

# Voltage Stabilization of A Hybrid System Using D-STATCOM with Super-Conducting Magnetic Energy Storage

M. Jeevan<sup>1</sup>, Prof. Subadhra P.R<sup>2</sup>

P.G. Student, Department of Electrical & Electronics Engineering, Govt. Engineering College, Thrissur, Kerala, India<sup>1</sup>

Assistant Professor, Department of Electrical & Electronics Engineering, Govt. Engineering College, Thrissur, Kerala,, India<sup>2</sup>

**ABSTRACT:** This paper discusses on the use of the integrated model of D-STATCOM with SMES-Super Conducting Magnetic Energy Storage system for the Voltage Stabilization of a hybrid power source which is connected to a low power distribution grid. At present we are not able to tap the renewable energy sources to its full efficiency. Researches are going on in order to improve the quality of materials used and the interconnection equipments. In this paper the integrated model of D-STATCOM and SMES is used to mitigate the voltage instabilities of the hybrid system developed. The system has been modeled in MATLAB/Simulink, with the help of Simpower Systems toolbox, tested for various conditions and verified.

**KEYWORDS:** SMES-Super Conducting Magnetic Energy Storage, D-STATCOM-Distribution Static Compensator, WECS-Wind Energy Conversion System, PV-Photovoltaic..

## I. INTRODUCTION

Growing demand for electric energy highlights the significance of renewable energy utilization. So we are trying to tap all forms of energy, i.e., renewable and non-renewable. But we haven't yet obtained the full efficiency on converting these energy sources into useful forms of energy, i.e., electrical energy. Among various renewable sources, solar power happens to be the foremost contender because of its availability, abundance and pollution free nature[1]. Also power quality and reliability is an issue which is gaining significant attention[2]. Practically wind energy systems are the most used ones. The modeling and the construction of a wind farm are also a topic of research even now, since we are not able to capture the wind energy[3][4]. The renewable sources such as wind power and photovoltaic power are combined to form a hybrid source. But the renewable energy is not available all the day[5]. There is a need to use many power electronic converters and inverters in the system in order to integrate it to the distribution grid. The solar and wind power systems themselves are inherited of many non-linearities along with the non-linearities of the power converters which makes the system more unstable. In [6][7] a model for the inhibitions of the harmonic and the voltage stability problems are given with a simple SRF control of D-STATCOM. To mitigate the voltage stability problems and frequency problems of the hybrid power plant when integrated with a low power distribution grid we use D-Statcom with a SMES[10][11]. By integrating SMES with the D-Statcom the total MVA capacity of the D-Statcom can be reduced to some extent and so the switching losses of the device can be reduced.

## II. HYBRID SYSTEM CONFIGURATION

The hybrid system comprises of a PV array and a WECS wind energy conversion system along with power electronic converters. The single line diagram of the system to be explained is given in fig.1. Photo voltaic array is modeled by eqn(1), which includes the ideal diode equation and a standard current source[1].

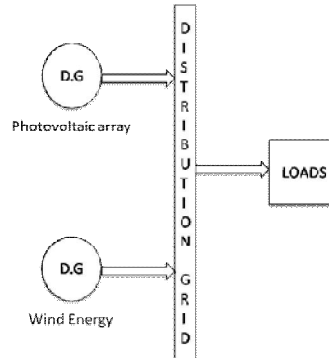


Fig.1. Single line diagram of the proposed system

$$I = I_{pv,cell} - I_d = I_{pv,cell} - I_{0,cell} \left[ e^{\left(\frac{qV_t}{akT}\right)} - 1 \right] \quad (1)$$

Where,  $I_{pv}$  and  $I_0$  are the photovoltaic (PV) and saturation currents, respectively of the array and  $V_t = N_s kT/q$  is the thermal voltage of the array with  $N_s$  cells connected in series. If the array is composed of  $N_p$  parallel connections of cells the PV and saturation currents may be expressed as  $I_{pv} = I_{pv,cell} N_p$ ,  $I_0 = I_{0,cell} N_p [1]$ .

