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An Isolated Wind–Hydro Hybrid System with Two Back-To- Back Power Converters & Battery

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ABSTRACT: This paper presents a three phase four wire local loads connected two squirrel cage induction generators (S.C.I.G) , one driven by a variable wind turbine and another driven by a constant power hydro turbine. The proposed system has a battery at the middle of the two back-to-back connected PWM controlled IGBT based voltage source converters(VSCs).The two VSCs are used to achieve maximum power tracking (M.P.T) at the machine side (Wind power generation side) and to regulate the magnitude and the frequency of the load voltage at load side(Hydro power generation).

KEYWORDS: maximum power tracking, VSC, Wind-Hydro.

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 5^{th} 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 31^{st} March, 2009 was 2430MW[1,2].

Among the renewable energy sources, small hydro and wind energy have the ability to complement each other. For power generation by small hydro or micro hydro as well as wind systems, the use of squirrel cage induction generators (SCIGs) has been reported in literature.

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. When SCIG is used for small or micro hydro applications, its reactive power is met by a capacitor bank at its stator termina[3]l.

The SCIG has advantages like being simple, low cost, rugged, maintenance free, absence of dc, brushless, etc., as compared with the conventional synchronous generator for hydro applications.

In recent years, wind-turbine technology has switched from fixed speed to variable speeds. The variable speed machines have several speeds advantages. The variable-speed machines have several advantages[4]. They reduce mechanical stresses, dynamically compensate for torque and power pulsations, and improve power quality and system efficiency.

Natural energy based power generation systems are commonly equipped with battery energy storage system (B.E.S.S) to balance the uncertainty in the system. In the case of stand-alone or autonomous systems, the issues of voltage and frequency control (VFC) are very important. A battery-based controller is proposed for control of voltage

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and frequency in the isolated Wind Energy Conversion Systems (WECS). However, maximum power tracking (MPT) could not be realized in this battery-based isolated system employing SCIG operated at fixed speed.

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[5].

The two back-to-back connected pulse width modulations (PWM) controlled IGBT based VSCs are connected between the stator windings of $SCIG_w$ at wind power generation side (machine side) and the stator windings of $SCIG_h$ at hydro power generation (load side) to facilitate bidirectional power flow. The stator windings of the $SCIG_h$ are connected to the load terminals at hydro power generation side. The two VSCs may be called as the machine side converter at $SCIG_w$ and the load side converter at $SCIG_h$.

For the proposed system, there are three modes of operation. In the first mode, the required active power of the load is less than the power generated by the $SCIG_h$, and the excess power generated by the $SCIG_h$ is transferred to the BESS through the load-side converter. Moreover, the power generated by the $SCIG_w$ is transferred to the BESS. In the second mode, the required active power of the load is more than the power generated by the $SCIG_h$ but less than the total power generated by $SCIG_w$ and $SCIG_h$. Thus, portion of the power generated by $SCIG_w$ is supplied to the load through the load-side converter and remaining power is stored in BESS. In the third mode, the required active power of the load is more than the total power generated by $SCIG_w$ and $SCIG_h$. Thus, the deficit power is supplied by the BESS, and the power generated by $SCIG_w$ and the deficit met by BESS are supplied to the load through the load-side converter.

II.PROPOSED SYSTEM & OPERATION

A new three-phase four-wire autonomous (or isolated) wind–small hydro hybrid system is proposed for isolated locations, which cannot be connected to the grid and where the wind potential and hydro potential exist simultaneously. The proposed system utilizes variable speed wind-turbine-driven SCIG*w* and a constant-speed/constant-power small hydro-turbine-driven SCIG*h* . A schematic diagram of a three-phase four-wire autonomous system is shown in Fig.1.

