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Hybrid Source and Hybrid Energy Storage for Wind Turbine Generating Systems

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ABSTRACT: Many are looking at Sustainable energy solutions to protect the earth for the Upcoming generations with growing distress of global warming and the Reduction of fossil fuel reserves. This design allows the hybrid wind/photovoltaic sources to supply the Load separately or simultaneously depending on the accessibility of the energy sources.

This paper presents a new system design by introducing fuzzy logic at line side converter for permanent magnet synchronous generator integrated with energy management algorithm in hybrid wind/photovoltaic energy system. A Remote Area Power Supply (RAPS) system consisting of a Permanent Magnet Synchronous Generator (PMSG), hybrid energy sources, hybrid energy storage, SEPIC converter, a dump load and a mains load is considered in this paper. Integration of these hybrid sources with ESS provides an opportunity for better voltage and frequency response. An energy management system (EMS) is proposed for the hybrid energy storage with a view to boost the battery life. SEPIC converter is used as both buck converter and boost converter. A synchronized control comes up to be developed to manage the active and reactive power flow among the RAPS components.

Through MATLAB Simulink, it has been demonstrated that the planned method is capable of Achieving: a) robust voltage and frequency regulation (in terms of their acceptable bandwidths), b) effective management of the hybrid storage system, c) reactive power capability and inertial support by the synchronous condenser, and d) maximum power extraction from renewable energy system.

KEYWORDS: Hybrid energy sources, hybrid energy storage system, Permanent magnet synchronous generator (PMSG), Remote area power Supply (RAPS), and synchronous condenser, energy management system (EMS)

1. INTRODUCTION

Wind and photovoltaic energy holds the most potential with rising concern of Energy security and sustainable development, renewable energy has become more significant. The known renewable energies are sunlight, wind, rain tides, biomass and geothermal heat. The common inherent drawback of wind and photovoltaic systems are their intermittent natures a RAPS system are to sustain the voltage and frequency level within suitable limits as these are the most vital parameters to be controlled from the customers' sight. Variable speed wind turbine generator that make them unreliable.

To overcome this trouble, Hybrid remote area power supply system are considered as new technology emerging solution in supplying electricity to remote areas. When a source is unavailable in meeting the load demands, the other energy source can compensate for the difference. The harmonic content in the generator current decreases its lifespan and increases the power loss due to heating. The main challenge in technologies are preferred in a power system, as they are able to provide better voltage and frequency response .Doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) are identified as preferred variable speed generator technologies for wind power applications. The application of energy storage to a standalone power system can be used to satisfy one or more

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of the following requirements: (1)(4) to improve the efficiency of the entire RAPS system, (2)(6) to reduce the primary fuel usage by energy conversion, and (3)(5) to provide better security of energy supply.

In this paper, hybrid wind/solar energy systems is proposed for uninterrupted power supply. The Fig. 1 consists of a Line Side Converter (LSC) to control the system voltage and frequency. Fuzzy logic control strategy has been employed for the LSC controls. The machine side is connected to an uncontrolled rectifier. It is identified that the PMSG alone is not capable of regulating the voltage and frequency in a standalone environment.

Therefore, a Hybrid Energy storage system has been incorporated into the DC link of the rectifier-inverter system via a SEPIC converter. For a Hybrid RAPS system, a single type of energy storage is not seen to Satisfy both power and energy requirements of the RAPS system thus requiring the combination of two or more energy storage systems to perform in a Hybrid manner. The operation of battery storage is coordinated with a super capacitor with a view to improve the battery life by reducing ripple content.

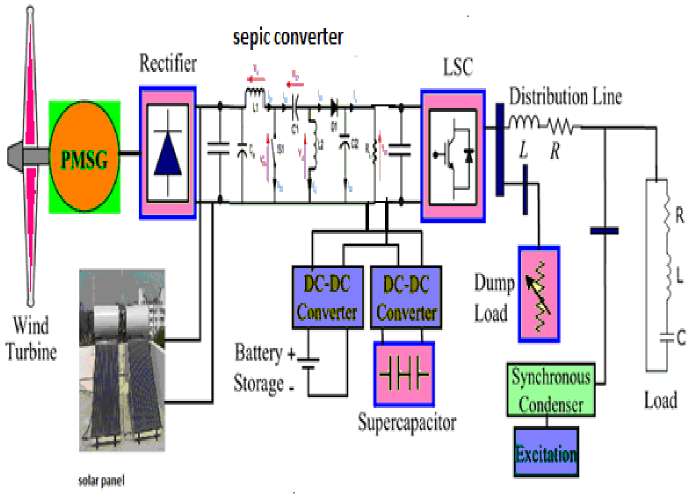

Fig. 1: PMSG based hybrid remote area power supply system with a hybrid energy storage.

The single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage.(10-12) It can support step up/down operations for each renewable source (can support wide ranges of PV and wind input). The LSC is modeled as a voltage controlled voltage source inverter. The objective of the LSC is to regulate the magnitude and frequency of the load side voltage. In this regard, fuzzy logic control has been employed to develop the control associated with the LSC. The system voltage control in a RAPS system is achieved by maintaining the reactive power balance of the system. Reactive power compensation in a RAPS system can be done either by synchronous condensers, Static VAR Compensators (SVC) which utilizes power electronics, or Flexible AC Transmission System (FACTS) devices. In this paper, a synchronous condenser is connected to the load side in order to maintain the system voltage within acceptable limits.

