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Design Hybrid Energy System For Supplying Remote Load With Supercapacitor Based Energy Storage

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ABSTRACT

Electrical energy forms the lifeline of every nation and the progress of every nation is directly related to the quantum of energy consumed. Economic growth can be achieved by means of industrialization and the industrial growth in turn depends on the consumption of energy. Developed countries have the privilege of using technically superior and safer nuclear reactors which can produce gargantuan amounts of electrical energy with much ease. Huge debates have sparked off from environmentalists and other activists about the feasibility of these reactors and Ultra mega thermal plants in connection with their safety and pollution concerns. This has forced power system engineers to look after alternative energy sources which are environmentally clean and at the same time augment the existing power supply. Electrical energy derived from solar arrays and wind are totally pollution free and also available at free of cost. Technological advancements in both WECS and PV array based systems are making huge inroads in the participation of them. This paper describes the application of Super capacitor based energy storage system which can be used for a Solar-Wind hybrid energy system and the design procedure to be adopted for implementing the same.

INTRODUCTION

Use of renewable energy sources especially WECS and PV array based systems have already made their impact the present world by producing a significant amount of electrical energy without much recurring costs. The presence of these sources has made even remote places to get access to electricity and enjoy its benefits. This is a great boon to the people who are living in interior parts of a country who do not have the privilege to be connected with the utility on account of their poor load factor. These sources can take up the load with ease and effectively supply them continuously. The greatest disadvantage of these systems is that they are totally dependent on the nature and the fluctuations climate will greatly influence the performance of the overall system. The solar radiation of the geographical area has a huge impact of the energy produced by the PV array and the local wind speed will determine the amount of energy produced by the WECS.Supercapacitors or Ultra capacitors which are capable of storing more energy than conventional capacitors can be utilized effectively in these situation to improve the transient stability of the system and also alleviate the problem of voltage sags. A schematic for such a system is as shown in figure (1)

SOLAR ENERGY

The model of a PV system is as shown in figure 1.The geographical details of the location plays an important role in the amount produced. The total amount of solar energy that lights a given area is known as irradiance and is measured in watts/meter. It is averaged over a period of time, say,per hour ,day or month. The location has to be finalized based on the 'solar history'. Statistical data has to be gathered first and then only be used for finalization.PV arrays are built with combined series/parallel combinations of PV solar cells.The PV cell output voltage is a function of photo current which is determined by the solar radiation level during the operation. In any PV based system the boost converter forms the most important part. As the power obtained from the array is a low voltage power this has to be boosted by the boost converter circuits. The power available at the output of the boost converter is filtered and converted to AC using single phase voltage source inverter circuits which employs SPWM.The SPWM scheme operates by comparing a carrier wave with a reference signal corresponding to single phase which generates the corresponding gating pulses for turning on and off the thyristor for required switching frequency in order to produce the rated voltage.

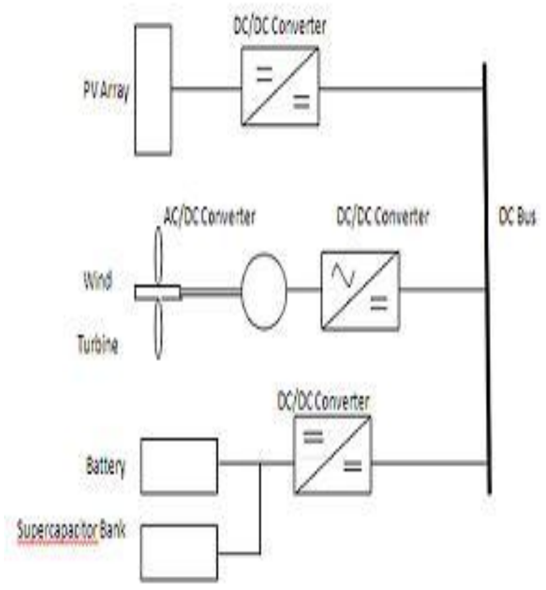

Figure.1

WIND ENERGY

The momentum of the blowing wind produces a torque which when acts on a rotor produces a rotational movement. This rotational torque is coupled using several gear mechanism so that it ultimately drives a rotor of a generator which is designed to produce electricity. Wind energy is also a source of renewable energy which is available in abundance. Technological advancements have made it possible to produce large quantities of power using wind energy. These wind turbines are generally of horizontal axis type and are mounted at a height of above 30 meters from the ground so as to capture the faster and less turbulent winds. In order to ensure efficient operation the wind turbine the wind must be above the cut in speed which is the minimum speed required to generate the usable power from the turbine. The rated speed of the wind refers to the minimum speed required to generate the turbine's power. The maximum speed before the turbine shuts off to protect it from damage is called as cut out speed.

