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APPLICATION OF SMES TECHNOLOGY IN MODERN POWER SYSTEM FOR IMPROVINGPOWER QUALITY

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ABSTRACT

Superconducting Magnetic Energy Storage (SMES) systems are based on storage of electrical energy in the magnetic field in a superconducting coil. It has been controlled by PI controllers and results have been evolved. In this paper a drift comparison has shown with FLC (Fuzzy Logic Controller) technology. In addition the application of these energy storage systems implemented in the areas of distribution and some transmission systems. The Basic advantage of the SMES technology to have independent and unique operation at any circumstances likewise voltage sag, voltage swell, power factor correction tends to Reactive Power compensation. The manufacturing cost of these SMES is getting cheaper and ready for Economic consideration due to introduction of various power electronic devices. It results in a solution for micro grids, and a distributed HESS (DHESS) are presented and compared.

Index Terms: *Power Quality, SMES, Voltage Sag, Fuzzy Logic Controller, DSMES, Hybrid Energy Storage System (HESS), and Energy Storage Systems (ESS) etc.*

1. INTRODUCTION

SMES (Superconducting Magnetic Energy Storage System) is a large superconducting coil that can store energy in the form of magnetic field generated by the dc current flowing through it. The demand of electricity is constantly changing time to time. Load leveling can be achieved by storing the excessive energy of source during off-peak hour and delivering the stored energy back in peak load hour.

With the fast development of information and high-tech industries, the ratio of load sensitive to quality of power is raising the proportion more and more, which means that the modern society has the urgent needs for higher quality of power supply. To avoid those power supply accidents, compensating reactive power and absorbing active power are required eagerly, resulting in the need and exploring the suitable energy storage systems. The investigation results show that the SMES can benefit the electricity system for its quick response character, high conversion efficiency, inhibiting low frequency oscillation and voltage volatility.

II.ANALYSIS OF SMES ANDCONTROLLING ELEMENT

2.1. *Basic Principles of the SMES Systems*

An SMES device is a device that stores energy in the form of magnetic field. High temperature SMES cooled by liquid nitrogen is still in the development stage and may become a viable commercial energy storage source in the future due to its potentially lower costs. SMES systems are large and generally used for short durations, such as utility switching events**.**The superconducting coil is the core part of the SMES, and the energy storage of which is expressed as the following, equation,

$$E_{SMES} = 0.5LI^2 \quad (1)$$

Where,

E_{SMES} is the electromagnetic energy,

L- inductance of coil,
I- current through coil.
Different factors are taken into account in the design of the coil to achieve the best possible performance of an SMES system at the least cost. Factors are coil configuration, energy capability, structure, and operating temperature. compromise is made between some of the factors considering the parameters of energy/mass ratio , stray magnetic field, and minimizing the losses for a reliable, stable, and economic SMES system. The coil can be configured as a solenoid or a toroid. The solenoid type has been used widely due to its simplicity and cost effectiveness.

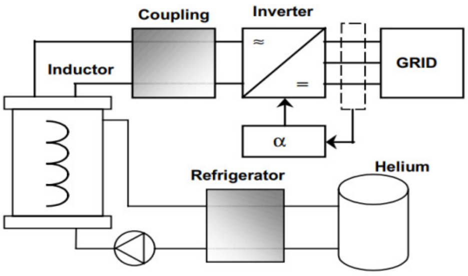

Figure 2.1: Basic Structure of SMES Unit

2.2 Practical usage of SMES:

They are, Induction heating, Fault current Limiter, Superconducting power cables, Superconducting Power Transformer ,Rotating electrical machines with superconducting windings, Cryo-machines and electrical machines with massive superconductors, Super conducting magnetic energy storage system (SMES), Magnetohydrodynamicgenerators(MHD), Electrodynamic Laviation (e.g, high speed trains), Particle accelerator (detector magnets, beam guidance magnets) and Synchrotron radiation sources.

