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Hybrid energy storage system using wind power system

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Abstract The research deals with energy storage and its management. In this hybrid wind system Li-ion battery charge status is controlled by DC/DC bidirectional converter based on load requirement. The battery system along with super-capacitor and load are being simulated for various conditions and the output parameters like voltage, current, power and state of charge are being plotted and analyzed for each condition. To meet the short-term peak, it is required to charge the power at a faster rate by using a super-capacitor. To meet medium-term peak requirement, it is required to fulfill the large-scale capacity by using Li-ion battery. The life of Li-ion battery depends upon the charging and discharging cycles. By using a super-capacitor, the efficiency and durability of the battery is increased by reducing the charge and discharge cycle of the battery. Due to this the maintenance cost of the battery is reduced, which reflects the overall cost of the system. Model is proposed with external energy maximization strategy (EEMS) and simulated on MATLAB R2015 b. This paper depicts the control and management strategy for the reduction of deviation cost by utilizing hybrid energy storage system by which we obtained a much more cost-effective solution as compared to conventional system.

Keywords: Energy storage system, EEMS, wind power, energy storage for short & long duration, super-capacitors, Li-ion battery.

1. Introduction

Due to the environmental pollution and energy depletion people will use renewable energy sources such as solar efficacy, wind efficacy, hydro energy. There has been a rapid growth in wind energy in the past few years. Wind energy has proved that it is a very clean and abundant renewable source. Unlike the other renewable sources there is a fluctuation in the output of wind power system with the variations in the speed of wind. Such variations sometimes cause problems in dispatching the required amount of power. Fluctuation in wind power systems is the main disadvantage over other renewable resources.

For designing energy storage systems there are two aspects which we should keep in mind. The first is there are many fluctuations present at different frequencies in the wind power system. There are some energy storage devices, which will give high-energy storage support. VRB or Li-ion battery and others are better for short terms storage such as super-capacitors, flywheels, superconducting magnetic energy storage (SMES). The fluctuation of power caused by the speed variation of wind is divided into two parts. One is a short-term component and the second is a medium-term component. A hybrid system consisting of a Li-ion battery and a super-capacitor is used to rectify this problem. The second aspect, which should be kept in mind, is the cost. We have minimized the cost as low as possible. The life of the battery depends on the charging and discharging cycle of the battery. After using super-capacitor for short-term load there is a decrease in the charging and discharging cycle of the Li-ion battery. Due to this there is less maintenance required by the Li-ion battery and also there is a reduction in the amount that is spent for the replacement of the faulted Li-ion battery. Due to this the overall cost of the system is reduced. Energy management has a desired goal setting, result development and opportunity identification. Energy management strategy helps in making paths between external drivers such as demand, need, performance etc. and internal targets such as expenses, income and risk management. It enables us to send energy and environmental performance which increases savings and efficiency. We also use EEMS controller to use super-capacitor for short term peak load and Li-ion battery for long term peak load. We can say that EEMS act as the brain of the whole system.

For determining the power and efficacy capacity of the energy-storage device we use a power analysis-based method. In this paper hybrid energy- storage modules are constructed for the two problems. The super-capacitor is constructed for the requirement of energy of short duration and Li-ion battery is used to meet the requirement of medium duration. The output analysis of wind power defines the ability of both devices. The model is proposed with EEMS and simulated in MATLAB Simulink environment where we obtained a cost-effective simulation with a benefit of 36.63% compared to previous proposed systems [1], [12].

2 Theory

For energy storage available techniques are MH-Ni battery, lead-acid battery, pumped storage, Na-S battery, Li-ion battery, superconductor magnetic energy storage (SMES), VRB, flywheel, also super-capacitor [11].

Short duration energy storage – the lifetime of super-capacitor is less than that of the battery, but the power density is much more than that of the Li-ion battery while the energy density is low. Short term energy storage is best for giving strong power support [1].

Medium duration energy storage - Li-ion battery and VRB (Vanadium Redox Battery) both are suitable for medium term application. The energy density of Li-ion battery is higher than that of super-capacitor and the rate of self-discharge is much lower than that of super-capacitor. The extremely large storage capacities of Li-ion battery made it the most appropriate option to use in large power storage applications, for example solar power and wind power [1] elimination.

