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Designing and control of isolated wind-hydro hybrid system With BESS

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Abstract:- This paper presents a three phase four wire local loads connected two squirrel cage induction generators, one driven by a variable speed wind turbine and another driven by a constant power hydro turbine. The proposed system has a battery at the middle of two back –to-back connected pulse width modulation (PWM) controlled insulated-gate-bipolar –transistor (IGBT) based voltage source converters (VSCs).The main objectives of the control algorithm for the VSCs are to achieve the maximum power tracking (MPT) through rotor speed control of a wind turbine driven SCIG under varying wind speeds at machine side and to control of the magnitude and frequency of the load voltage at load side. The proposed system has a capability of bidirectional active and reactive power flow, by which it controls the magnitude and frequency of the load voltage. The fuzzy based control techniques with wind-hydro hybrid power generation are modeled and simulated in MATLAB using Simulink and Sim Power System set tool boxes. The resultant project is studied under various load conditions under varying wind speeds.

I. INTRODUCTION

Many countries are aware with global warning problems. One of the main problems is the pollution from burning fossil fuels to produce energy. Then the solution of this problem is to produce the clean energy .So more attention and interest have been paid to the utilization renewable energy sources, like solar, hydro, wind, biomass etc... Wind energy is the fastest growing and most promising renewable source among them due to economically variable. In India total installed capability of wind power generation is 8754M.W in the year 2008. India now ranks 5th in the world with an installed capacity of 11807MW as on 31-3-2010 according to Ministry of New and Renewable energy (MNRE), India.

According to MNRE, in India the total installed capacity as on 31st March, 2009 was 2430MW. [1],[2].Among the renewable energy sources, small hydro and wind energy have the ability to complement each other [5].For power generation by small hydro or micro hydro as well as wind systems, the use of squirrel cage induction generators (SCIG) has been reported in literature. [3],[6]

There are two main parameters in the hydro power generation, i.e., discharge and head of the water for the determination of generating potential for a hydro electric power generation [3]. When SCIG is used for small or micro hydro applications, it's reactive power is met by a capacitor bank at its stator terminal. In recent years, wind-turbine technology has switched from fixed speed to variable speeds. The variable speed machines have several speeds advantages has been reported.[4].Natural energy based power generation systems are commonly equipped with storage batteries to balance the power [10].For the rest of this paper, the subscript $'w'$ is used to denote the parameters and variables of wind turbine generator and subscript $'h'$ is used to denote the parameters and variables of hydro turbine generator.

A schematic diagram of three phase four wire autonomous system is shown in fig. 1. The two back-to-back connected pulse width modulation (PWM) controlled IGBT based VSCs are connected between the stator windings of $\mathrm{SCIG_w}$ and the stator windings of $\mathrm{SCIG_h}$ to facilitate bidirectional powerflow.

The stator windings of the $\mathrm{SCIG_h}$ are connected to the load terminals. The two VSCs may be called as the machine side converter at $\mathrm{SCIG_w}$ and the load side converter at$\mathrm{SCIG_h}$.

