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# Energy Storage Systems in DGR Based Microgrid

K Shravani[1], S.Nagini[2]

*(EEE, KL University, INDIA)
** (EEE, NOVA College of Engineering, INDIA)

## ABSTRACT

**After digging deep into the current status of the state of energy storage technologies dominated by batteries in rural India, Energy Storage Systems qualitative analysis, advantages, disadvantages and applications for Microgrid have been discussed in this paper. Various aspects for improving the power quality, continuity, reliability of Microgrid have been suggested by addressing issues like providing ride through, making non-dispatchable power into dispatchable, improving overall performance of power system by developing adequately designed ESS. Storage Systems of importance in this paper are SCES, SMES design, development and deployment. The platform used for presenting theory with proper simulations and result analysis is MATLAB where valid assumptions and specifications of various power system components are constructed using strong basic fundamentals of engineering electric power systems.**

*Keywords* **- Microgrid, Interconnected mode, Storage Systems, Super Conducting Energy Storage (SCES), Super conducting Magnetic Energy Storage (SMES), Distributed Generation (DG), Distributed Generation Resources (DGR), Energy Storage Systems (ESS).**

## I. INTRODUCTION

Vision 2012 has set India on an overarching target of providing electricity to its billion populations by 2012. Power systems market is getting deregulated day by day deploying more localized systems nearer to load centers. By the year 2012, India's peak demand would be 157,107 MW. Based on the demand projections made in the 16th Electric Power Survey, over 1,00,000 MW additional generation capacity needs to be added by 2012 to bridge the gap between demand and supply of power. But still 40% of the households, mostly in rural areas have no access to electricity even in 2009. At this demanding situation Microgrid is an excellent solution in reaching these whopping targets at fast pace. Microgrid is a collection of renewable decentralized Distributed Generation Resources (DGR) with proper storage technologies and power quality conditioners promising to bridge the gap of supply in rural India. In Microgrid Energy Storage Systems (ESS) play very important role in unifying, distributing and augmenting the capabilities of alternative and renewable Distributed Generation Systems (DGS). Unlike conventional generation, transmission and distribution systems Microgrid is exposed to load and source fluctuations to a larger extent since the transmission system is absent in its construction. ESS capable of enhancing energy stabilization, ride through capability and dispatch-ability makes up for seasonal variations, reaching to fast transient power quality needs contributing to efficient energy management policies and faster economic investments in Microgrid. In designing and developing ESS a variety of power ratings Kilowatts to Megawatts scale and energy discharge ratings Millisecond to Hour scale are needed to match the wide spectrum of energy storage applications, in the current and forecasted architecture of Microgrid. They can be connected in parallel with the load to supply unscheduled demand permitting DGR to have a smooth steady state. The ride through capability of these systems promises proper amounts of energy to loads in the absence of DGR. Dispatch-ability for certain time regardless of power produced by DGR brings worthiness due to its availability and commit-ability. ESS stabilizes and permits DGR's to run with a constant and stable output despite fluctuations. ESS along with DGR can be classified as that which stores energy directly in electrical form (Batteries) and the other type which stores energy in various forms finally converting to electrical.

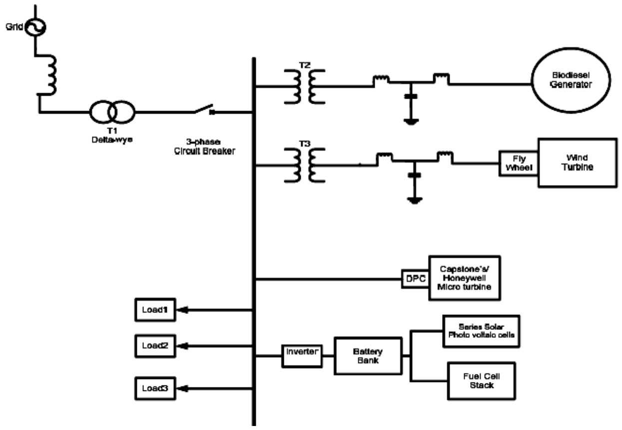

Fig 1: Architecture of Microgrid with a typical Storage System in Interconnected mode.

