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Modeling and Simulation of Superconducting Magnetic Energy Storage Systems

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ABSTRACT

This paper aims to model the Superconducting Magnetic Energy Storage System (SMES) using various Power Conditioning Systems (PCS) such as, Thyristor based PCS (Six-pulse converter and Twelve-pulse converter) and Voltage Source Converter (VSC) based PCS. Modeling and Simulation of Thyristor based PCS and VSC based PCS has been carried out. Comparison has also been carried out based on various criteria such as Total Harmonic Distortion (THD), active and reactive power control ability, control structure and power handling capacity. MATLAB/Simulink is used to simulate the various Power Conditioning Systems of SMES.

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1. INTRODUCTION

A Superconducting Magnetic Energy Storage (SMES) device is a dc current device that stores energy in the magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field.

Generally it consists of:

- Superconducting coil
- Cryogenic system
- Power Conversion/Conditioning System (PCS) with control and protection functions.

The total efficiency of a SMES system can be very high since it does not require energy conversion from electrical to mechanical or chemical energy. Depending on the control loop of its power conversion unit and switching characteristics, the SMES system can respond very rapidly (MWs/milliseconds). The ability of injecting/absorbing real or reactive power can increase the effectiveness of the control, and enhance system reliability and availability. Consequently, SMES has inherently high storage efficiency about 90% or greater round trip efficiency.

Comparing with other storage technologies, the SMES technology has a unique advantage in two types of applications:

- Power system transmission control and stabilization
- Power quality improvement.

For instance, SMES can be configured to provide energy storage for Flexible AC Transmission Systems (FACTS) controllers at the transmission level or custom power devices at the distribution level. The efficiency and fast response capability of a SMES can be further exploited in different applications in all levels of electric power systems [1], [2].

1.1. Need for SMES

Superconductivity, the total lack of resistance of conducting materials below critical temperatures, is one of the most fascinating phenomena in nature. Although Superconductivity was discovered in 1911 by Onnes, it was not until 1970s SMES was first proposed as a technology in power systems. Energy is stored in the magnetic field generated by circulating the DC current through a superconducting coil. SMES is a technology that has the potential to bring essential functional characteristics to the utility transmission and distribution systems [3], [4].

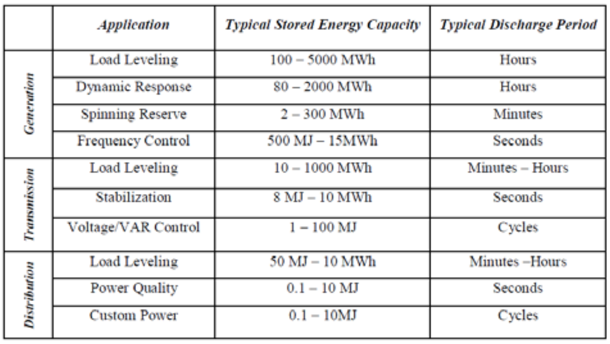
A SMES system consists of a superconducting coil, the cryogenic system, and the power conversion or conditioning system (PCS) with control and protection functions.

Advantages of SMES over other energy storage system:

- The total efficiency can be very high since it does not require energy conversion from one form to the other.
- Depending on its power conversion unit’s control loop and switching characteristics, the SMES system can respond very rapidly (MWs/milliseconds).
- Because of its fast response and its efficiency, SMES systems have received considerable attention from electric utilities and the government.
- SMES systems are reliable (no moving parts) and environmentally benign.

Compared to other storage technologies, the SMES technology has a unique advantage in two types of application, power system transmission control and stabilization and power quality. Although SMES systems may not be cost effective, at the present time, they have a positive cost. SMES’ efficiency and fast response capability has been and can be further exploited in different applications in all level of electric power systems. SMES systems have the capability of providing; overall enhance security and reliability of power systems. The characteristics of potential SMES applications for generation, transmission, and distribution are given in Table 1.

Table 1. Characteristics of potential SMES applications in power systems



	Application	*Typical Stored Energy Capacity*	*Typical Discharge Period*
Generation	Load Leveling	100 – 5000 MWh	Hours
	Dynamic Response	80 – 2000 MWh	Hours
	Spinning Reserve	2 – 300 MWh	Minutes
	Frequency Control	500 MJ – 15MWh	Seconds
Transmission	Load Leveling	10 – 1000 MWh	Minutes – Hours
	Stabilization	8 MJ – 10 MWh	Seconds
	Voltage/VAR Control	1 – 100 MJ	Cycles
Distribution	Load Leveling	50 MJ – 10 MWh	Minutes –Hours
	Power Quality	0.1 – 10 MJ	Seconds
	Custom Power	0.1 – 10MJ	Cycles

1.2. SMES Technologies

In SMES systems, it is the power conditioning system (PCS) that handles the power transfer between the superconducting coil and the ac system. There are many topologies available for the purpose of charging and discharging of SMES.

Some of the technologies are,

- Thyristor-based PCS
- Voltage source converter (VSC)-based PCS

The Thyristor-based SMES can control mainly the active power, and has a little ability to control the reactive power; also the controls of active and reactive powers are not independent. On the other hand, both the VSC- and CSC-based SMES can control both active and reactive powers independently and simultaneously. Therefore, the applications in which mainly the active power control is required, the thyristor-based SMES is used, while the applications in which reactive power or both active and reactive power controls are required, the VSC-Based SMES is used.

In this paper section 2 deals with the basic concepts of SMES. The modeling of Thyristor based SMES has been dealt in section 3.The modeling of Voltage Source Converter based SMES has been discussed in section

4. The comparison between Thyristor based SMES and Voltage Source Converter based SMES has been done in section 5. The result of the project has been summarised in final section 6. It further discusses about the future scope of the work.

