# Diminishing Power Fluctuations for Energy Storage in WECS using Super Capacitors

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*Abstract :* In power system, major issues are in power quality and reactive power of renewable energy system such as solar, wind etc. In WECS, voltage fluctuations are caused by varying nature of wind energy. It causes interruptions to the DC charge controller. It affects the life of battery as well as the power quality of the system. To deals with the power quality issues, here proposes a wind energy conversion system that integrating super capacitors as energy storage device. The DC charge controller is made to work in the constant voltage and constant current modes. The maintained DC link voltage helps to eliminate the power fluctuations caused by variable wind speed and instantaneous load switching, also lowers the stress on the switches of charge controller and increases efficiency of the system. It causes improvement in power factor at permanent magnet synchronous generator terminals. Also, quality of load voltage is improved as stable power and improvement in reactive power. To confirm the proposed idea, the working of wind energy conversion system, battery life, reactive power and power quality are inspected through simulations in MATLAB and results are verified.

*IndexTerms* - ***energy storage device, super capacitor, WECS***

## I. INTRODUCTION

Non-conventional energy sources are better than conventional energy sources. The Wind energy conversion system (WECS) is built of mechanical and electrical components. Mechanical components include wind turbine and gear box. The electrical parts consist of generator, control and other interconnected devices. The generator is the integral part of a turbine, because, it is responsible for converting mechanical energy into electrical energy. Most WECS uses a permanent magnet synchronous generator (PMSG). The PMSG doesn't need a gear box, because this generator is typically used to charge a battery through a rectifier. Wind power sources which are placed far from inhabited areas and are capable of small-scale power generations, need to store electrical energy [1]. Energy storage devices (ESD) are attached to these types of sources either directly, by means of rectifier or DC-DC converter or by their cascaded combination. The three phase rectifier coverts the AC voltage generated by the wind turbine and the output of the rectifier is irregular DC voltage, a DC-DC converter is used to regulate DC voltage. Due to non-linear behaviour of diode rectifier the terminal voltages are distorted. Due to variable output of generator, the reactive power waveforms are distorted in conventional system. It leads to power factor issues.

Proposed WECS, that locate a supercapacitor in between DC charge controller and battery.in the proposed WECS, the DC charge controller is made to operate in CCM and CVM depending on the SOC of energy storage device. The supercapacitor offers high power density and fast responds to load variations. Owing to the fast charge-discharge rate of super capacitors, supercapacitor as ESS is ideal for reducing power fluctuations [2], [4]. However, a super capacitor alone cannot be used as an energy storage device (ESS) where, in several 100 to 1000 amperes of current is supplied for a short period. The energy capacity of a supercapacitor is typically 100 times more than that of an electrolytic capacitor of the same size. A super capacitor has a long range of operating temperatures and it holds high power density of approximately 10 Kw/Kg, which is more than that of a battery. It has long lifecycle of around 500,000 cycles. It can store charge without any chemical reaction. Thus, it can charge and discharge at a much faster rate in a matter of a few seconds. Lead acid batteries re electrochemical devices that convert chemical energy into electrical energy through a redox process. As a result of chemical reaction charging process is slow. Energy density of battery is 10-100 Kw/Kg. charge cycles are approximately 1000 cycles. Thus, a battery cannot sustain a high number of charge / discharge cycles. Under extreme load variations, batteries cannot respond immediately and remain under high stress, which reduces the lifetime of the battery. Hybrid energy storage can decrease the overall cost of a system [3].

## II. BLOCK DIAGRAM

It includes of a wind turbine mimicking converter, super capacitor, charge controller, energy storage system. The wind turbine mimicking converter is the combination of wind turbine, a permanent magnet synchronous generator, three-phase diode bridge rectifier and a DC-DC converter.

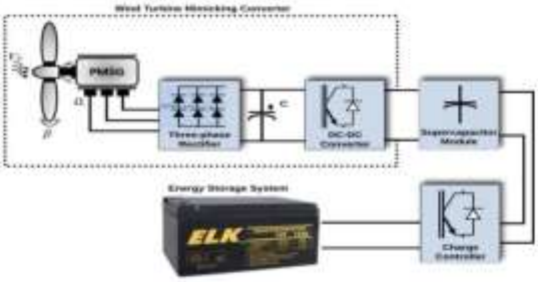

Fig.1 Block diagram of proposed WECS

The DC supply from the DC-DC converter is given to charge the super capacitors. The super capacitor supplies the stored power to the charger controller to charge the battery. The control of the charge controller is made to operate in constant current (CC)/ voltage (CV) [6]. The proposed wind energy conversion system is designed to operate independently in a single microgrid or collaboratively with other microgrids. The battery voltage (DC) can be fed to the power converter (DCAC) to supply AC loads.

