Wind Energy Storage System by SOC Balancing Control for a Stand-Alone Windmill

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ABSTRACT:
In the wind energy storage procedures, fluctuating nature of wind is problematic for stand-alone operation. Different efforts have been done to stabilize the wind source; boost converter with controller, bidirectional converter with controller, and energy storage devices need to be used for stabilizing the wind source. During the boost operation, the voltage parameter is boosted only in the output while power is constant, therefore, maintaining the constant power is required. One of the important aspects for maintaining the constant power is considering the speed of wind. This concept is applicable for both boost DC-DC Converter and Bidirectional DC-DC Converter (BDC). Estimation of battery State of Charge (SOC) is an important task for maintaining the effective operation as well as protecting the battery from deteriorating. Charging and discharging the battery is a cyclic process; which requires to be effective. Several methods have been used for estimating SOC of the battery; the coulomb counting method is an effective method for the battery charging and discharging operations. This paper proposes consideration of battery SOC and wind speed for an effective wind harnessing operation. The proposed system is designed in MATLAB/Simulink, and validates the system in hardware prototype model in order to SOC balancing control.

KEYWORDS: Wind Energy, SOC, Energy Storage, Stand-Alone System.

1. INTRODUCTION

Electrical energy is generating from natural sources, these sources consist of fossil fuels and natural power. The fossil fuel form of power generation is also known as conventional or non-renewable form of power generation. This form of power generation is very harmful for living things, because these resources are converting into thermal and again converts to electrical energy. During this process, not only it produces electrical energy, but also the residues of this process produce environmental pollution and global warming. Another type of source is Non-conventional or renewable form of power generation, during this process natural power directly converts into electrical. So, this form of power generation is helpful to living things and eco-friendly, because of clean and green form of power production. The source of proposed system is one of the clean energy forms and a green form of power production. Wind energy is the main source of this proposed system

One of the main drawbacks in the second form of power generation is reliability, by the nature, it is not a reliable power. Since it may available or may not be available, effective utilization is required whenever it is available. For this effective utilization, some power converters are used in this system. To increase life of the battery, the SOC parameter also is considered for effective operation.

It consists of two types of DC-DC converters, unilateral boost DC-DC convert and bilateral buck-boost DC-DC converter. Unilateral or unidirectional boost converter converts wind from any level of voltage to constant 48V DC, using PID controller. Bilateral buck-boost converter is used for charging and discharging operations of battery. Two MOSFET switches are used for buck and boost operations, thus, two PID controllers are used for controlling operations for maintaining a constant output. During battery discharging, boost operation maintains constant 48V DC in the output side and getting 24V source from battery, during charging buck operation, it maintains 24 V at the output side. This 48V DC is applied to both

DC load and AC load by means of DC-AC conversion.

The switching of single-phase DC-AC conversion is controlled by the PWM based PID controller. Overall operation is controlled by speed goat by considering two parameters of wind speed and SOC. It operates the system in four modes. The modes of operations are wind power charging mode, wind power charging-load mode, wind power load mode and battery power load mode.

2. SYSTEM CONFIGURATION

2.1. Wind Energy Conversion System (stand-alone)

To reduce the burden of power producer and to meet global demand; consumer side stand-alone system is required. Consumer side contribution is an important task to compensate the power in global demand. In this proposed system, wind energy conversion system consists of horizontal axis wind turbine, permanent magnet DC generator and boost converter with PID controller that converts variable wind energy to constant electrical energy. This boost converter consists of inductor and capacitor, main purpose of these passive components is to reduce ripples in the output side. This reduction of ripples should not be 100%. This ripple is required for reactive power compensation.

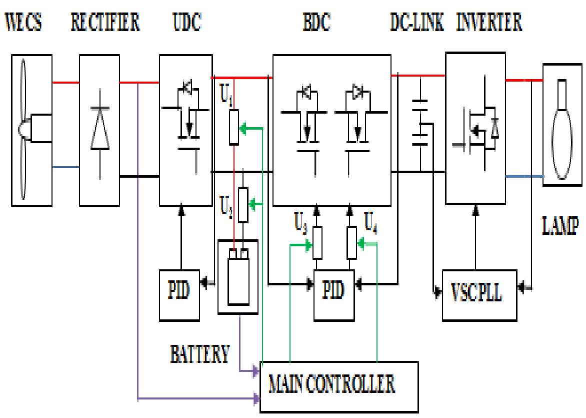

Fig. 1. Wind energy conversion systems.