## II. TYPES OF STORAGE SYSTEMS

From application point ESS can be divided into three categories namely Short Term Storage Systems (STS) - maintains energy reserves sufficient to provide rated power from a few milliseconds up to a minute [2]. Faster responses of power conversion systems with storage technologies provide power within fraction of a cycle when the grid supply fails or a voltage depression occurs. Medium Term Storage Systems (MTS) - maintains energy reserves sufficient to provide rated power from few minutes up to few hours. They can be used mainly for peak shaving, network reinforcements, area control, frequency regulation and rapid reserve. They can reduce amount of spinning reserve capacity, resulting in better economic loading and less mechanical and thermal stresses on generators. Long Term Storage Systems (LTS) hold energy for durations ranging from a few hours to weeks or months. The existing distribution systems are greatly suffering from- frequent interruptions due to overloads, insufficient generation, load imbalance, harmonics, transients, sags, swells, The major contributing factors for proper design and implementation of ESS for power distribution systems, both in grid-connected mode as well as in the grid-independent mode/Isolated mode are identification of problems, specifying the energy density, power density, voltage, current and efficiency requirement, optimizing the specifications in accordance with applications. In power deficient countries like India where scheduled and unscheduled power outages take place and quality of power supply is also poor, areas of exploration includes ESS optimal utilization, dispatch-ability of power by DGR, transient stability improvement and, dynamic stability integrated hybrid systems along with efficiencies.

## III. SMES

This system has numerous advantages in electrical power system applications over other conventional means of electrical energy like pumped hydro energy storage, compressed air energy storage etc. Apart from being the most efficient, SMES has attracted the attention because of its fast response in switching over from charging mode to discharging mode, high rate of energy discharge capability. Detailed designs of massive SMES installations (of the order of 1GWh) for load levelling and peak shaving have been evolved. SMES can store electricity and discharge continuously. Super conductivity is a flow of electric current without electrical resistance and is achieved when electrical resistance is made zero by cooling certain chemical compounds. In super conducting state a constant magnetic field is continuously produced even if electricity is conducted, the resultant electrical energy can be stored as magnetic energy. This SMES system uses zero electrical resistance phenomenon to store electricity and achieve an extremely high efficient input and output of electricity. And as a result, the system can be used to provide a stable power supply and to improve quality of power. SMES can be used as a back-up electricity source which can compensate the load damage caused by an instant voltage drop due to lightning, and other factors. It can supply reliable power even in occasions of frequency fluctuations, drastic load changes. Chubu Electric Power Co Inc of Japan with co-operation from Furukawa Electric Co Ltd installed an SMES with 10,000KW of output power.

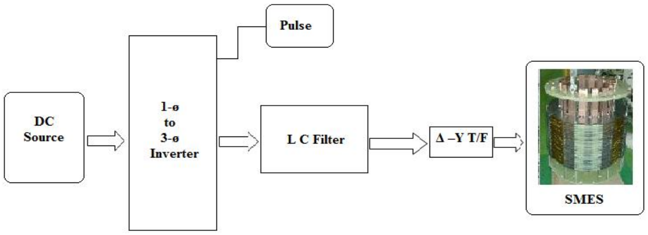

Fig 2: Typical configuration of Single source SMES system.

## IV. SMES DESIGN

This system consists of three main parts namely super conducting coil, power conditioning system and cryogenically cooled refrigerator. SMES systems store energy in the magnetic field created by the flow of DC in a superconducting coil which has to be cryogenically cooled to a temperature below its super conducting critical temperature. Once the super conducting coil is charged, current will not decay and the magnetic field can be stored indefinitely. The stored energy can be released back to the network by discharging the coil. The power conditioning system uses a universal bridge to transform Alternating Current to Direct current and Direct Current

back to AC. The bridge accounts for 2-3% energy loss in each direction. SMES loses the least amount of electricity in the energy storage process compared to other methods of storing energy. SMES systems are highly efficient with round trip efficiency greater than 95%. With the discovery of high Tc ceramic superconductors the application of SMES in power system may acquire more commercial viability. At present SMES is currently devoted to improve power quality, several 1MW units are used for power quality control in installations around the world especially at manufacturing plants requiring ultra-clean power. If SMES were to be used for utilities it would be a diurnal storage device, charged from base load power at night and meeting peak loads during the day. Cryogenics are a necessity. A robust mechanical structure is usually required to contain the very large Lorentz forces generated by and on the magnet coils. The dominant cost for SMES is the superconductor, followed by the cooling system and the rest of mechanical structure where research is to be carried out in reducing the cost [7]. To achieve commercially useful levels of storage around 1GW-h, a SMES installation would need a loop of 100 miles (160km). Fabrication of bulk cable suitable to carry high currents will be challenging but not impossible. Until room temperature super conductors are found, the 100 mile loop of wire has to be contained within a vacuum flask of liquid nitrogen.