The presented work on remote area power supply systems with hybrid energy storage is summarized below. An isolated operation of a PMSG with a battery storage system is discussed.(15) It covers a RAPS system consisting of single source PMSG and hybrid battery storage, synchronous condenser, dump load and main load. However, authors of this paper have presented results associated with the performance of the components in relation to the voltage/frequency .Different control strategies proposed for the battery-super capacitor hybrid energy storage are discussed in [9]. It only examines the different control strategies that could be applied to a hybrid energy storage system. In [10], an optimal energy management scheme for battery-super capacitor hybrid energy storage is proposed.

In this paper, Hybrid RAPS system is representation to estimate the absolute system performance as well as the act of the individual components in relation to the voltage/frequency and power sharing among the system-components.(7-9) A coordinated control approach is proposed for the system components in the RAPS system. Power sharing strategy is formulated for battery energy storage and super capacitor based on the demand-generation variations of the RAPS system. The aim of the proposed control methodology is to operate the hybrid energy storage in such a behavior that battery storage is used to mitigate low frequency fluctuation and the super capacitor is to mitigate high frequency fluctuation. An energy management algorithm is proposed and implemented while harvesting maximum power from the wind. Hybrid Remote Area Power Supply (RAPS) system consisting of a Permanent Magnet Synchronous Generator (PMSG), hybrid energy sources, hybrid energy storage, SEPIC converter, a dump load and a mains load is considered in this paper. A new system design by introducing fuzzy logic at line side converter for permanent magnet synchronous generator integrated with energy management algorithm in hybrid wind/photovoltaic energy system.

The paper is organized as follows: Section II presents proposed SEPIC topology for the RAPS system. Section III discusses the fuzzy logic control strategy applied for LSC control. The detailed information of PV panel and wind turbine is given in Section IV and V. The Battery storage and super capacitor well explained in section VI. The proposed Energy management system established among the battery storage and super capacitor is explained in Section VII.(13-14) The operations of synchronous condenser and dump load are illustrated in Section VIII respectively. The simulated results of the proposed RAPS system are presented in Section IX. Conclusion of the paper is given in Section X.

II. PROPOSED SEPIC TOPOLOGY

Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor. A SEPIC is essentially a boost converter followed by a buck-boost converter, advantages of having non-inverted output using a series capacitor to couple energy from the input to the output

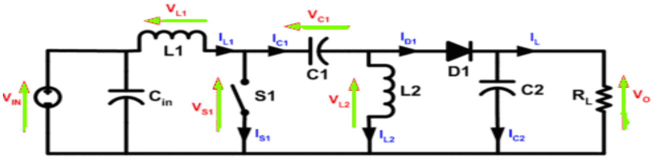

Fig 2: Schematic of SEPIC.

CIRCUIT OPERATION: The schematic diagram for a basic SEPIC is shown in Fig2. As with other switched mode power supplies (specifically DC-to-DC converters), the SEPIC connections energy between the capacitors and inductors in order to convert from one voltage to another. (16-18)The amount of energy exchanged is controlled by switch S1, which is normally a transistor such as a MOSFET; MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with (BJTs).

Continuous mode: A SEPIC is said to be in continuous-conduction mode if the current through the inductor L1 never falls to zero. During a SEPIC steady-state operation, the average voltage across capacitor C1 (VC1) is equal to the input voltage (VIN). Because capacitor C1 blocks direct current (DC), the average current across it (IC1) is zero, making inductor L2 the only source of load current. Therefore, the average current through inductor L2 (IL2) is the same as the average load current and hence independent of the input voltage. Looking at average voltages, the following can be written:

$$V_{IN} = V_{L1} + V_{C1} + V_{L2} \qquad (1)$$

Because the average voltage of V_{C1} is equal to V_{IN}, $V_{L1} = -V_{L2}$. For this reason, the two inductors can be wound on the same core. Since the voltages are the same in magnitude, their effects of the mutual inductance will be zero, assuming the polarity of the windings is correct. Also, since the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude. The average currents can be summed as follows:

$$I_{D1} = I_{L1} - I_{L2} \qquad (2)$$

When switch S1 is turned on, current I_{L1} increases and the current I_{L2} increases in the negative direction. The energy to increase the current I_{L1} comes from the input source. Since S1 is a short while closed, and the instantaneous voltage V_{C1} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$. Therefore, the capacitor C1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L2. The easiest way to visualize this is to consider the bias voltages of the circuit n a D.C. state, then close S1.

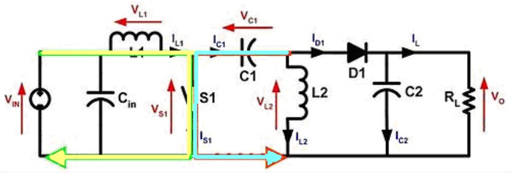

Fig 3: With S1 closed current increases through L1 (green) and C1 discharges increasing current in L2 (red).

When switch S1 is turned off, the current I_{C1} becomes the same as the current I_{L1}, since inductors do not allow instantaneous changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load. Using Kirchhoff's Current Law, it can be shown that $I_{D1} = I_{C1} - I_{L2}$. It can then be concluded, that while S1 is off, power is delivered to the load from both L2 and L1. C1, however is being charged by L1 during this off cycle, and will in turn recharge L2 during the on cycle.

