The Stand-Alone Wind Energy System with Battery Inverter System

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Abstract- This paper consists of a network which includes wind turbine, battery energy systems (BES) and load has been simulated. Voltage and frequency control of the load by following wind speed alterations by gentle control of BES is the main purpose of this paper. For power system stability and power quality, energy storage systems are needed in stand-alone wind energy systems. The precise model of BESS and wind turbine is added up with real power system conditions. Moreover, in MATLAB SIMULINK non-linear time domain simulations are carried out in order to exhibit the real world results. The presented scheme is simulated on a typical self-governed network which includes wind turbine, BESS and load. The simulation outputs show the change of voltage and current with respect to change in wind speed.

Keyword- *Variable Speed Wind Turbine, Voltage And Current Control, Batter Energy*

I. NOMENCLATURE

A	:	swept area of turbine in m^2
c_p	:	performance coefficient of turbine
c_{p_pu}	:	turbine performance coefficient in pu of the maximum value of c_p
f	:	frequency (Hz)
k_p	:	power gain for cp_pu=1 pu and v_{wind_pu}=1 pu, k_p is less than or equal to 1
P_m	:	mechanical output power of the turbine (W)
P_{m_pu}	:	power in pu of nominal power for particular values of ρ and A
T_m	:	turbine torque output
V	:	voltage (pu)
V_{wind}	:	wind speed (m/s)
V_{wind_pu}	:	wind speed in pu of the base wind speed
ρ	:	air density (kg/m^3)
β	:	blade pitch angle (deg)
λ	:	tip speed ratio of the rotor blade tip speed to wind speed

II. INTRODUCTION

Recently, wind energy utilizations have achieved rapid developments all over the world[1]. In the year 2015, 63.5 GW more wind power was generated and added to the power grid worldwide. So the total wind energy power was raised to 432.9 GW. It is expected that the total wind power installed in the whole world will be around 1430–1933 GW by 2030. However, as the penetration level of wind power gets increased, the main matter of concern is that the operation of the interconnected power system with other sources predominantly weak power systems will be affected by varying output power of wind generators. In Such case, there may be requirement of some techniques to facilitate the output variations to have a power system of higher reliability. Wind power has a lot of advantages, but technical problems such as grid interconnection, reliability, power quality, generation dispatch and control, power system protection etc. may be introduced due to high involvement of wind power.

The main challenge regarding control of wind turbines are voltage and frequency regulations. In wind energy system, the input mechanical power to the wind turbine varies together with wind speed fluctuations. So, the electrical power generated by wind energy system incorporates voltage-frequency alterations. Due to its frequency and voltage alterations, this fluctuating energy system is not able to be connected to the electrical grid straight. The standalone loads cannot be supplied by this because the load's voltage and frequency would vary along with the load demand fluctuations. As an example, with increase of load demand the voltage and frequency will reduce together and vice versa without genteel control of voltage and frequency in the standalone mode. So this results in requirement of a proper control needed for making the wind generating system practical in both conditions, inter-connected to the grid mode[2] or standalone operation mode. Putting differently, the resulting voltage generated by wind energy systems must be synchronized properly with regard to magnitude and frequency.

In the standalone wind energy operation, it is requisite to prepare a proper control approach for wind power generators so that they can control power, voltage, and frequency.[3] The rendition of alternator and interfacing converter is significantly affected by the control strategy. Many varieties of generators for example permanent magnet synchronous generator (PMSG) and induction generator can be installed with the wind turbines. The AC voltage magnitude, frequency and the DC voltage of the standalone inconsistent speed wind turbine instated with PMSG are balanced by load-side converter. The maximum energy of wind can be drawn by the control of generator-side inverter. Many control methodologies have been used already to improve the performance of fluctuating-speed wind turbine system. Most crucial benefits of PMSG is that it does not require any external excitation current. The significant cost aid of use of the PMSG is that a diode bridge rectifier can be used at the alternator terminals since there is no need of external excitation current. Utilizing energy storage systems (ESS) (especially battery energy storage systems (BESS)) together with stand-alone wind units is one of the best correct methods to deal with wind variations.[4] Alike the renewable energy, energy storage system (ESSs) is one of the most appropriate technical process in electric power systems which can provide both technical and economic merits. Various methods for energy storage are electrical, thermal, mechanical, chemical and electro-chemical approaches. Battery storage system stores electrical energy in electrochemical form and after that the stored energy is re-established to electrical energy and can be returned to the power system. Some of the BESS utilizations for wind generating stations involve a plain methodology to charge and discharge the BESS, such as storing superfluous power, if the wind power output overshoots a threshold.

BESS can independently control both active and reactive powers successfully. Both active and reactive powers are controlled in both directions as well as independent of each other, in such a de-coupled P-Q control system. Supplementary stabilizers can support the decoupled P-Q control of BESS so that network stability will be enhanced. The active and reactive powers have directly associated with frequency and voltage respectively. So, the P-Q control can be executed as decentralized frequency-voltage control system. The acceptable ranges of frequency and voltage are considered as the discretion of optimization problem and the network stability can be enhanced by such models.[5][6]

In conclusion, highlights of the main contributions of the current work are as follows;

• The suggested structure regulates voltage, controls frequency, and increases sturdiness at the same time of the standalone wind-BESS load system.

• To find the most optimal operating condition of the network all the inward controllers (voltage and frequency controllers) and auxiliary stabilizers are tuned simultaneously. The proposed strategy results in the best operation for the whole system including BESS, wind turbine and load.

