability and quality with STATCOMs. Supercapacitor have higher power exchanging capability even though they can store less compare to batteries. Supercapacitor is coupled with bi dc/dc converters. They help in the boost and buck operations to charge and discharge energy respectively.

A. STATCOM

By utilizing STATCOMs power system stability and quality can be improved to a good extent. STATCOMs are one of the FACTS (Flexible AC Transmission System) devices. They will exchange reactive power with the system. STATCOMs can be designed in either ways (with or without energy
storage). STATCOMs will deliver reactive power only in the absence of energy storage, while the STATCOMs coupled with energy sources can exchange both reactive and real power.

B. SCESS

The interest using Supercapacitor has grown recently even though it got introduced in 1960’s in using them as energy sources for STATCOMs. Now-a-Days super capacitors are named as ultra-capacitors. Supercapacitor with high capacitance are electrochemical double layer capacitors. The surface area of super capacitors is very large. Therefore the capacitance value is large compared to normally used capacitors. Supercapacitor power ratings are comparatively much higher than the ordinary battery. The prime reason for high ratings is that they can release energy quickly in large while in batteries chemical process makes them slow in releasing energy. The flow of current from the Supercapacitor can controlled with DC/DC converter and Supercapacitor of the SCESS system

2. DESIGN OF SUPERCAPACITOR ENERGY STORAGE SYSTEM

In order to design the Supercapacitor energy storage number of series super capacitors and number of parallel capacitors should be calculated considering the total capacitance of the storage system. If \( V_{cell} \) is the rated supercapacitor voltage then the Supercapacitor bank total voltage bank is given by

\[
V_{sc(max)} = n_s \cdot V_{cell}
\]

Where \( n_s \) is number of Supercapacitor cells in series together they form a string. In the same manner \( R_{cell} \) is the equivalent series resistance, then the series ESR of string is given by

\[
R_s = n_s \cdot R_{cell}
\]

Series capacitance (Cs) of \( n_s \) individual series super capacitor cells in string is given by

\[
C_s = \frac{C_{cell}}{n_s}
\]

The nominal current in the super capacitor bank is \( I_{sc(max)} \) is given by the formula

\[
I_{sc(max)} = \frac{P_{sc}}{V_{sc(min)}}
\]

Where \( P_{sc} \) the super capacitor bank is rated power

Current in each series string \( (I_{cell}) \) of \( n_s \) series super capacitor cells is less than \( I_{sc(max)} \). With help of \( I_{sc(max)} \) and \( I_{cell} \) number of series strings in parallel can be given by

\[
n_p = \frac{I_{sc(max)}}{I_{cell}}
\]

Equivalent super capacitor capacitance due to \( n_p \) of each \( C_s \)

\[
C_{sc} = n_p \cdot C_s
\]

Equivalent series resistance \( (R_{sc}) \) due to \( n_p \) resistances of each \( R_s \)
Energy of Supercapacitor ($E_{sc}$) with the help of $V_{sc}$ and $C_{sc}$

$$E_{sc} = \frac{1}{2} * C_{sc} * V_{sc}^2$$

Supercapacitor capacitance ($C_{sc}$) can be calculated using the nominal voltage (Maximum voltage) $V_{scnom}$ and minimum voltage $V_{scmin}$ by

$$C_{sc} = \frac{2 * P_{sc} * t_d}{(V_{scnom} - V_{scmin})^2}$$

Where $E_{sc} = P_{sc} * t_d$

3. BI-DIRECTIONAL DC-DC CONVERTERS

Supercapacitor cannot directly inject the power into the grid so the converter is used to link the DC link. Inductor is connected in series with Supercapacitor to filter current ripples.

Fig. 1 shows the complete circuit diagram of SCESS

In this two IGBT switches are used. The shunt connected IGBT will act as boost mode switch and series connected will act as buck mode switch. This circuit will operate in four modes. When the DC link voltage is above the reference voltage super capacitor will be charged in buck mode and when DC voltage is below the reference voltage Supercapacitor will discharge in boost mode

![Fig.1: SCESS circuit](image1)

The PWM signal is given to boost mode IGBT (IGBT1)
The PWM signal is given to boost mode IGBT (IGBT2)

The circuit will operate in four modes

**Fig.3: SCES buck mode control**

**Fig.4: Buck mode, Inductor & Capacitor Charging**

**Fig.5: Buck mode, Inductor Discharging**

**Fig.6: Boost mode, Inductor charging**
In mode 1 Supercapacitor will charge and inductor current increases slowly. Supercapacitor will be charged in buck mode. In mode 2 inductor current decreases where as Supercapacitor will be getting charged. In mode 3 super capacitor will discharge energy to the system in boost mode. In mode 4 inductor current and Supercapacitor discharge will be delivering to across C1. In model 1 the power will flow through Q1 path, in mode 2 power will take D2 path, mode 3 power will take Q2 path and in mode 4 power will take D1 path.

### Table 1: modes and power flow

| Mode/switches | Q1 | Q2 | D1 | D2 |
|---------------|----|----|----|----|
| Mode 1        | YES| NO | NO | NO |
| Mode 2        | NO | NO | NO | YES|
| Mode 3        | NO | YES| NO | NO |
| Mode 4        | NO | NO | YES| NO |

### 4. SIMULATION OF SCESS

Fig.8 shows the simulation diagram of SCESS in MATLAB software. In this a voltage source of magnitude 600V is considered.

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**Fig.8: MATLAB simulation diagram of SCESS**
Parameters of SCESS are:

Table 2: Parameters of SCESS

| Parameter   | Value   |
|-------------|---------|
| Csc         | 600µF   |
| Vsc         | 600V    |
| L           | 75mH    |
| R           | 0.001Ω  |
| Cdc_link    | 800µF   |
| Rd_c        | 0.01Ω   |
| Rload       | 120Ω    |
| Vs          | 610V    |
| R           | 0.01Ω   |

Fig. 9 shows the MATLAB simulink diagram to generate gate signals for buck and boost IGBTs. Fig. 9 act as subsystem in Fig. 8.

Fig. 9: GATE pulse generator for IGBTs
5. RESULTS OF SCESS

Fig.10: Vdc link without Supercapacitor

Fig.11: Vdc link with supercapacitor, b) Supercapacitor Voltage c) Supercapacitor current

6. CONCLUSION

From Fig.10 can be noted that the DC link voltage will reach zero without super capacitor after the DC voltage source is removed but from Fig.11 can be note that DC link voltage will not reach zero because of the presence of Supercapacitor storage unit.
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