Horizontal axis wind turbine converts wind energy into mechanical energy and permanent magnet direct current generator (PMDC) converts mechanical energy into electrical. This mode of conversion system is called WECS as shown in Fig. 1. The specification of the wind energy conversion system is listed in Table 1 and Table 2.

Table 1. The WECS Parameters.

Parameter	Description
DC Generator	PMDC
EMF (E)	24V DC
Power rating	200 watts
Hub type	Fixed pitch
Diameter of rotor	0.5 m
Blade swept area	2.4 m^2
No. of blades	3
Speed of Rotor	1500 RPM
Tip speed of rotor	30 m/s
Tower type	RTP
Tower height	4 m

Table 2. The Windmill performance parameters.

Parameter	Description
Power rated output	200 W
Wind speed	8 m/s
Speed (cut-in)	5 m/s
Speed (cut-out)	20 m/s
Maximum survival	60 m/s
The proposed annual output	1200 KWH @ average of 5 m/s

2.2. Wind Energy Storage System

To store wind energy, a lot of energy storage devices such as battery, super capacitor and ultra-capacitors are investigated. These energy storage devices analyses based on the performance, storage level and life. Among these storage devices, lead-acid battery is suitable for this system because of its long life and storage capacity. A lead-acid battery bank is used for wind energy storage and utilizes this power to output AC and DC loads.

The battery bank of proposed system consists of series connected two batteries with total capacity of 40AH. The standby use is (13.5 - 13.7) V and maximum current rating of 5.2 A. Number of batteries using in the battery bank is two. This type of specifications is listed in Table 3. The equivalent circuit of battery is as shown in Fig. 2.

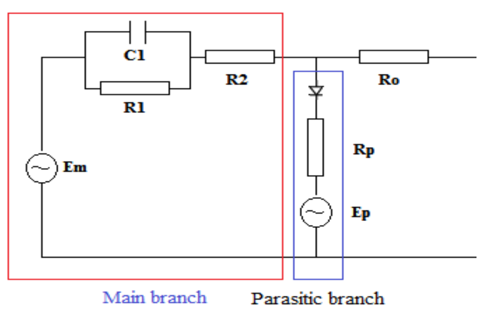

Fig. 2. Battery equivalent circuit.

Table 3. Parameters of Battery bank.

Parameter	Description
Battery Type	Lead-Acid
Voltage (V)	DC12V
Total Capacity	40 AH
Voltage (Standby)	13.5 V – 13.7 V
Cycle use	14 V – 14.5 V
Maximum initial current	5.2 A
Temperature	27ºC
Battery	2 Nos.

2.3. PID Controller for Bidirectional Converter

The schematic diagram is as shown in Fig. 3 that explains the implementation of PID controller for a bi-directional converter.

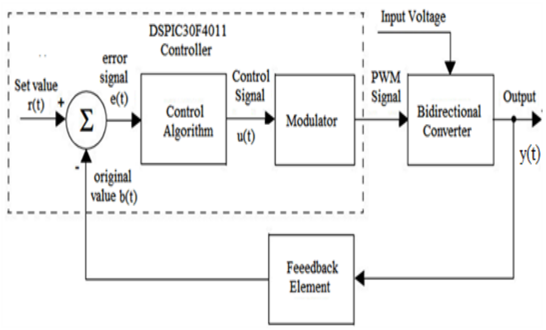

Fig. 3. Schematic diagram of BDC with PID.

The original value b(t) of the bi-directional converter output and the constant set r(t) is compared, to form the error signal e(t). The error signal is given to the control algorithm block which is based on PID controller. It generates the control signal u(t) based on the error signal for varying the PWM signal to the switches (Q1 and Q2) of the bi-directional converter; it maintains the constant output voltage (Vo) irrespective of the input voltage and load variations.

The feedback element output signal is called original signal b(t). The b(t) is then compared with the reference input r(t) to generate error e(t)=r(t)-b(t), which is the input signal of control algorithm. This process is handled by DSPIC30F4011.