2. SUPERCONDUCTING MAGNETIC ENERGY STORAGE SYSTEM

A SMES device is a dc current device that stores energy in the magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field [3]. The inductively stored energy (E in Joule) and the rated power (P in Watt) are commonly given specifications for SMES devices,

$$\mathrm{E} = \frac{1}{2}\mathrm{LI}^2 \tag{1}$$

$$\mathrm{P} = \frac{\mathrm{dE}}{\mathrm{dt}} = \mathrm{LI}\frac{\mathrm{dI}}{\mathrm{dt}} = VI \tag{2}$$

where,
L - Inductance of the coil
I - DC current flowing through the coil
V - Voltage across the coil

A SMES system consists of a superconducting coil, the cryogenic system, and the power conversion or conditioning system (PCS) with control and protection functions. IEEE defines SMES as “A superconducting magnetic energy storage device containing electronic converters that rapidly injects and/or absorbs real and/or reactive power or dynamically controls power flow in an ac system”. Such a device has a number of advantageous and unique characteristics: No conversion of energy from one form to another is required; consequently SMES has inherently high storage efficiency, a 90% or greater round trip efficiency. Depending on the power conversion unit’s control loop and switching characteristics, the SMES device can respond very rapidly (MWs/ milliseconds) to power demands from maximum charge to maximum discharge. SMES systems can offer very reliable and long lifetime service. Except for certain designs, they are considered to be environmentally benign systems [5], [6], [7].

2.1. Components of SMES

As can be seen from Figure 1, a SMES system connected to a power system consists of several subsystems [4]. A large *superconducting coil* is the heart of the SMES systems. It is contained in a cryostat or dewar that consists of a vacuum vessel and contains liquid vessel that cools the coil. A *cryogenic system* is to keep the temperature well below the critical temperature for the superconductor.

An ac/dc *power conversion or conditioning system* (PCS) is used for two purposes:

- One is to convert from dc to ac
- To charge and discharge the coil.

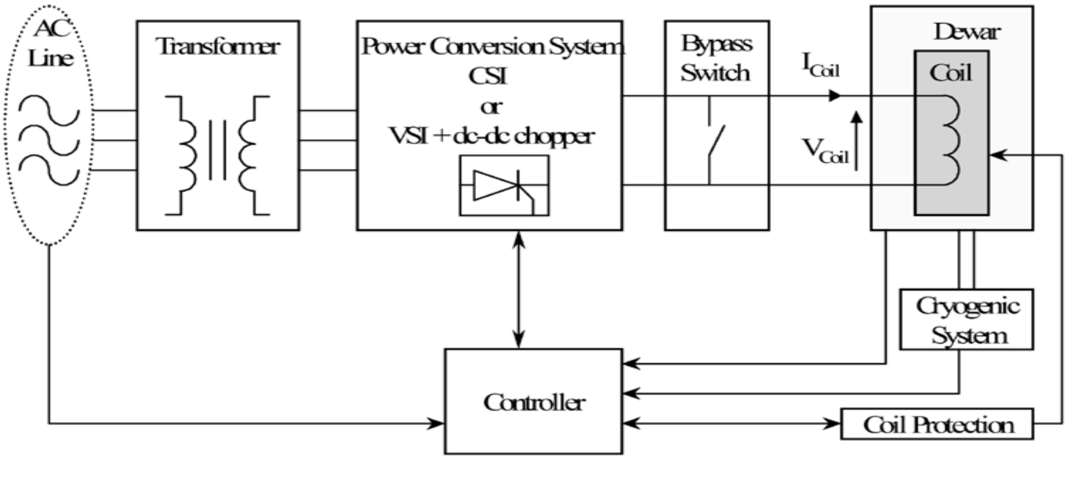


Figure 1. Components of a typical SMES system

A *transformer* provides the connection to the power system and reduces the operating voltage to acceptable levels for the PCS.There is two *types of superconductors* used to form a SMES coil:

- Low Temperature Superconductors (LTS)
- High Temperature Superconductors (HTS)

A composite of alloys of Niobium and Titanium (Nb-Ti) copper is used most commonly for low temperature superconductors (LTS). The HTS material is, at present, bismuth-strontium-calcium copper-oxide (BSCCO). During SMES operation, the magnet coils has to remain superconducting.

A *refrigerator* in the cryogenic system maintains the required temperature for the proper superconducting operation. The refrigeration load can affect the overall efficiency and cost of a SMES system. Therefore, the refrigeration load that has loss components, such as cold to warm current leads, ac current, conduction and radiation, should be minimized to achieve a higher efficient and less costly SMES system.

Any abnormal condition that may cause a safety hazard to personnel or damage to the magnet should be detected and protected through the magnet protection system.

A *PCS* provides a power electronic interface between ac power system and the superconducting coil. It allows the SMES system to respond within tens of milliseconds to power demands that could include a change from maximum charge rate to maximum discharge power. This rapid response allows a diurnal storage unit to provide spinning reserve and improve system stability. The converter / SMES system is highly efficient, as there is no energy conversion from one form to another. Converters may produce harmonics on the ac bus and in the terminal voltage of the coil. Using higher pulse converters can reduce these harmonics.

The superconducting coil is charged or discharged by making the voltage across the coil positive or negative.

- The coil absorbs power from the ac system and acts as a load during one half cycle when the converter voltage is positive.
- During the next half cycle, the coil operates as a generator sending power back into the ac systems when the converter voltage is made negative.
- When the unit is on standby, independent of storage level, the current is constant, and the average voltage across the superconducting winding is zero.