• In order to cope with real conditions, the real models of wind turbine and converter are derived and simulated. The real world modelling and nonlinear time-domain simulations are carried out in MATLAB software.

III. LITERATURE REVIEW

Ardal et al.[7] took an oil platform connected wind turbine and implemented automatic voltage regulation (AVR) for voltage and droop control for frequency which can control the system voltage by changing the rotor magnetization of the synchronous generator. He studied all the overshoot and undershoot of the voltage and frequency.

Elmorshedy et al.[8] analysed a stand-alone wind turbine connected with PMSG connected with components like three phase voltage source inverter, DC-DC boost converter, LC filter etc. He studied effect of load variation under steady wind speed, effect of wind-speed variation under constant load, effect of abrupt fluctuating unbalanced load under steady wind speed.

Chinchilla et al.[9] used a permanent magnet synchronous alternator with the fluctuating wind speed system which is connected to the power system employing a fully controlled frequency converter, which consists of a PWM (pulse width-modulation) rectifier, a PWM inverter and an intermediary dc circuit. He observed that the system achieves the maximum power point until rated generator speed is reached.

Herrera et al.[2] used a wind turbine with back to back full conversion power converter which leads to complete decoupling of the wind turbine behaviour from that of grid generator. He has also used rectifier or multi-pulse transformer with advantages such as (i) the harmonics of input AC-current reduces. (ii) the output DC-V ripple reduces. His study illustrated the technical feasibility of use of a diode-based rectifier to connect to a large wind farm, through the proposed control, by controlling it externally.

Kassem et al.[10] took a stand-alone wind system with battery source and implemented Takagi-Sugeno fuzzy logic algorithm. He studied improvements of all the load waveforms like voltage, current, torque, stator and rotor parameters etc.

IV. STRUCTURE OF THE SYSTEM

The figure below shows the single-line diagram of the system considered for study.

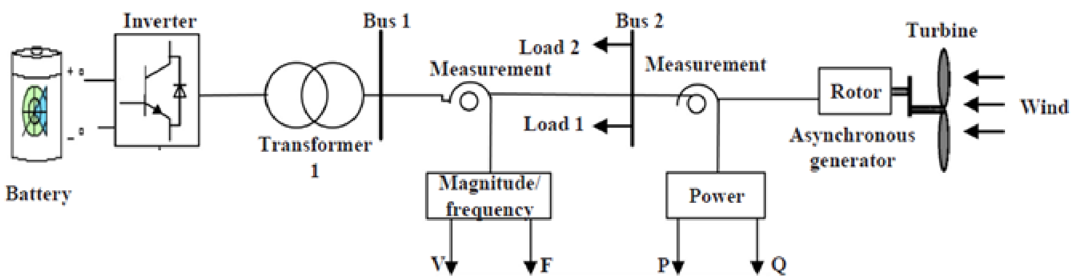


Fig.1: Network diagram of the wind turbine connected with BESS system

The BESS is coupled to the system through a three-phase inverter. The standalone system comprises of asynchronous generator, load, and wind turbine. Control of the voltage and current of wind turbine in grid-unconnected operation is the main purpose. The system shown in the above figure is proper for such purpose.

a. Wind turbine connected with Asynchronous generator:

The network of wind turbine and generator is based on the steady-state power characteristics of the turbine. The output power of the turbine is given by (1)

$$p_m = c_p(\lambda,\beta)\frac{\rho A}{2} V_{wind'}^3 \quad (1)$$

It can also be normalized in per unit as (2).

$$P_{m,pu} = k_p c_{p,pu} V_{wind,pu'}^3 \quad (2)$$

A comprehensive equation is used to design $c_p(\lambda,\beta)$ as (3)[9]

$$c_p(\lambda, \beta) = c_1(\frac{c_2}{\lambda_i} - c_3\beta - c_4)e^{-c_5/\lambda_i} + c_6\lambda \quad (3)$$

Where,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.35}{\beta^3+1} \quad (4)$$

Fig.2 shows the model of the wind turbine.

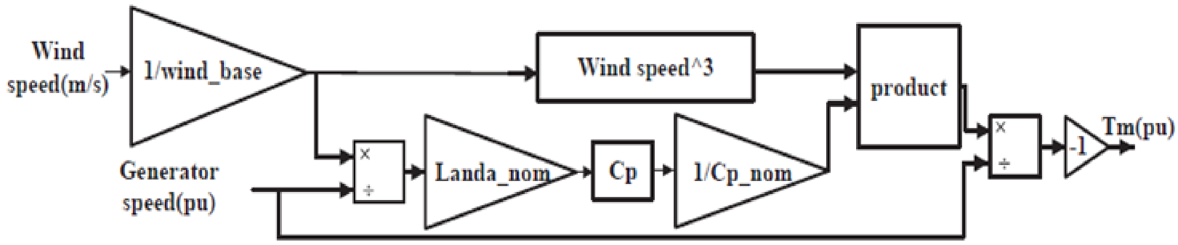


Fig.2. Model of wind turbine

The wind turbine connected with the induction generator (WTIG) is shown in Fig. 3.