2.3 Applications of SMES:

a. *Bulk energy management*
b. *Transient voltage dip improvement*
c. *Dynamic voltage stability*
d. *Energy storage*
e. *Load following*
f. *Under frequency load shedding reduction Circuit breaker reclosing Power quality improvement*
g. *System stability*
h. *Automatic Generation Control*
i. *Spinning reserve*
j. *Reactive volt-ampere (VAR) control and power factor Correction*
k. *Black start capability*
l. *Tie line control*

2.4. Fuzzy Logic Controller

FLC is based on human thinking and decision making quality that uses natural language to define its rules. It provides an effective means of capturing the approximate, inexact nature of the real world It was first proposed by Lotfi Zadeh, Professor at University of California in 1965 as away to process imprecise data.Zadeh thought process behind Fuzzy Logic was “Attempt to mimic human control logic”. He used fractions, partial membership instead of crisp set, Boolean, true/false. Some basic designs of fuzzy sets and fuzzy operations are given below in [fig:4.2.1].

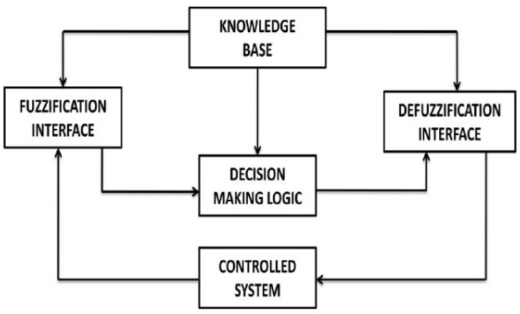

Figure 4.2.1: Block Diagram of FLC

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III. PRINCIPLEOF OPERATION

3.1. *Principle of Operation*

The source current is the sum of load current and inverter current. The source current can be represented as,

$$I_s = I_l \pm I_i \qquad (1)$$

Where,

I_S= Source Current
I_l= Load current
I_i = inverter current

The output current of inverter is,

$$\mathbf{I_i = f\,(I_o\,,D,M\,)(2)}$$

Where,

I_o - SMES coil current
D - Duty cycle of the dc/dc converter
M - Modulation index of inverter

Amore comprehensive model of power electronics switches and resistive losses will be represented in the simulation and will be naturally included in the laboratory representation. The performance of the system with the voltage tolerance on capacitor voltage and current tolerance on the source current is carried out. When the superconducting coil is being charged, the voltage across the capacitor will be reduced by,

$$\mathbf{V_{dc}(t + \Delta t) = V_{dc}\,(t) - (\tfrac{Is(t)}{c})\,\Delta t \qquad (3)}$$

Where is the capacitor Voltage (V), C is the capacitance (F), and inductor that is the current in the increases to a value of

$$\mathbf{I_S\,(t + \Delta t) = I_S\,\,(t) + (\,\tfrac{Vs-Vdc(\,t\,)}{Ls}\,)\,\Delta t \qquad (4)}$$

When the superconducting coil discharges its energy, the voltage across the capacitor builds up to,

$$\mathbf{V_{dc}(t + \Delta t) = V_{dc}\,(t) + (\tfrac{Is(t)}{c})\,\Delta t \qquad (5)}$$

And current in the inductor decreases to a value of

$$\mathbf{I_S\,(t + \Delta t) = I_S\,\,(t) + (\,\tfrac{Vs-Vdc(\,t\,)}{Ls}\,)\,\Delta t \qquad (6)}$$

During current build up, i.e., source current increasing toward the upper-band value,

$$I_o\,(t + \Delta t) = I_o\,\,(t) - \,(\,\tfrac{Vdc(\,t\,)}{L}\,)\,\Delta t \qquad (7)$$

The capacitor voltage will be increased,

$$V_{dc}(t + \Delta t) = V_{dc}\,(t) + (\tfrac{Io(t)}{c})\,\Delta t \qquad (8)$$

Similarly, when the upper band is reached, the current will now start to reduce toward the lower band; the value of the source current then becomes and capacitor voltage will be decreased

$$I_o\,(t + \Delta t) = I_o\,\,(t) + \,(\,\tfrac{Vdc(\,t\,)}{L}\,)\,\Delta t \qquad (9)$$

The power flow under load leveling is shown in [fig 3.1].