A PCS could be either a current source inverter or a voltage source inverter with a dc-dc chopper interface [8].

3. THYRISTOR BASED SMES

In SMES systems, Thyristor based PCS is one of the power conditioning system that handles the power transfer between the SMES and the ac system. The thyristor based SMES can control mainly the active power, and has a little ability to control the reactive power. Moreover, the controls of active and reactive powers are not independent. Therefore, the applications in which mainly the active power control is required, thyristor based SMES is used [9-11].

The thyristor-based PCS can be implemented by using,

- Six pulse converter
- Twelve pulse converter

The working of six pulse and twelve pulse converter are as follows:

3.1.Charging and Discharging of SMES using Six Pulse Converter

Figure 2, shows the basic configuration of a thyristor-based SMES unit, which consists of a Wye-Delta transformer, an ac/dc thyristor controlled bridge converter, and a superconducting coil or inductor [5]. The converter impresses positive or negative voltage on the superconducting coil. Charge and discharge are easily controlled by simply changing the delay angle that controls the sequential firing of the thyristors.

- If α is less than 90, the converter operates in the rectifier mode (charging)
- If α is greater than 90, the converter operates in the inverter mode (discharging)

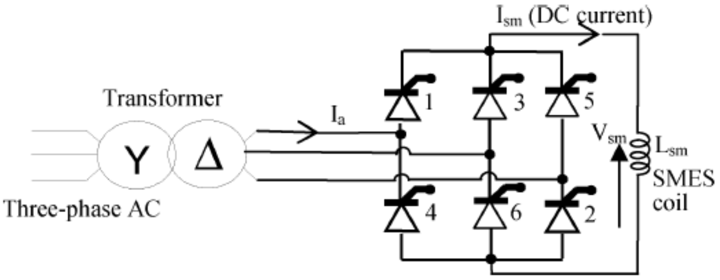


Figure 2. Basic circuit of the thyristor based SMES

As a result, power can be absorbed from or released to the power system according to requirement. At the steady state, SMES should not consume any real or reactive power.
The voltage $V_{sm}$of the dc side of the converter is expressed by,

$$V_{sm} = V_{sm0} \cos \alpha \tag{3}$$

Where, $V_{sm0}$is the ideal no-load maximum dc voltage of the bridge.
The current and voltage of superconducting inductor are related as,

$$I_{sm} = \frac{1}{L_{sm}} \int_{t_0}^{t} V_{sm}\, dt + I_{sm0} \tag{4}$$

Where, I_{sm0} is the initial current of the inductor.
The real power, P_{sm} absorbed or delivered by the SMES can be given by,

$$P_{sm} = V_{sm} I_{sm} \tag{5}$$

The energy stored in the superconducting inductor is

$$W_{sm} = W_{sm0} + \int_{t0}^{t} P_{sm}\, dt \tag{6}$$

where, $W_{sm0} = \frac{1}{2} L_{sm} {I_{sm0}}^2$ is the initial energy in the inductor.
This is applicable for the twelve pulse converter also [5].

Since the bridge current I_{sm} is not reversible, the bridge output power P_{sm} is uniquely a function of, which can be positive or negative depending on V_{sm}. If $V_{sm}$is positive, power is transferred from the power system to the SMES unit. While if $V_{sm}$is negative, power is released from the SMES unit.

3.2. Simulation of Thyristor Based SMES using Six Pulse Converter

The Thyristor based SMES using Six Pulse Converter is simulated in MATLAB/Simulink as shown in Figure 3. The SMES coil is charged from t=0*s* to t=0.16*s* by applying the Firing angle $\alpha=30^0$. The SMES current is maintained constant from t=0.16*s* to t=0.32*s* by applying the Firing angle $\alpha=90^0$. The SMES coil is discharged from t=0.32*s* to t=0.48*s* by applying the Firing angle $\alpha=150^0$. The Firing Angle circuit of the Thyristor based SMES is shown in Figure 4. The Output waveform is shown in Figure 5.