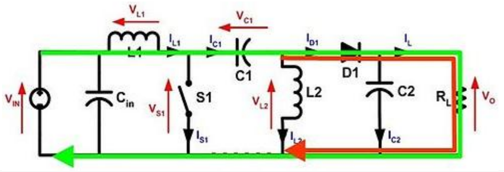

Fig 4: With S1 open current through L1 (green) and current through L2 (red) produce current through the load

Because the potential (voltage) across capacitor C1 may reverse direction every cycle, a non-polarized capacitor should be used. However, a polarized tantalum or electrolytic capacitor may be used in some cases, because the potential (voltage) across capacitor C1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L2, and by this time the current in inductor L1 could be quite large.(19)

The capacitor C_{IN} is required to reduce the effects of the parasitic inductance and internal resistance of the power supply. The boost/buck capabilities of the SEPIC are possible because of capacitor C1 and inductor L2. Inductor L1 and switch S1 create a standard boost converter, which generates a voltage (V_{S1}) that is higher than V_{IN}, whose magnitude is determined by the duty cycle of the switch S1. Since the average voltage across C1 is V_{IN}, the output voltage (V_O) is $V_{S1} - V_{IN}$. If V_{S1} is less than double V_{IN}, then the output voltage will be less than the input voltage. If V_{S1} is greater than double V_{IN}, then the output voltage will be greater than the input voltage.

The evolution of switched-power supplies can be seen by coupling the two inductors in a SEPIC converter together, which begins to resemble a Fly back converter, the most basic of the transformer-isolated SMPS topologies.

Discontinuous mode: A SEPIC is said to be in discontinuous-conduction mode if the current through the inductor L1 is allowed to fall to zero.(20)

III. FUZZY LOGIC CONTROL

Fuzzy logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel pc or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. Fl’s approach to control problems mimics how a person would make decisions, only much faster.(21-23)

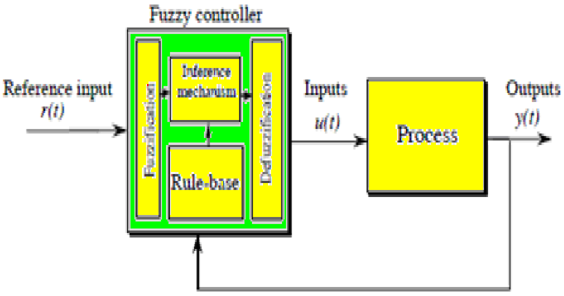

Fig 5: fuzzy logic controller

The fuzzy logic controller is designed to maintain the load voltage constant. The FLC consists of four components; they are fuzzification interface, and knowledge base, decision making logic, and defuzzification interface as shown in fig 4.

The conventional PI controllers are fixed-gain feedback controllers. Therefore they cannot compensate the parameter variations in the process and cannot adapt changes in the environment. Pi controlled system is less responsive to real and relatively fast alterations in state and so the system will be slower to reach the set point.(24) Therefore the fuzzy control algorithm is capable of improving the tracking performance as compared with the classical methods for both linear and nonlinear loads. Also, fuzzy logic is appropriate for nonlinear control because it does not use complex mathematical equation. The two FLC input variables are the error E and change of error _E. The behavior of a FLC depends on the shape of membership functions of the rule base. In this paper a fuzzy logic control scheme (Fig.4) is proposed for maximum solar power tracking of the PV array with an inverter for supplying isolated loads. They have advantages to be robust and relatively simple to design since they do not require the knowledge of the exact model. On the other hand the designer needs complete knowledge of the hybrid system operation.

Fuzzification: The membership function values are assigned to the linguistic variables using seven fuzzy subset called negative big (nb), negative medium (nm), negative small (ns), zero(zr), positive small (ps), positive medium (pm), Positive big (pb). Fuzzy associative memory for the proposed system is given in Table-1. Variable e and ‘Δe’ are selected as the input variables, where e is the error between the reference voltage (Vr) and actual voltage (Vo) of the system, ‘Δe’ is the change in error in the sampling interval. The output variable is the reference signal for PWM generator U. Triangular membership functions are selected for all these process. The range of each membership function is decided by the previous knowledge of the proposed scheme parameters.(25)

Inference engine: Inference engine mainly consist of Fuzzy rule base and Fuzzy implication sub blocks. The inputs are now fuzzified are fed to the inference engine and the rule base is then applied. The output fuzzy set are then identified using fuzzy implication method. Here we are using MINMAX fuzzy implication method.

Defuzzification: Once fuzzification is over, output fuzzy range is located. Since at this stage a non-fuzzy value of control is available a defuzzification stage is needed. Centroid defuzzification method is used for defuzzification in the proposed scheme. The membership function of the variables error, change in error and change in reference signal for PWM generator are shown in Fig. 5a-5c respectively.