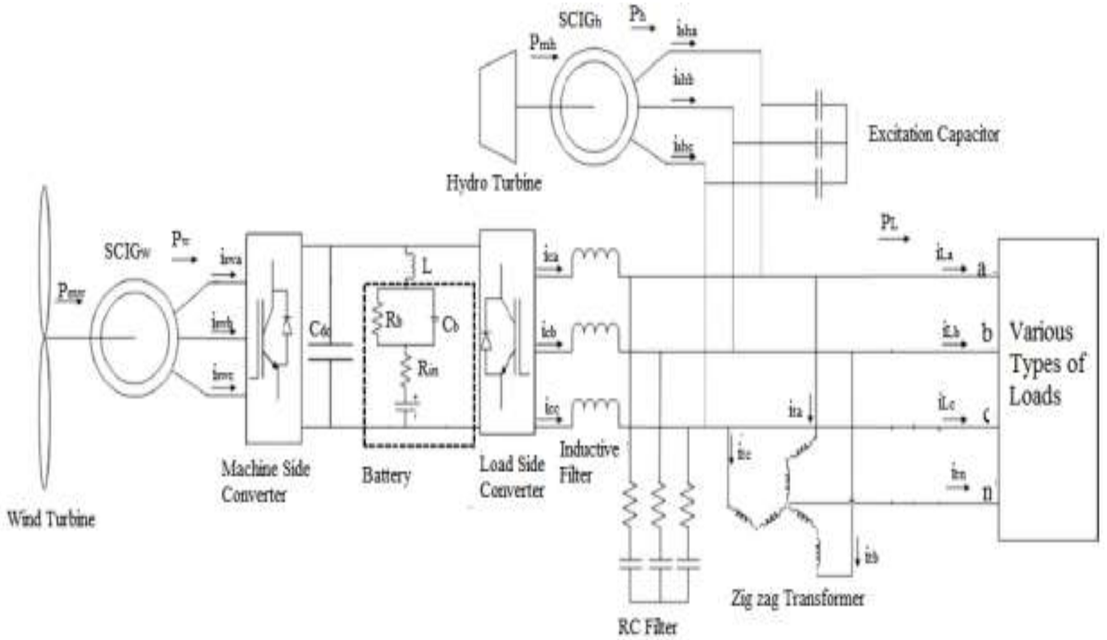

Fig.1.Schematic diagram of wind-hydro hybrid system

An inductor is connected in series with the BESS to remove the ripples from the battery current. A zigzag transformer is connected in parallel to the load for filtering zero sequence components of the load currents. Further, the zigzag transformer windings trap triple harmonics. As shown in fig.1 the transformer consists of three single phase transformers with a turn's ratio of 1:1. The neutral wire of the transformer is connected to the neutral wire of the load.

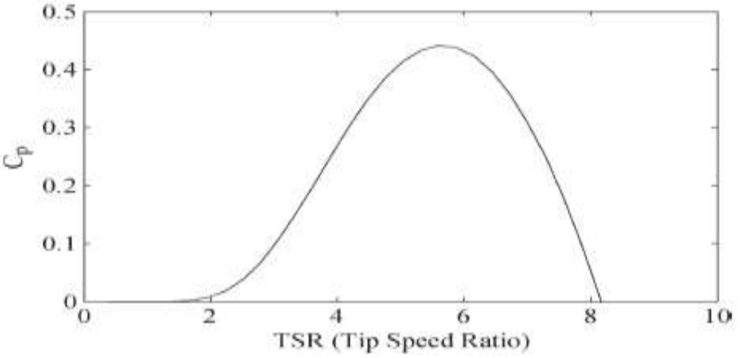

Fig.2: Power coefficient (c_p) versus tip speed ratio (λ) for wind turbine.

We can study the proposed project, under the various types of loads with the varying wind speeds .In every condition we can observe that the power is balanced in the system by means of BESS, achieve the MPT at wind power generation side and constant frequency at local load side by means of machine side and load side converters.

II. PRINCIPLE OF OPERATION

A.Machine side converter control algorithm:

The objective of the machine (SCIG_w) side converter is to provide the requisite magnetizing current to the SCIG_w and to achieve the maximum power tracking (MPT).

To achieve MPT, the SCIG_w is required to be operated at optimal tip speed ratio (TSR) as shown in fig.2. The TSR determines the SCIG_w rotor speed set point for a given wind speed, and the mechanical power generated at this speed lies on the maximum power lines of the wind turbine as shown in fig.3.