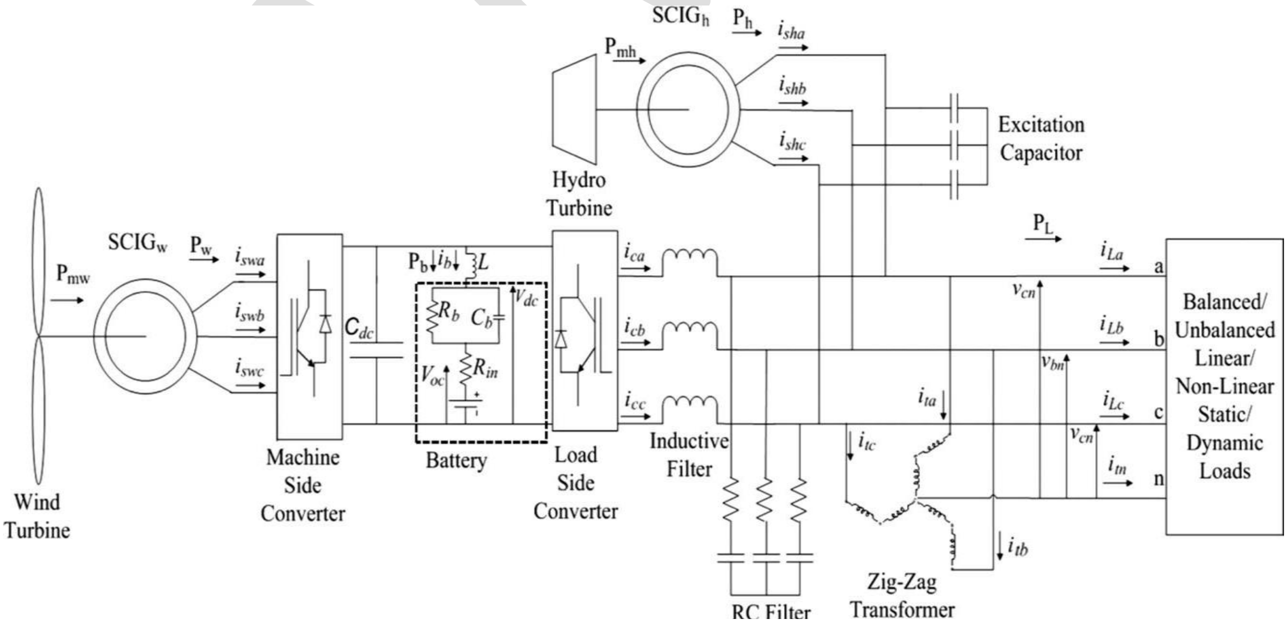

Fig.1. Schematic diagram of wind–hydro hybrid system.

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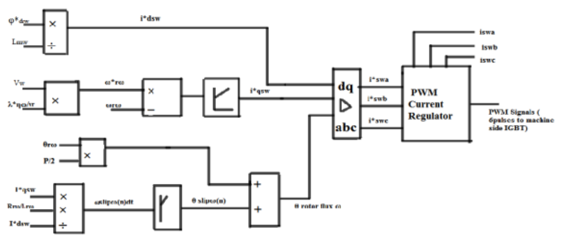
The BESS is connected at the dc bus of the PWM converters. A 1;1 linear zigzag transformer is connected in parallel to the load for filtering zero-sequence components of the load currents. The proposed system uses two back to-back-connected PWM-controlled IGBT-based VSCs. These VSCs are referred to as the machine ($SCIG_w$) side converter and load-side converter.

The objectives of the machine ($SCIG_w$) side converter are to provide the requisite magnetizing current to the $SCIG_w$ and to achieve MPT. The Control Scheme of Machine side converter is shown in fig.2.



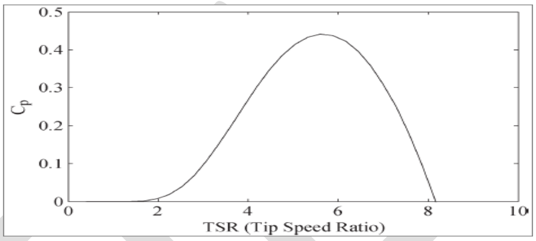


Fig2.Control Scheme of Machine side converter

Fig.3. Coefficient of performance (Cp) versus tip speed ratio (λ) for wind turbine.