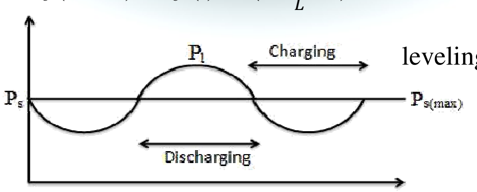

Figure 3.1: Operation of PCS under Load Leveling

With increase in load , source power increases with load to its maximum and coil discharges to make energy balance between source, load and SMES. In this entire operation dc link voltage is kept constant.
The maximum demand that can be delivered by the supply can now be controlled. Under load leveling condition the source current charges the coil when load power is less then source power.

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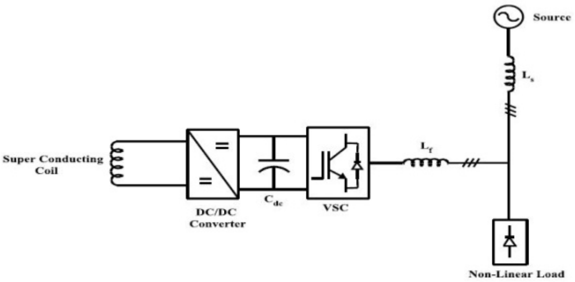
3.2 System Topology:

The topology of the system which is being studied is presented in [fig 3.2.1]. It consists of a supply network with a source supplying a nonlinear load and SMES is connected to the network through
Power Conditioning system (PCS) at the PCC. According the configuration of PCS, SMES is broadly divided into two types , VSC based SMES and CSC based SMES.
During standby condition one of the switches is 'ON' and current circulates between that switch and one diode.



3.2.1 Proposed System Topology

The switching of this is controlled to get a constant dc-link voltage. Here, VSC is a six-pulse conventional full bridge converter. IGBT anti-parallel with a diode is used as the switch to get bidirectional current.

IV CONTROLLER STRATEGY

4.1 Hysteresis Band Controller

Several linear as well as nonlinear control techniques are there to control the required physical quantity that is mostly the current. Different PWM techniques are mostly used where the reference is compared with a high frequency carrier wave. But Hysteresis controller has emerged as a robust nonlinear controller which is simple and can be easily implemented. Other advantages are

(i) Unconditional stability
(ii) Fast dynamic response
(iii) Good accuracy
(iv) Low cost

Despite of these advantages it exhibits several unsatisfactory features. The main one is that it produces switching pulses of varying switching frequency. This creates major problems in designing the input filter and unwanted resonances in the input side and produces acoustic noise.

Fig shows the conventional hysteresis band current control scheme used for the control of the source current. It composed of a hysteresis around the reference source current. The reference source current is referred to as **Is*** and actual source current is referred to as **Is**. The switching logic is formulated as follows:

If **is** < (i_s^*- **HB**) upper switch is OFF and lower switch is ON for leg "a": **(SA=l).**
If **is** > (i_s^*+ **HB**) upper switch is ON and lower switch is OFF for leg "a": **(SA=O)**.

The switching frequency of the hysteresis band current control method depends on how the current changes from upper limit of the hysteresis band to the lower limit of the hysteresis band. The switching frequency of the system depends on the capacitor voltage and the line inductances.

In this paper both the VSC and DC/DC bidirectional converter are controlled by simple Hysteresis band controller. It is a nonlinear controller. [Fig: 4.1] shows the controller diagram of VSC which is to control the source current. The difference between actual and reference source current is given as input to hysteresis controller that generates switching pulses for VSC. Whenever the error reaches the upper boundof hysteresis band the upper switch becomes 'ON' and when it touches lower bound lower switch becomes 'ON'.
The switching is controlled by hysteresis controller to regulate the dc link voltage. The error between reference and instantaneous dc link voltage is fed to hysteresis controller to generate switching pulses of both the switch.