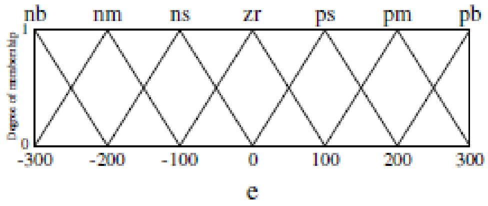

Fig 6(a): Membership function plots for ‘e’

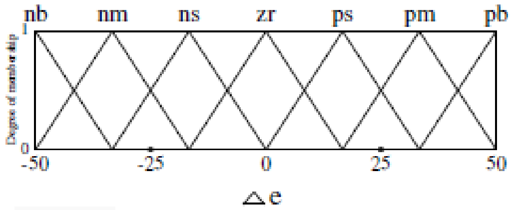

Fig 6(b): Membership function plots for ‘Δe’

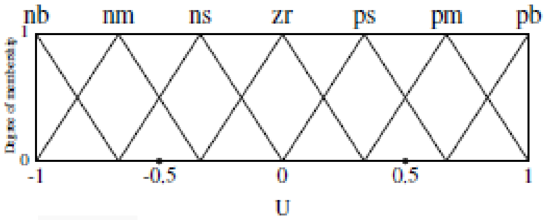

Fig 6(c): Membership function plots for ‘U’
Fig 6: Membership function

e	Δe						
	nb	nm	ns	zr	ps	pm	pb
nb	nb	nb	nb	nm	nm	ns	zr
nm	nb	nb	nm	nm	ns	zr	ps
ns	nb	nm	nm	ns	zr	ps	pm
zr	nm	nm	ns	zr	ps	pm	pm
ps	nm	ns	zr	ps	pm	pm	pb
pm	ns	zr	ps	pm	pm	pb	pb
pb	zr	ps	pm	pm	pb	pb	pb

Tab1: Fuzzy associative memory

IV. MODELLING OF PV Panel

A photovoltaic cell is comprised of a P-N junction semiconductor material such as silicon that produces currents via the photovoltaic effect. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current. This electricity can then be used to power a load. Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel (for high current) to form a PV module for desired output.

PV Cell Characteristics:

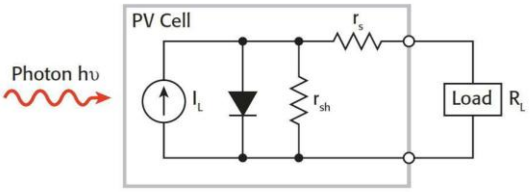

Fig.7: PV Cell Equivalent Circuit

A PV cell may be delineated by a current supply connected in parallel with a diode, since it generates current once it's well-lighted and acts as a diode once it is not. The equivalent circuit model additionally includes a shunt and series internal resistance. R_s is that the intrinsic series resistance. R_p is the equivalent shunt resistance which has a very high value. The current – voltage characteristic equation of a PV cell is given by

$$I = n_p I_{ph} - n_p I_{rs}\left(\exp\left(\frac{qV}{kTAn_s}\right) - 1\right) \quad (3)$$

$$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)^3\left(\exp\left[\frac{qE_G}{kA}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right]\right) \quad (4)$$

$$E_G = E_G(0) - \frac{\alpha T^2}{T + \beta} \quad (5)$$

$$I_{ph} = \left(I_{scr} + k_i(T - T_r)\right)\frac{S}{100} \quad (6)$$

Where I_{ph} is the Isolation current, I is the Cell current, Io is the Reverse saturation current, V is the Cell voltage, ns is the number of cells in series, np is the number of cells in parallel, Irs is the reverse saturation current, Rs is the Series resistance, Rp is the Parallel resistance, VT is the Thermal voltage, K is the Boltzmann constant, A is the ideality factor, and T is the Temperature in Kelvin, q is the Charge of an electron, Tr is the cell reference temperature, Irr is the cell reverse saturation current at Ir, EG is the band gap of the semiconductor, Iscr is the cell short circuit current at reference temperature, ki is the short circuit current temperature coefficient, S is the solar radiation in mw/sq cm. From equation 1, Output voltage of the PV module is obtained as:

$$V = \frac{n_s kTA}{q} ln\left[\frac{n_p I_{ph} - I}{n_p I_{rs}} + 1\right] \quad (7)$$

V. MODELLING OF WIND TURBINE

The turbine is that the 1st and foremost part of wind generation systems. Wind turbines capture the facility from the wind by means that of aerodynamically designed blades and convert it to rotating mechanical power. This mechanical power is delivered to the rotor of an electrical generator wherever this energy is reborn to electricity. Electrical generator used is also associate degree induction generator or synchronous generator. The turbine model is connected to a cage asynchronous Generator. The energy obtained from the turbine is fed to the generator that converts it to the electricity. The mechanical power that is generated by the wind is given by: Where

$$P_{\text{wind}} = \frac{1}{2}\rho A V_{\text{wind}}^3 \quad (8)$$

Where ρ is the air density (kg/m), A is the area (m) swept by wind blades, V_{wind} and is the wind speed (m/s). It had been proven that the energy conversion efficiency, C_p, of the wind turbine is a function of the tip speed ratio, λ_{tip} which is defined as

$$\lambda_{tip} = \omega r / V_{wind} \tag{9}$$

Where ω is the rotational speed (rad/sec) of wind turbine blades, r is the radius of the area swept by wind turbine blades, where the maximum value of is only achieved at a particular tip speed ratio. The speed of the wind is not constant; the rotational speed of the wind turbine must be adjustable to ensure a constant tip speed ratio to gain the maximum Cp. The output current change of the wind turbine will cause of the rotational speed as well as λ_{tip} to change. Since Cp is a function of λ_{tip}, the output power of the wind turbine will change, too. Therefore, by controlling the output current of the wind turbine, the rotational speed of the wind turbine blades can be adjusted to achieve the appropriate tip speed ratio. Eventually, the maximum value of Cp can be obtained and the maximum power can be transferred from the airstream to the wind turbine to produce the maximum electrical power.