## III. COMPONENTS REQUIRED AND DESIGN

### *A. Permanent Magnet Synchronous Generator*

In PMSG, the excitation field is provided by a permanent magnet. The term synchronous implies that rotor and magnetic field having same speed. Since, the permanent magnet gives magnetic field and the current is induced in armature. Rotor contains a magnet. Stator is the stationary armature that is electrically connected to a load. There is no need of sliprings and carbon brushes which make the machine less expensive, light weight and maintenance of generator is less. The generator attached with the power electronic conversion circuitry can work on the less speed and so there is no role of the gearbox. PMSG is called synchronous generators, because, voltage produced the frequency in the stator in the Hertz is directly proportional to the rotation cycles of the rotor.

### *B. Three-Phase Diode Bridge Rectifier*

It converts alternating current signals to constant current signals. The conduction angle of diode is 2π/3. There are 6 diodes and a resistor as load connected to three-phase supply. The conduction sequence for diodes is D1 - D2, D2 - D3, D3 - D4, D4 - D5, D5 - D6 and D6 – D1.

Average output DC voltage, Vdc

$$Vdc = Vm\,\frac{3\sqrt{3}}{\pi} = 1.654\ Vm \qquad (1)$$

Rms value of terminal voltage, Vrms

$$Vrms = Vm\sqrt{\frac{3}{2}+\frac{9\sqrt{3}}{4\pi}} = 1.655\ Vm \qquad (2)$$

Rms current through the diode is, Id

$$Id = 0.552\ Im \qquad (3)$$

Where, $Im = 1.73\ vm/R \qquad (4)$

### *C. DC-DC Boost Converter*

All it consists of is an inductor, a semiconductor switch, a diode and a capacitor. Also, needed is a source of a periodic square wave. The biggest advantage, boost converter offers high efficiency, 99% of the input energy is converted to useful output energy.

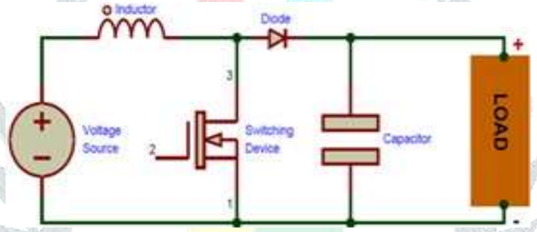

*Fig.2 Circuit diagram of DC-DC boost converter*

### *a) Selection of parts*

Switching transistor: The MOSFET is used in all applications. Because, they are efficient. Choose a transistor of breakdown voltage that is greater than the maximum output voltage of the converter. It might also be a good choice to look at the MOSFET datasheet and determine the input capacitance / gate capacitance. The lower this value is the easier the riving requirements are. Anything below 3500 pF is acceptable and moderately easy to drive. Better choice is IRF3205, which has an on resistance of 8mΩ and a breakdown voltage 55V, with a manageable input capacitance of 3247pF besides being an easily available part. Recommendation C4427.

Output diode: The choice of diode plays a major role in efficiency. Unfortunately, the common 1N4007 won't work, because, it is slow. I have checked the designs that. Here, use the UF4007, having same voltage rating similar to 1N4007.

### D. Super Capacitor Modul

A super capacitor supplies energy in an electrostatic field form.

Energy stored, $E = ½\, CV^2 \qquad (5)$

However, batteries are appropriate for systems with infrequent charging/discharging cycles and take a longer charging/discharging duration than super capacitors. Combining both into a hybrid form meets the energy and power need in wind energy conversion system and reduces battery stress, which reflects in the increment in life span. The discharge method of a super capacitor can be determined by the following equation.

$$V(t) = Vc\,(0)\, e^{RpC}\underline{\hspace{2em}} \qquad (6)$$

Where, Vc (0) is the initial voltage of the super capacitor. Rp represent parallel resistance and C represent capacitance.