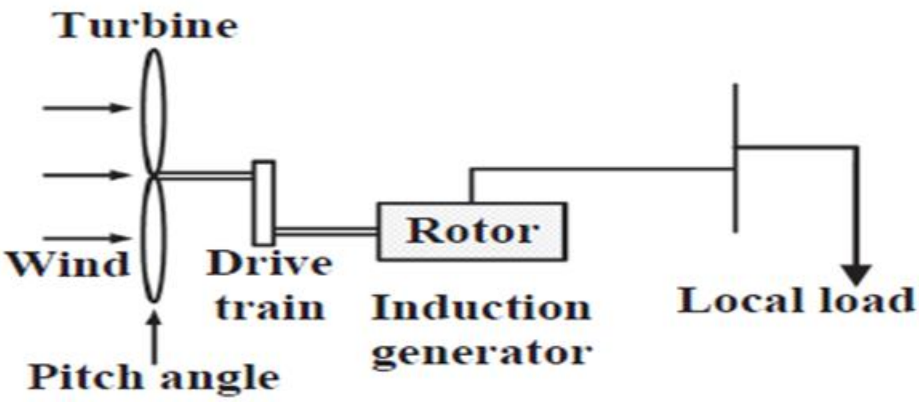


Fig.3: Wind turbine connected with the induction generator

The local load is connected with the stator winding of the generator and wind turbine operates the rotor. The mechanical energy obtained from wind turbine is converted into electrical energy by the induction generator and was sent to the load through the stator winding. To restrict the out coming power of generator to a certain nominal value under high wind speed, the control of pitch angle is being done. To work on the generator mode, the induction machine requires to operate slightly more than the synchronous speed. The speed variation is considered to be generally so small and the wind turbine induction generator is considered as fixed-speed generator. The reactive sources such as capacitor banks provides the reactive power required by the induction generator.

b. Battery energy storage systems (BESS):

Owing to the highly variable characteristics of the wind, employment of an energy storage device can remarkably enhance the solidity of a small stand-alone wind systems. Merging a suitable energy storage system such as a battery in addition to a wind-generator excludes the voltage and frequency fluctuations. It can also build up maximum reliability of the power supplied to the loads.

The rapid advancements in battery technologies provides an optimistic opportunity of coping with stochastic wind power. The electrifying and discharging conditions of BESS often takes some hours. For illustration, a 100 kWh battery of 10 kW rating power takes longer than 10 h to be completely electrified, and in same way it takes several hours for its full discharge. When the BESS gets the electrifying command, it starts electrifying the battery. After it gets fully electrified, the electric power drives towards zero and the electrifying state gets finished. The electrifying command can be either from SOC (state of charge) controllers or from the operator (manual operation). It is assumed that there is a command to charge. Moreover, this paper does not design a separate SOC controller. If a proper controller for SOC has to be represented, an extra control structure is to be added to the presented control scheme for SOC control. The state of charge control can balance the charged and discharged power subjected to capacity of the battery (kWh) and rated power of inverter (kW).

V. DATA OF THE PROBLEM

The DC voltage of battery is 500 (V) and the wind speed is taken as 10 m/s. The admissible extent of voltage is 0.9p.u. to 1.1p.u. (±10% variations is allowed). The suitable extent of frequency is between 49.5 Hz and 50.5 Hz under islanding operation. Under transient and contingency condition, the frequency is allowed to range between 47 and 55 Hz. The parameters of the asynchronous generator, wind turbine, transformer and load are listed in table 1. All the parameters of the control systems are listed in table 2

TABLE 1Test system parameters

Generator	P_n=275VA V_n=480V f_n=50Hz
Transformer	Δ-Yg V_1 ph-ph (V_{rms})=208V R_1 (p.u.) =0.002 X_1 (p.u.)=0.04 V_2 ph-ph (Vrms)=480V R_2 (p.u.) =0.002 X_2 (p.u.)=0.04
Load1	P_{load}=0Kw Q_c=22kvar
Load2	P_{load}=50kW Q=0kvar

TABLE 2PI controllers and stabilizers Parameters

	Parameters	Nominal Value
Proportional gains	K_{P1}	0.0002
	K_{P2}	0.0002
Integral gains	K_{i1}	1.98
	K_{i2}	1.98
Auxiliary gains of the stabilizers	K_{DC1}	0.0020
	K_{DC2}	0.0079
	T1	0.190
	T2	0.010
	T3	0.001
	T4	0.010
	T5	0.410

Time constants of the stabilizers	T6	0.010
	T7	0.001
	T8	0.010

VI. SIMULATION RESULTS

The considered autonomous wind turbine with BESS is build up and simulated in MATLAB SIMULINK environment. The system model is simulated under MATLAB environment for 2 seconds i.e. the simulation time taken was 2 seconds.

The system performance with the control strategy is tested under three different levels of wind speed as shown in fig.4.

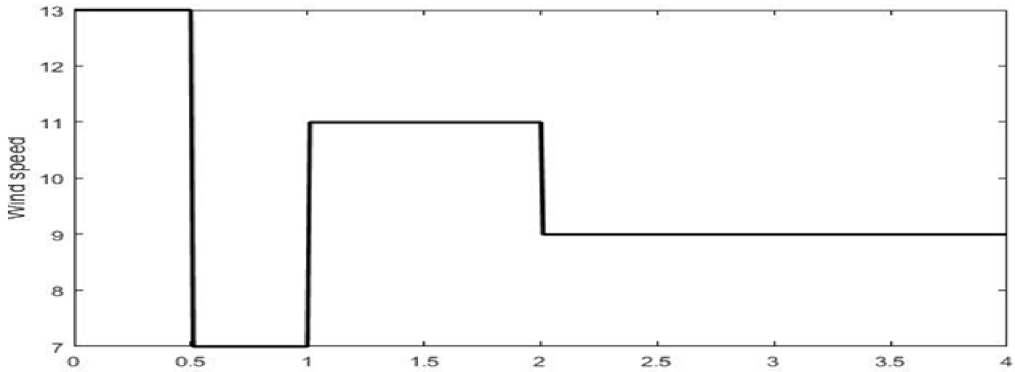


Fig.4: wind speed

When only stand-alone wind energy system is taken for simulation for 2 seconds, then the produced voltage and current is demonstrated in fig. 5(a) and fig. 5(b).