To achieve MPT, the $SCIG_w$ is required to be operated at optimal tip speed ratio as shown in Fig.3. The tip speed ratio 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 line of the turbine, as shown in Fig.4. The operating principle of the controller for the machine ($SCIG_w$) side converter is based on the decoupled control of *d*- and *q*-axes stator currents of the $SCIG_w$ with the *d*-axis aligned to rotor flux axis as shown in Fig. 5.

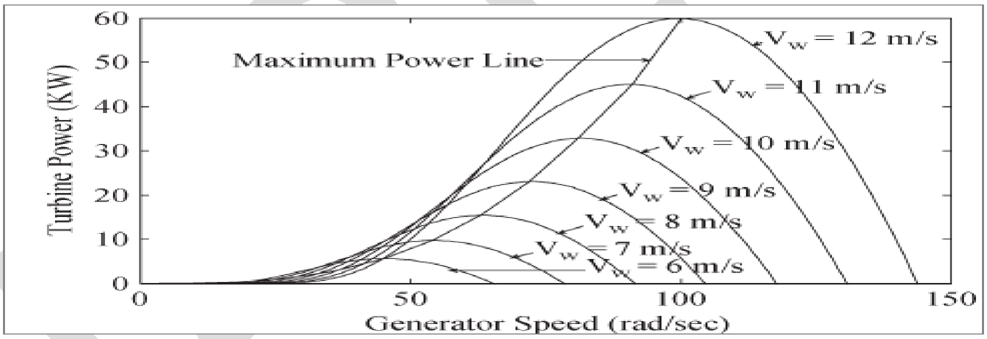


Fig.4. Mechanical power output of the wind turbine versus $SCIG_w$ speed for different wind speeds.

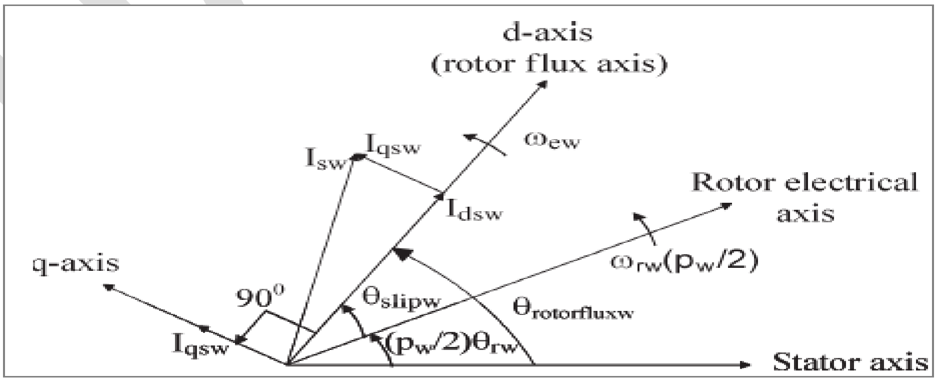


Fig.5. Phasor diagram of rotor flux oriented control of SCIG.

As the wind speed varies, the rotor-speed set point changes, and the difference in the reference rotor speed and the sensed rotor speed is fed to the controller for the machine ($SCIG_w$) side converter, also referred to as the speed controller. The output of the speed controller gives the reference *q*-axis stator current for $SCIG_w$. The reference *d – q* $SCIG_w$ stator currents are transformed to the reference three-phase $SCIG_w$ stator currents and compared with the sensed three phase $SCIG_w$ stator currents to generate control signals for the machine ($SCIG_w$) side converter.

The objectives of the load-side converter are to maintain rated voltage and frequency at the load terminals irrespective of connected load. The power balance in the system is maintained by diverting the surplus power generated to the battery or by supplying power from the battery in case of deficit between generated power and load requirement. Similarly, the required reactive power for the load is supplied by the load-side converter to maintain constant value of the load voltage. The control strategy for the load-side converter control is shown in Fig. 6.