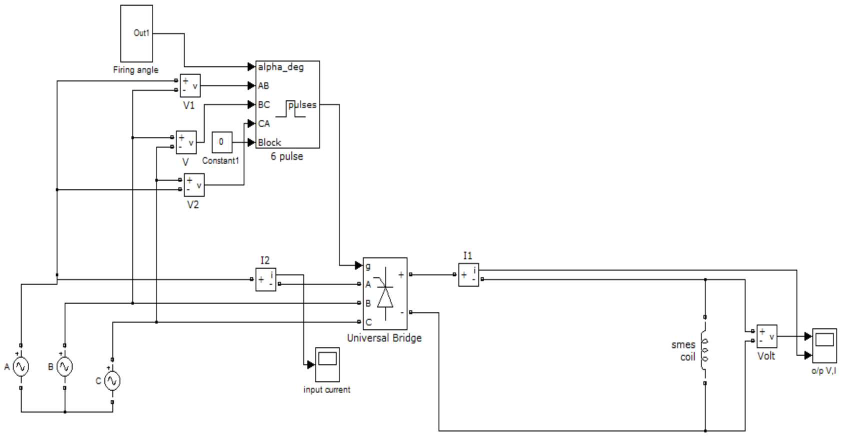


Figure 3. Circuit of thyristor based SMES using six pulse converters

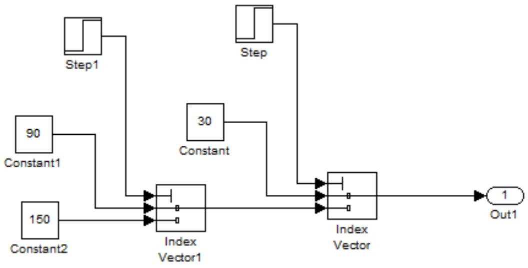


Figure 4. Firing angle circuit

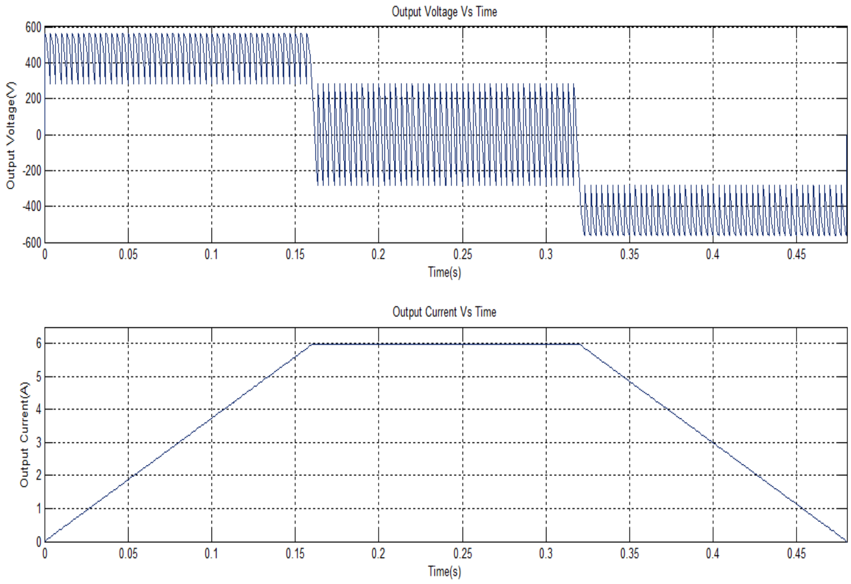


Figure 5. Output voltage and Output current for thyristor based SMES using six pulse converters

3.3. Simulation of Thyrister based SMES using Twelve Pulse Converter

The Thyristor based SMES using Twelve Pulse Converter is simulated in MATLAB/Simulink as shown in Figure 6. The SMES coil is charged from t=0*s* to t=0.16*s* by applying the Firing angle α=30^0. The SMES current is maintained constant from t=0.16*s* to t=0.32*s* by applying the Firing angle α=90^0. The SMES coil is discharged from t=0.32*s* to t=0.48*s* by applying the Firing angle α=150^0. The Output Waveform is shown in Figure 7.

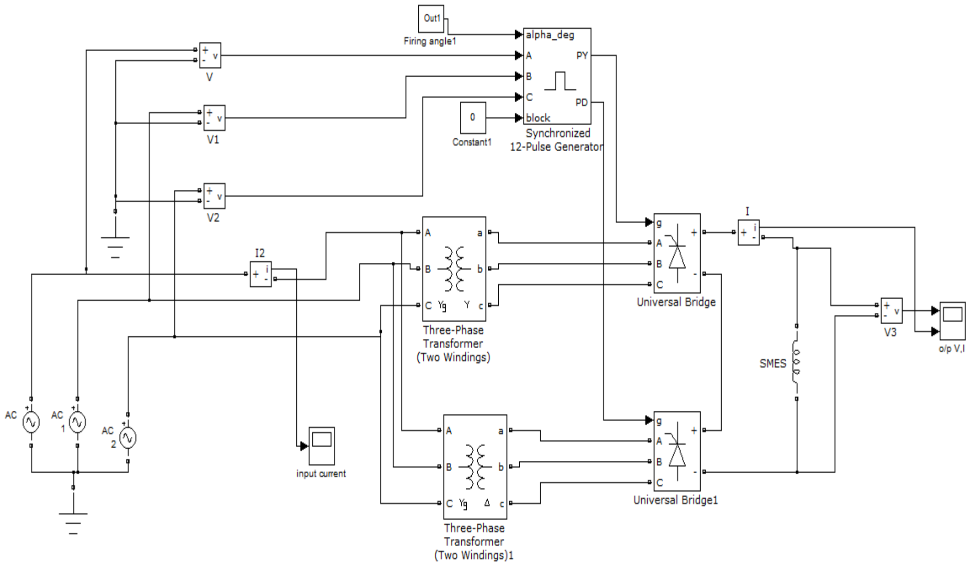


Figure 6. Circuit of thyristor based SMES using twelve pulse converters

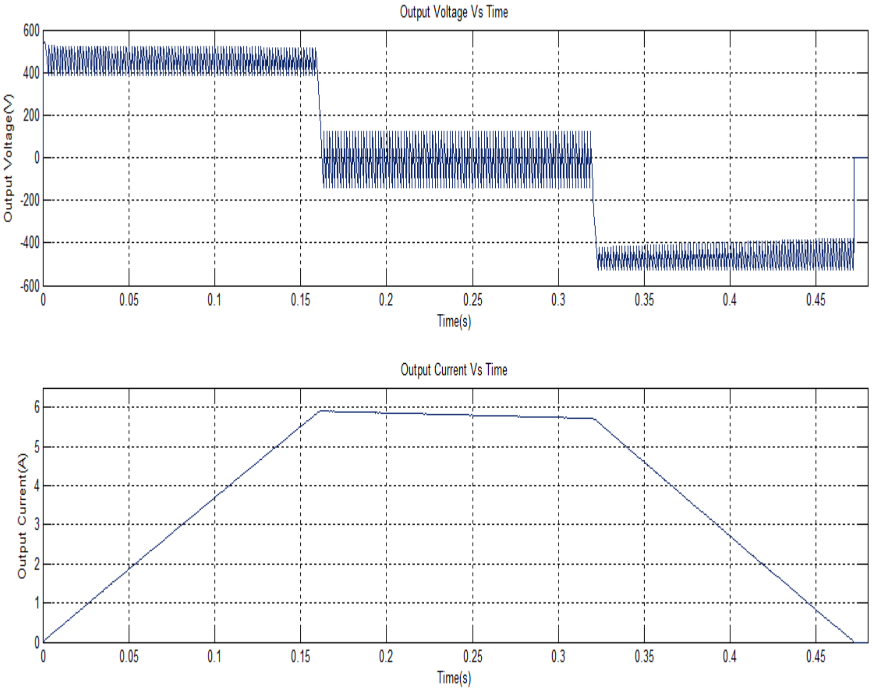


Figure 7. Output voltage and Output current for thyristor based SMES using twelve pulse converters