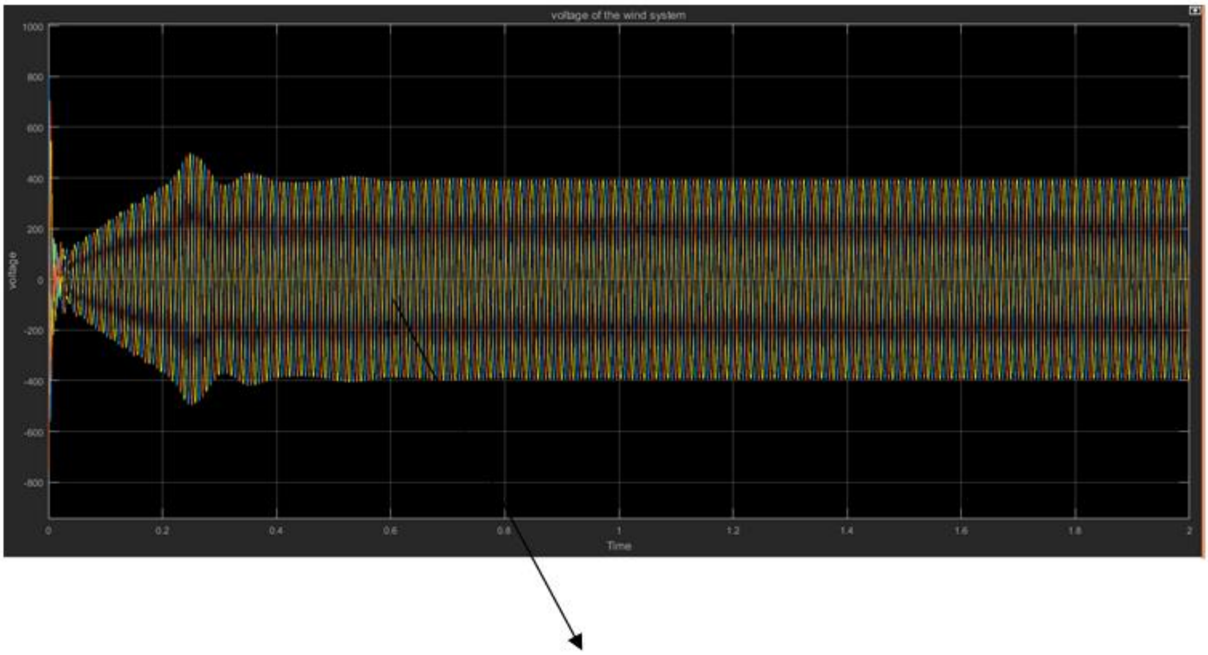
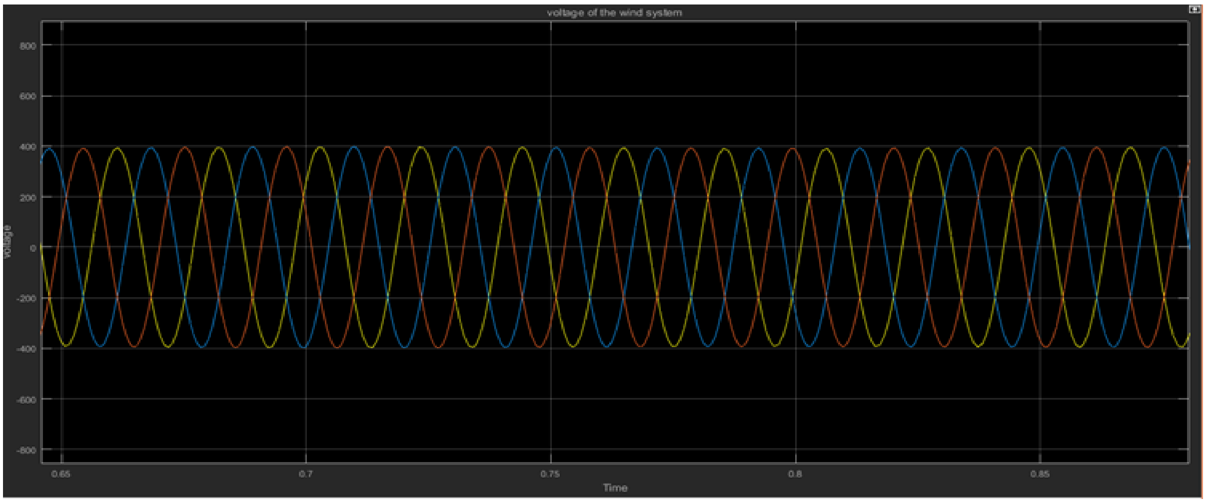


