IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. IV (Jan – Feb. 2015), PP 23-29
www.iosrjournals.org

System for Better Synchronism in DFIG Wind Energy Conversion System Using SMES Energy Storage

Pallavi Date,[1] Joydeep Sarkar,[2]
[1]*PG Student, Electrical Power System, MCOERC, Nashik*
[2]*Asst. Professor, Department of Electrical Engineering, Sandip Foundation's SIEM, Nashik*

Abstract: *The use of Wind Energy for Electrical Power generation has increased considerably over past few decades and emphasis is continuously given for its integration with power grids. It has been found difficult to keep doubly fed induction generator (DFIG) connected to grid under various dynamic conditions like Fault, etc. One of the most important parameters of the system where wind turbine generators (WTGs) are connected is voltage profile at the point of common coupling (PCC). Superconducting magnetic energy storage (SMES) can improve the dynamic performance of a wind turbine equipped with DFIG during voltage sag and swell events. The converter and the chopper of the SMES unit are controlled using a hysteresis current controller (HCC) and a fuzzy logic controller (FLC), respectively. Detailed simulation will be carried out using MATLAB/SIMULINK software to highlight the impact of the SMES unit in improving the overall system performance under voltage profile.*

Keywords: *DFIG, Dynamic system, SMES, TSO, PCC, HCC, FLC*

I. Introduction

The limited amount and high demand for energy resources will affect the rise in oil prices from time to time. Therefore, attention is directed now onto the renewable energies which are clean and abundantly available in the nature [1]. Connection of power generation system includes WTGs installation and their connection. The doubly fed induction generator (DFIG) is one of the most popular variable speed wind turbine generators.

WTGs were disconnected from the grid during faults at the grid side to avoid any possible damages to wind turbines. DFIG is very sensitive to grid faults, where, even though the DFIGs are connected far away from the grid, the grid faults will influence the voltage profile at the PCC. During grid fault, voltage drop at the DFIG terminal, high current flow at both grid and rotor side converters, and high voltage across the dc link capacitor may lead to converter station blocking. This condition will be ended by the disconnection of the DFIG from the system. Most of the studies about the DFIG are concerned about the improvement of its FRT capability during voltage sag [5-6]. No attention however is given to improve the DFIG performance under voltage sag and voltage swell conditions using the same controller. Power quality issue is the common consideration for new construction or to the existing power system. In this paper, voltage dip (sag) and swell will be considered as the conditions of the fault ride through capability of WTG equipped with DFIG. This review & analysis presents an application of the SMES unit to improve the performance of a wind turbine equipped with DFIG during voltage sag and voltage swell at the grid side. A new control system for the SMES unit based on hysteresis current control in conjunction with fuzzy logic control is proposed. Results are analyzed to highlight the improved dynamic performance of WECSs in conjunction with the SMES unit.

II. System Under Study

There are two major classifications of wind turbine generator, fixed-speed turbine and variable-speed turbines. A doubly fed induction generator (DFIG) uses a medium scale power converter. Slip rings are making the electrical connection to the rotor. If the generator is running super-synchronously, electrical power is delivered to the grid through both the rotor and the stator.

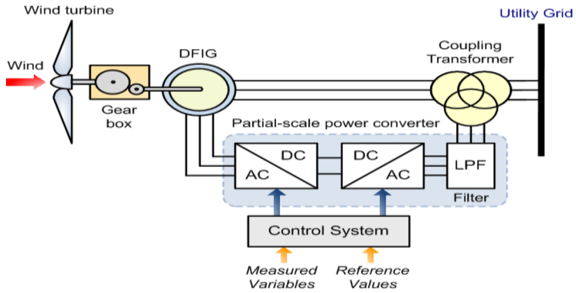


Fig 1- Typical configuration of an individual DFIG.

If the generator is running sub-synchronously, electrical power is delivered into the rotor from the grid. The stator winding of the generator is coupled to the grid, and the rotor winding to a power electronic converter, nowadays usually a back-to-back voltage source converter with current control loops. In this way, the electrical and mechanical rotor frequencies are decoupled, because the power electronic converter compensates the different between mechanical and electrical frequency by injecting a rotor current with variable frequency. Variable speed operation thus became possible. The typical of generic model of DFIG is shown in figure:

The system under study shown in Fig-2 consists of six-1.5 MW DFIG connected to the AC grid at PCC via Y/_ step up transformer. The grid is represented by an ideal 3-phase voltage source of constant frequency and is connected to the wind turbines via 30 km transmission line. For an average wind speed of 15 m/s which is used in this study, the turbine output power is 1 p.u. and the generator speed is 1.2 pu. SMES Unit is connected to the 25 KV (PCC) bus and is assumed to be fully charged at its maximum capacity of 1 MJ.