This error signal is then modified by control algorithm and gives the proportional control output signal u(t) to the modulator. The converter generates the control demand of corresponding control signal to run real time process of the plant. The resultant plant output y (t) is again feedback to the controller to work continuously in closed loop operation by the equations (1) and (2).

$$u(t) = K_p * e(t) + K_i \int_0^t e(t)dt + K_d * \frac{de(t)}{dt} \qquad (1)$$

$$U_n = K_p * E_n + K_i \sum_{i=1}^{n} E_i * T_s + K_d * \frac{E_n - E_{n-1}}{T_s} \qquad (2)$$

2.4. Design of the PID Controller

The block diagram of closed loop control scheme is shown in Fig. 4. In the time domain control system involves the evolution of steady state and transient response of the system primarily.

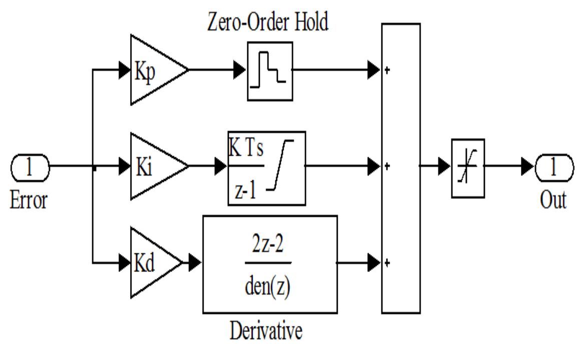

Fig. 4. Block diagram of closed loop control.

The bi-directional converter output response of a linear control system is revealed by the standard output response as shown in Fig. 5. From the response characteristics initially, the curve starts from 30V of magnitude and dip at 0.05 ms at the amplitude of 24V. Then the magnitude of voltage rises to 60V at 0.17 ms and follows by a small drop at 0.24 ms then finally comes to steady state at 0.36 ms in a size of constant 48V. From this response to the final value, the time required in the first dip is called delay time TD. From the response characteristics, the variations of the initial value of the time needed for over damped & under damped and attains the final value is called rise time. The time required for the response to reach its peak value. It is defined as the time at which response undergoes the first overshoot which is always peak overshoot, is called the peak time.

Peak overshoot Mp: It is the largest error between reference input and output during the transient period. It can be defined as the amount by which output exceeds its reference steady state value during the first overshoot. Setting time Ts: It is defined as the time required for the response to decrease and stay within the specified percentage of its final value within the tolerance band. For a tolerance band of 2% of the steady state is typically allowable. Steady state error Err: It is an index of the steady-state response of a system to a specified input. It indicates the error between the actual output and the desired output as time tends to infinity.

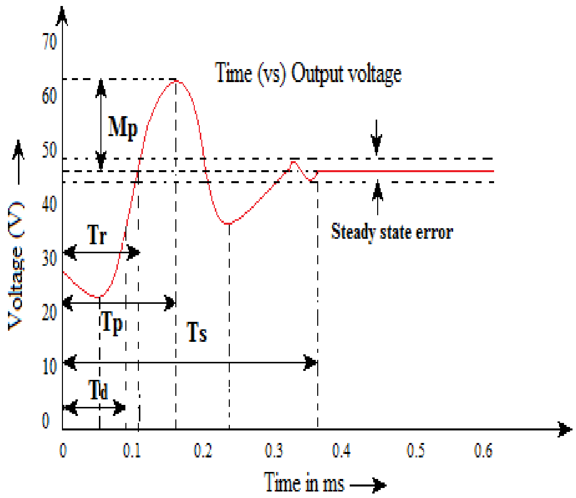

Fig. 5. Response of the Bidirectional converter.

2.5. Control Flowchart of UDC

The closed loop PID control structure flowchart converter is as shown in Fig. 6, based on this flowchart the DSPIC30F4011 generates the PWM signal and control the unidirectional boost converter.

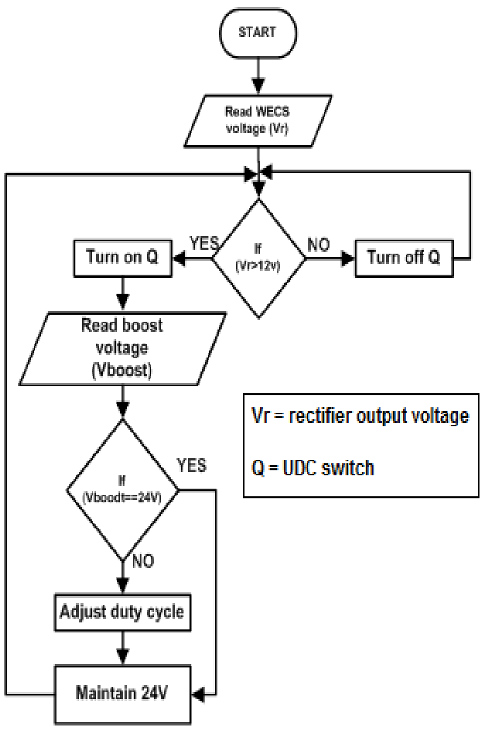

Fig. 6. Control flowchart for UDC using PID.