Wind energy have been tapped and used for various activities by mankind since time immemorial. In this paper a Permanent Magnet Synchronous Generator model is used having low maintenance cost. It can operate at low speeds, and no external excitation is required over the other models [3]. A simple model is considered here. The model is based on the steady-state power characteristics of the turbine. The output power of the turbine is given by the following equation.

$$P_{tur} = \frac{1}{2} \rho \pi R^2 V^3 C_p(\lambda, \beta) \quad (2)$$

Where,

$P_m$  is the mechanical output power of the turbine (W)

$C_p$  is the performance coefficient of the turbine

$\rho$  is the air density( $\text{kg/m}^3$ )

$A$  is the turbine swept area

$V_{wind}$  is the wind speed(m/s)

$\lambda$  is the tip speed ratio of blade tip speed to wind speed

$\beta$  is blade pitch angle (deg)

Eqn(2) expresses the relationship between performances of the air flow and of the wind turbine, i.e. the efficiency of the wind turbine, in dependence on the wind speed or on the tip speed ratio of the turbine. From the value of the rotational motion performance, it is possible to determine the value of the torque acting on the shaft as given in eqn(3).

$$T_w = \frac{\frac{1}{2} \rho \pi R^2 V^3 C_p(\lambda, \beta)}{\omega_m} \quad (3)$$

Where,

$\omega_m$  is the generator speed of the WECS

$T_w$  is the torque produced by the wind turbine

. Aerodynamic control has considerable impact on the performance coefficient and on the value of the turbine torque. During the modeling of this controller, it is very important to take into account that changes of the blades angle must be fluent with a finite rate, maximal 10 degrees per second[5], depending on the size of the wind turbine. The structure of the aerodynamic controller, is shown in Fig.2 .

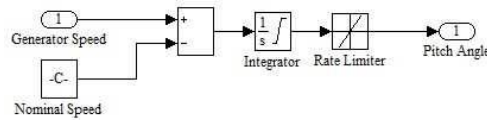


Fig.2.Model of Aerodynamic Control

The basic parameters set is formed by the nominal generator speed, the rate of pitch angle change and by the maximal and minimal value of this angle.

### III. D-STATCOM-SMES

A distribution static compensator (DSTATCOM) is a voltage source inverter (VSI)-based power electronic device. Usually, this device is supported by short-term energy stored in a DC capacitor[6]. When a D-STATCOM is associated with a particular load, it can inject compensating current so that the total demand meets the specifications for utility connection. Also, it can also clean up the voltage of a utility bus from any unbalance and harmonic distortion[7]. Block diagram of a D-Statcom based on Voltage source inverter is shown in fig.3.

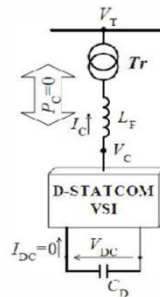


Fig.3.Block diagram of a D-STATCOM[6]

A SMES device is a dc current device that stores energy in a magnetic field. The dc current flowing through a superconducting wire in a large magnet creates the magnetic field[8]. The inductively stored energy (E in Joule) and the rated power (P in Watt) are the commonly given specifications for these devices and they can be expressed as follows:

$$E = \frac{1}{2} LI^2 \quad (6.1)$$

$$P = \frac{dE}{dt} = LI \frac{dI}{dt} = VI \quad (6.2)$$

Where, L is the inductance of the coil, I is the dc current flowing through the coil, and V is the voltage across the coil.

Any large magnet can store energy, and the relationship between the volumetric energy density ( $E_v$  in J/m<sup>3</sup>) and magnetic field intensity (B in Tesla) is given by

$$E_v = \int B \cdot dH = \frac{B^2}{2\mu\mu_0} \quad (6.3)$$

Where,

$B = \mu H$ ,  $\mu$  is the average relative magnetic permeability and  $\mu_0$  is permeability of free space.

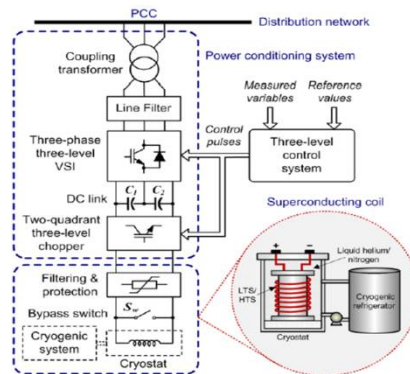


Fig.4 General components of the proposed SMES unit.