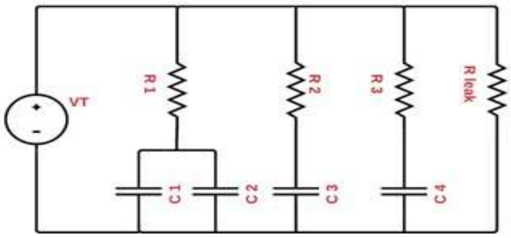

Fig.3 Supercapacitor model

It is a simple RC circuit that provides the terminal behaviour of a supercapacitor. The three- branch model of supercapacitor charge distribution is developed from the RC circuit configuration. The resistive component represents the resistivity of active carbon material. Rleak is the self-discharge leakage and it is modelled by the parallel resistor Rleak. The capacitive element C1, C2, C3 and C4 represent capacitance between the carbon and electrolyte. The capacitance of the super capacitor depends on the potential difference between carbon and electrolyte material. The ESR and the leakage resistances are accounted for the energy wastage, which lowers the efficiency of the super capacitor. Owing to the high charge/discharge power levels, the super capacitor is suitable for energy buffering. The efficiency of the super capacitor,

$$\text{Efficiency, } \eta = \frac{P}{P+Pw} * 100\% \qquad (7)$$

Where, Pw is the wasted power. *a) Sizing of super capacitor*

It has a limitation to withstand a voltage range of 2.5V to 2.7V. typically, a super capacitor should work in series and parallel combination to achieve high levels of power. The recharging current depends on the value of super capacitance and internal losses known as leakage resistance. Current, voltage, charging/discharging time, and power determine the quantity of super capacitor cells.

$$\text{Csystem} = \text{Ccell} * \frac{Parallel\ cells}{Series\ cells} \qquad (8)$$

The equivalent series resistance of the super capacitor as;

$$\text{Rsystem} = \text{Rcell} * \frac{series\ cells}{parallel\ cells} \qquad (9)$$

*E. Charge Controller*

The buck type DC-DC converter is selected here. It has endurance, design symmetry, and power management capability.

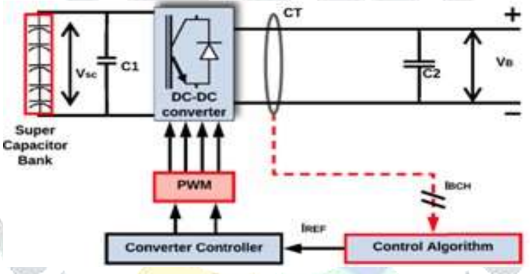

Fig.4 Charge controller

The full bridge controller is responsible for providing constant voltage and current output for charging the battery. For this purpose, the built-in error amplifier of the PWM controller continuously senses feedback current (If) from the current transducer and matches it with the reference voltage level of the error amplifier to maintain the charging current delivered to the battery, (Ibat).

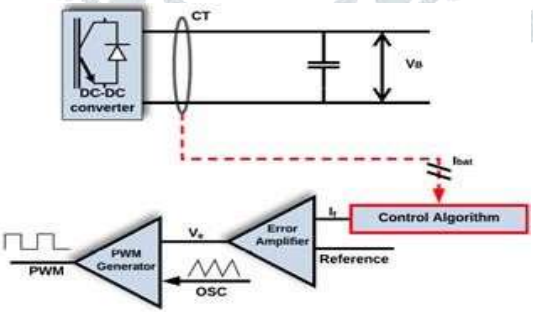

Fig.5 Structure of error amplifier

The error amplifier results in a command signal to the PWM controller to vary the PWM signals by varying the duty cycle, D of square wave pulses. The PWM signals to fed to a metal oxide semi-conductor field effect transistor (MOSFET) switches from Q1 to Q4 to accomplish the desired current output of the converter. The super capacitor bank with a variable input of 24V to 16V feeds to this controller.

*a) Control algorithm of charge controller*

The charge controller uses the multi-stage charge algorithm for effective charging. The control algorithm should comply with the requirements of the battery voltage and current. The state of charge of the battery is taken into count to set the references for current and voltage control. The battery discharging can be indicated by DoD and it can be expressed as follows,

$$\text{DoD (\%)} = \frac{Qd}{Qrated} * 100 \qquad (10)$$

Where, Qd is the discharge capacity of the battery, and Qrated is the rated capacity.