4. VOLTAGE SOURCE CONVERTER BASED SMES

In SMES systems, Voltage Source Converter (VSC) based PCS is one of the power conditioning systems that handles the power transfer between the SMES and the ac system. The VSC-based SMES can control both active and reactive powers independently and simultaneously. Therefore, while the applications in which reactive power or both active and reactive power controls are required, the VSC-based SMES is used [7]. Figure 8 shows the basic configuration of the VSC-based SMES unit, which consists of a Wye-Delta transformer, a six-pulse pulse width modulation (PWM) rectifier (or) inverter using insulated gate bipolar transistor (IGBT), a two-quadrant dc-dc chopper using IGBT, and a superconducting coil or inductor [5]. The PWM converter and the dc-dc chopper are linked by a dc link capacitor. The PWM VSC provides a power electronic interface between the ac power system and the superconducting coil [8-11].

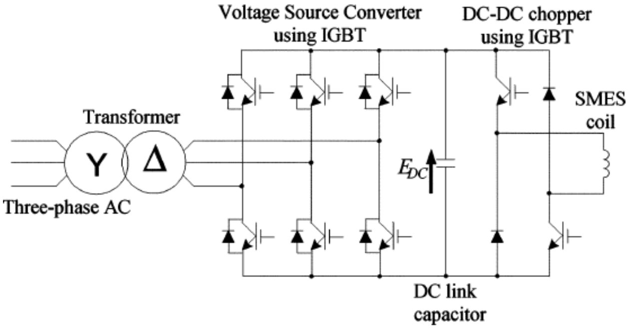


Figure 8. Basic configuration of VSC-based SMES system

- The Superconducting coil is charged or discharged by a two- quadrant dc-dc chopper (Class D Chopper). In Class D chopper voltage changes are both positive and negative, but the current is maintained constant.
- The dc-dc chopper is controlled to supply positive (IGBT is turned ON) or negative (IGBT is turned OFF) voltage to SMES coil and then the stored energy can be charged or discharged. Therefore, the superconducting coil is charged or discharged by adjusting the average voltage across the coil which is determined by the duty cycle of the two-quadrant dc-dc chopper.
- When the duty cycle is larger than 0.5 or less than 0.5, the stored energy of the coil is either charging/ discharging.
- In order to generate the PWM gate signals for the IGBT of the chopper, the reference signal is compared with the triangular signal.

4.1. Simulation of Voltage Source Converter Based SMES

Modeling of Voltage Source Converter based SMES have two important circuits:

- Control Circuit
- Chopper Circuit

The VSC based SMES is simulated in MATLAB/Simulink as shown in Figure 9. The control circuit of VSC is shown in Figure 10 and the chopper circuit is shown in Figure 11.