General components of a SMES is shown in fig.4. The PCS consists of an ac/dc converter and incorporates a dc/dc converter as interface with the SMES coil. The control of SMES is based on the state-space averaging method, a three-level control scheme, comprising of a full decoupled current control strategy in the synchronous-rotating  $d-q$  reference frame with a controller to prevent the voltage drift/imbalance of the inverter dc bus capacitors. The proposed control scheme of the SMES unit consists of an external, middle and internal level. Its design is based on concepts of instantaneous power on the synchronous-rotating  $d-q$  reference frame [9]. The three level control scheme for SMES is shown in fig.5

#### A. External Level Control

The external level control, is responsible for determining the active and reactive power exchange between the SMES and the distribution grid. The design of this control loop in the rotating reference frame is simpler than using stationary frame techniques, and employs a standard proportional-integral (PI) compensator. A voltage regulation droop  $R_d$  of typically 5 % is included in order to allow the terminal voltage of the VSI to vary in proportion with the compensating reactive current and thus, a PI controller with droop characteristics becomes a simple phase-lag compensator, resulting in a stable fast response compensator.

The FCM aims at controlling the microgrid frequency through the modulation of both, the reactive component of the output current  $i_q$  (as a conventional var compensator) and the active component  $i_d$  (case of a SMES) and is the highest-priority control mode. In order to control the set point of  $i_q$ , the lower-priority VCM is used, i.e. the voltage reference signal  $V_r$ , is adjusted with a stabilizing voltage signal proportional to  $\Delta f$  which directly represents the power oscillation of the power system. This newly added signal enables the output quadrature current of the VSI  $I_q$  to vary around the operating point defined by reference signal  $V_r$ . In this way, the voltage at the PCC is forced to decrease when frequency deviation  $\Delta f$  is positive aiming at reducing the transmitted power through the distribution system and thus providing an effective fast-acting voltage reduction reserve which opposes the deceleration of generators in the microgrid.

#### B. Middle level control scheme

The middle level control makes the positive sequence components of  $i_d$  and  $i_q$  to dynamically follow the reference values set by the external level controller. Here both the components of the SMES voltage source inverter output current through the synchronous angular speed of the grid voltage at the fundamental frequency are cross coupled. Therefore, in order to achieve a fully decoupled active and reactive power control it is simply required to decouple the control of  $i_d$  and  $i_q$  and two conventional PI controllers are used for this purpose.

#### C. Internal level control scheme

The internal level provides a dynamic control of the input signals for the DC/AC and DC/DC converters. This level generates the triggering/firing control signals for the VSI, according to the Sinusoidal Pulse Width Modulation Techniques (SPWM).

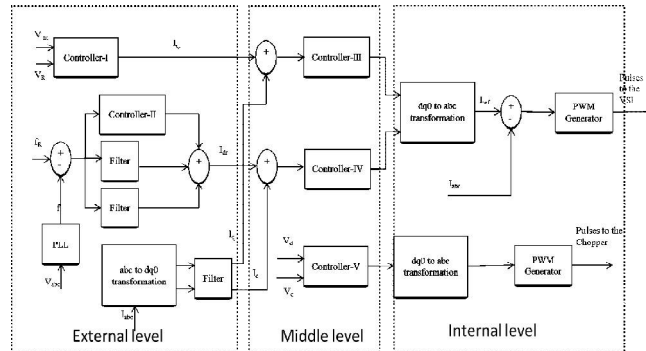


Fig.5.Three level Control scheme for SMES

In SPWM technique, output voltage reference waveform which is obtained from the middle level controller is compared with the triangular waveform generated by the carrier generator. These states are decoded by the states-to-pulses decoder for getting the corresponding firing pulse.

#### IV. EXPERIMENTAL RESULTS

A complete power network comprising of PV array and WECS together with D-STATCOM-SMES is modeled in Matlab/Simulink. The simulation model of the system is given in fig. The datasheets needed for the simulation studies are given in table 1 and table 2.

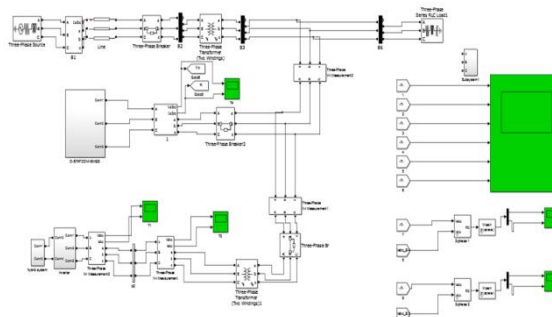


Fig.6.Simulation Diagram of the hybrid system Integrated to the grid through D-STATCOM and SMES

Table.1 gives the datasheet of a practical PV array of 200W. The design data for the SMES coil and its control data are given in table.2. Table .3 gives the design data for the wind energy conversion system. A hybrid system of 8700W is developed and connected to the low power distribution grid of 400V. A circuit breaker is used between the SMES system and the distribution system, so that the simulation of the hybrid system can be carried out with and without the SMES. This will be useful in the comparison studies.