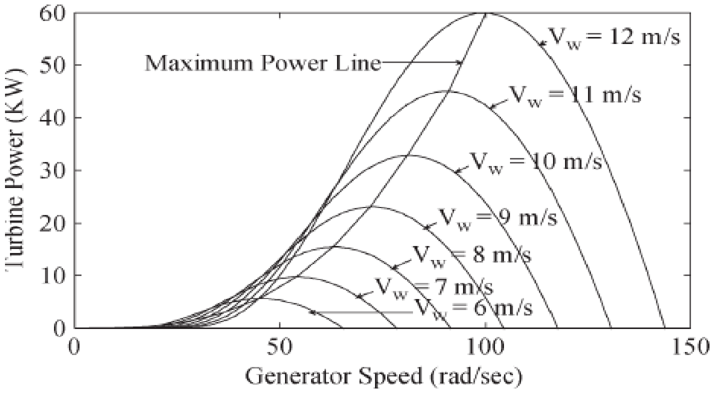

Fig.3: Mechanical output power of the wind turbine versus generator ($SCIG_w$) speed For different wind speeds.

The operating principle of the machine side converter is based on the decouple control of d-and q-axis stator currents of the SCIG with the d-axis aligned to rotor flux axis.

In the proposed algorithm, the tip speed ratio (λ_w) for a wind turbine of radius (r_w) and gear ratio (η_w) at a wind speed of (v_w) is defined as

$$\lambda_w = \frac{\omega_{rw}\ r_w}{\eta_w\ v_w} \qquad (1)$$

For MPT in the wind turbine generator system, the $SCIG_w$ should operate at the optimum tip speed ratio (λ_w^*) as shown in fig. (2). Thus the reference rotor speed (w_{rw}^*) and the optimal optimal tip speed ratio (λ_w^*) for MPT is

$$\lambda_w^* = \frac{\omega*_{rw}\ r_w}{\eta_w\ v_w} \qquad (2)$$

At the n^{th} sampling instant, the resultant rotor error is fed to the Proportional Integral (PI) controller, gives the reference q-axis stator current (I_{qsw}^*).

The reference d-axis $SCIG_w$ stator current I_{dsw}^* is determined from the rotor flux set point (φ^*drw) at the n^{th} sampling instant is given by

$$I_{dsw\,(n)}^* = \frac{\varphi_{drw}^*}{L_{mw}} \qquad (3)$$

Where L_{mw} is the magnetizing inductance of SCIGw

For generating the three phase reference $SCIG_w$ stator currents (i_{swa}^* ,i_{swb}^* and i_{swc}^*), the transformation angle is given by

$$\theta_{rotor\ \ flux\ w} = \theta_{slip\ \ w} + \left(\frac{pw}{2}\right)\theta_{rw} \qquad (4)$$

The references for d-q components of $SCIG_w$ stator currents are converted to three phase reference $SCIG_w$ stator currents by $d-q$ to abc transformation using angle

$\theta_{rotor\ \ flux\ w}$ as

$$i_{swa}^* = I_{dsw}^*\ \sin(\theta_{rotor\ \ flux\ w}) + I_{qsw}^*\ \cos(\theta_{rotor\ \ flux\ w}) \qquad (5)$$

$$i_{swb}^* = I_{dsw}^*\ \sin\left(\theta_{rotor\ \ flux\ w} - {}^{2\pi}\!/_{3}\right) + I_{qsw}^*\ \cos\left(\theta_{rotor\ \ flux\ w} - {}^{2\pi}\!/_{3}\right) \qquad (6)$$

$$i_{swc}^* = I_{dsw}^*\ \sin\left(\theta_{rotor\ \ flux\ w} + {}^{2\pi}\!/_{3}\right) + I_{qsw}^*\ \cos\left(\theta_{rotor\ \ flux\ w} + {}^{2\pi}\!/_{3}\right) \qquad (7)$$

The above reference currents are then compare with sensed $SCIG_w$ stator currents to compute the $SCIG_w$ stator current errors, and those are amplified with gain (k=5) and the amplified signals are compared with a frequency (10 kHz) triangular carrier wave of unity amplitude to generate gating signals for the IGBTs of the machine side VSCs.

B. Load side converter control algorithm:

The objective of the load side ($SCIG_h$) side converter is voltage frequency control at the load terminals by maintaining active and reactive power balance.