ULTRACAPACITORS

Ultracapacitors are a new energy storage technology ideally suited for applications needing repeated bursts of power for fraction of seconds to several minutes. They are capable of packing up to 100 times the energy of conventional capacitors and deliver ten times the power of ordinary batteries. During the past few years, electric double-layer capacitors with very large capacitance values have been developed. Those capacitors are frequently called super capacitors, ultracapacitor, or electrochemical capacitors. The term ultra capacitor is used because the power industry seems to use it more frequently. Advantages are high power density, fast charging, long life time, low-temperature performance, environmentally friendly and so on. Because super capacitor is voltage source, easily charged and inverted, energy is released through inverters. Its charging voltage may exceed 400 V, super capacitor directly charges through rectifiers. The whole control process is very simple.

An ultracapacitor is an electrical energy storage device that is constructed much like a battery because it has two electrodes immersed in an electrolyte with a separator between them.

The electrodes are fabricated from porous high surface- area material that has pores of diameter in the nanometer range. Charge is stored in the micro pores at or near the interface between the solid electrode material and the electrolyte. The charge and energy stored are given by the same expressions as those for an ordinary capacitor, but the capacitance depends on complex phenomena that occur in the micro pores of the electrode. The energy and power density of ultracapacitors fall between those of batteries and conventional capacitors. They have more energy than a capacitor but less than a battery and more power than a battery but less than a capacitor. Unlike in batteries, the ultracapacitor voltage varies linearly with the state of charge. The voltage range between full charge and end of charge is higher for ultracapacitors than for batteries. Because of such drastic variation with state of charge, series connection is often required for high-voltage applications, and power electronic circuits must be integrated with the stack to control charge, discharge, and voltage equalization. An ultracapacitor has a distinct advantage of good power density but at the cost of lower energy density. This unique utility of them makes it the best option to provide energy bursts during short power peaks. Moreover the lifetime of the ultracapacitor is also longer which makes it suitable enough to smooth out the power of battery. Care must be taken in such a way that the ultracapacitor is neither subjected to too high voltage or temperature which may reduce the lifetime.

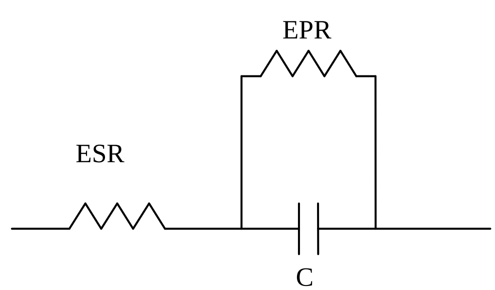

Figure 2

Ultracapacitors are designed to work in a series of discharge and charge cycles. The internal losses and the value of capacitance determine the recharge current. A simple model as given in figure (2) for an ultracapacitor is represented by a capacitor in series with an equivalent series resistance (ESR) and an equivalent parallel resistance (EPR).The ESR models the losses by joule effects. The EPR represents the current losses.