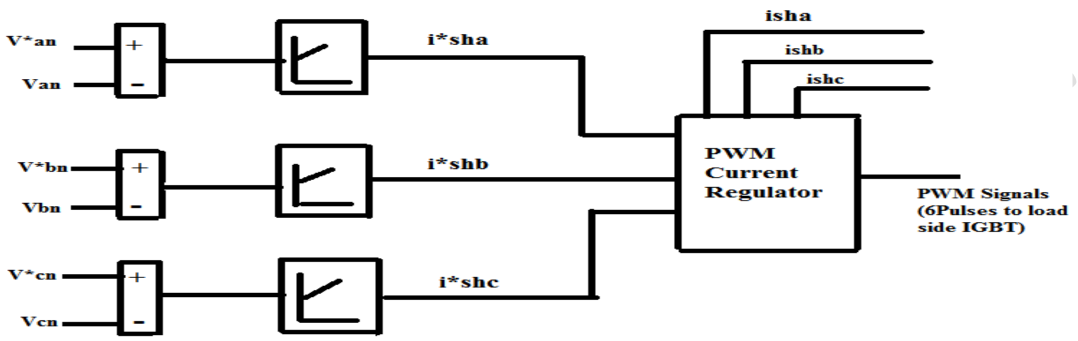


Fig.6. Control scheme of load side converter

The load-side converter is controlled for the regulation of load-voltage magnitude and load frequency. Further, for maintaining the load-frequency constant, it is also essential that any surplus active power in the system is diverted to the battery. Alternatively, the battery system should be able to supply any deficit in the generated power. Similarly, the magnitude of the load voltage is maintained constant in the system by balancing the reactive-power requirement of the load through the load side converter.

III.CONTROL ALGORITHM

The objectives of the machine ($SCIG_w$) side converter are to achieve optimum torque for MPT for $SCIG_w$ and to provide the required magnetizing current to the $SCIG_w$.

A. Speed-Control Loop for MPT and Reference q-axis $SCIG_w$ Stator-Current Generation:

In the proposed algorithm, the rotor position (θ_{rw}) of SCIG*w* and the wind speed are sensed. The rotor speed (ω_{rw})of SCIG*w* is determined from its rotor position (θ_{rw}). 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

$$\lambda_w = \frac{\omega_{rw} r_w}{\eta_w v_w} \tag{1}$$

For MPT in the wind-turbine-generator system, the $SCIG_w$ should operate at the optimum tip speed ratio (λ_w^*) Thus the reference rotor speed (w_{rw}^*) for MPT is generated using equation (1) as

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

The reference rotor speed of $SCIG_w$ is compared with (ω_{rw})to calculate the rotor-speed error (ω_{rwer}) at the n^{th} sampling instant as

$$\omega_{rwer\,(n)} = \omega_{rw\,(n)}^* - \omega_{rw\,(n)}^* \tag{3}$$

The aforementioned error is fed to the speed proportional integral (PI) controller. At the n^{th} sampling instant, the output of the speed PI controller with proportional gain $K_{p\omega}$and integral gain $K_{i\omega}$ gives the reference *q*-axis $SCIG_w$ stator current (I_{qsw}^*).

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B. Reference d-axis $SCIG_w$ Stator-Current Generation:

The reference *d*-axis $SCIG_w$ stator current (I^*_{dsw}) is determined from the rotor flux set point ($\varphi^*{}_{drw}$) at the n^{th} sampling instant as

$$I^*_{dsw(n)} = \frac{\varphi^*_{drw}}{L_{mw}} \tag{4}$$

Where L_{mw} is the magnetizing inductance of $SCIG_w$

C. Generation of PWM Signal for Machine-Side Converter:

For generation of three-phase reference $SCIG_w$ stator currents (i^*_{swa}, i^*_{swb} , andi^*_{swc}), the transformation angle $\theta_{rotor flux\ w}$ is

$$\theta_{rotor\ flux\ w} = \theta_{slip\ w} + \left(\frac{pw}{2}\right)\theta_{rw} \tag{5}$$