The reference voltages (v_{an}^* ,v_{bn}^* and v_{cn}^*) for control of the load voltages at time't' given by

$$v_{an}^* = \sqrt{2}\ v_t\ \sin(2\pi ft) \qquad (8)$$

$$v_{bn}^* = \sqrt{2}\ v_t\ \sin(2\pi ft - 120^0) \qquad (9)$$

$$v_{cn}^* = \sqrt{2} v_t\ \sin(2\pi ft + 120^0) \qquad (10)$$

Where f is the nominal frequency (50Hz) and v_t is the phase-neutral load voltage, which is 240 V.

The sensed load voltages (v_{an} , v_{bn} and v_{cn}) are compared with the reference voltages at n^{th} sampling instant to compute the error voltage signals and these are fed to a PI voltage controller to obtain the three phase $SCIG_h$ reference currents (i^*_{sha} , i^*_{shb} and i^*_{shc}).
Now the above reference currents are compared with the sensed three phase currents of $SCIG_h$ and these error signals are amplified with gain (k=5) , and amplified signals are compared with a fixed frequency (10KHz) triangular carrier wave of unity amplitude to generate gating signals for IGBTs of the load side converter.
BESS used in the system is designed by Thevinen's equivalent model and its ratings are given in appendix section.

The system being considered has a wind turbine of 55kW and a hydro turbine of 35kW. The ratings of the SCIGs are equal to the ratings of its turbine ratings and the ratings of the reaming devices calculated values are given in the appendix section.