3 Motivation & proposed framework

In remote area renewable power system can generate a distributed generation in which the system is not connected with national power grid as it is very expensive and becomes very difficult logistically [2]. In the remote regions where transportation of fuel and coordination are expensive, the sustainable power source assumes a significant role in it. Remote territory control framework has an inexhaustible age source. For example, photovoltaic generators, wind energy transformation framework, diesel generators, some type of energy storing devices and load. The rating of such framework has a range from small scale frameworks of barely any hundred watts to huge scale detached network supply with >>100 KW control rating [2]. A block diagram of remote area power control framework is shown as follows:

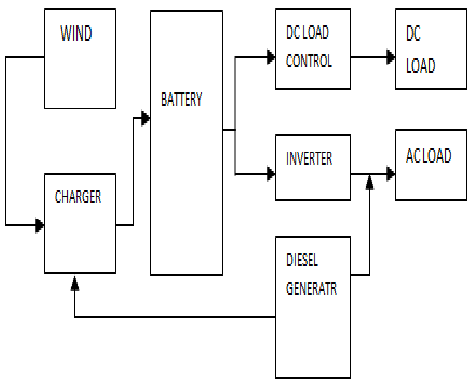


Figure 1: Block diagram of remote area power control framework

In the proposed model we will use a hybrid system which is a combination of battery and super-capacitor connected via DC-DC converter. In this system a diesel generator is also connected as the backup of the whole system. This will run the system when the stored amount of energy is finished and there is not enough wind available to generate the power. In that case we use a diesel generator for supplying the load and fulfilling the user requirement.

4 Integration of wind and storage model

To join the energy storage system with wind power system there are several electronic topologies available. One of the topologies is fixing efficacy storage in between DC-link of back-to-back converters of generators [1], [9]. During the fluctuation in the generated power, the network is connected to the PMSG (permanent magnet synchronous generator) system. Still there are many examples of research going on to study the effort of energy storing devices placed in between the DC-Links of back-to-back converters of doubly fed induction generator [1], [10].

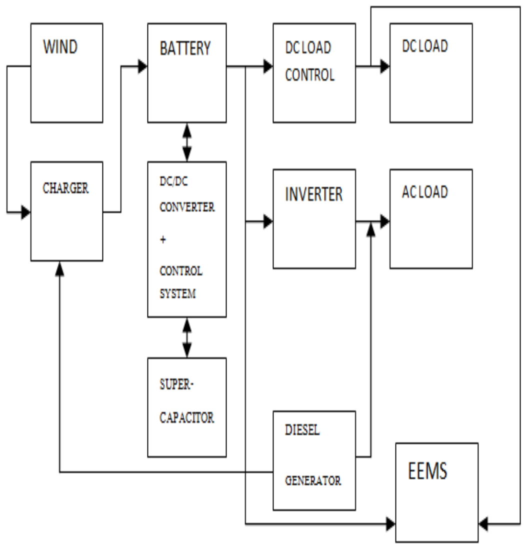


Figure 2: Block diagram of proposed remote power system

In topology energy storage system is connected in parallel with the wind turbine which relates to the grid [1]. The proposed system consists of the farm which is actually a wind power generator, and an ESS is connected with it in parallel. The energy storage system is situated in the location of a wind generation plant and connected with the power grid through a power electronic device.

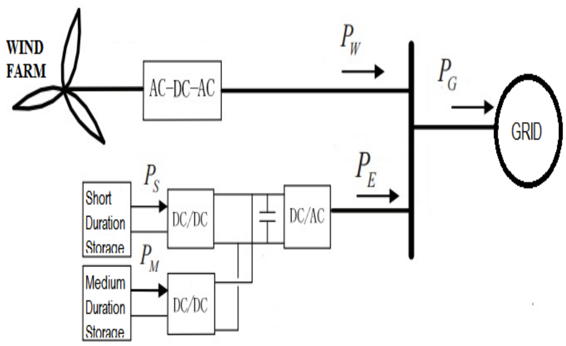
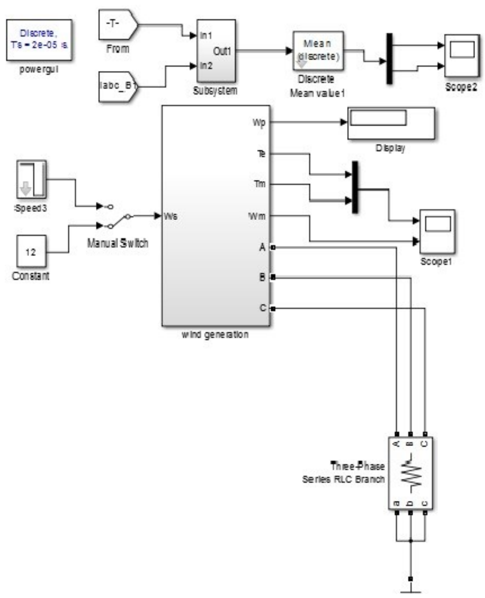


Figure 3: Two Level Energy Storage



4.1 Wind generation model

The wind energy conversion system is a complex system that converts wind energy to mechanical energy and electric energy. Output power or moment of wind turbine is defined by basic factors such as wind speed, turbine shape, and dimension.