The references for d-q components of $SCIG_w$ stator currents are converted as

$$i^*_{swa} = I^*_{dsw}\sin(\theta_{rotor\ flux\ w}) + I^*_{qsw}\cos(\theta_{rotor\ flux\ w}) \tag{6}$$

$$i^*_{swb} = I^*_{dsw}\sin\left(\theta_{rotor\ flux\ w} - {}^{2\pi}/_{3}\right) + I^*_{qsw}\cos\left(\theta_{rotor\ flux\ w} - {}^{2\pi}/_{3}\right) \tag{7}$$

$$i^*_{swc} = I^*_{dsw}\sin\left(\theta_{rotor\ flux\ w} + {}^{2\pi}/_{3}\right) + I^*_{qsw}\cos\left(\theta_{rotor\ flux\ w} + {}^{2\pi}/_{3}\right) \tag{8}$$

The three-phase reference $SCIG_w$ stator currents (i^*_{swa}, i^*_{swb} , and i^*_{swb}) are then compared with the sensed $SCIG_w$ stator currents (i_{swa} , i_{swb} and i_{swc})to compute the SCIG*w* stator current errors, and these current errors are amplified with gain (K = 5) and the amplified signals are compared with a fixed frequency = (10 kHz) triangular carrier wave of unity amplitude to generate gating signals for the IGBTs of the machine-side VSC. The sampling time of the controller is taken as 50 μs, as this time is sufficient for completion of calculations in a typical DSP controller.

Load-Side side converter control algorithm

The objectives of the load-side converter are to maintain rated voltage and frequency at the load terminals irrespective of connected load. The power balance in the system is maintained by diverting the surplus power generated to the battery or by supplying power from the battery in case of deficit between generated power and load requirement. Similarly, the required reactive power for the load is supplied by the load-side converter to maintain constant value of the load voltage.

A. Generation of Reference Three-Phase SCIGh Currents:

The reference voltages (v^*_{an}, v^*_{bn} and v^*_{cn}) for the control of the load voltages at time *t* are given as

$$v^*_{an} = \sqrt{2}\ v_t \sin(2\pi f t) \tag{9}$$

$$v^*_{bn} = \sqrt{2}\ v_t \sin(2\pi f t - 120^0) \tag{10}$$

$$v^*_{cn} = \sqrt{2} v_t \sin(2\pi f t + 120^0) \tag{11}$$

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

The load voltages (v_{an} , v_{bn} andv_{cn}) are sensed and compared with the reference voltages. The error voltages (v_{anerr} , v_{bnerr} and v_{cnerr}) at the n^{th} sampling instant are calculated as

$$v_{anerr(n)} = \{v^*_{an(n)} - v_{an(n)}\} \tag{12}$$

$$v_{bnerr(n)} = \{v^*_{bn(n)} - v_{bn(n)}\} \tag{13}$$

$$v_{cnerr(n)} = \{v^*_{cn(n)} - v_{cn(n)}\} \tag{14}$$

The reference three-phase SCIG*h* currents (i^*_{sha}, i^*_{shb} and i^*_{shc}) are generated by feeding the voltage error signals to PI voltage voltage controller with proportionate gain K_{pv} and integral gainK_{iv}.

The reference three-phase SCIG*h* currents are then compared with the sensed SCIG*h* currents (i_{sha} ,i_{shb} and i_{shc}) to compute the SCIG*h* current errors as

$$i_{shaerr} = i^*_{sha} - i_{sha} \tag{15}$$

$$i_{shberr} = i^*_{shb} - i_{shb} \tag{16}$$

$$i_{shcerr} = i^*_{shc} - i_{shc} \tag{17}$$

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These current errors are amplified with gain (*K*=5), and the amplified signals are compared with a fixed-frequency (10 kHz) triangular carrier wave of unity amplitude to generate gatingsignals for IGBTs of the load-side