BLOCK DIAGRAM OF THE SYSTEM

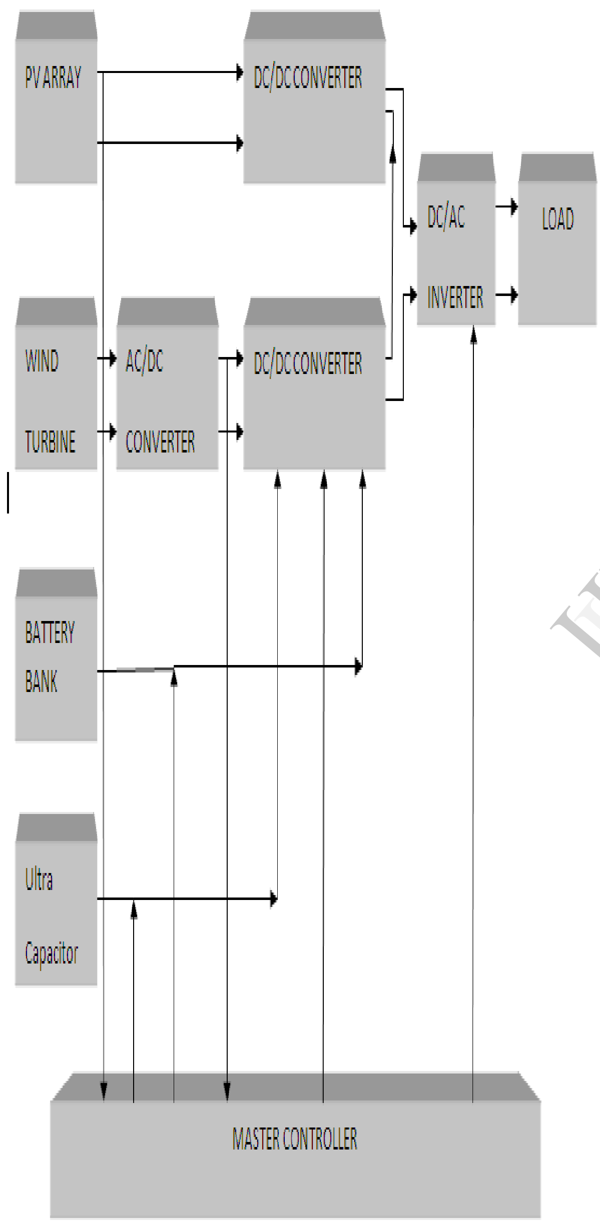

Figure .3

PROPOSED SYSTEM

The proposed system which is taken for design is a remote load which has an annual demand of 12000Kwh.This load is supplied by a hybrid system comprising the PV array and the WECS.The design procedure also includes the sizing the ultracapacitor bank which is used in addition to the battery for relieving the same in cases when extra power is demanded.the sizing of ultracapacitor bank primarily depends on the time for which back up is needed and at the same time the amount of power for which the backup is necessary.The block diagram for the proposed system is as shown in figure (3),which includes a master controller whose purpose is to control the entire process of the system.Its primary job is to monitor the voltage levels and to take care of charging and discharging the supercapacitor bank to ensure that the rated voltage is maintained for the specified period,in addition to giving control signals for converters.

NOMENCLATURE

V_{max}	Maximum Voltage
V_{min}	Minimum allowable voltage
V_w	Working operating voltage
P	Power requirement
t	Time of discharge
dv	Change in voltage
i_{av}	Average current
I_{max}	Maximum current
I_{min}	Minimum current
C_{cell}	Cell capacitance
C_{total}	Total capacitance of the bank
R_{cell}	Resistance of cell
R_{total}	Total resistance of the bank

DETERMINING THE SIZE OF SUPERCAPACITOR BANK

Sizing supercapacitor bank forms the critical part of the design as the cost of it is on the higher side. The procedure to be followed for determining the exact size of the bank is elaborated in the flow chart as given in figure .4

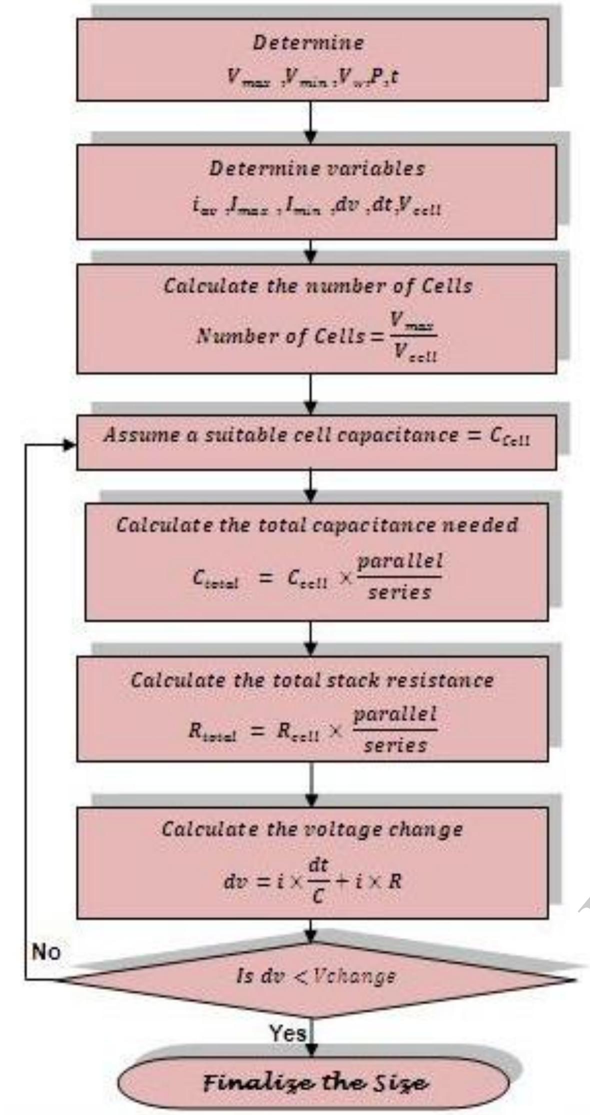

Figure .4

CALCULATIONS

$1. Assuming\ a\ load\ of\ 1000 \frac{KWh}{month} amounting$

$an\ annual\ load\ of\ 12000KWH$

$2. Let\ 15\%\ loss\ is\ accounted\ for\ the$

$Power\ Conditioning\ Unit = 1.15 \times 12000$
$$= 13{,}800 \frac{KWh}{Annum}$$

$3. Determine\ the\ total\ Ampere\ hour\ used$

$by\ all\ loads\ and\ choosing\ an\ \ input\ voltage\ of\ 48\,V$

$$Therefore\ \frac{13{,}800}{48} = 287.5\ KAh\ per\ annum$$

$4. Convert\ Annual\ Ampere\ Hour\ for\ a\ day \frac{287.5}{365}$
$$= 786.30\ Ah\ per\ day$$