The electrical energy generated is supplied to the connected power grid via DC-Link of back-to-back converters. In this model we can control DC voltage at the required level. However, we didn't adjust the system for frequency, L and R by connecting C filter after rectification. This model depicts regulation of output voltage delivered by the hybrid system consisting of PMSG based wind energy system with 3-phase controllable rectifier. If required by interfacing MPPT algorithm we can obtain the modified output of the system.

Figure 4: Wind generation model

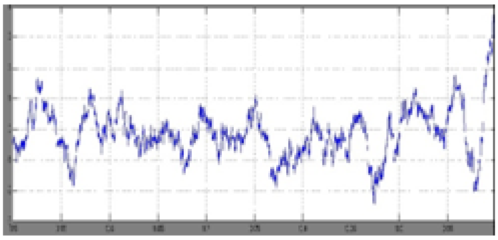


Figure 5: Power vs. Time graph of WPMSG

5 Problem formulation

The problem related to the wind power system is that most of the remote area wind power system is not connected to the national grid [2]. The reason behind this is that if we connect this wind power system with the national grid a huge amount of cost is required [2]. So that to spare that cost we cannot connect remote area wind power system with the national grid. Instead of connecting this system with the national grid we will store the huge amount of energy generated in the plant and then use that energy for fulfilling the user requirement. For storing the energy, we use LI-ion battery and a super-capacitor. If the condition of no wind availability is arising and we don't have enough stored energy, then for the generation of power we use a diesel generator which will help in the power generation [2]. But the maintenance and fuel costs have increased. So, after using the energy storage system there is also a reduction in the maintenance of diesel generator cost and fuel transportation cost.

During the short-term peak hours (whose duration is around 6 to 7 hours). We use the super-capacitor because the super-capacitor has a fast-charging rate as well as fast discharging rate. So due to this reason we can use super-capacitor for short term peak hours. By using the super capacitor, the lifetime of the battery will also increase because the lifetime of the battery will depend on the charging and discharging cycles, the reduction in the charging and discharging cycle will lead to the increase in the life of the battery. Apart from this the maintenance cost of a super-capacitor is less than that of the Li-ion battery. So, there is also a decrease in the maintenance cost of the system.

5.1 Analysis of energy storage system

To check the performance of energy storing device of power flow we have considered that the dispatched power P_G from the wind farm to main grid is stored constantly. The unbalance between the wind power P_W and P_G is replete by energy storage system power [1].

$$P_E(t) = P_G - P_W \quad (1)$$

When $P_G > P_W$, P_E is positive. It means the energy storage system injects the power in the grid and Li- ion battery is draining. When $P_G < P_W$, P_E is negative It means the energy storage system absorbs the wind power and battery is changing. The energy storage system is running all the time to give power P_W. In this hybrid energy storage system, the capacity of super-capacitor can decrease the frequency of Li-ion battery and improves the life of battery [1].

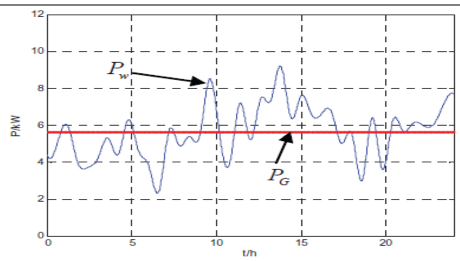


Figure 6: Output power curves

The super capacitor power capacity can be evaluated by using the maximum imbalance power in between P_G and P_W. At "T" the energy storage system power reaches the maximum point

$$P_{SC} = P_{E\,MAX} \quad (2)$$

Now integration of P_E with respect to time gives energy stored in energy storage system.

$$E_{e(t)} = E_{eo} + \sum_{k=1}^{n} P_e, k\Delta t \quad (3)$$

Where E_{eo} = Initial energy of energy storage system.

5.2 Cost benefits

The energy storage module is able to be controlled by wind farm side or grid side. In most parts of India, the energy generated through wind is preferred to be sold to the grid but at night, when load is lower the output of wind power system is bounded and also causes the power wasting. With the energy storage system devices, when the load is low the power can be stored and dispatched in daytime [1].

$$B = a\,(PG - PG*) - b\,PSC - cELi \quad (4)$$

Where PG - PG* = power sold to the grid with energy storage system devices.