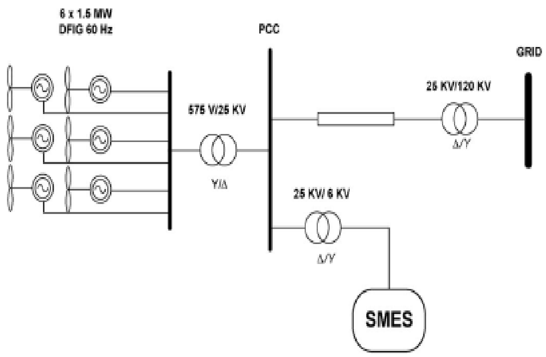


Fig 2 - System under study [1]

Rated Power	9 MW
Stator Voltage	575 V
Frequency	60Hz
Rs	0.023
Rr	0.016
Vdc	1150V

Table 1 - Parameters of the transmission line [1]

III. Smes Configuration And Control

The selection of SMES Unit in this paper is based on its advantages over other energy storage technologies. Compared to other energy storage options, the SMES unit is ranked first in terms of highest efficiency which is 90-99% [9-10]. The high efficiency of the SMES unit is achieved by its lower power loss because electric currents in the coil encounter almost no resistance and there are no moving parts, which means no friction losses. SMES stores energy within a magnetic field created by the flow of direct current in a coil of superconducting material. Typically, the coil is maintained in its superconducting state through immersion in liquid helium at 4.2 K within a vacuum – insulated cryostat. A power electronic converter interfaces the SMES to the grid and controls the energy flow bi-directionally. The stored energy in the SMES coil can be calculated as:

$$E = 0.5*L_{SMES}*I^2_{SMES}$$

Where, E is the SMES energy; I_{SMES} is the SMES Current and L_{SMES} is the SMES inductor coil. The SMES unit configuration used in this paper consists of voltage source converter (VSC) and DC-DC chopper which are connected through a DC shunt capacitor. The VSC is controlled by a hysteresis current controller (HCC) while the DC-DC chopper is controlled by fuzzy logic controller (FLC) as shown in Fig 3.

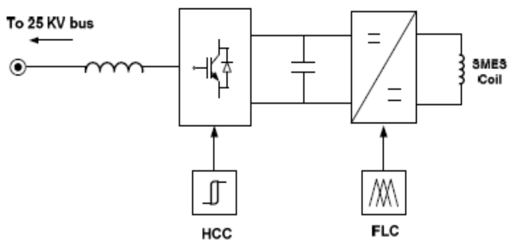


Fig 3- SMES configuration [1]

DC-DC Chopper along with FLC is used to control charging and discharging process of the SMES coil energy. The generator active power and the current in the superconductor coil are used as inputs to the fuzzy logic controller to determine the value of the DC chopper duty cycle, active power of DFIG and SMES coil current are used as inputs of the fuzzy logic controller. The duty cycle (D) is compared with 1000 Hz saw-tooth signal to produce signal for the DC-DC chopper as can be seen in Fig 4. [1]

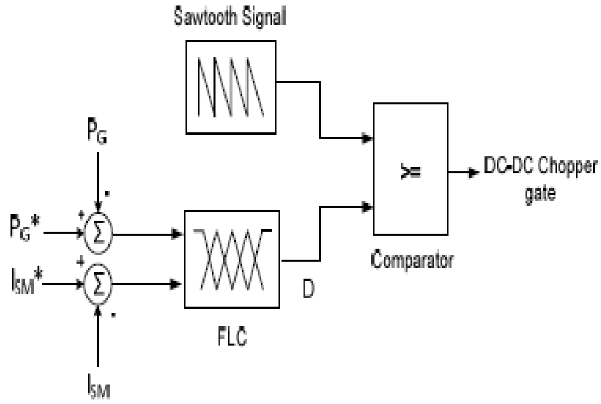


Fig 4- Control algorithm of DC-DC chopper.

a) Hysteresis Current Controller

Compared with pulse width modulation (PWM) technique, the hysteresis band current control has the advantage of ease implementation, fast response, and it is not dependent on load parameters. Hysteresis current control (HCC) is used to control the power flow exchange between the grid and the SMES unit. HCC is comparing the 3-phase line currents with the reference currents (I_d* and I_q*).