## V. ENERGY CALCULATIONS

The magnetic energy stored by a coil carrying a current is given by one half of the inductance of the coil times the square of the current [7].
$E= \frac{1}{2} L I^2$ Where
E= energy measured in joules
L= inductance measured in henries
I= current measured in amperes
If we consider cylindrical coil with conductors of a rectangular cross section, mean radius 'R', 'a' and 'b' respectively width and depth of the conductor , 'f' the form function different for different shapes of the coil, Ê(xi) and Δ(delta) being the two parameters that characterize the dimensions of the coil. Now with above assumptions the magnetic energy stored in such a cylindrical coil can be written as
$E= \frac{1}{2} F(\hat{E}, \Delta) .R.N^2.I^2$
Where E= energy measured in joules
I= current measured in joules
F(Ê, Δ)= form function, joules per ampere-meter.
N= number of turns of coil.

## VI. SCES

Super capacitors are less weighty than that of battery of same energy storage capacity, a fast access to the stored energy is the hallmark of super capacitors [1]-[8]. Basic needs like super fast charging and improved discharging cycles up to $10^{\wedge 6}$ times the charging times is possible with super capacitors. High storage capacities independent of number of charging and discharging cycles , energy densities of the order of 10 to 100 times to that of traditional capacitors , life cycles of 25-30 years, high efficiencies , higher power densities greater than batteries are essential features of super capacitors.

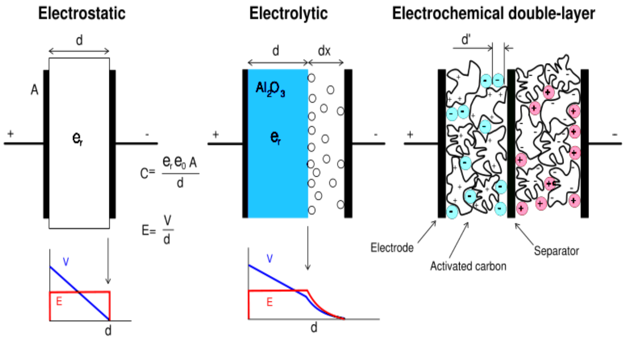

Fig3. Types of Super capacitor/ultra capacitors

Typical characteristics of Super-capacitors include nominal voltages ranging from 2.3 to 400 volts, rated current ranging from 3-600 amperes, operating temperatures of -40°c to 85°c, maintenance free and very low leakage currents. Constructional features of Super-capacitors include double layers. The energy is stored by charge transfer at the boundary between electrode and electrolyte. The amount of stored energy is function of the available electrode and electrolyte surface, size of the ions and level of electrolyte decomposition. The two electrodes made of activated carbon provide a high surface area part, defining so energy density of the component on the electrodes, current collectors with a high conducting part assure the interface between the electrodes and the connections of the super capacitor.

Fig4: Maxwell technologies Super-capacitors ("MC" and "BC" series up to 3000 farads).

## VII. SCES WITH FUEL CELL

The Fuel Cell Stack block in Mat lab implements a generic model parameterized to represent most popular types of fuel cell stack fed with hydrogen and air. PEMFC-50KW-625Vdc block is utilised here to transform assumed theory into simulative result.

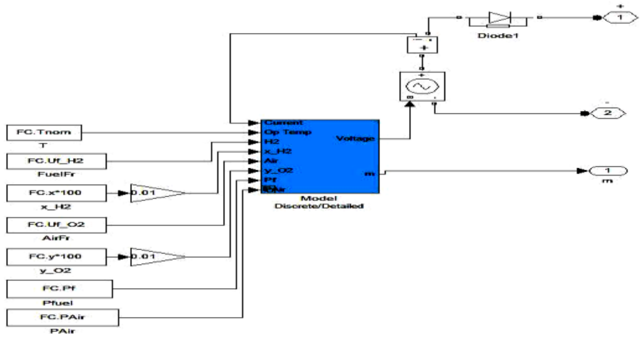

Fig5: A PEMFC-50KW-625Vdc Fuel Cell.

A diode is used to prevent the negative current into the stack. Nominal voltages, open circuit voltage, operating points have to be calculated with the basic equations governing the output from the fuel cell module.

$E^{OC} = N\,[E^{n} - A\ln(i^{o})]$ and

$A=RT/Z$œ$F$

Where $R = 8.314$ J/ (Mol K)

$F = 96485$ A

Z= Number of moving electrons

$E^{n}$=Nernst voltage

$I^{o}$=Exchange current

An IGBT based inverter is used to convert the DC from fuel cell to AC and harmonic filter is used to reduce the harmonics. A Super Capacitor bank is used for storing the output and also for peak shaving. Power quality conditioning is done by proper synchronization of inverter, filter and super capacitor bank. A PWM Generator provides pulses to the inverter at appropriate time intervals playing a major role in the quality.