The simulation of the system with the SMES system disconnected is performed first. It is seen from fig.7. that the distribution system voltages are about 400 Volts and from the waveforms we can see that they are distorted. By running the Fast Fourier Transform analysis it is seen that the total harmonic distortion of the system is about 170% on average.

Table.1.Parameters Of The Kc200gt Solar Array At 25 °C, A.M1.5, 1000 W/M<sup>2</sup>

Parameters	Values and Units
$I_{mp}$	7.61 A
$V_{mp}$	26.3 V
$P_{max,m}$	200.143 W
$I_{sc}$	8.21 A
$V_{oc}$	32.9 V
$a$	1.3
$K_v$	-0.1230 V/K
$K_t$	0.0032 A/K
$R_p$	415.405 $\Omega$
$R_s$	0.221 $\Omega$
$N_s$	54

Table.2. Smes coil and control data

SMES COIL DATA

# Sng	$L_i$ (H)	$M_i$ (H)	$C_2$ ( $\mu$ F)	$C_{10}$ ( $\mu$ F)	$X_{sc}$ ( $\Omega$ )	$R_{sc}$ ( $\Omega$ )	$C_{S1}, C_{S2}$ ( $\mu$ F)	$R_{S1}, R_{S2}$ (k $\Omega$ )	$C_f$ ( $\mu$ F)
6	4.67	1.12	0.006	0.237	0.024	2.55	0.5	13.5	3.5

SMES CONTROLLER DATA

Middle level data			
$K_p, K_{p2}$	$K_i, K_{i2}$	$K_{v2}$	$K_{t2}$
3.5	12	0.01	65

External Level Data																						
$K_{p1}$	$K_i$	$R_c$	$R_s$	$K_s$	$T_1, K_{t1}$	$T_2$	$K_{m1}, C, E$	$K_c, D$	$R_{e1}$	$K_{p2}$	$K_c, K_{c2}$	$T_{i1}, T_{i2}$	$T_{s1}$	$T_{s2}$	$T_{m1}, T_{m2}$	$T_{s3}$	$K_{m2}, K_{c2}$	$T_{L2}$	A	B		
3.0	35	0.05	1.0	1.2	6.7	0.7	80	125	250	3.0	30	0.13	0.16	0.19	0.022	0.018	0.022	32	67	-1.76e-3	1.274	1.79e-2

Table .3. Datasheet for WECS

Parameter	Values and units
Air Density	1.205 kg/m <sup>3</sup>
Rotor radius	38 m
Rated wind speed	12 m/s
Maximum Cp	0.4412

The behavior of the hybrid system without using SMES system is analyzed for different conditions of temperature, irradiation and wind speeds. The system under consideration comprises of six buses of which the hybrid system is connected in fifth one.

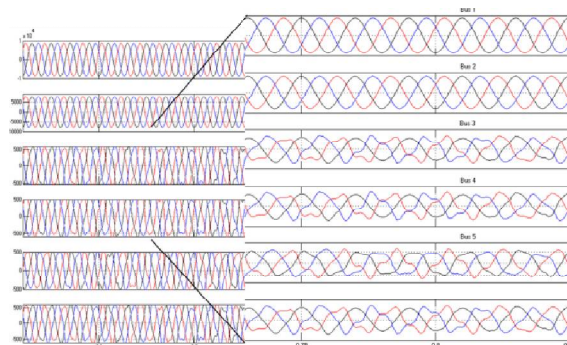


Fig.7. Bus Voltages at various buses when integrated to the grid without D-STATCOM or SMES

The hybrid source is able to supply the system in all the varying conditions but they are not satisfied since the total harmonic distortion values are way above the limit, i.e. 5%. The above observation can be analysed from the table.4.