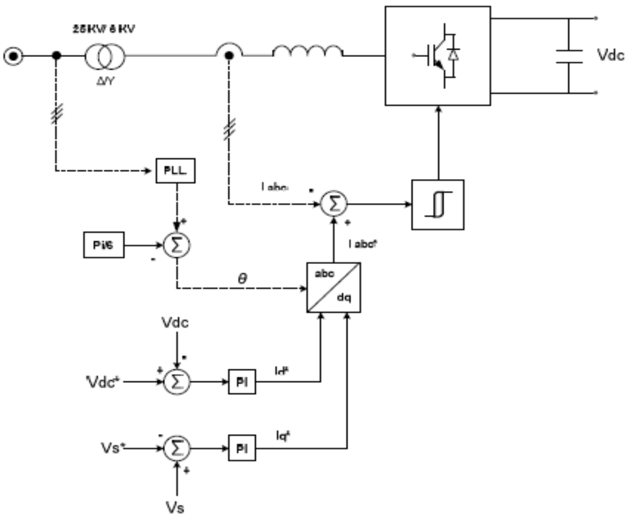


Fig 5 - Control scheme of VSC [1]

The value of I_d* and I_q* are generated through the conventional PI controller both from the deviation of the capacitor voltage V_{dc} and system voltage V_s. These value is converted through Park transformation (dq0 − abc) to produce the reference current range of the SMES coil. To minimize the effect of phases interference while maintaining the advantages of the hysteresis methods, phase-locked loop (PLL) technique is applied to limit the converter switching at a fixed predetermined frequency [11].

b) Fuzzy Logic Controller

To control power transfer between the SMES coil and the ac system, a dc–dc chopper is used, and fuzzy logic is selected to control its duty cycle (D).The FLC is a process of formulating the mapping from a given input to the designated output. Input variables for the model are the real power generated by the DFIG and the SMES coil current. The output of the FLC is the duty cycle (D) for a class-D dc–dc chopper that is shown in Fig. 5(a). The V –I operational range for the SMES coil is shown in Fig 5(b). The duty cycle determines the direction and the magnitude of the power exchange between the SMES coil and the ac system, as presented in Table II.

Duty cycle(D)	SMES coil action
D=0.5	Standby condition
0≤D<0.5	Discharging condition
0.5<D≤1	Charging condition

Table II- Rules of Duty Cycle [1]

If the duty cycle (D) is equal to 0.5, no action will be taken by the coil, and the system is under normal operating conditions. Under this condition, a bypass switch that is installed across the SMES coil, which will be closed to avoid the draining process of SMES energy during normal operating conditions.

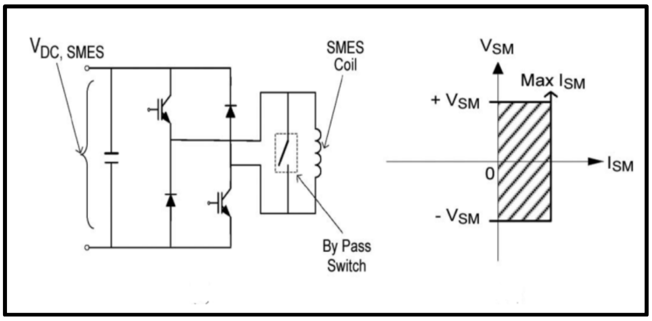
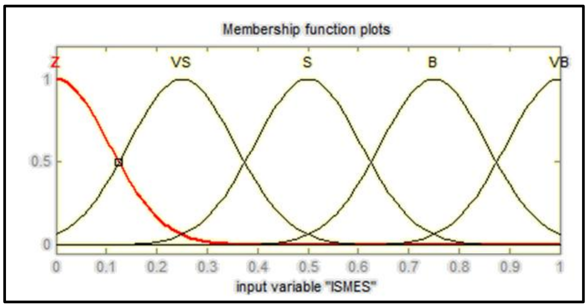
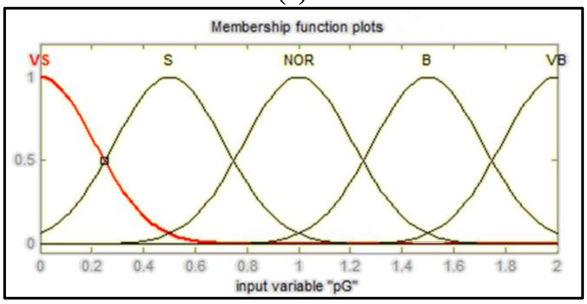


Fig 6: Type D-chopper and its quadrant operation [1].