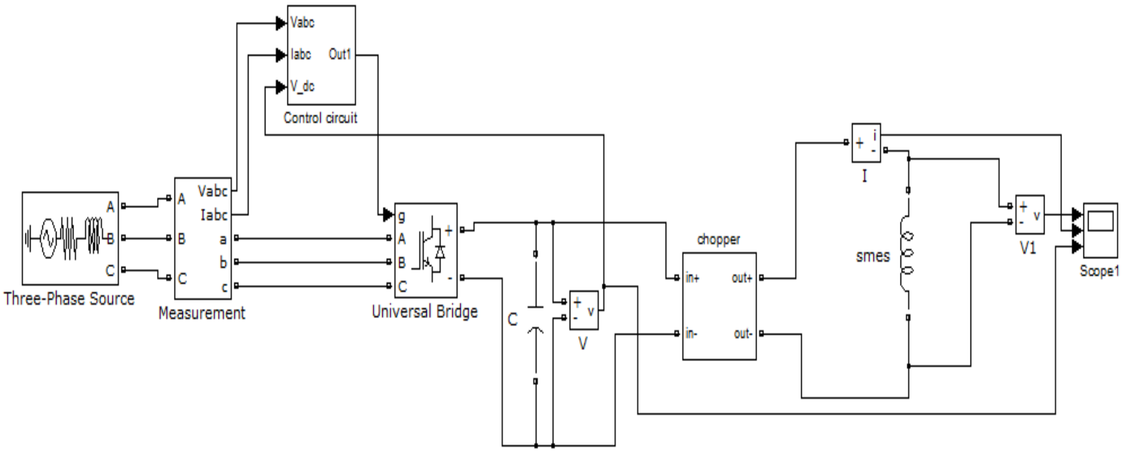


Figure 9. VSC based SMES

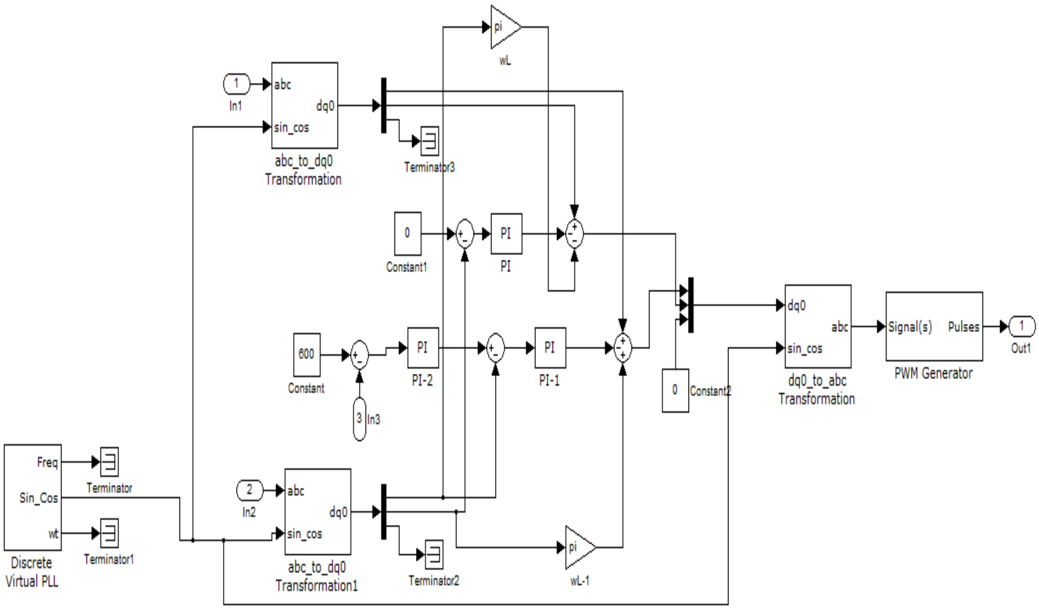


Figure 10. Control circuit

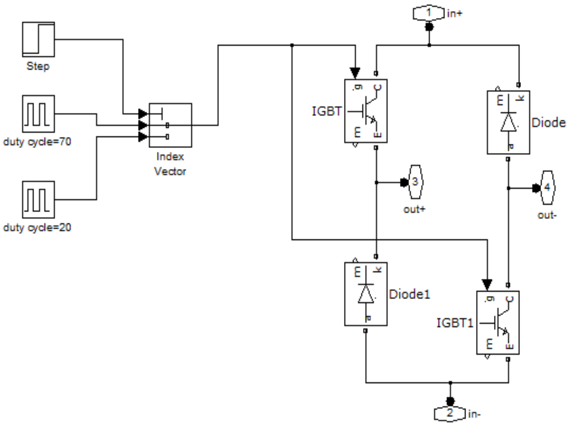


Figure 11. Chopper circuit

4.2. Result Analysis of VSC Based SMES

The VSC based SMES is simulated and the results are obtained. The SMES coil is charged from t=0*s* to t=0.65*s* by applying the duty cycle of chopper as 70%. The SMES is fully charged when t=0.4*s* and the constant current flows through the SMES coil. The SMES coil is discharged at t=0.65*s* by applying the duty cycle of chopper as 20%. The Voltage across SMES, Current through SMES and Voltage across VSC is shown in Figure 12. The Voltage across SMES, Current through SMES and Voltage across VSC during charging is shown in Figure 13. The Voltage across SMES, Current through SMES and Voltage across VSC during discharging is shown in Figure 14. The Voltage across SMES, Current through SMES and Voltage across VSC after discharging is shown in Figure 15.

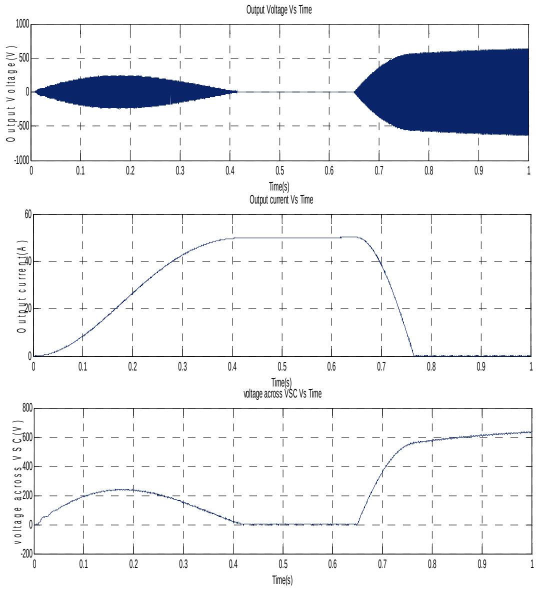


Figure 12. Voltage across SMES, current through SMES, voltage across VSC

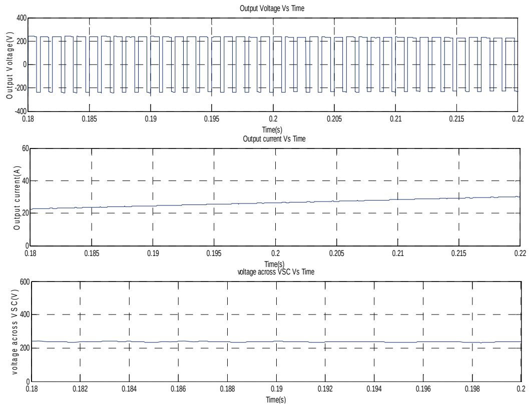


Figure 13. Voltage across SMES, current through SMES, voltage across VSC during charging