VI. BATTERY STORAGE AND SUPER CAPACITOR

Energy storage essentials play an important role in standalone systems to reduce generation-demand variance, especially during the following conditions:
- Reduced power generation due to low wind speed and
High load demand,
- Increased power generation due to high wind speed and low load demand.

No single energy storage scheme meets these requirements. In the proposed RAPS system, hybridization of two energy storage systems: one with high energy capability and the other with high power density is seen to handling the transients.

. Nickel-Cadmium battery is employed in this paper. An Energy management system is proposed for the hybrid operation of Battery and super capacitor. According to EMS, the super capacitor should be able to absorb the ripple or high frequency power component and leaving the steady component for the Battery storage system.

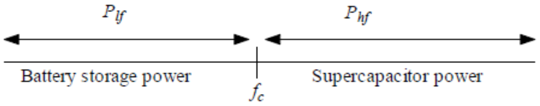

Fig.8: frequency ranges of the energy storage systems

The safe operating voltage of a super capacitor is

$$(v_{sc})_{min} < v_{sc} < (v_{sc})_{max} \tag{10}$$

The safe operating voltage limits of the super capacitor is

$$275\,V < v_{sc} < 375\,V.$$

The maximum possible peak current of a super capacitor is given by

$$(I_c)_{pk} = \frac{0.5 C_{sup} v_{sc}}{C(ESR_{dc}) + 1} \tag{11}$$

During its operation, the maximum allowable power from the super capacitor

$$(P_{sc})_{max} = \pm C_{sup} v_{sc} \left| \frac{dv_{sc}}{dt} \right|_{max} \tag{12}$$

Where Csup is capacitance value of the super capacitor, $(v_{sc})_{max}$, $v_{sc})_{min}$ are maximum and minimum operating voltages of super capacitor respectively, ESR_{DC} is equivalent series resistor of the super capacitor, Csup is the capacitance value of the super capacitor , $(P_{sc})_{max}$ is maximum power rating of the capacitor and $|\frac{dv_{sc}}{dt}|_{max}$ is the maximum rate of change of voltage across the super capacitor. The size of the super capacitor can be estimated using

$$E_{sc} = \frac{1}{2} C_{sup} v_{sc}^2 \qquad \textbf{(13)}$$

$$E_{sc} = \frac{1}{2} C_{sup} (v_{sc})_{\max}^2 - \frac{1}{2} C_{sup} (v_{sc})_{min}^2 \qquad \textbf{(14)}$$

$$C_{sup} = \frac{2E_{sc}}{[(v_{sc})_{\max}^2 - (v_{sc})_{min}^2]} \qquad \textbf{(15)}$$

The size of the super capacitor is calculated in the absence of wind power where the super capacitor provides the rated power of PMSG,P_{PMSG} (i.e., 200 kW) to mains load for a time-duration, say t=20s. For this condition, the capacitance value of the super capacitor will be as below:

$$C_{sup} = \frac{2(P_{PMSG})_{rated} t}{((v_{sc})_{\max})^2 - ((v_{sc})_{min})^2} \qquad \textbf{(16)}$$

$$\mathbf{C_{sup}} = \frac{\mathbf{2 \text{ X } 200\text{X}1000 \text{ X } 20}}{\mathbf{375^2\text{-}275^2}} =_{\sim 123\text{F}}$$

$$\mathbf{C_{sup}} = \sim 123\text{F}$$

The main objective of the battery storage system is to regulate the DC bus voltage V_{dc}

$$\text{Battery status} = \begin{cases} \text{chariging mode;} & \Delta v_{dc} > 0 \\ \text{discharging mode;} & \Delta v_{dc} < 0 \\ \text{idling mode;} & \Delta v_{dc} = 0 \end{cases}$$

The battery storage capacity is estimated using

$$\gamma \times I_{rated} \times \left(\frac{t}{60}\right) = (\text{Ah Rating}) \times k \qquad \textbf{(17)}$$

Where γ - fraction of the rated current of the load demand, I_{rated}—rated current of the load demand, *t*—time duration that battery provides power into the system and *k*—a fraction that defines the average discharge/charge current of the battery.

It is assumed that battery storage is used to supply 30 percent of the rated load current (i.e. γ=0.3) for the time-duration of 20 min (i.e.=20min). To demonstrate how the size of the battery can be estimated, assume that the rated power of PMSG is 200kW and the rated AC voltage, V_{rated} is 300 V. The rated current of the PMSG can be calculated as follows:

$$I_{rated} = \frac{(P_{PMSG})_{rated}}{\sqrt{(3)} v_{rated}} \approx 384.9\text{A}$$

$$\text{Ah Rating} = \frac{384.9\text{x}20\text{x}0.3}{0.3\text{x}60} = 128\text{Ah}$$

For this condition, the Ampere-hour (Ah) rating of the battery
Storage system can be estimated using as above.

VII. ENERGY MANAGEMENT SYSTEM

There are several types of Energy management algorithm can be designed and executed for Hybrid energy storage system. In this paper energy management algorithm is considered about the battery storage and super capacitor with a view to reach the following objectives:

1) To assist keep up the power stability of the RAPS system,
2) To drive wind turbine generator at variable-speed based on the maximum power point tracking algorithm, and
3) To advance the performance of the battery storage system by avoiding its process with high frequency ripple currents and elevated rate of DODs. This will mitigate the battery stress and boost the battery life.