Fig.5: (a) Voltage of a only wind energy system without BESS



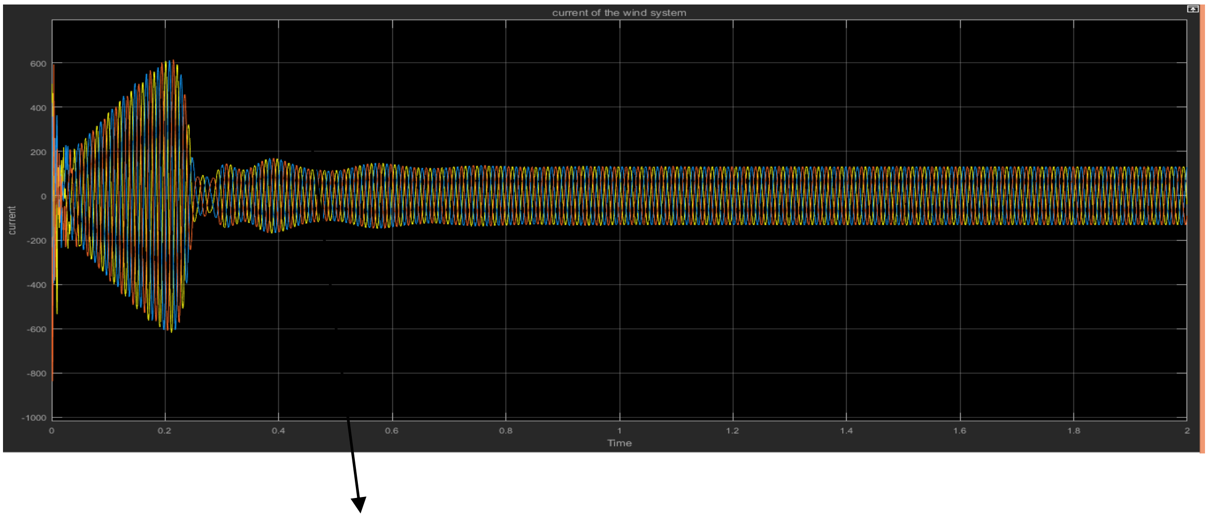
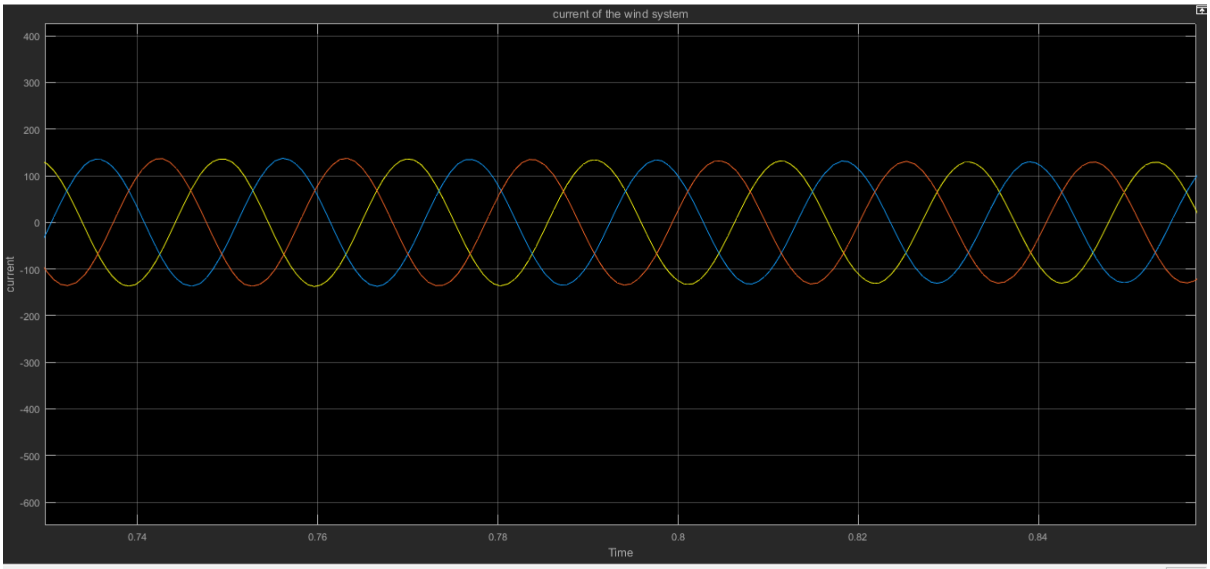


Fig.5: (b) Current of the only wind energy system without BESS



The above figure shows that after the initial transients in voltage and current waveform it gives a sinusoidal output as required.

When battery with inverter system is simulated for 2 seconds then the voltage and current is obtained as in fig. 6(a) and (b).