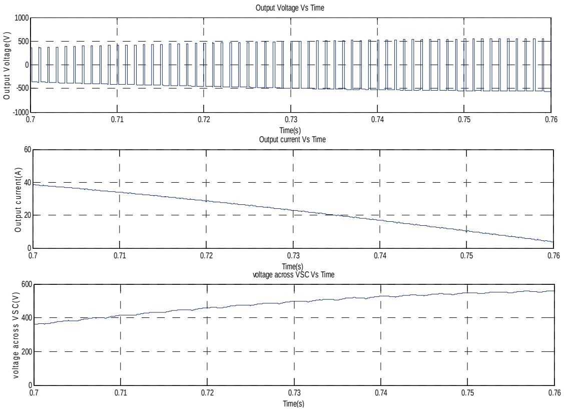


Figure 14. Voltage across SMES, current through SMES, voltage across VSC during discharging

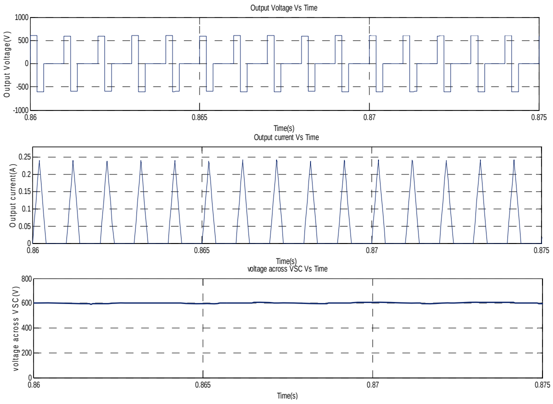


Figure 15. Voltage across SMES, current through SMES and Voltage across VSC after discharging

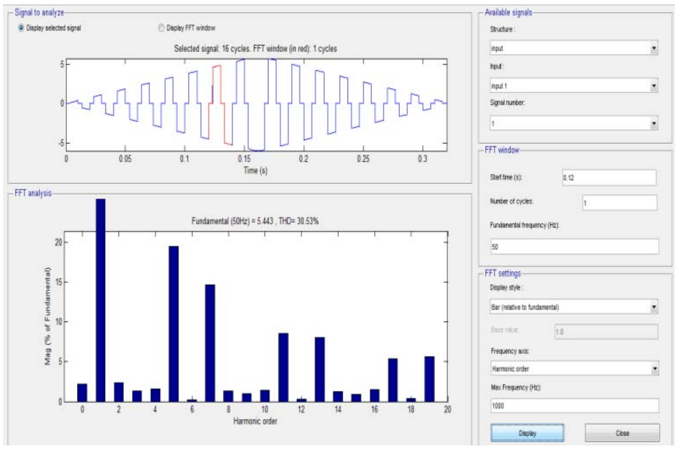
5. COMPARISON BETWEEN SMES TOPOLOGIES

The comparison between SMES topologies is done in terms of Total Harmonic Distortion (THD), Real and Reactive Power Control Ability, Control Structure and Power Handling Capacity.

5.1. Based on the Total harmonic Distortion (THD)

The FFT analysis is done for Thyristor based SMES and Voltage Source Converter based SMES. The THD of Thyristor based SMES using Six Pulse Converter is shown in Figure 16. The THD of Thyristor based SMES using Twelve Pulse Converter is shown in Figure 17. The THD of Thyristor based SMES using Voltage Source Converter is shown in Figure 18.

From the analysis, it is clear that the Total Harmonic Distortion of Thyristor based SMES using six pulse converter (30.53%) is much higher than Thyristor based SMES using twelve pulse converter (13.66%). Also, the Total Harmonic Distortion of Thyristor based SMES using twelve pulse converter (13.66%) is much higher than voltage source converter based SMES (0.07%).Therefore, VSC based SMES is much better than other power conditioning circuits.

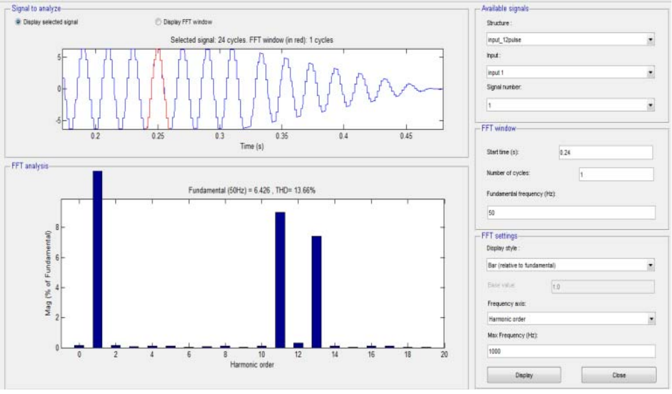


Selected signal: 16 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 5.443 , THD= 30.53%

Structure : input
Input : input 1
Signal number: 1
Start time (s): 0.12
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order
Max Frequency (Hz): 1000

Figure 16. Harmonic spectrum and THD of thyristor based SMES using six pulse converters

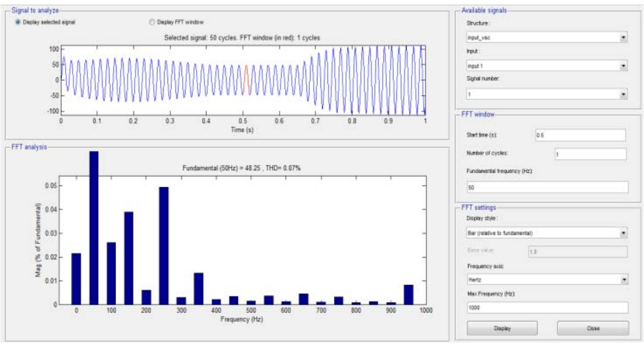


Selected signal: 24 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 6.426 , THD= 13.66%

Structure : input_12pulse
Input : input 1
Signal number: 1
Start time (s): 0.24
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order
Max Frequency (Hz): 1000

Figure 17. Harmonic spectrum and THD of Thyristor Based SMES using twelve pulse converters



Selected signal: 50 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 48.25 , THD= 0.07%

Structure : input_vsc
Input : input 1
Signal number: 1
Start time (s): 0.5
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Figure 18. Harmonic spectrum and THD of VSC based SMES

5.2. Based on the Real and Reactive Power Control Ability

- The thyristor-based SMES can control mainly the active power, and has a little ability to control the reactive power. Also the controls of active and reactive powers are not independent.
- The VSC-based SMES can control both active and reactive powers independently and simultaneously.