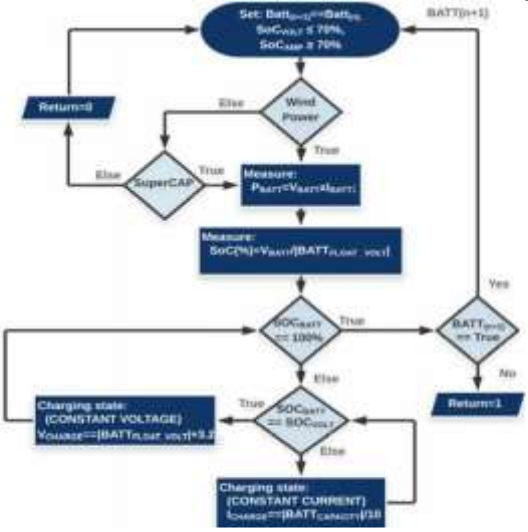

Fig. 6 Control algorithm of charge controller

The SOC term is to describe the remaining energy reserves of the battery in percentage form. The SOC of a battery which fully charged is 100% and that of free battery is 0%. The SOC of the battery is as follows,

$$SOC(\%) = \frac{Qrem}{Qrated} * 100 \qquad (11)$$

Where, Qrem specifies the remaining battery capacity.

*b) Charging/Discharging characteristics of battery*

The lead acid battery including two electrodes, an electrolyte and terminals. The construction of the electrodes consists of a grid and active materials. The grid provides physical support to the active material and distributes the discharging and charging current. In lead acid batteries, the discharging process turns electrodes into lead sulphate crystals, whereas the electrolyte is converted into water. The sulphate crystals come to form a solution and get into $PbO_2$ and Pb on positive and negatives electrodes, respectively. The charging mechanism should have the ability to save the battery from under-overvoltage to increase its lifetime. In lead acid batteries, the process of charging leads to the transformation of the sulfuric acid of the electrolyte as follows,

$SO_4 + 2H^{+} = H_2SO_4$ (12)

The net recharge reaction on both electrodes and the electrolyte is represented by following equation,

$2PbSO_4 + 2H_2O = PbO_2 + 2H_2SO_4 + Pb$ (13)

The battery parameters Cb, Vcb represents the lumped capacitance and electromotive force, respectively.

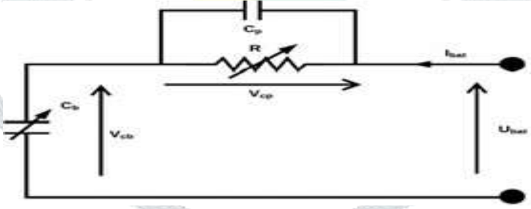

Fig. 7 Equivalent circuit diagram for the battery

Whereas, Cp and Vcp are the polarization capacitor and polarization voltage, respectively. Ibat and Ubat are the current and voltage of battery respectively. To increase the lifetime of the battery, constant current/voltage charging techniques are considered [5].

Here, the current must be reduced to a 0.25 C Amps maximum. Suppose, if the full battery capacity is 4Ah, the charging current should not exceed 1 Amp. This method is given to reduce time of charging, and it requires precise SOC detection of a battery. Constant current is applied up to battery voltage comes at 70% to 80% of the upper threshold voltage. The battery terminal voltage is continuously monitored until it hits 14.4 V in the case of a 12V battery in this mode. The CVM is automatically triggered as the output voltage of battery hits 14.4 V. At the stage, the charging current is monitored. When it drops to 0.05 C Amps, the battery voltage reduces to 13.65 V. This reduction indicates that the battery has recovered its charge to 70%–80% of its capacity. The remaining 20%–30% is to be charged with lower voltage to fend off overcharging.