"*a*" = Unit price of the energy generated through wind *PSC* and *b* = super-capacitor power capacity and unit power cost of super-capacitor.

Li and *c* = Li-ion battery energy capacity and unit energy cost of Li-ion battery cost of system without *ESS* = *a* (*PG* - *PG**) = 3.75*10500 = *Rs*39375 (*PG* - *PG**) = 10.5 *MW* (10500 *KW*).

a = *Rs* 3.75.

PSC = 291.6 *V*.

b = *Rs* 200.03 *c* = *Rs*16.4872 *ELi* = 48 *V*.

B= (10500*3.75) - (16.4872*291.6) - (200.3203*48)

= 39375-4807.6675-9615.3744 = Rs 24951.9581.

Reduction in cost = cost without *ESS*–*Cost* with *ESS*= Rs 39375 – Rs 24951.9581 = Rs 14423.0419.

Reduction of cost in percentage = $\frac{14423.0419*100}{39375}$

= 36.63 %

Here the cost and energy cost of battery and super capacitor is shown in Table Table 1.

Table 1: Cost analysis of storage module

Component	Power Cost (Rs/KW)	Energy Cost (Rs/KWh)	Cycle Number
Li-ion	3209	32090.4	500-2000
Super-Capacitor	10956.9	50646.4	>100000

6 Proposed system

The circuit explains the simulation model of storage of power generated from wind PMSG system. The peak load seen by the wind power system increases. Consequently, there is an overload at lower wind speed where the generated power is near to zero. A more robust emergency power system is needed to ensure a safe wind generation power system. This model presents an alternative emergency power system based on wind generation. Li-ion and super-capacitor are used as energy storage devices. The wind power system was designed based on an emergency load profile of the city.

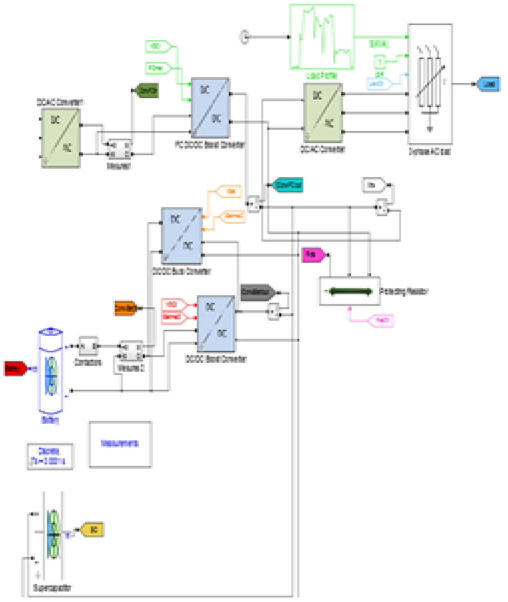


Figure 7: Proposed Storage Model

The 40 Ah, 48-volt Li-ion battery system. A 15.5 F 291.6-volt super-capacitor system (series combination of six 48.6-volt cells). A DC/DC boost converter of 12.5 kW with synchronized output voltage and constraint input current. Two DC/DC converters for charging (1.2Kw buck converters) and discharging (4 kW boost converters) are used in the system. These converters also regulate the output voltage with current limitation and are also used normally. A single bidirectional DC/DC converter can also be used to minimize the load of the power system. A 270volt DC, 15kVA in 200-volt AC Hz inverter system is used. A 3 phase AC load which has variable power factor and apparent power to evaluate the emergency load profile is used. To avoid the overcharging of the battery system and super-capacitor we use a 15kW protecting resistor. All these components together show the storage model of wind power system (storage model of wind power system), and this model is integrated with another model of wind generation (this model only generates power) through DC/AC converter.

7 Simulation & result

We integrate two models through AC/DC converter and performance of the wind generation-based hybrid energy storage system for 350 seconds, demonstrated on MATLAB R2015(b). Depending upon which type of energy management approach is considered, it controls the power of each source. The power is controlled by EEMS through the reference signals of wind generation system, DC/DC converter and Li-ion battery.