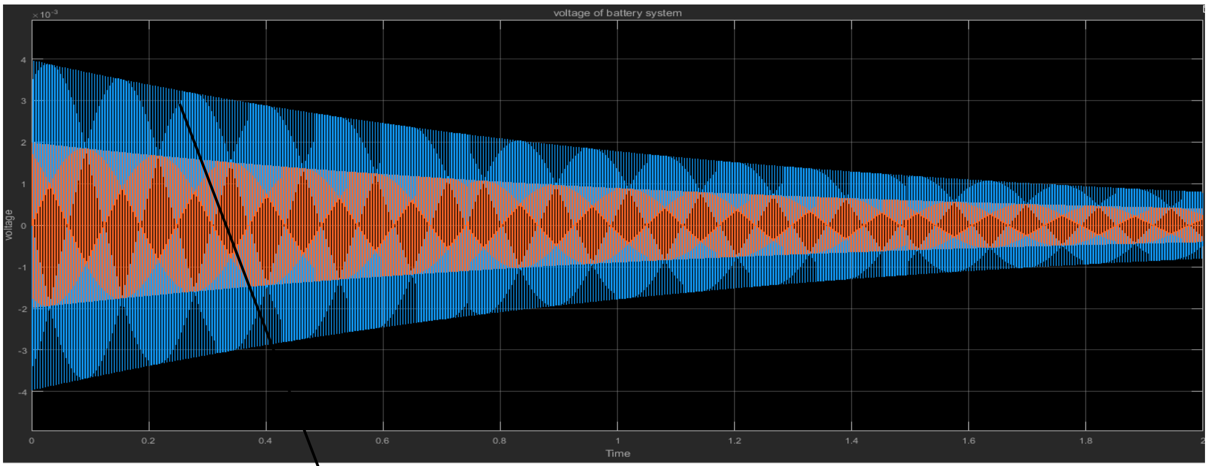
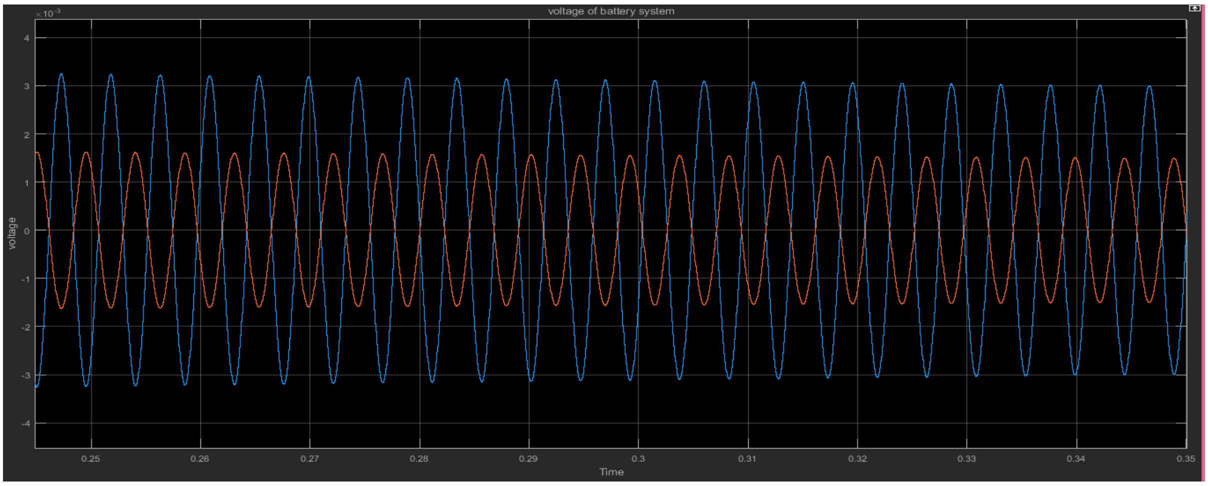


Fig.6: (a) Voltage of the battery and inverter system



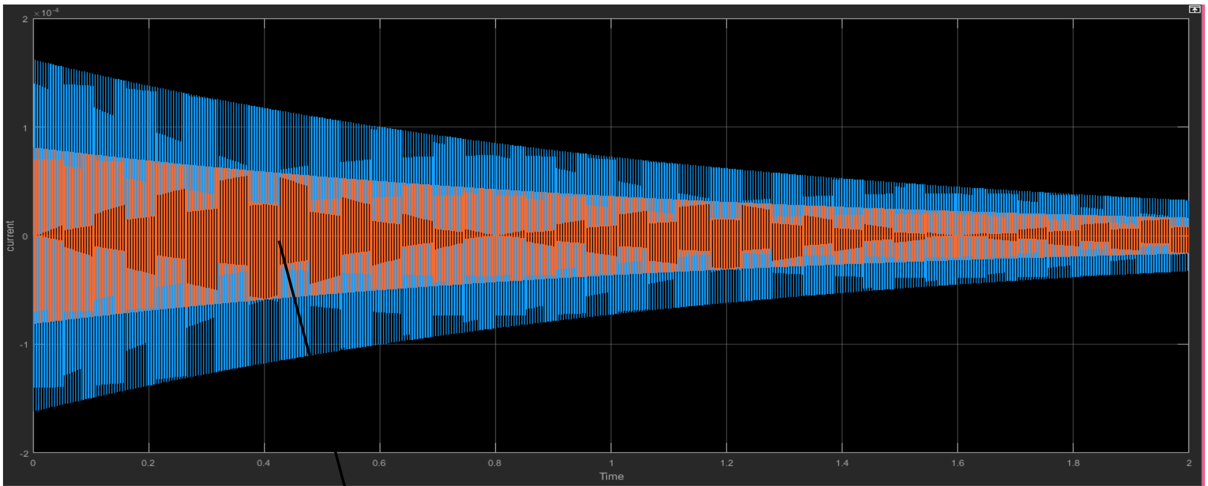
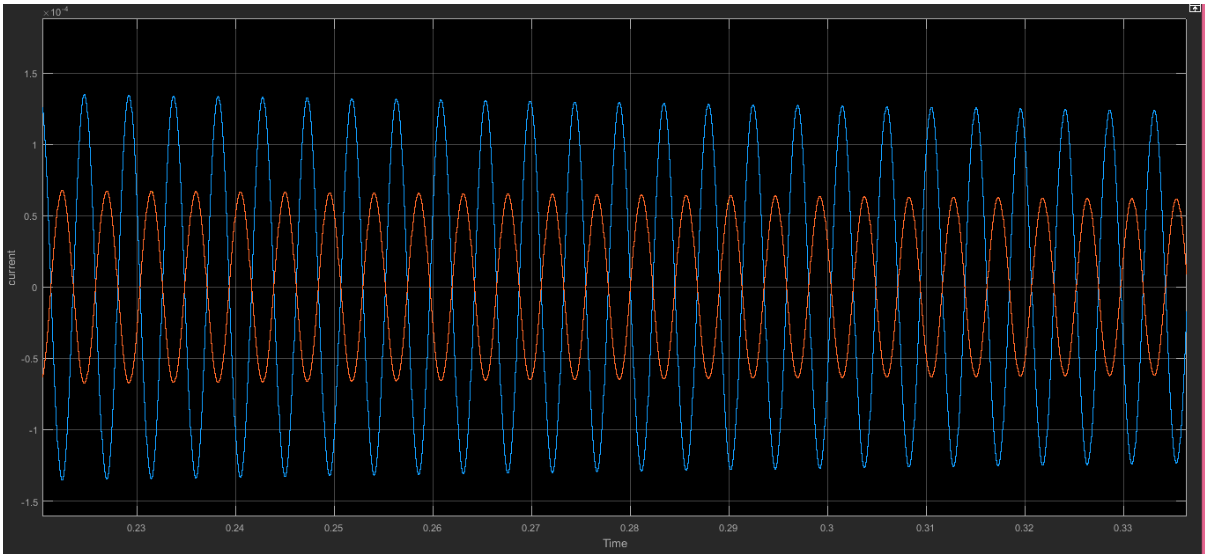