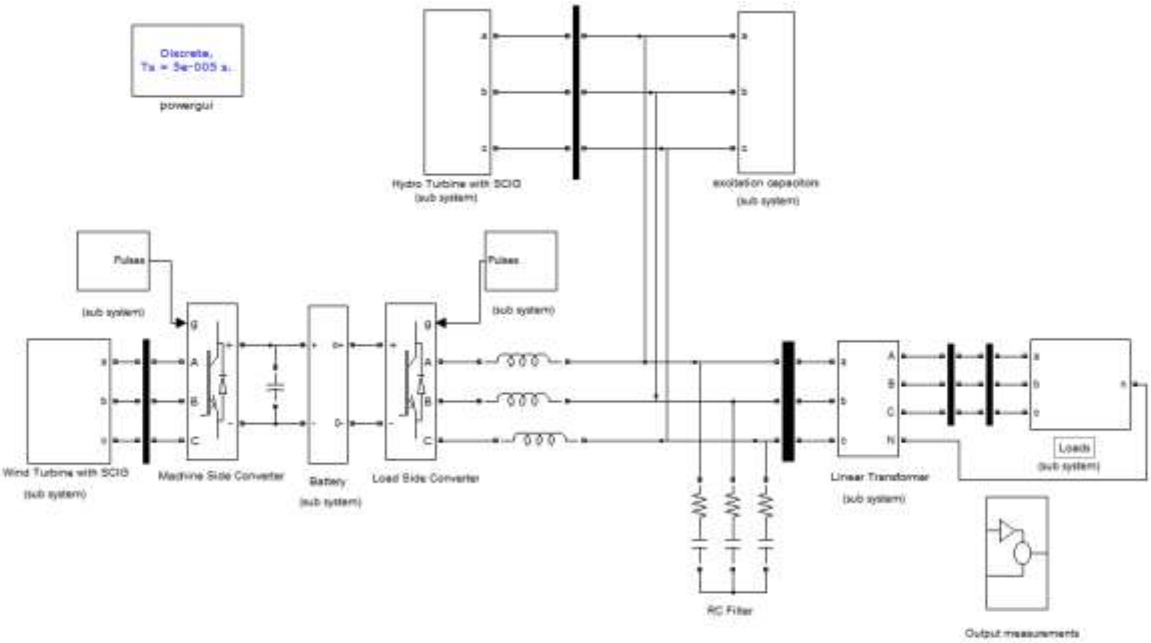

Fig.4: MATLAB simulation diagram of wind-hydro hybrid system

The simulated transient wave forms of stator $SCIG_w$ current(i_{sw}) $SCIG_h$ stator current(i_{sh}),load side converter current (i_C),load frequency(fL) , wind frequency(fw),three phase load voltage(v_L) ,three phase load current (i_L) , single phase load currents (i_{La} , i_{Lb} ,and i_{Lc}) , zig zag transformer currents (i_{ta} , i_{tb} , and i_{tc}),load frequency (f_L) ,battery current (i_b) ,battery voltage (v_{dc}) ,$SCIG_w$ stator power (P_w) , $SCIG_w$ stator power (P_w) ,$SCIG_h$ stator power(P_h) , load power (P_L),battery power (P_b), power coefficient (C_P),$SCIG_W$ rotor speed (ω_{rw}) , and wind velocity(V_w) are shown in graphs for different operating conditions in the fallowing output discussions.

III. RESULTS AND DISCUSSIONS

The system is designed for an isolated location with the load varying from 30 to 90 kW at lagging power factor of 0.8

A. MATLAB simulation results with balanced linear loads:

At wind speed of 11.2m/s the corresponding rotor speed of $SCIG_w$ is 100 rad/s and the generated power from the $SCIG_w$ is 52.1kW at power coefficient of 0.45 and the generated power from $SCIG_h$ is 33.3 kW, which is constant in all the conditions in this project. The system is feeding electrically balanced three single phases linear loads of total rating 60kW and 30 kvar. The total generated power is more than the load power so the battery observes the excess
generation power to maintain frequency of the load voltage constant. The load side converter supplies the load reactive power to maintain the magnitude and frequency of the load voltages are constant. The resultant MATLAB graphs are shown in fig.5.

B. MATLAB simulation results with unbalanced linear loads:

At wind speed of 8m/s the corresponding rotor speed of SIG_w is at 72rad/s and it's generated power is 20.1 kW.The system is feeding electrically the same as the before case and here an unbalance in load is created by using a timer circuit at 2.1 and 2.5 seconds, the resultant MATLAB results are shown in fig6.From the fig.6.Under the unbalanced condition the currents in the zig zag transformer is non zero , but the currents in all the three phase windings are the same, that means that the zero sequence currents flowing through these windings. It is clear that from fig.6, magnitude of load voltage and load frequencies are maintained constant even if the unbalance is created in the system.

C. MATLAB simulation results under varying wind speeds with linear balanced load:

As shown in fig.7, the wind-hydro hybrid system is started with a three single phase linear loads of totaling 45kW at wind speed of 7m/s .At this condition, the output power from the $SCIG_w$ 13kW and the total power is (13+33.3) = 46kW.Since the generated power is almost equal to the active power of the load, the battery power is zero. At 3.5 m/s , the wind speed is increased from 7 to 8m/s and it's generated power is 20kW, hence the excess power is used for charging of battery.

At 3.4 s, the wind is decreased from 8 to 6 m/s and it's generated power is 7.5kW, here the total generated power is less than the active load power, so the deficit power is delivered by the battery. From the MATLAB resultant graph of fig.7, it is clear that in all the conditions frequency and voltage at side is constant