SIZING PV ARRAY

$It\ is\ assumed\ that\ half\ of\ the\ load$

$is\ supplied\ from\ PV\ array\ and\ the\ remaining$

$half\ is\ supplied\ from\ \ WECS$

$1. Therefore\ the\ AH\ requirement\ from\ PV\ is\ \frac{786.30}{2}$
$$= 393.15\ Ah$$

$2. Determining\ the\ total\ Ah$

$supplied\ by\ PV\ array\ as\ \frac{393.15}{5.5}\ ,71.48\ Amperes$

$3. From\ the\ data\ sheet, the\ maximum\ power\ current$

$I_{mp} = 4.47\ Ampere$

$4. Calculate\ the\ number\ of\ modules$

$to\ be\ connected\ in\ parallel\ \frac{71.48}{4.47} = 14.98$
$$\cong 15\ Modules$$

$5. Since\ 48\ V\ D.C. level\ is\ used\ two\ subarrays$

$are\ needed\ i.e\ 30\ modules\ are\ required$

$consisting\ of\ two\ subarrays\ in\ series$

$6. Rated\ power\ rating\ of\ PV\ system\ is\ 71.55 \times 48$
$$= 3.434\ KW$$

CALCULATION OF WIND ENERGY

$1.50\%\ of\ energy\ is\ supplied\ by\ the\ WECS\ i.e\ \frac{13{,}800}{2}$
$$= 6900\ KWh\ per\ annum$$

$Divide\ by\ 36\ for\ single\ day\ output\ i.e\ \frac{6900}{365}$
$$= 18.9\ KWh$$

$2. Assuming\ that\ the\ wind\ blows\ for\ an$

$average\ of\ 5.5\ hours\ a\ day\ at\ an\ average$

$speed\ of\ 10\frac{m}{s}\ we\ have\ \frac{18.90}{5.5} = 3.45\ KW$

SIZING OF THE SUPERCAPACITOR BANK

1. *Assuming that we have an application requiring 10 KW for 5 seconds*

$V_{max} = 55V$

$V_w = 48V, V_{min} = 35V$

$Power = 10KW$

$Time = 5\ Seconds$

2. *Calculate change in voltage* $dv = V_w\text{-}V_{min}$

$i.e\ 48 - 35 = 13V$

3. $I_{max} = {Power}/{V_{min}} = \frac{10000}{35} = 285\ Amperes$

4. $I_{min} = {Power}/{V_{max}} = \frac{10000}{55} = 181\ Amperes$

5. $i = Average\ current = {Power}/{V_w} = \frac{10000}{48} = 233\ Amperes$

6. *Change in time* $dt = 5\ Seconds$

7. $C = Total\ Stack\ capacitance$

8. *Assuming a cell voltage of 2.5 V the number of cells required* $= \frac{55}{2.5} = 22\ Cells\ in\ series$

9. $C_{total} = C_{cell} \times \frac{Parallel}{Series} \begin{cases} Assuming\ 1500\ F\ one\ parallel \\ string\ with\ 22\ series\ capacitors \end{cases}$

$$\Rightarrow C_{total} = 1500 \times \frac{1}{22} = 68.18\ Farad$$

$$R_{total} = R_{cell} \times \frac{Series}{Prallel}$$

$$\Rightarrow R_{total} = 0.00047 \times \frac{22}{1} = 0.01034\ Ohms$$

10. *Change in voltage* $dv = i \times \frac{dt}{C} + i \times R$

$$\Rightarrow dv = 233 \times \frac{5}{68.18} + 233 \times 0.01034$$

$$\Rightarrow dv = 17.087 + 2.409 = 19.49\ Volts$$

CONCLUSION

Ultracapacitors are one latest solution which is employed to alleviate the problems of loads which demands short power bursts. They outperform batteries in this aspect and are widely used in applications like hybrid vehicles, remote renewable applications and many more. Due to the variation in climatic conditions , the output power and terminal voltage of a remote renewable power source which employ either a wind or a solar system varies drastically.Ultracapacitors prove handy for these applications and can improve the transient stability of the system. This paper presents the methodology to be adopted to design an ultracapacitor based system .It also suggests the steps to be followed to determine the size of the capacitor bank and is explained clearly for a given system.

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