According to EMS, the super capacitor should be able to absorb the ripple or high frequency power component and leaving the steady component for the Battery storage system. To ensure the power balance of the RAPS system a coordinated control approach is developed. During over generation conditions where the power output from the wind turbine generator P_w is greater than the load demand P_L the hybrid energy storage (i.e., battery storage and super capacitor) should absorb the excess power (P_w-P_L), according to the energy management system

$$P_w = P_L + P_d + P_b \tag{18}$$

During under generation conditions, where ($P_w < P_L$), it is assumed that the hybrid energy storage is capable of providing the required power into the system.

$$P_w + P_b = P_L + P_d \tag{19}$$

Where P_w is power output of the WTG, P_b is power from battery storage system, Pd is Dump load power and PL is load demand. The reactive power sharing is made between the synchronous condenser and inverter as given by

$$Q_{inv} + Q_{syn} = Q_L \tag{20}$$

Where Q_{inv} is inverter reactive power, Q_{syn} - reactive power from synchronous condenser and Q_L is reactive power demand of mains loads.

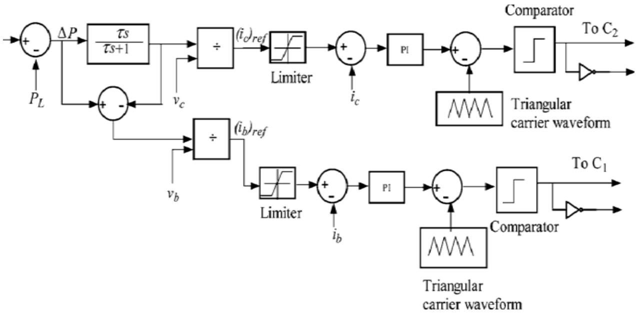

Fig.9: Energy management algorithm for hybrid energy storage system.

VIII. SYNCHRONOUS CONDENSER AND DUMP LOAD

The synchronous condenser can be incorporated into the RAPS system to provide enhanced reactive power and inertial support. Its field is controlled by a voltage regulator to generate or absorb reactive power to support a system's voltage or to keep the system power factor at a specified level. Synchronous condensers installation and Operation are identical to large electric machines. Once the machine is connected to the system, the reactive power that it supplies can be varied continuously over the entire range from 50 per cent or more lagging to full leading KVA by simple adjustment of its field current.

Dump load consists of resistive elements which can be connected to either DC or AC sides of a wind energy system. The operation of the dump load is limited to the case where excess power is available in the system. Also, the dump load will start absorbing the additional power only after battery storage reaches its rated capacity .The maximum power that can be dissipated through a dump load can be expressed as

$$(P_{dump})_{\max} = (2^n - 1)P_{step}. \qquad (21)$$

Where n is the number of three phase resistive elements, and P_{step} is power that can be absorbed per resistor step.

To demonstrate how the rating of the dump load is estimated, assume that P_{step}=0.2KW and n=5 (i.e., number of three phase resistive elements present in the dump load). For this condition, the size of the dump load will be as below:

$$(P_{dump})_{\max} = (2^n - 1)(P_{step}) \approx \qquad (22)$$

IX. SIMULATION RESULTS AND DISCUSSIONS

Matlab / simulink are a block of library tool for modeling, simulating and analyzing dynamic systems. The performance of the proposed RAPS system is investigated under (a) variable load and (b) fluctuating wind speed conditions. In this regard, the simulated behavior of the voltage and frequency at load side, DC link stability, performance of the hybrid energy storage and maximum power extraction capability from wind were examined. This simulates an over generation condition where the excess power from the wind given by. (P_w-P_L) is shared between the hybrid energy storage and dump load. However, the power sharing between hybrid energy storage units occurs according to the energy management algorithm discussed in Section VII.

The system experiences an over-generation condition causing the battery storage to move from discharging to charging mode of operation to maintain the power balance of the RAPS system. Throughout the operation, the super capacitor absorbs the high frequency power component of demand-generation mismatch during transient conditions which occur due to wind and load step changes.

A.SIMULATION MODEL

The simulation model for PMSG with RAPS system is shown in fig 10.