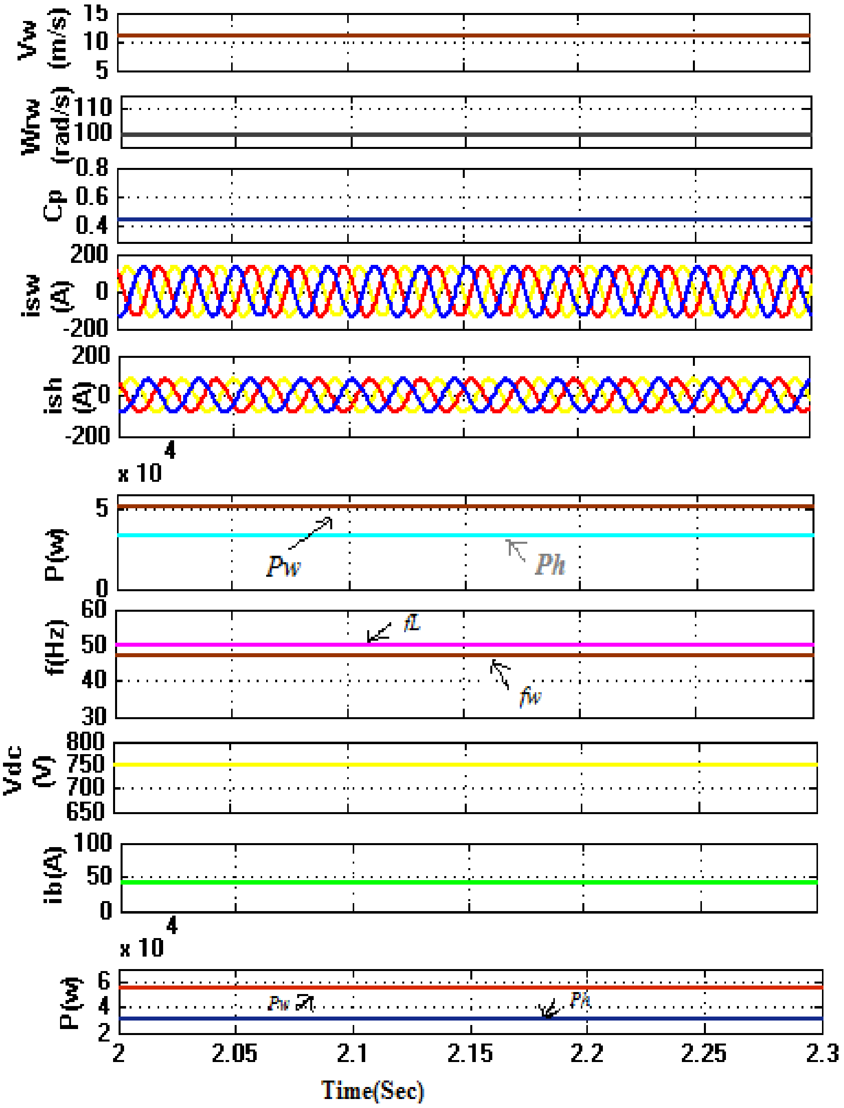

Fig.5: MATLAB results of the hybrid system at wind speed of 10m/s with balanced linear loads.