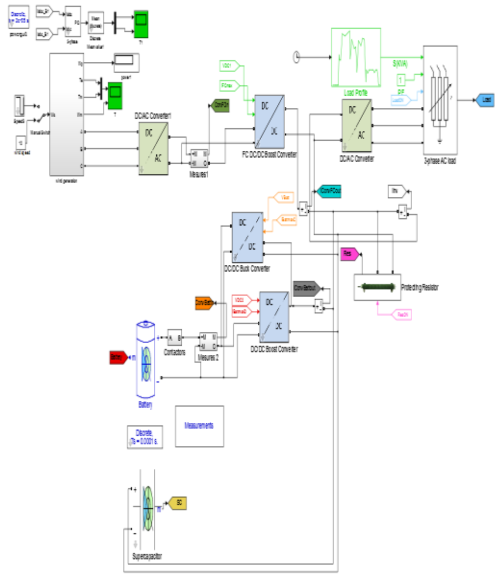


Figure 8: Proposed model

Double click on the measurement block and now open the battery scope together with that of the super-capacitor and load scopes. The following explains what happened during the peak load hours. At t=0 seconds the required loads are fed by the wind power system when there is enough wind available for the generation of power. At t=5seconds the wind generation system starts to recharge the Li-ion battery to its optimal power (1 kW). At t=40 seconds the generating system is lost now. The hybrid energy storage system feeds all the loads. At this time the peak loads are fed by the super-capacitor due to its fast response. When the power generated rises up slowly, at t=45 seconds the super-capacitor is now discharged below the required DC bus voltage (270volt) and now Li-ion battery starts supplying power to control the bus voltage of 270 volt. At t = 48.5 second the DC bus or super-capacitor voltage arrives at 270 volt and Li-ion battery decreases and decays to zero potential. The wind energy plant delivers the power, and it continues to recharge the super-capacitor. If the wind generation plant is not able to restart again it means that there is no wind flowing in the atmosphere and now, we will supply the required power by the diesel generator.

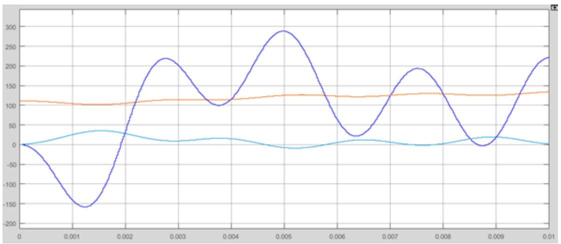


Figure 9: Power vs. Time graph of Storage model

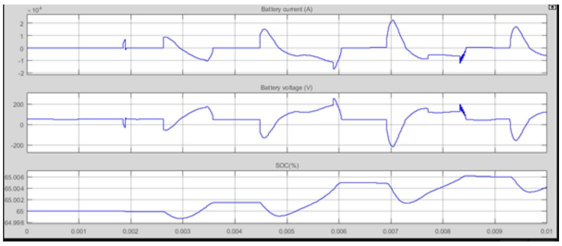


Figure 10: Voltage, Current and State of Charge graph of Battery

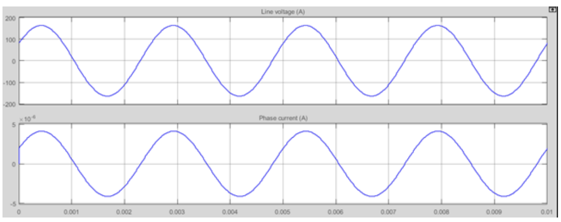


Figure 11: Current and voltage graph of load

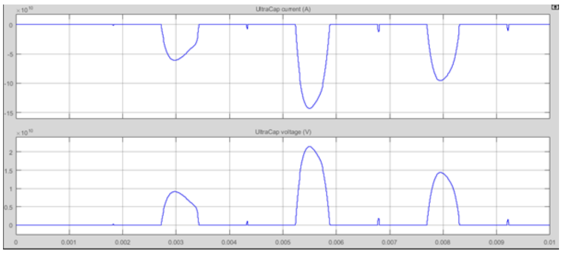


Figure 12: Current and voltage graph of super-capacitor

8 Conclusion

This paper shows the battery –super-capacitor-based hybrid energy storage system. The battery system along with super-capacitor and load are being simulated for various conditions and the output parameters like voltage, current, power and state of charge are being plotted and analyzed for each condition. It depends on the analysis of characteristics of two-level storage technologies. After analyzing the data, EEMS helped the system to decide at what time the super-capacitor will supply the load and at what time Li-ion battery will do the same. Li-ion battery is not in use during short term peak hours due to which the numbers of charging and discharging cycles are reduced and the lifetime of the battery is increased. Due to the usage of hybrid systems the maintenance is minimized which in turn results in minimized expenditure for the system. Due to which the overall cost of the system will be reduced. The model is proposed with EEMS and simulated in MATLAB Simulink environment where we obtained a cost-effective simulation with a benefit of 36.63% compared to previous proposed systems.

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