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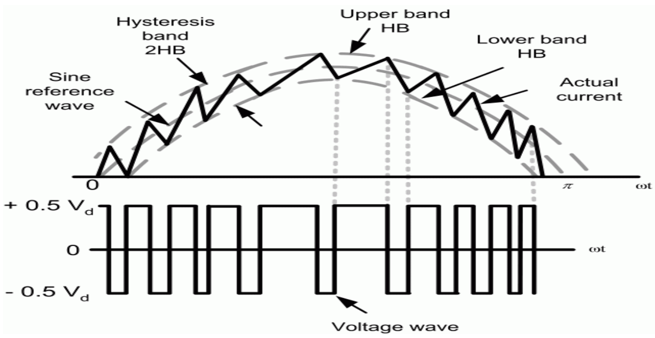

Figure 4.1: Operation of Hysteresis Band Controller

4.2 Fuzzy Logic Controller

FLC is a set of linguistic control rules. It is based on human thinking and decision making quality that uses natural language to define its rules. Conventional linear controller linearizes the nonlinear system to an approximate model that does not guarantee satisfactory performance. Non-linear controllers are developed, but they require accurate mathematical model of the system which is difficult to achieve for a complex nonlinear system. Hence, fuzzy logic controller is preferred as it does not require accurate mathematical model of the system. FLC incorporates four basic things

(i) Fuzzification Interface
(ii) Knowledge Base
(iii) Decision Making Logic
(iv) Defuzzification

It performs a scale mapping which converts the fuzzy output variables to the corresponding universe of discourse. Here, a two input one output Fuzzy Logic controller with 49 rules is implemented. Error and change in error between the reference and actual SMES energy are taken as input and change in magnitude of reference current is taken as output .

4.3 Control Strategy

For load leveling and current-harmonics filtration operations the SMES is controlled. It is a constant dc current source that is controlled to meet the required demand of active and reactive power independently and simultaneously. The amount of energy received by SMES depends directly on the magnitude source current increases and it gets charged; when source current decrease SMES current decrease and it discharges under the period of off-load source supplies power to load as well as the SMES so that the coil gets charged. In peak-load hour source current increases with the increase in load up to its maximum value and the additional active power demand is supported by SMES as it discharges. After charging the current in the coil remains constant at its rated value, called standby period where no energy is consumed or delivered by the coil except the loss due to circulatingcurrent.

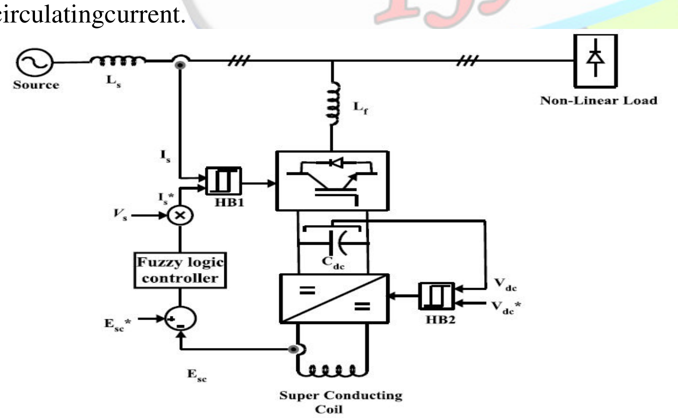

Figure 4.3.1: Proposed control strategy

To control SMES energy during charging and discharging a FLC is used. It maintains the SMES instantaneous energy at its reference value. FLC has been introduced in this paper to get better performance. It has been proved that fuzzy Logic controller has fast response, small overshoot and better stability in comparison to PI controller. Also design of controller is less complex in FLC as it requires authentic modeling rather exact mathematical modeling of the system.

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The error in actual and reference SMES energy is fed to FLC to get change in magnitude of reference source current as the output as shown in [fig 4.3.2].This magnitude of reference source current is then multiplied with the unit vector of line to neutral source voltage to get reference source current. Difference in actual and reference source current is then compared and given to hysteresis controller to get switching pulses for IGBTs of VSC

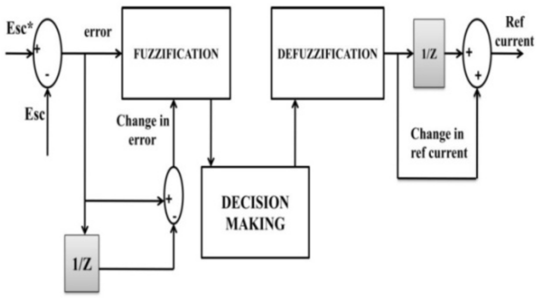

Figure 4.3.2: Proposed Fuzzy Controller

Instantaneous dc-link voltage is compared with reference dc-link voltage to make the dc-link voltage constant, and fed to hysteresis band controller of a tolerance limit of 0.11%.