Fig.6: (b) Current of battery and inverter system



In the above figures the magnitude of the voltage and current decreases gradually as the SOC of the battery system is decreased gradually.

When the battery and wind energy systems are connected together and simulated for 2seconds the following results are obtained as fig. 7(a) and (b).

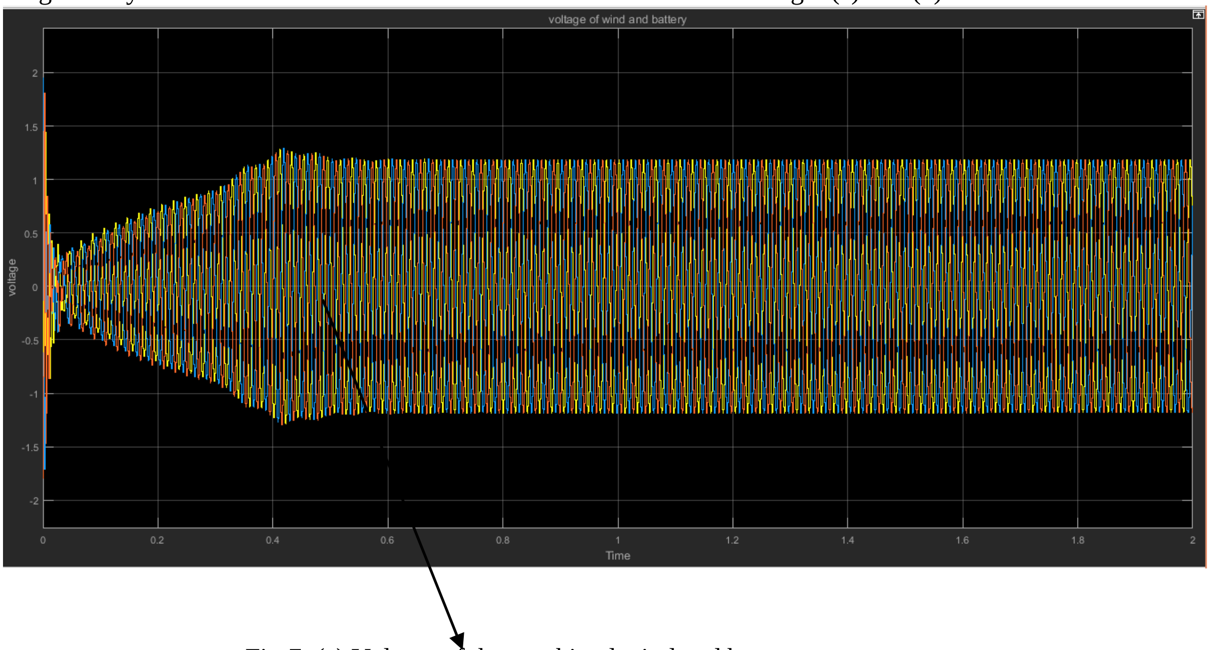
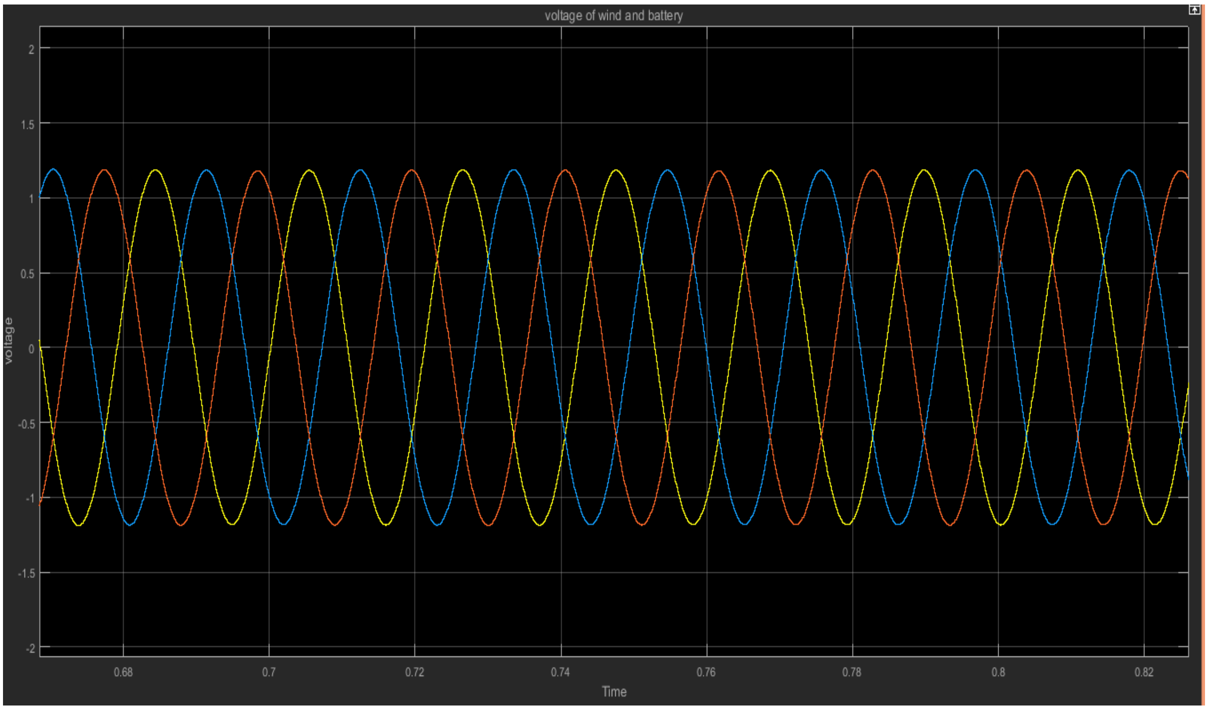