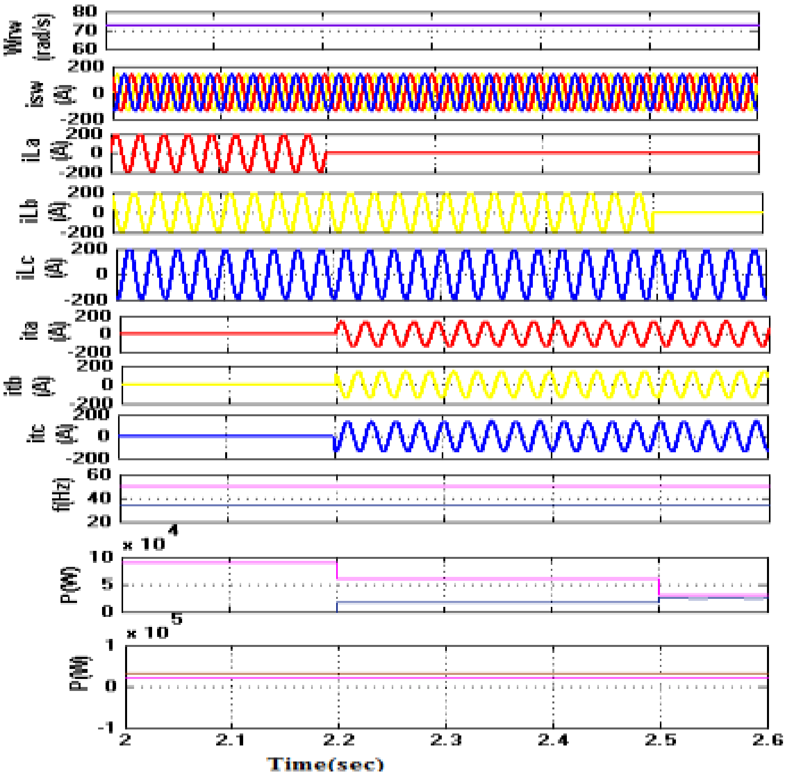

Fig.6: MATLAB results of the hybrid system at wind speed at of 8 m/s with unbalanced linear loads.

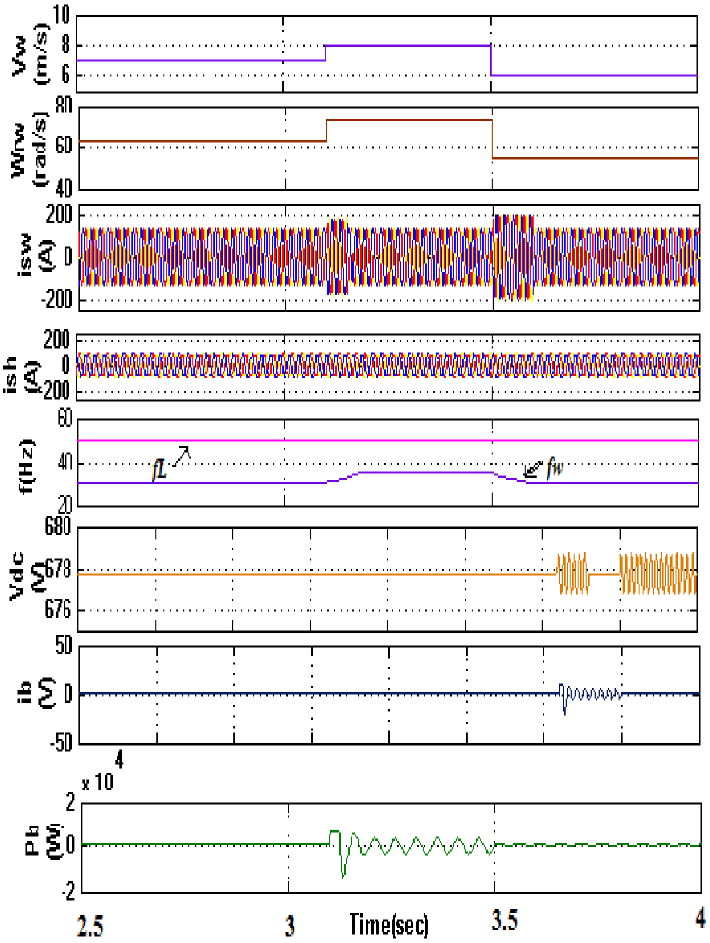

Fig.7: MATLAB results of the hybrid system at variable wind speeds with linear balanced loads.

IV. CONCLUSION

A three phase four wire local load wind –hydro hybrid system, using one squirrel cage induction generator driven by wind turbine and another squirrel cage induction generator driven by hydro turbine along with BESS and back-to-back power converter set , has been modeled and simulated in MATLAB software using Simulink and Sim Power System tool boxes. It has been demonstrated that the proposed hybrid system performs satisfactorily under different conditions while maintain constant voltage and frequency at load side by means of load side converter. Moreover, it has shown capability of MPT at wind turbine side (Machine side converter side), neutral-current compensation.