Table.4. Analysis of Hybrid System under various conditions when integrated to the grid without D-STATCOM or SMES

PV Array		Wind Energy	Bus Parameters at PCC		
Irradiation (W/m <sup>2</sup> )	Temperature (°C)	Wind Velocity (m/s)	Voltage (V)	Output Power (kW)	THD(%)
1000	10	8	400	3.2	178.56
800	20	10	400	2.2	200.69
600	25	12	400	1.5	175.98
500	30	14	400	2.9	190.10
400	40	14	400	1.5	160.34
200	50	8	400	2.7	185.84
1000	25	12	400	3.5	166.99
800	50	10	400	3.1	170.90
600	40	12	400	2.5	200.81
400	30	14	400	2.9	190.68

Now, simulation of the integration of hybrid system with SMES system to the grid is performed for various loads and test conditions.

The voltage profile of all the buses is given in Fig.8. All the bus voltages are upto the standard ie, 400V. In spite of the variations in the atmospheric conditions such as the temperature, irradiation, wind speed, the voltage at the point of common coupling is maintained as 400V which is the distribution grid voltage. Also apart from the small dips and variations the active and reactive power is a constant values as shown in fig.9.

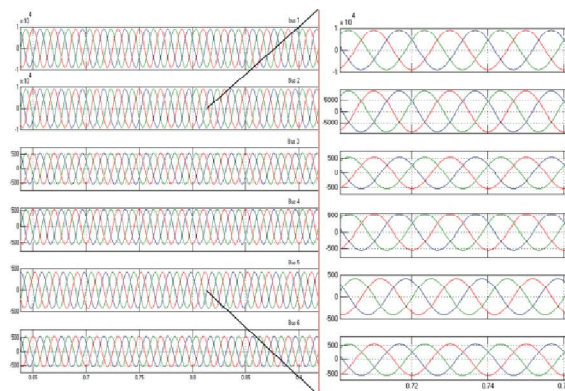


Fig.8. Bus Voltages at different buses when system is integrated to the grid using a combination of D-STATCOM and SMES

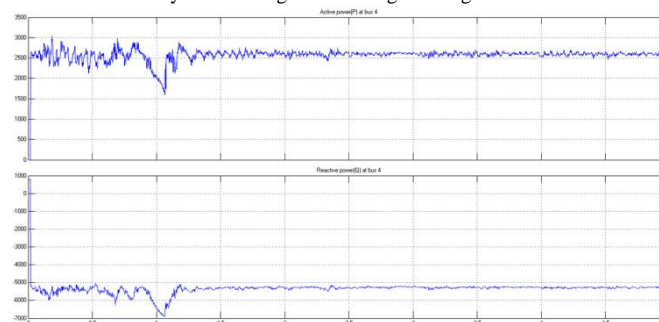


Fig.9. Active and Reactive power at load bus when Hybrid system is integrated using D-STATCOM and SMES

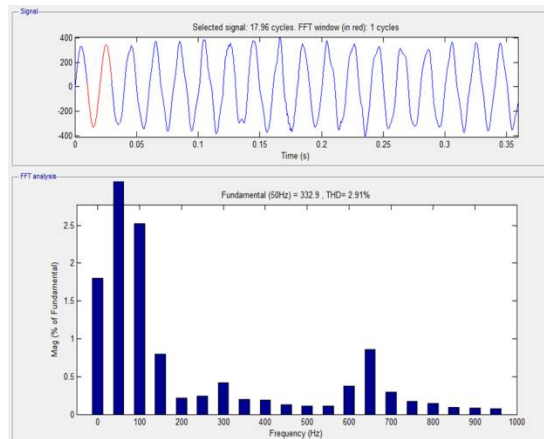


Fig.10.FFT analysis when hybrid system is connected to grid using D-STATCOM with SMES

It is seen from fig.10 that the total harmonic distortion value is 2.91% which is way below the standard limits. So that the system can be integrated to the grid. Table.5 gives an idea of how the system acts for various atmospheric conditions satisfactorily and the system performance for various loads are shown in table.6. By using the SMES system along with the hybrid system for the integration to the grid the voltage stabilization is achieved.