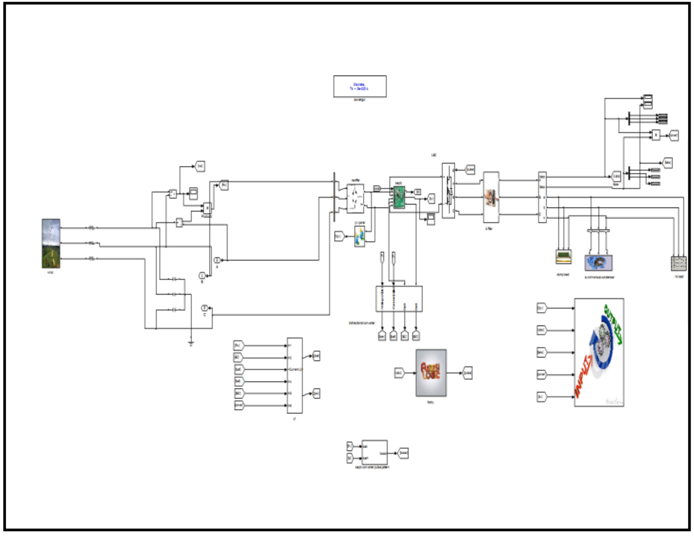

Fig: 10 Simulation circuit diagram

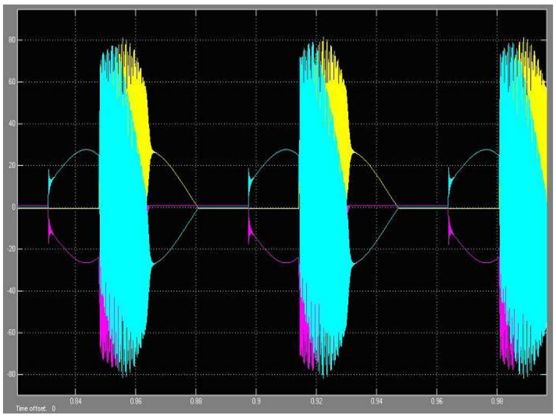

Fig: 11 Wind Input voltage

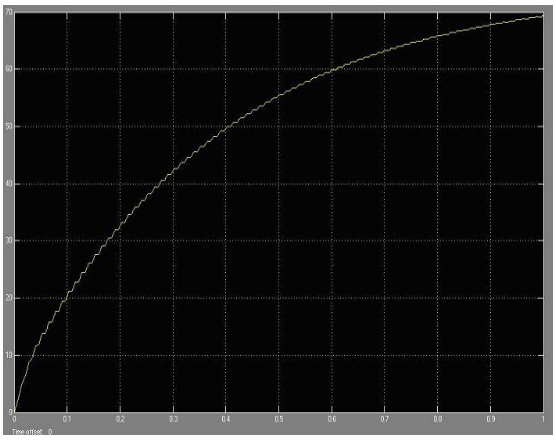

Fig: 12 Dc link voltage

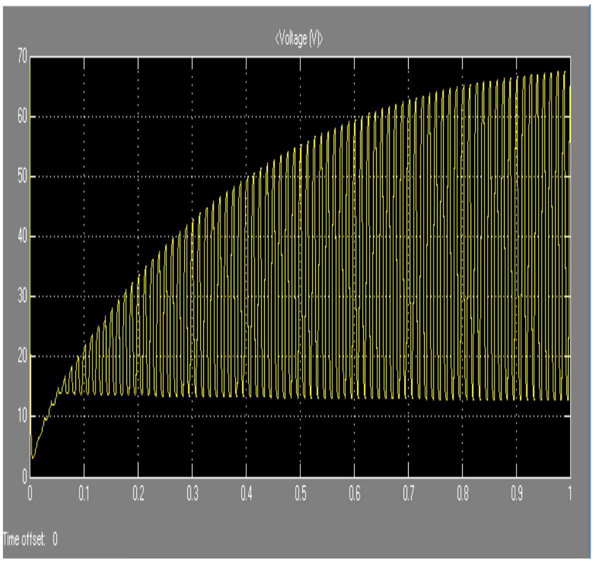

Fig: 13 Battery voltage

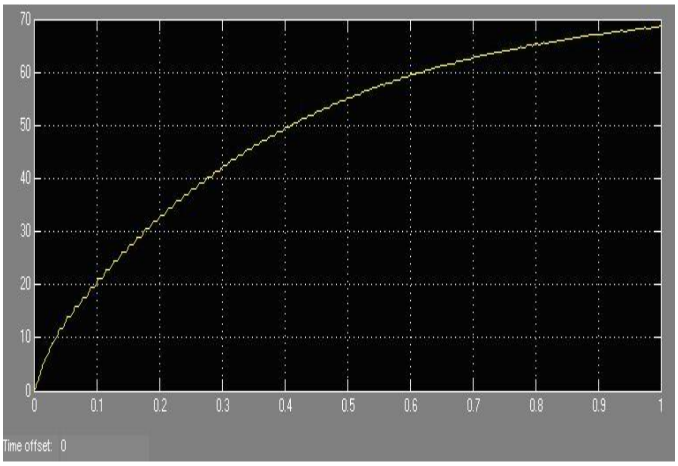

Fig: 14 Super capacitor voltage

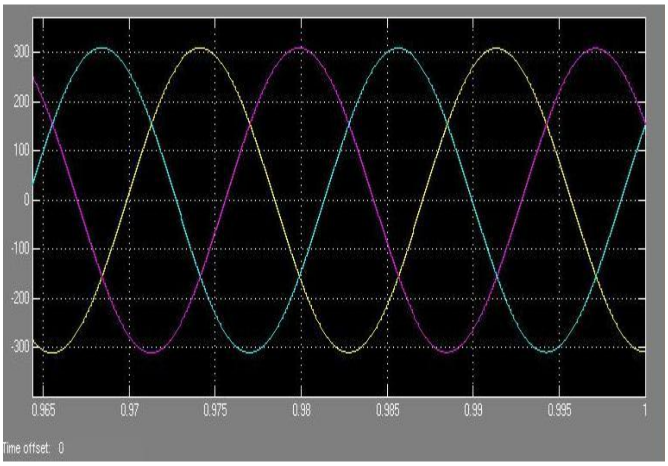

Fig: 15 3- phase Voltage with LC filter

X. HARDWARE IMPLIMENTATION

Fig: 16 Hardware

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(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 12, December 2014