Fig.7: (a) Voltage of the combined wind and battery energy system



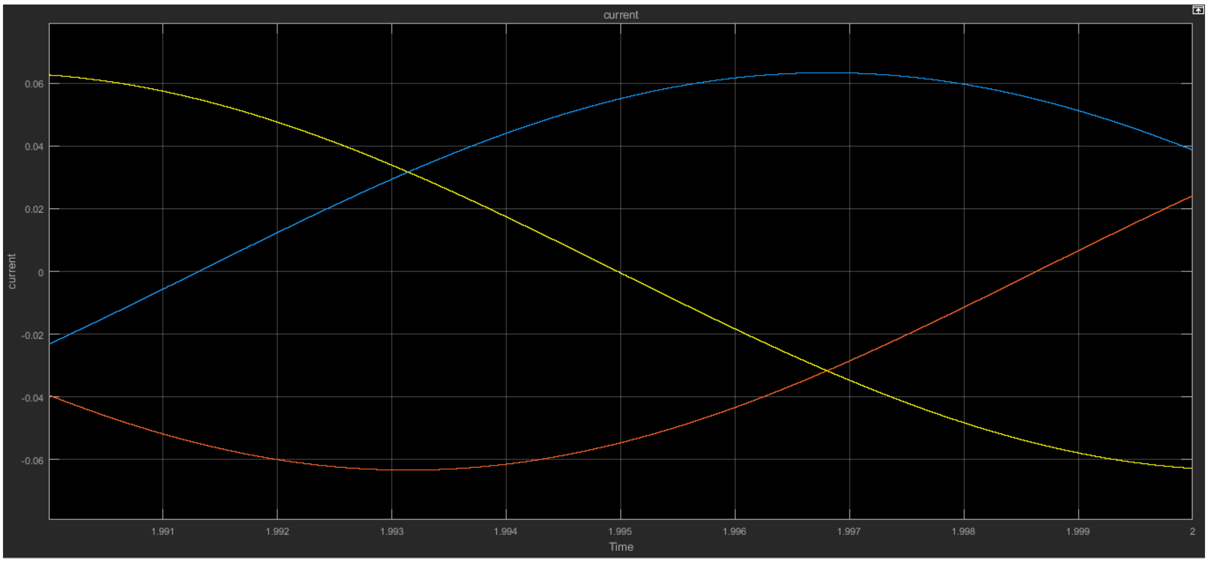


Fig.7: (b) Current of the combined wind and battery system

The above figures demonstrates that the voltage and current of the wind turbine connected with the battery system is at first shows the transients in voltage and current but after some time they give the sinusoidal outputs as required.

The above figures also show the alteration of different variables with step change in wind speed with battery. These figures show that the load voltage is not able to be constant at its required values because wind turbine is not able to generate all the desired energy at small wind speed.

VII. CONCLUSION

The voltage regulation of an isolated wind energy system is analysed in this paper. This encompasses a consorted energy storage system such as battery, with the role to stabilise the output voltage in autonomous applications. A brief review of a stand-alone wind system with a BESS is presented. The effectiveness of the proposed system have been evaluated by carrying out simulations. The grid unconnected hybrid wind-battery generation system has been experimented through step change of wind speed. From the results, it is confirmed that the stand-alone hybrid wind-battery generation system can maintain its voltage current against wind speed excursion.

VIII. REFERENCES

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