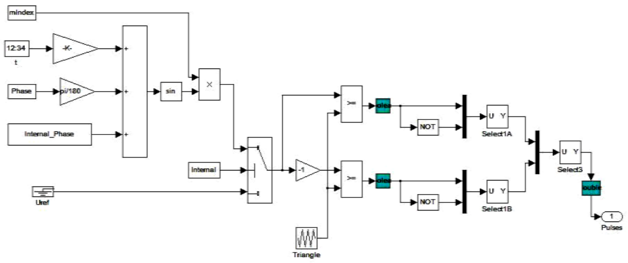

Fig6: PWM generator for IGBT Inverter.

## VIII. SCES WITH 3-DGR MICROGRID

A Microturbine generation system along with wind power generation system and fuel cell power generation system are integrated with appropriate combinational outputs guided by PID controllers for wind system to get assumed torque, speed, and pitch angle at variable wind speeds. The configuration of PID is shown below.

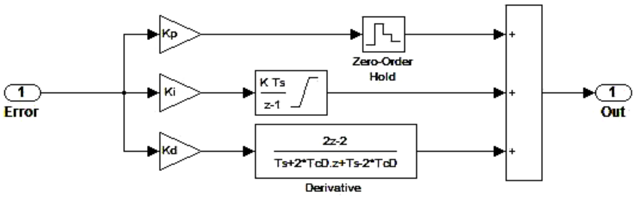

Fig 7: PID Controller for Wind Gen System.

The output from the High Speed Gas based Micro turbine is heavily dependent on the configuration of steam turbine and governor. The speed governing system consists of a proportional regulator, a speed relay, and a servomotor controlling the gate opening. The steam turbine has four stages, each modeled by a first-order transfer function. The first stage represents the steam chest while the three other stages represent either Reheaters or crossover piping. The boiler is not modeled and boiler pressure is constant at 1.0 PU.

## IX. RESULT ANALYSIS

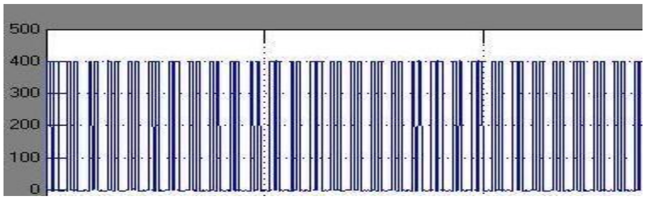

Fig 8: Vab of inverter for SMES system with 400 V as input.

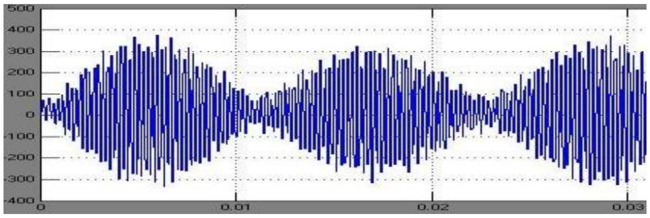

Fig 9: $V_{ab}$ of Load for SMES system with 400V as input.

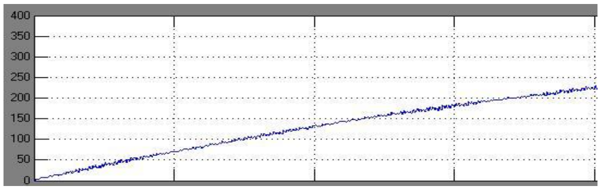

Fig 10: Single Source SMES system Phase Currents (Iab~400 amps).

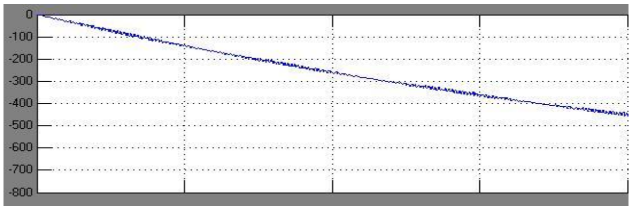

Fig 11: $I_{bc}$~800 amps in 0.1 seconds.

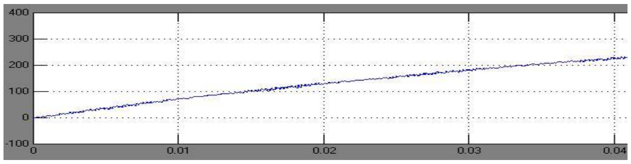

Fig 12: Ica~400 amps in 0.1 seconds.