3. SIMULATION RESULTS

Simulation is an imitation process in the real world system in software level approach. A well-designed simulation model can help to garner consensus and generate confident of trial and testing improvements that have never had been done before. MATLAB is a high-level language and interactive environment for numerical computation of simulating the real world process. Simulink is a tool from MATLAB which offers an interactive graphical way of programming for system modelling instead of complex coding. Simulink provides a set of blocks in its libraries and unique simulation features for modelling dynamic and physical systems, including Sim-Power System, Simscape, and Toolboxes.

3.1. Battery Sourced Load Mode

Battery sourced load mode of operation happens when the storage device level greater than 40%, load is in ON position and wind speed is less than 5 meters per second. During the time that load is in ON(manual) position, the control breakers (U_3U_4)U_6 turn ON by speed goat and battery power is supplied to the load or when the load is in OFF (manual) the control breakers remain in OFF condition. The other two conditions are when wind speed is < 5m/s and state of charge >40%.

Output waveforms of mode-4 battery energy conversion are as shown in the Fig. 7. The carrier and reference signal is compared and the output signal of PWM controlled by the converter switches. The carrier and reference signal are compared, and PWM signal is generated given to the converter switches. The battery output 24V DC is now obtained and provided to the bidirectional converter, it operates in boost mode and the getting input voltage from the battery is step-up to 48 V, and current value is 1A.

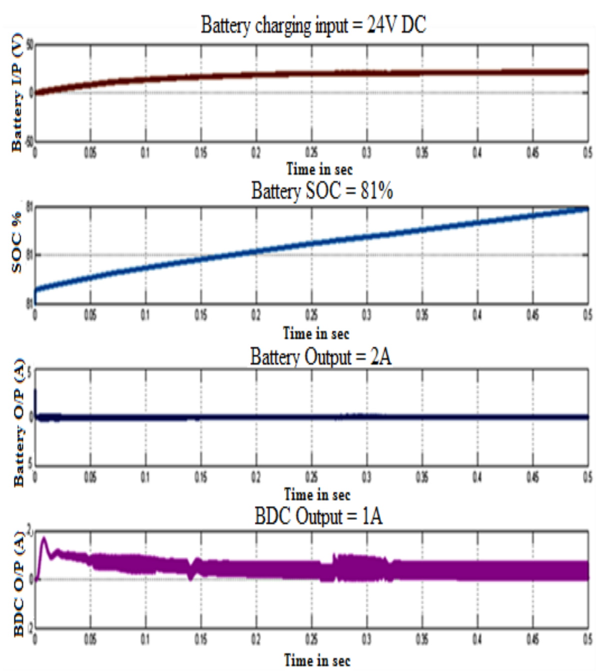

Fig. 7. Output of mode-4 battery energy conversion waveforms.