V. SIMULATION AND RESULTS

5.1 Simulation Results:

The proposed power system has been simulated using MATLAB/Simulink. Performance of the control system is presented for each mode of SMES. A three phase star connected source of 400V rms voltage is used to supply power to a nonlinear load that is a three phase six pulse diode rectifier. For energy storage, a 1Henry SMES coil rated with 100A, 5 KJ is connected with the supply system. Initially the coil is charged when source current, whose maximum value is 50A, is more than load current, which is 20A. Hence, SMES is charged in voltage controlled mode. SMES gets fully charged in 0.33 sec and current in the coil becomes steady at 100A. At this instant source current decreases and becomes nearly equal to load current. At 0.6 sec load demand is increased up to 60A and SMES starts discharging. Source current also increases up to its maximum value that is 50A which is less than the load demand. So, the extra demand of the load is fulfilled by SMES.

In all three modes source current is made in phase with line-neutral source voltage and SMES acts as a shunt active power filter. Total Harmonics Distortions of source current in all cases are shown in the figures individually. The responses of SMES coil current and voltage, source voltage, source current, load current and dc-link voltage are shown in below figures. Firstly, simulation is performed using PI controller to control the source current by controlling SMES energy. The desired responses are shown in [fig: 5.1.1-5.1.8].

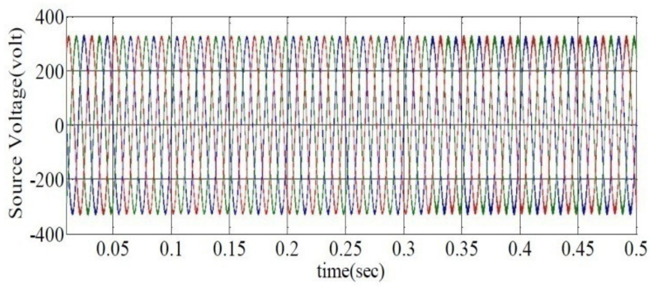

Figure 5.1.1: Variation of source voltage with time using FLC

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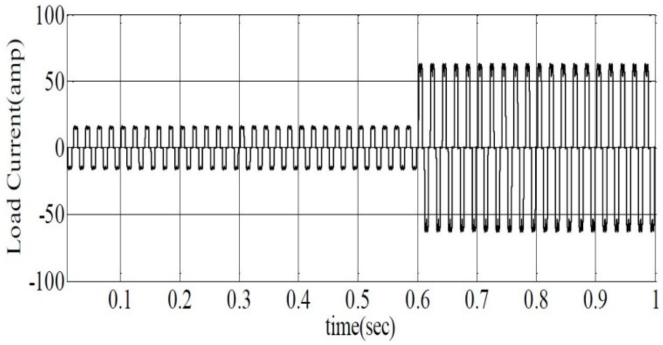

Figure 5.1.2: Variation of load current with time. At 0.6 sec there occurs a change in load which increases the load current

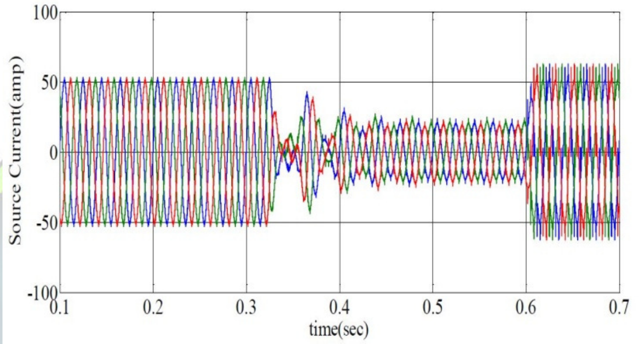

Figure 5.1.3: Variation of source currents in all the phases with time using Fuzzy controller. At 0.32 sec it decreases as the coil gets fully charged and at 0.6 sec it reaches its maximum when load demand increases.