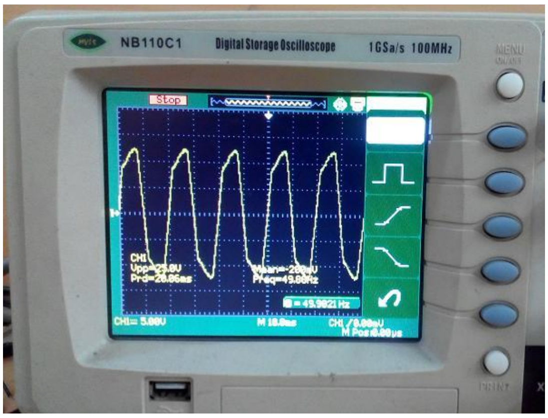

Fig: 17 Wind Input voltage

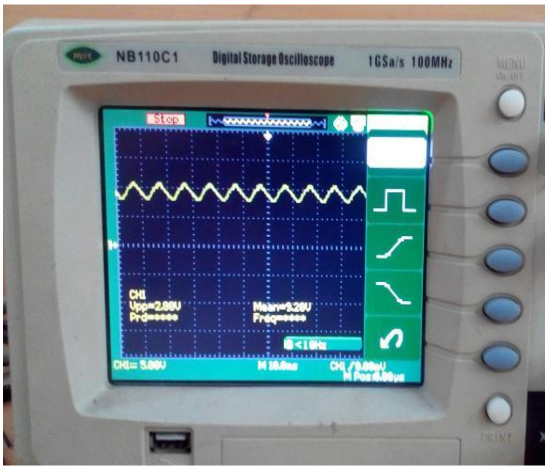

Fig: 18 PV Input voltage

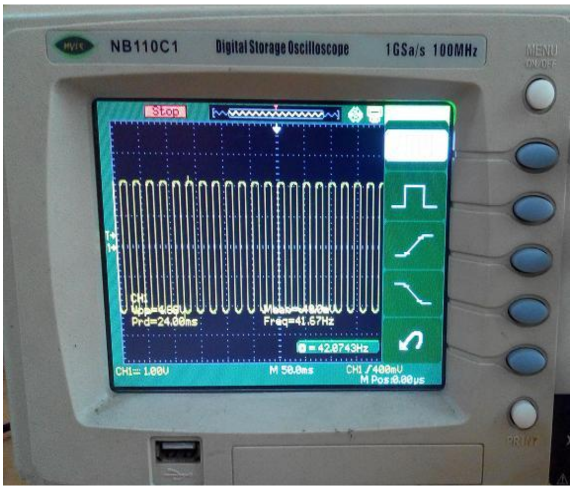

Fig: 19 output voltage with Load

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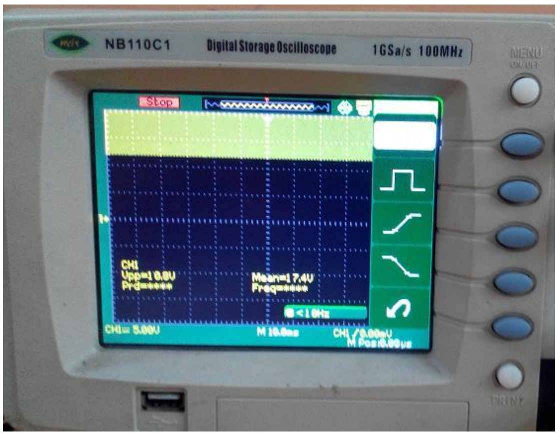

Fig: 20 Battery output voltage

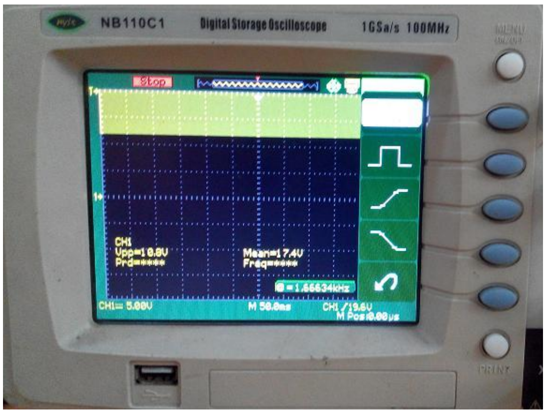

Fig: 21 super capacitor voltage

Fig: 22 SEPIC output voltage

XI. CONCLUSION

This project has investigated the standalone operation of a PMSG and photovoltaic power source with a hybrid energy storage system consisting of battery storage and a super capacitor, a synchronous condenser and a dump load. The entire RAPS system is simulated under over-generation and under-generation conditions covering the extreme operating conditions such as load step changes and wind gusts. The suitability of the adopted control strategy for each system component is assessed in terms of their contributions towards regulating the load side voltage and frequency.

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Investigations have been carried out in relation to the voltage and frequency regulation at load side, DC bus stability, wind energy and PV energy and the performance of the hybrid energy storage system. From the simulated behavior, it is seen that the proposed approach is capable of regulating both voltage and frequency within tight limits for all conditions including the worst-case scenarios, Such as wind gusts, solar irradiance and load variations. Also, the performance of the battery storage is improved with the implementation of the proposed energy management system, as Super capacitor absorbs the ripple or high frequency power component of demand generation mismatch while leaving the steady component for the battery storage. Moreover, the Super capacitor helps in avoiding battery operation in high rate of depth of discharge regions. The proposed control system is able to manage power balance in the RAPS system while extracting the maximum power output from the wind and solar throughout its entire operation. With the integration of the synchronous condenser, it has been proven that the RAPS system is able to maintain the load voltage within acceptable limits for all conditions including the situation when reactive power demand becomes very high.

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