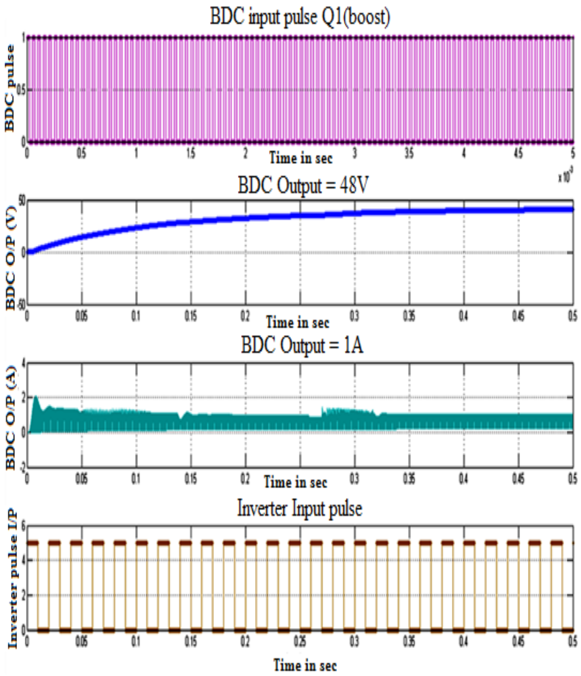

Fig. 8. Output of mode-4 electrical energy conversion waveforms

The output waveforms of mode-4 battery energy conversion are as shown in the Fig. 8. Then the filtered pure DC is given to the inverter, then the inverter converts DC-AC and also step-up to 98V. Finally, the electrical AC output is applied to the Load. In this mode, the rectifier and inverter units operate in inverter mode. The output of the inverter is supplied to load. Output waveforms of mode-4 electrical energy inversion are as shown in the Fig. 9. In this stage of production, the pure DC from the bidirectional converter is inverted i.e. 48V DC to 96VAC conversion by using the 3-level inverter.

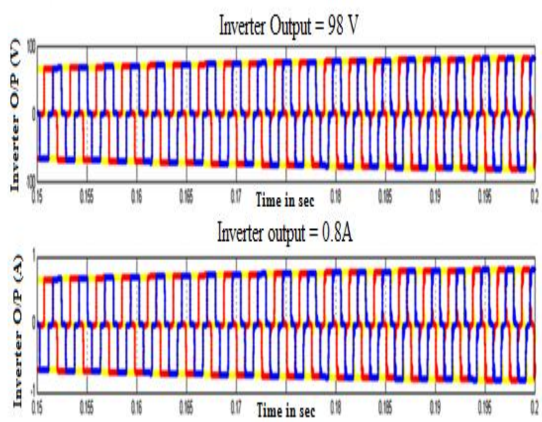

Fig. 9. Output of mode-4 electrical energy inversion waveforms.

The output voltage of PMSG is varying according to the input wind speed of the wind turbine and its tabulated in Table 4. The rated voltage of wind speed attained in the wind speed of 8.65 m/s, and the minimum input voltage required of the electrical system is 12V, from Table 4 and the 50% of rated voltage is obtained in wind speed at 5m/s. So, the minimum needed wind speed is 5m/s, and below this speed, the system output power is deficient. The results are taken when the input wind speed is at 10 m/s. The voltage values of the converter are almost constant, and the current values are approximately inversely proportional to the voltage. These current values depend on the load. If the load increases in the typical system, the voltage may be the dip or reduced some values, however, in this system, the two DC-DC converters and inverter with closed loop control always maintain the constant voltage level.

Table 4. The wind energy conversion results.

Input wind Speed (v) in (m/s)	PMSG output voltage in (V)
3	8.4
4	11.2
5	13.9
6	16.7
7	19.5
8	22.2
8.65	24.1
9	25.3
10	27.8
11	30.6

4. REAL TIME IMPLEMENTATION

Every innovative circuit model and new inventions are necessary to prove the real-time model through experimental setup or hardware implementation. Before supplying a real time product to industry, an experimental setup from the laboratory test bench is required to conduct and verify the performance for approval. The proposed circuit model is represented in the block diagram as shown in Fig. 10 which is implemented in hardware. Hardware and software integration based experimental implementation is developed using speedgoat real-time target machine through MATLAB/SIMULINK. This type of experimental setup reduces the complexity in design. The DSPIC30F4011 controller provides complete control in converters operation through program coding by PID control structure. This chapter presents a complete hardware implementation of the proposed wind energy electrical system operation from two different sources.

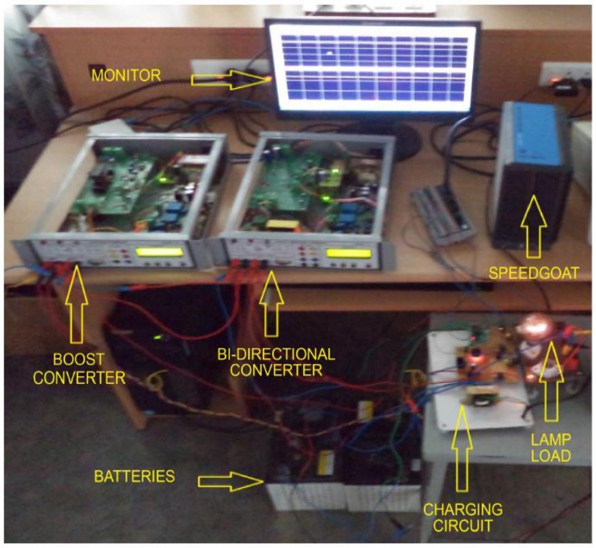

Fig. 10. Electrical energy storage systems.