The bypass switch is controlled in such a way that it will be closed if D is equal to 0.5; otherwise, it will be opened. When the grid power is reduced, D will be reduced accordingly to be in the range of 0–0.5, and the stored energy in the SMES coil will be transferred to the ac system.



(a)



(b)

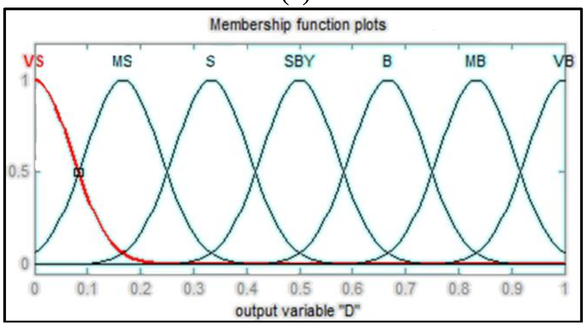


Fig 7: Plot of I_{smes}, P_g, output of D.

The charging process of the SMES coil takes place when D is in the range of 0.5–1. The relation between VSMES and VDC, SMES can be written as:

$$V_{smes} = (1\text{-}2D)V_{dc.smes}$$

Where, V_{smes} is the average voltage across the SMES coil, D is duty cycle, and $V_{dc.smes}$ is the average voltage across the dc-link capacitor of the SMES configuration.

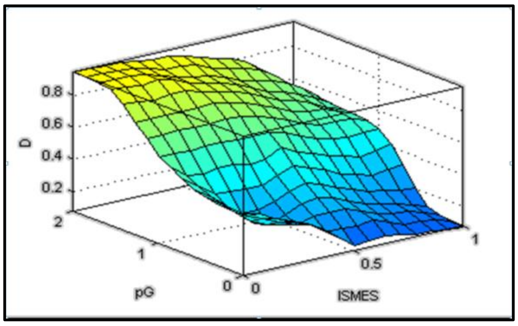


Fig 8- Surface Graph

IV. Simulations Result

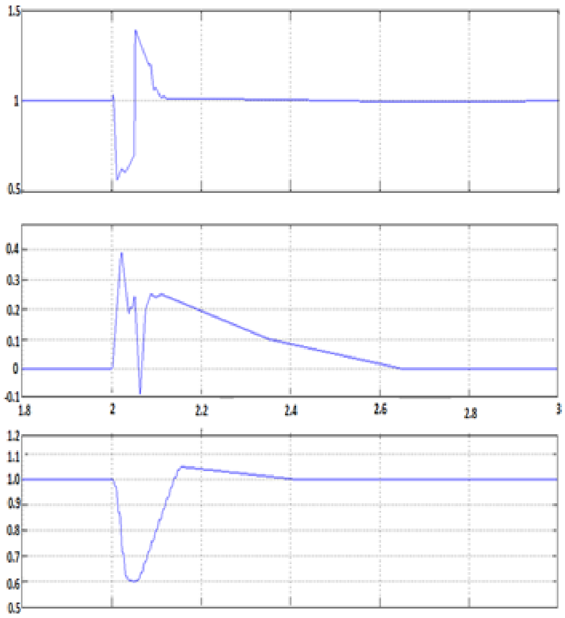
The voltage dip at the grid side complies with the low voltage ride through (LVRT) while the voltage swell at the grid side is examined to comply with the high voltage ride through (HVRT). Voltage dip is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 minute. Voltage dips are usually associated with system faults but can also be caused by switching of heavy loads or starting of large motors. A swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 minute. Typical magnitudes are between 1.1 and 1.8 pu.