## IV. SIMULATION AND RESULTS

### *A. Simulation Block Diagram*

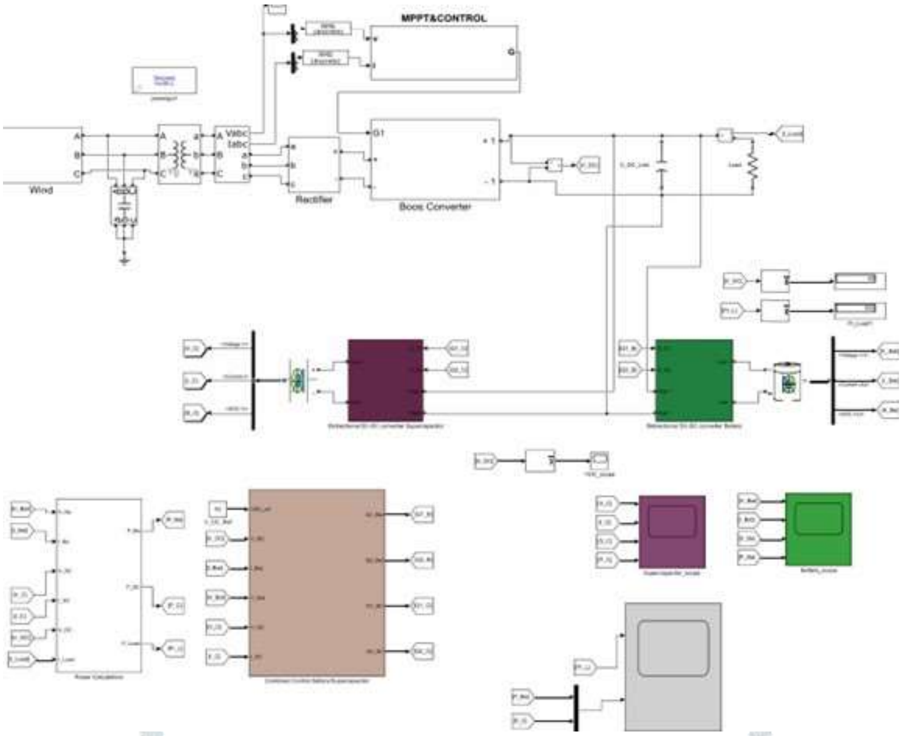

Fig.8 Simulation block diagram in MATLAB

### *B. Simulation Results*

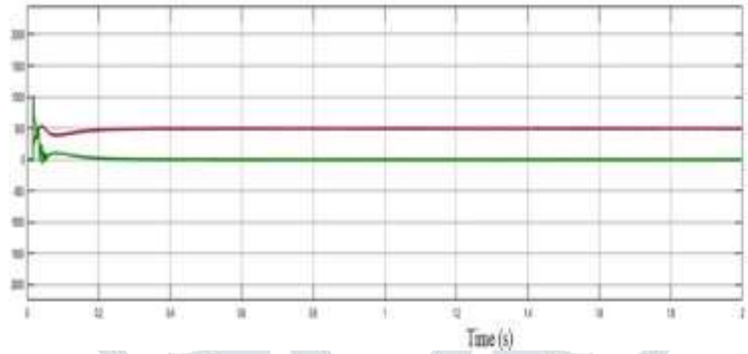

*Fig. 9 Power output of battery and power of super capacitor vs Time*

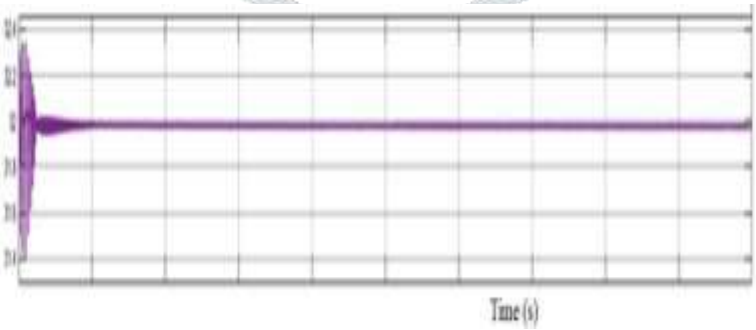

*Fig.10 Voltage of super capacitor vs Time*

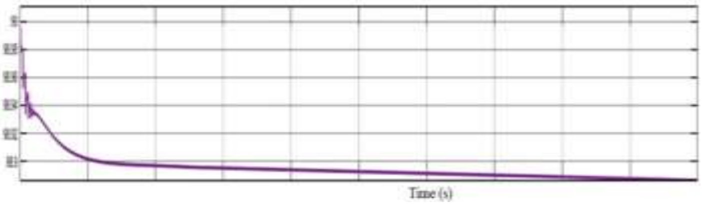

*Fig.11 SOC of super capacitor vs Time*

Fig.12 voltage output of battery vs Time

Fig.13 SOC of battery vs Time

## V. CONCLUSIONS

The voltage fluctuations in WECS are made by turbulent behaviour of wind energy. It influences the life of battery and system's power quality. The maintained DC link voltage helps to eliminate the power fluctuations caused by variable wind speed and instantaneous load switching, also minimizes the stress on the switches of charge controller and increases efficiency of the system. It causes improvement in power factor at PMSG terminals. Also, quality of terminal voltage is improved as stable power, as well as improvement in reactive power. A Simulation was arranged on proposed WECS to highlight the development in battery life. The incorporation of a supercapacitor provides a smooth charging and extended discharging of the battery and keeps the power electronic circuit safe from current spikes at the time of charging cycles of battery. To substantiate the proposed system, the working of wind energy conversion system, battery life, reactive power and power quality are inspected through simulations in MATLAB and results are verified.

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