4.1. Battery Sourced Output Mode

Output waveform of mode-3 PMSG and rectifier output is as shown in the Fig. 11 and battery sourced output mode is as shown in the Fig. 12, the output is taken when the wind speed is at 3m/s. During the time when the load is in ON (manual) position, the control breakers (U_3U_4 and U_6) turn ON by speed goat and battery power is supplied to the load or when the load is OFF (manual), the control breakers remain in OFF condition. The other two conditions are when wind speed is < 5m/s and state of charge >40%.

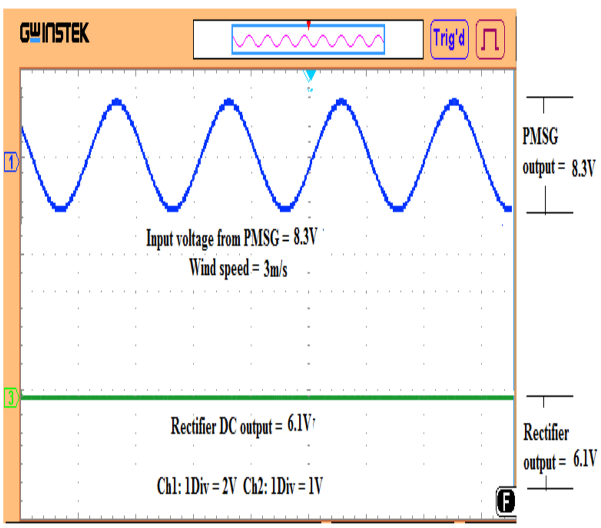

Fig. 11. PMSG and rectifier output at wind speed (3m/s).

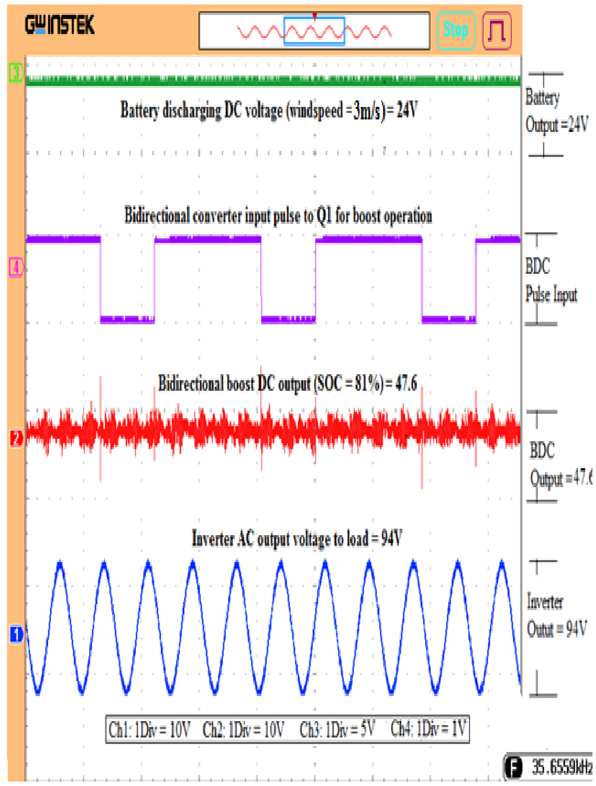

Fig. 12. Mode-4 Battery sourced output mode, output at wind speed (3m/s).

The Unidirectional converter control breaker (U_7) turn to OFF condition and bidirectional converter control breaker (U_5 boost) remains in ON condition until the level of battery SOC reduced to 40% and also wind energy is in the range of less than 5 m/s. When the load is in OFF (manual) the control breakers remain in OFF condition. The other two conditions are when wind speed is < 5m/s and state of charge >40%.

5. CONCLUSION

This concept is applicable for both boost DC-DC Converter and Bidirectional DC-DC Converter (BDC). Estimation of Battery State of Charge (SOC) is an important task to maintain effective operation as well as protect battery from ageing. Charging and discharging is a cyclic process of battery but effective process is required. Several methods are used to battery estimate battery SOC, but coulomb counting method is an effective method for battery charging-discharging operations. This paper proposes consideration of battery SOC and wind speed for effective wind harnessing operation of wind. The proposed system is designed from MATLAB/Simulink and validates the system in Hardware prototype model in order to SOC Balancing control.

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