Rated Energy	1MJ
L_{smes}	0.5H
I_{smes}	2000A

Table III- Parameters of the SMES Unit

a) Without SMES

A voltage sag depth of 0.5pu lasting for 0.05 s is applied at t = 2 s at the grid side of the system under study [Fig. 3]. Without the SMES unit, the real power produced by the DFIG will drop to 0.6 pu, and it reaches a maximum overshooting of 40% during the clearance of the fault, as shown in Fig 9(a). The voltage at the PCC is shown in Fig. 9(c), where without SMES, voltage will drop to 0.6 pu. The DFIG power drop causes the generator speed to be accelerated to compensate for the power imbalance. As can be observed in Fig. 9(d), the generator speed will accelerate and oscillate without the SMES unit.



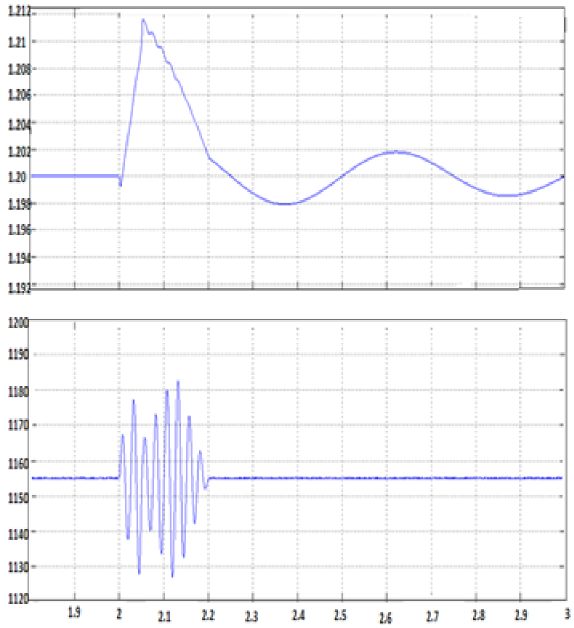
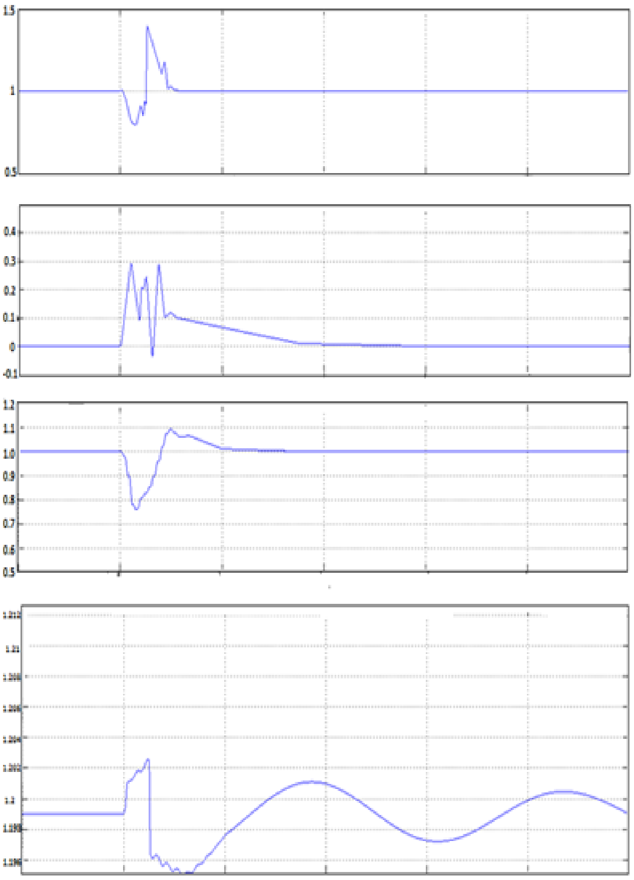


Fig 9: DFIG responses during voltage sag without SMES: (a) Active power. (b) Reactive power. (c) PCC voltage. (d) Shaft speed. (e) Voltage at the dc-link of the DFIG.

b) With SMES

As can be seen in Fig 10(a), with the SMES unit connected to the system, the DFIG output power will drop to only 0.875 pu. Fig. 10(b) implies that, with the connection of the SMES unit and during the event of voltage sag, the reactive power support by the DFIG is reduced, and the steady-state condition is reached faster, compared to the system without SMES.