Table.5. Analysis of the hybrid system integrated to the grid through D-STATCOM with SMES for various conditions

PV Array		Wind Energy	Bus Parameters at PCC					THD(%)
Temperature (°C)	Irradiation (W/m <sup>2</sup> )	Wind Velocity (m/s)	Voltage (V)	Power at bus 4		Power at bus D-STATCOM and SMES(kW)		
				kW	kVAr	kW	kVAr	
10	1000	8	400	3.5	6	40.5	1.45	5.01
30	1000	10	400	3.5	6	40.5	1.4	2.91
50	1000	12	400	3.5	6	40.45	1.4	3.02
70	1000	14	400	3.5	6	40.4	1.3	4.29
100	200	14	400	3.5	6	40.35	1.4	5.01
100	400	8	400	3.5	6	40.5	1.4	4.23
100	600	10	400	3.5	6	40.5	1.4	5.67
100	800	12	400	3.5	6	40.44	1.4	3.29
100	1000	14	400	3.5	6	40.35	1.35	6.74
120	1200	15	400	3.5	6	40.2	1.1	8.67

Table.6. hybrid system integrated to the grid through D-STATCOM and SMES with various Loads

Loads	Active power supplied by grid(kw)	Active power(kw)	Reactive power(kvar)	Voltage(V)	THD(%)
linear	40	2.5	5.2	400	2.91
Non linear	41	4.1	6	400	5.09
unbalanced	40	4	8.1	400	4.58
Combined loads	39	3.56	8.5	400	5.46

The voltage of the system is maintained to the standards for different linear and nonlinear loads. The total harmonic distortion of the system is on average 2.91% which is below the acceptable limits(5%).

## V. CONCLUSION

Hybrid generation scheme for a distribution grid using renewable technology is presented here. A hybrid power system incorporating solar and wind are modeled and the performance of each generation system was individually



analyzed taking into consideration various environmental conditions related to the sources. Also for improving the performance and voltage stability of the hybrid system a D-STATCOM and SMES was designed and modeled. A comparative study was done between systems when integrated to the grid with, without and with the combination of both the stability improvement devices.

It has been observed that the combination of PV array and WECS can deliver sufficient amount of power to the load. If there is a failure of these sources, battery provides the back-up power. D-STATCOM is used in the integration of the hybrid source to the grid improves the voltage profile and provides sufficient power to the distribution grid. But the harmonic distortion is above the limits. Hence D-STATCOM and SMES unit used which improves THD and the voltage profile of the hybrid system and the grid.

#### REFERENCES

- [1]. Marcelo GradellaVillalva, Jonas Rafael Gazoli, and Ernesto RuppertFilho, Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 24, NO. 5, MAY 2009
- [2]. S. Sedra and K. C. Smith, Microelectronic Circuits. London, U.K.:Oxford Univ. Press, 2006.
- [3]. Jasmin Martinez, Modelling and Control of Wind Turbines, September 21, 2007, Imperial College London, London SW7 2AZ, UK
- [4]. VlastimilŠantín Model of wind power plant with asynchronous Generator in simulink platform Intensive Programme "RenewableEnergy Sources" May 2011, ŽeleznáRuda-Špičák, University of West Bohemia, Czech Republic
- [5]. Bongers, P. Van Baars, G. (1992) Wind turbine control design and implementation based on experimental models. IEEE, [Online] 2, 2454-2459
- [6]. R.Indumathi, M.Venkateshkumar, Dr.R.Raghavan,Integration of D-Statcom Based Photovoltaic Cell Power in Low Voltage Power Distribution Grid, IEEE- International Conference On Advances In Engineering, Science And Management (ICAESM -2012) March 30, 31, 2012
- [7]. Bhim Singh, P. Jayaprakash, D.P. Kothari New control approach for capacitor supported DSTATCOM in three-phase four wire distribution system under non-ideal supply voltage conditions based on synchronous reference frame theory Electrical Power and Energy Systems 33 (2011) 1109–1117
- [8]. Mohd. Hasan Ali, Senior Member, IEEE, Bin Wu, Fellow, IEEE, and Roger A. Dougal, Senior Member, IEEE, An Overview of SMES Applications in Power and Energy Systems, IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 1, NO. 1, APRIL 2010
- [9]. Marcelo Gustavo Molina, Member, IEEE, and Pedro Enrique Mercado, Senior Member, IEEE Power Flow Stabilization and Control of Microgrid with Wind Generation by Superconducting Magnetic Energy Storage SPECIAL ISSUE ON POWER ELECTRONICS FOR MICROGRIDS, 2010
- [10]. Mohd. Hasan Ali, Senior Member, IEEE, Bin Wu, Fellow, IEEE, and Roger A. Dougal, Senior Member, IEEE, An Overview of SMES Applications in Power and Energy Systems, IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL. 1, NO. 1, APRIL 2010
- [11]. W.V. Hassenzahl, "Superconducting Magnetic Energy Storage," IEEE Transactions on Magnetics, vol.25, no.2, p.750-758, March 1989.