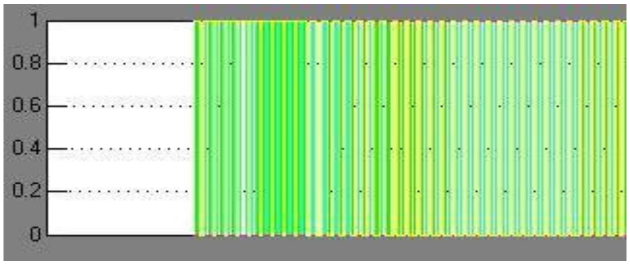

Fig 13: Fuel Cell (PEMFC-625V-50KW) based SCES system pulses.

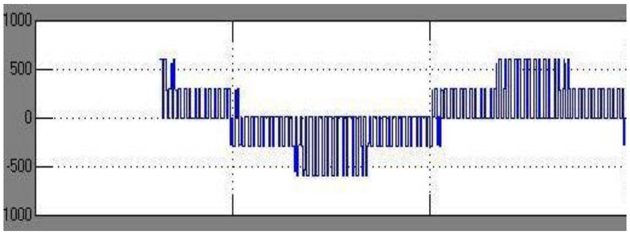

Fig14: Fuel cell based SCES system $V_{ab}$.

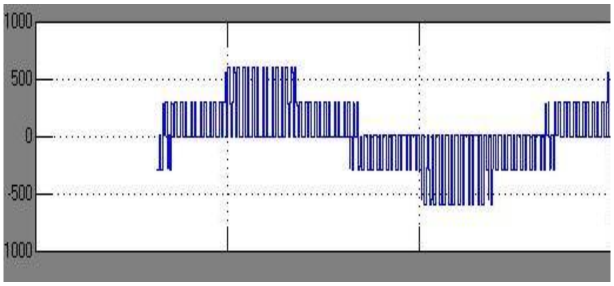

Fig 15: Fuel cell based SCES system $V_{bc}$.

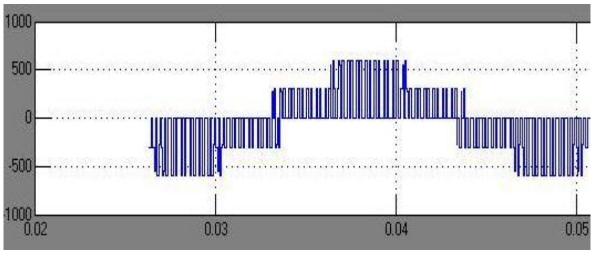

Fig 15: Fuel cell based SCES system $V_{ca}$.

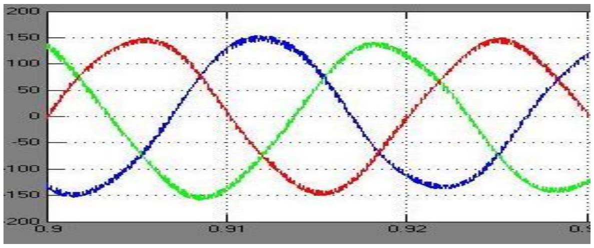

Fig 16: 3-DGR Microgrid with SCES system Vabc~150Volts.

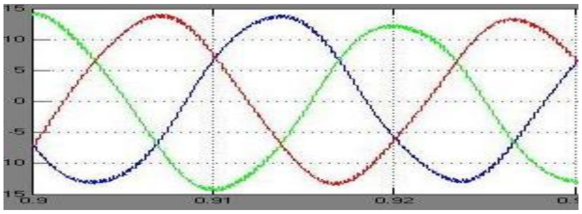

Fig 17: 3-DGR Microgrid with SCES system $I_{abc}$~15 amps.

## IX. CONCLUSION

Distributed generation with load and source at vicinity to each other is on fast track in India with lot of importance given in the current financial year. At this peak these kind of unconventional storage systems deployment will definitely prove successful in maintaining the quality and quantity on par with demand. SMES need to be supported with further research in reducing the cost of superconductor and cryogenic facilitation. SCES along with power electronic conditioning systems will be a sure success in many industrial and renewable generation systems design, development and deployment. The major benefits that can be achieved are distribution upgrade deferral, transmission upgrade deferral, availability-based use, end user electric service reliability. This would also lead to positive impact on environment by virtue of reduced fuel consumption, reduced emissions of dangerous green house gases, and reduced global warming and renewable capacity optimal utilization.

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