Thus, VSC-based SMES is suitable for controlling real and reactive power in the AC network [6].

5.3. Based on the Control Structure

- Having only AC/DC module, the thyristor based SMES is easy to control.

- The VSC based SMES includes AC/DC module, DC/DC chopper and therefore the control is complicated.

Thus, Thyristor based SMES is better for easy control.

5.4. Based on the Power Handling Capacity

The Power Handling Capacity depends on the rating of the switches which used in the converter.

- Thyristor based SMES has high power handling capacity i.e. it can absorb/inject large amount of Real power. This is because of the higher power rating of the Thyristors which are used in the Thyristor based Converter.
- VSC based SMES has low power handling capacity i.e., it can absorb/inject small amount of Real power. This is because of the lower power rating of the IGBTs which are used in the VSC.

6. CONCLUSION

The Superconducting Magnetic Energy Storage System (SMES) is modeled using various Power Conditioning Circuits (PCS) such as Thyristor based SMES (using both Six-pulse converter and Twelve-pulse converter) and Voltage Source Converter (VSC) based SMES and the power conditioning circuits are compared among them based on various criteria such as Total Harmonic Distortion (THD), Active and Reactive Power control ability, control structure and Power Handling Capability. Matlab/Simulink is used for the purpose of simulating the model of SMES.

From the comparison made, it is found that:

- Voltage Source Converter based SMES is mostly used for the power system applications such as load levelling, Voltage/VAR control and Frequency control since VSC based SMES is capable for absorbing/injecting real and reactive power.
- If the SMES is to be used as a spinning reserve, the Thyristor based SMES is suitable because the Thyristor based SMES is capable of absorbing /injecting large amount of real power.

There is room for improvement in the above simulated models. Some of them are given below:

- Current Source Converter (CSC) based SMES is another Power Conditioning Circuit (PCS) for charging and discharging the SMES. CSC based SMES can be modelled for charging and discharging of SMES.
- The integration of SMES to a Static Synchronous Compensator (STATCOM) or a unified power flow controller can be investigated.
- The impact of SMES in mitigating other transmission level problems such as transient stability, damping inter-area oscillatory modes, power quality can be studied.

REFERENCES

[1] P.G. Therond, Joly I., and Volker. M., Superconducting Magnetic Energy Storage (SMES) for Industrial Applications-Comparison with Battery Systems. *IEEE Transactions on Applied Superconductivity.* 1993; 3(1): 250-253.

[2] R.H. Lasseter and S.G. Jalali, Power Conditioning Systems for Superconductive Magnetic Energy Storage, *IEEE Transactions on Energy Conversion*, 1991; 6(3): 388-393.

[3] Toshifumi Ise, Masanori Kita, and Akira Taguchi, Hybrid Energy Storage with a SMES and Secondary Battery. *IEEE Transaction on Applied Superconductivity*, 2005; 15(2): 1915 – 1919.

[4] IEEE Task Force on Benchmark Models for Digital Simulation of FACTS and Custom-Power Controllers, T&D Committee. Detailed Modeling of Superconducting Magnetic Energy Storage (SMES) System. *IEEE transaction of Power Delivery*. 2006; 21(2): 699 – 710.

[5] Mohd. Hasan Ali, Bin Wu, and Roger A. Dougal. An Overview of SMES Applications in Power and Energy Systems. *IEEE Transaction on Sustainable Energy*. 2010; 1(1): 38 – 47.

[6] Jae Woong Shim, Youngho Cho, Seog-Joo Kim, Sang Won Min and Kyeon Hur. Synergistic Control of SMES and Battery Energy Storage for Enabling Dispatchability of Renewable Energy Sources. *IEEE Transaction on Applied Super Conductivity.* 2013; 23(3).

[7] J.J. Skiles, R.L. Kustom, K.P. Ko, V. Wong, K.S. Ko, F. Vong, and K. Klontz. Performance of a power conversion system for superconducting magnetic energy storage (SMES). *IEEE Transaction on Power Systems.* 1996; 11(4): 1718 – 1723.

[8] J. X. Jin, W. Xu, X.Y. Chen X.Y, X. Zhou, J.Y. Zhang, W.Z. Gong, A.L. Ren, Y. Xin. *Developments of SMES Devices and Potential Applications in Smart Grids*. IEEE PES ISGT ASIA. 2012; 1-6.

[9] Marcelo G. Molina. *Distributed Energy Storage Systems for Applications in Future Smart Grids.* Transmission and Distribution: Latin America Conference and Exposition (T&D-LA), Sixth IEEE/PES. 2012; 1-7.

[10] M. Gnana Prakash, *et al.*, A New Multilevel Inverter with Reduced Number of Switches. *International Journal of Power Electronics and Drive System (IJPEDS).* 2014; 5(1): 63-70.

[11] Zulkifilie Bin Ibrahim, *et al.*, Comparative Analysis of PWM Techniques for Three Level Diode Clamped Voltage Source Inverter. *International Journal of Power Electronics and Drive System (IJPEDS).* 2014; 5(1): 15-23.

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