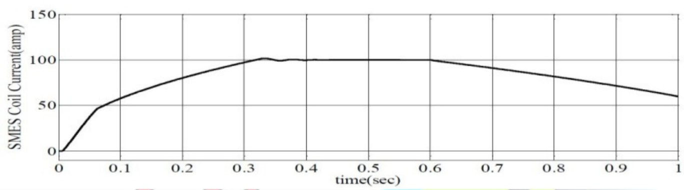

Figure 5.1.4: Variation of SMES coil current with time using fuzzy controller. At 0.32 sec SMES coil gets fully charged with current 100A and it discharges at 0.6 sec when load current increases.

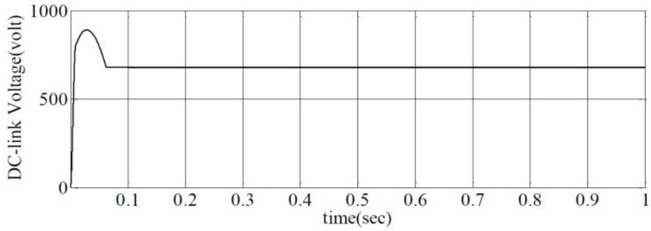

Figure 5.1.5: Variation of dc-link voltage with time using Hysteresis controller.

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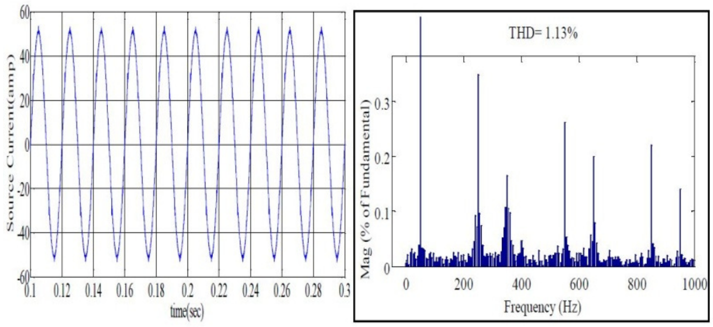

Figure 5.1.6: THD in source current in charging mode of SMES using Fuzzy controller

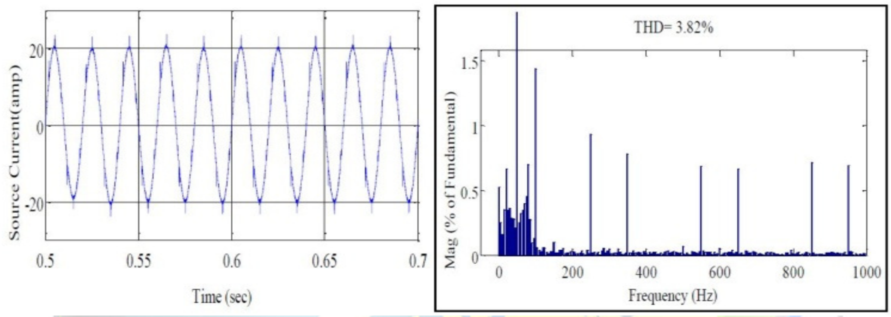

Figure 5.1.7: THD in source current in stand-by mode of SMES using Fuzzy controller

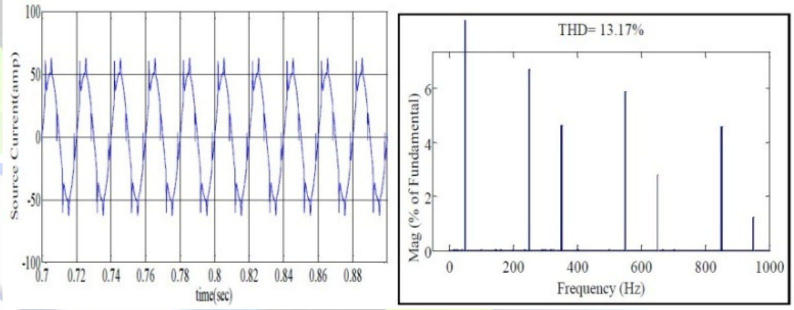

Figure 5.1.8: THD in source current in discharging mode of SMES using Fuzzy controller

The performance in terms of THD count of both PI and Fuzzy controllers are compared and enlisted in the following [table: 5.1].