APPENDIX

1) Parameter of 37.3-kW 415-V 50-Hz Y- connected $SCIG_h$: R_s=0.09961Ω , R_r=0.058 Ω, L_s=0.869 mH , L_r=0.030369 H , and Inertia=0.4 kg.m^2 .
2) Parameters of 55-kW 415-V 50-Hz, Y-connected six-pole SCIGw: R_s=0.059Ω, Ls=0.687mH, $R_{r=}$0.0513Ω, L_m=0.0298 H, and Inertia =1.5 kg.m^2.
3) Parameters of 55-kW wind turbine: wind speed range = 6.0-12m/s, speed range = 43-81r/min, I=13.5 kg.$m^{2,}$ r = 7.5 m, C_{pmax}=0.04412, and λ^*=5.66
4) Machine side converter: Active power (P_{sw}) = 55kW, Reactive power (Q_{sw})=18.4kvar.
5) Load side converter: Reactive power (QL) = 67.5 kvar, KVA rating =112.5kVA.
6) RC Filter and AC inductor: R=5Ω, C=5μF, $L_{f\,=}$ 0.76 mH.
7) BESS specifications: C_b=43156 F, R_b=10kΩ, R_{in}=0.2Ω, Voc max = 750V, Voc min= 680V, Storage = 600 kW.h, L= 1 mH.
8) PI controllers: K_{pv}=15 and K_{iv}=0.05.
9) Transformer Specifications: three single phase transformer of 15 kVA 138/138 V, connected in zig zag manner.

REFERENCES

[1]. D.P Kothari, K.C Signal and Rakesh Ranjan, “Renewable Energy Sources and Emerging Technologies”.

[2]. [Online]: Available: http://mnre.gov.org.in

[3]. J. B. Ekanayake, “Induction generators for small hydro schemes,” IEEE Power Eng. J., vol. 16, no. 2, pp. 61–67, 2002.

[4]. B. Fox, D. Flynn, L. Bryans, N. Jenkins, D. Milborrow, M. O’Malley, R. Watson, and O. Anaya-Lara, Wind Power Integration Connection and System Operational Aspects. London, U.K.: IET, 2007, ch. 3.

[5]. G. Quinonez-Varela and A. Cruden, “Modeling and validation of a squirrel cage induction generator wind turbine during connection to the local grid,” IET Genre., Transmits. Distrib., vol. 2, no. 2, pp. 301–309, Mar. 2008.

[6]. L.Tamas and Z.Szekely, “Modeling and Simulation of an Induction Drive with Application to a Small Wind Turbine Generator,” in Proc. IEEE Int. Conf. Autom., Quality Test., Robot., May 22–25, 2008, pp. 429–433.

[7]. E.D. Castronuovo and J.A.Pecas,″Bounding active power active power generation of a wind-hydro power plant,” in Proc. 8th Coft. Probabilististic Methods Appl. Power Syst., Ames.IA, 2004, pp.705-710.

[8]. B. K. Bose, Modern Power Electronics and AC Drives. Singapore: Pearson Education, Pvt. Ltd., 2005, ch. 8.

[9]. B. Singh and G. K. Kasal, “Voltage and frequency controller for a three-phase four-wire autonomous wind energy conversion system,” IEEE Trans. Energy Convers., vol. 23, no. 2, pp. 505–518, Jun. 2008**.**

[10]. M. Black and G. Strbac, “Value of bulk energy storage for managing wind power fluctuations,” IEEE Trans. Energy Convers., vol. 22, no. 1, pp. 197–205, Mar. 2007.

[11]. Bhim Singh and V.Rajgopal, “Digital Control of Voltage and Frequency of Induction Generator in Isolated Small Hydro System,” 2012IEEE International Conference on power Electronics, Drives and Energy System, vol.no1, pp 4673-4508.

[12]. Margaret and Ziyad,”Determination of Lead-Acid Battery Capacity via Mathematical Modelling Techniques,”IEEE Transaction on Energy Conversion, Vol.7, pp 442-446 -IEEE, 1992.

[13]. S.Ranjith Kumar, S.Surendhar, Ashish and P.Raja,”Zig Zag Transformer performance analysis on harmonic reduction in distribution load,” International Conference on Electrical, Control and Computer Engineering, 2011, pp107-112, 2011 IEEE.