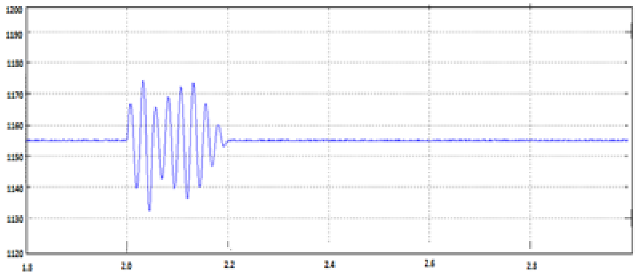


Fig. 10: DFIG responses during voltage sag with SMES :(a) Active power. (b) Reactive power. (c) PCC voltage. (d) Shaft speed. (e) Voltage at the dc-link of the DFIG.

However, by connecting the SMES unit, voltage drop at the PCC will be reduced to only 0.8 pu, which will lead to a voltage drop at the generator terminal to a level of 0.8pu, which is referenced as safety margin by the wind turbine manufacturers. With the SMES connected to the system, the power drop is reduced, the settling time of the generator speed is substantially reduced, and the overshooting level is significantly decreased. Another effect of the voltage sag on the DFIG's behavior is on the voltage across the DFIG dc link capacitor that is shown in Fig. 10(e). The voltage overshoot across the dc-link capacitor during fault clearance is slightly reduced with the SMES unit connected to the system

V. Conclusion

Application of the SMES unit to improve the transient response of WTGs equipped with DIFG during voltage sag has been proposed. Simulation results have shown that the SMES unit is very effective in improving the dynamic performance of a power system with wind turbine equipped with DFIG during voltage sag at the grid side. DFIG must be disconnected from the power system to avoid the turbines from being damaged. However, using the proposed converter and chopper of the SMES unit which are controlled using a hysteresis current controller (HCC) and a fuzzy logic controller (FLC), respectively, both the VRT capability of the DFIGs can significantly improve and their connection to the grid can be maintained to support the grid during faulty condition and to ensure the continuity of power supply.

Refernces

[1]. A.M.Shiddiq Yunus, Mohammad A. S. Masoum, A. Abu-Siada, "Application of SMES to Enhance the Dynamic Performance of DFIG During Voltage Sag and Swell, IEEE Transactions on Applied Superconductivity, Vol. 22, No. 4, August 2012

[2]. M. Tsili and S. Papathanassiou, ―A review of grid code technical requirements for wind farms, IET Renew. Power Gener., vol. 3, Sep. 2009

[3]. M. Altin, O. Goksu, R. Teodorescu, P. Rodriguez, B. B. Jensen, and L. Helle, "Overview of recent grid codes for wind power integration," in Proc. 12th Int. Conf. OPTIM, 2010, .

[4]. J. Lopez, E. Gubia, E. Olea, J. Ruiz, and L. Marroyo, "Ride through of wind turbine with doubly fed induction generator under symmetrical voltage dips," IEEE Trans. Oct. 2009.

[5]. Mohseni, Islam, and Masoum, "Impacts of symmetrical and asymmetrical voltage sags on DFIG-based wind turbines considering phase-angle jump, voltage recovery, and sag parameters," IEEE Trans, May 2011.

[6]. Rogers, Boenig, Schermer, and Hauer, "Operation of the 30 MJ superconducting magnetic energy storage system in the Bonneville Power Administration electrical grid," IEEE Trans. Mar. 1985.

[7]. Ali, Bin, and Dougal, "An overview of SMES applications in power and energy systems," IEEE Trans. Sustainable Energy, vol. 1, April 2010.

[8]. Ali, Minwon, Y,In-eun, J.Tamura" Improvement of wind-generator stability by fuzzy-logic-controllers SMES" IEEE.May-Jun.2009.

[9]. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu, "Energy storage systems for advanced power applications," Proc. IEEE, vol. 89, Dec. 2001.

[10]. Prasad; Maheshwar Rao, Sri Hari, " Design and simulation of a fuzzy logic controller for buck and boost converters" IJATER Journal.

[11]. Molina, Mercado, "Power flow stabilization and control of microgrid with wind generation by superconducting magnetic energy storage," IEEE Trans. Mar. 2011.

[12]. L. Malesani and P. Tenti, "A novel hysteresis control method for current-controlled voltage-source

[13]. PWM inverters with constant modulation frequency," Industry Applications, IEEE Transactions on, 1990.