MODE OF operation of SMES	THD obtained in source current using PI controller	THD obtained in source current using Fuzzy controller
Charging	1.26 %	1.11 %
Standby	10.58 %	3.82 %
Discharging	13.51 %	13.17 %

Table 5.1: Comparison of THD between PI and Fuzzy controller in different modes of operation of SMES

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5.2. Future Scope

Several energy storage types and their technical development, application foreground, advantages and disadvantages have been presented in this paper.

Compared to other energy storages, SMES has better performances, firstly, the current density of SMES coil can be 100 times higher than the common coil, and the SMES coil carrying current operates at cryogenic temperature having virtually no resistive losses. Secondly, SMES can enhance power system stability and improve the power quality through active and reactive power compensation because of its high conversion efficiency and fast reaction speed. The major

Benefits of the SMES are:

1. *High energy-storage efficiency,*
2. *Fast energy charge (in a few milliseconds) and discharge capability, and*
3. *Independent controllability of active and reactive power.*

Although it's practical development and commercial applications are still to be achieved, progresses in the applications will be made in near future along with the development of HTS technology. Typical application of super capacitors in power grid is shown . C_{sc} represents combination of capacitor units, which absorb and release energy necessarily by the two-wayDC/DC converter through C_{dc}. The energy storage Equation is

$$E = 0.5CU^2 \qquad (2)$$

Where,

E is the electromagnetic energy,
C is capacitance of super capacitors,
U is voltage of super capacitors.

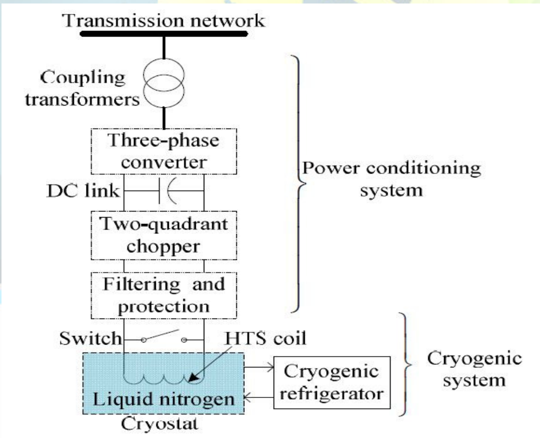

Figure 5.1. A SMES system.

(2) Application in photovoltaic power generation:

The combined PV/SMES system is shown in below fig5.2. The PV generation system and the SMES system are joined by a common bus which is connected to the utility grid. The following results are obtained with (without) the modulation by PV/SMES system. power generated by the SMES system can be able to well smooth out PV power fluctuations, resulting that the combined PV/SMES output is dispatched with free of fluctuations.

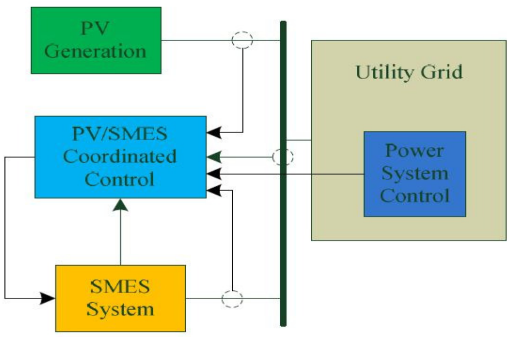

Figure5.2. Schematic diagram for the combined PV/SMES system.

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VI. CONCLUSION AND DISCUSSION

The results and analysis given above shows that the complete cycle of SMES that is charging, stand by and discharging can be controlled along with the sinusoidal nature of source current irrespective of load conditions by using Fuzzy logic controller. Then the results were shown as the THD obtained in Fuzzy controller is less. In case of charging mode of SMES THD are below IEEE standard, which is 5%. But during standby mode THD in Fuzzy controller is within 5%.The discussion above finally concludes that, overall performance of Fuzzy Logic controller is satisfactory. Load leveling, the primary function of SMES is obtained quite satisfactorily, even the operation of harmonics elimination of SMES using FL is unsatisfactory in discharging mode

Regarding controlling mechanism the THD in discharging mode can be lowered by a better design of fuzzy controller using optimization techniques to make an adaptive Fuzzy system. The range of membership function of input variables in Fuzzy controller can also be optimized to get more accuracy. This problem can be avoided by the use of Adaptive hysteresis controller in which the switching frequency is kept constant and the hysteresis band is varied accordingly. Further improvements can be done by increasing the level of DC/DC converter and controlling its switching using PWM controller so that harmonics can be minimized.

VII. REFERENCES

[1] W. V. Torre and S. Eckroad, "Improving power delivery through the application of superconducting magnetic energy storage (SMES)," in *Proc. IEEE Power Eng. Soc. Winter Meeting*, vol. 1, 2001, pp. 81–87.
[2] I. D. Hassan, R. M. Bucci, and K. T. Swe, "400 MW SMES power conditioning system part-1 performance requirement and configuration," *IEEE Conference on Power Electronics Specialists* Jun 1991 page no: 338-344.
[3] Mohd. Hasan Ali, Bin Wu *and* Roger A. Dougal, "An Overview of SMES Applications in Power and Energy Systems," *IEEE* Transactions on Sustainable Energy, vol. 1, no. 1, april 2010
[4] *R W Boom and H A Peterson,* "Superconductive Energy Storage for Power Systems". IEEE *Trans. Magnetics,* MAG-8, *No. 3, pp 701 - 703, 1972.*
[5] M. H. Ali, W. Bin, and R. A. Dougal, "An overview of SMES applications in power and energy systems," IEEE Transactions on Sustainable Energy, vol. 1, no. 1, pp. 38-47, April 2010.
[6] Xin Zhou, Xiao Yuan Chen, Jian Xun Jin *"Development of SMES Technology and Its Applications in Power Grid"* IEEE International Conference, December 14-16, 2011.
[7] P. M. Balasubramaniam and S. U. Prabha "*Power Quality Issues, Solutions and Standards: A Technology Review" Journal of Applied Science and Engineering, Vol. 18, No. 4, pp. 371_380 (2015)*
[8] Dr.Paulo Ribeiro, Dr.Yilu Liu, Aysen Arsoy *"Transmission Power Quality benefits Realized by a SMES-FACTS Controller"* 0-7803-6499-6/00/$10.00 2000IEEE.
[9] R. E. Kalman and N. DeClaris. Ed. New York: Holt, Rinehart and Winston, "towards a theory of Fuzzy Systems," in *Aspect of Network and System Theory,* 1971, pp. 469-490.
[10]J D Rogers etal."*30-MJ Superconducting Magnetic Energy Storage System for Electric Utility Transmission Stabilization"*, Proc. IEEE, Vol. *71, NO. 9,pp 1099-1107.1983*
[11] SMSchoenung, WVHassenzahlandPGFilios, "*US ProgramtoDevelop Superconducting Magnetic Energy Storage."* Proc. of 23rd Inter Society Energy Conversion Engineering Conference Vol. 2, pp 537440,1988.
[12] D. Casadei, G. Grandi, U. Reggiani, and G. Serra, *"Analysis of a power conditioning system for superconducting magnetic energy storage (SMES),"* in Proc. IEEE Int. Symp. Industrial Electronics (ISIE'98), vol. 2, 1998, pp. 546–551.
[13] L. A. Zadeh, "Fuzzy sets," *Informat. Control,* vol. 8. pp. 338-353. 1965.
[14] E. H. Mamdani, "Applications of fuzzy algorithms for simple dynamic plant." *Proc. IEE,* vol. 121. no. 12. pp. 1585-1588. 1974. [15] E. H. Mamdani, "Advances in the linguistic synthesis of fuzzy controllers," *Int. J . Man Mach. Studies.* vol. 8, no. 6, pp. 669-678, 1976.
[16] E. H. Mamdani, "Application of fuzzy logic to approximate reasoning using linguistic synthesis," *IEEE Trans. Computer,* vol. C-26, no. 12, pp. 1182-1 191. 1977