In this paper, it proposes efficient communication between CR nodes and spectrum utilization. Secondly the security concerns of spectrum sensing to ensure trustworthiness. It uses two selection schemes called node selection scheme (NSS) and channel selection scheme (CSS). The aim of NSS is to allow each node to check its gain in copying a message to a relay while examining its transmission effort. Using NSS, each node decides which paths should be used in order to provide minimum energy consumption without sacrificing end-to-end delay performance. Based on CSS, each node decides and switches to a licensed channel to maximize spectrum utilization while keeping the interference in a minimum level. This eventually enables CR-Networks nodes to determine optimum path nodes and channels for an efficient communication in CR-Networks. The CR technology allows Secondary Users (SUs) to seek and utilize "spectrum holes" in a time and location-varying radio environment without causing harmful interference to Primary Users (PUs). This opportunistic use of the spectrum leads to new challenges to the varying available spectrum. Using a Trust-Worthy algorithm, it improves the trustworthiness of the Spectrum sensing in CR-Networks.

IV. DESIGN PARAMETERS

1. *Parameter of 37.3-kW 415-V 50-Hz Y- connected SCIGh:* 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*$SCIG_w$.R_s =0.059Ω, L_s=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. *BESS specifications:* C_b=43156 F, R_b=10kΩ, R_{in}=0.2Ω, $V_{oc\ max}$= 750V, $V_{oc\ mix}$= 680V, Storage = 600 kW.h,L= 1 mH.
5. *PI Controllers:*K_{pv} =15 and K_{iv}=0.05.
6. *Transformer Specifications:* three single phase transformer of 15 kVA 138/138 V, connected in zig zag manner.

V. SIMULATION & RESULTS

A simulation model is developed in MATLAB using Simulink and Sim Power System set toolboxes. The simulation is carried out on MATLAB version 7 with ode3 solver. The electrical system is simulated using Sim Power System. The different loads are modeled using resistive and inductive elements and diode-rectifier-fed resistive loads combined with an *LC* filter. The unbalanced load is modeled using breakers in individual phases. The developed MATLAB model for the wind-hydro hybrid system is shown in Fig. 7.

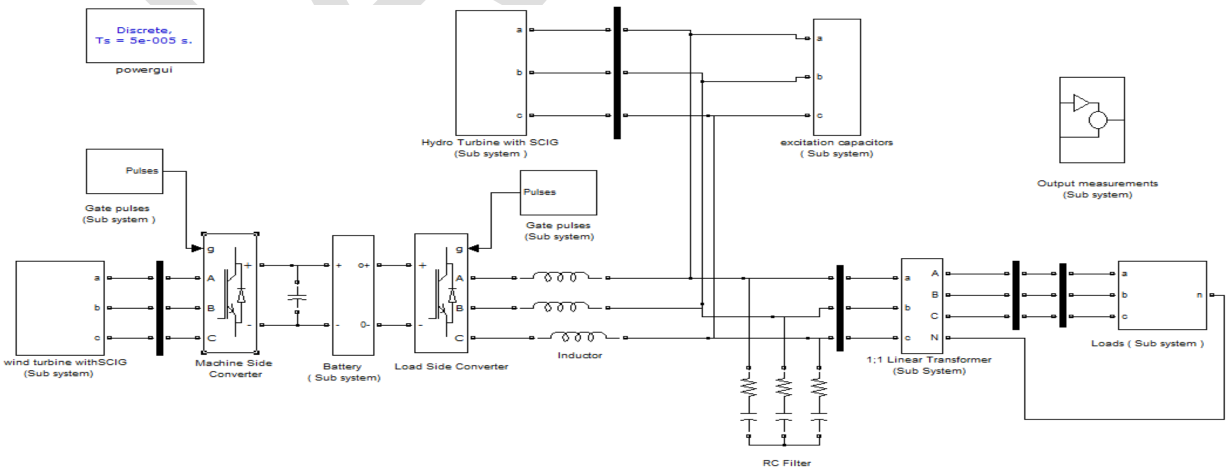

Fig.7.MATLAB Simulation diagram of wind-hydro hybrid system.

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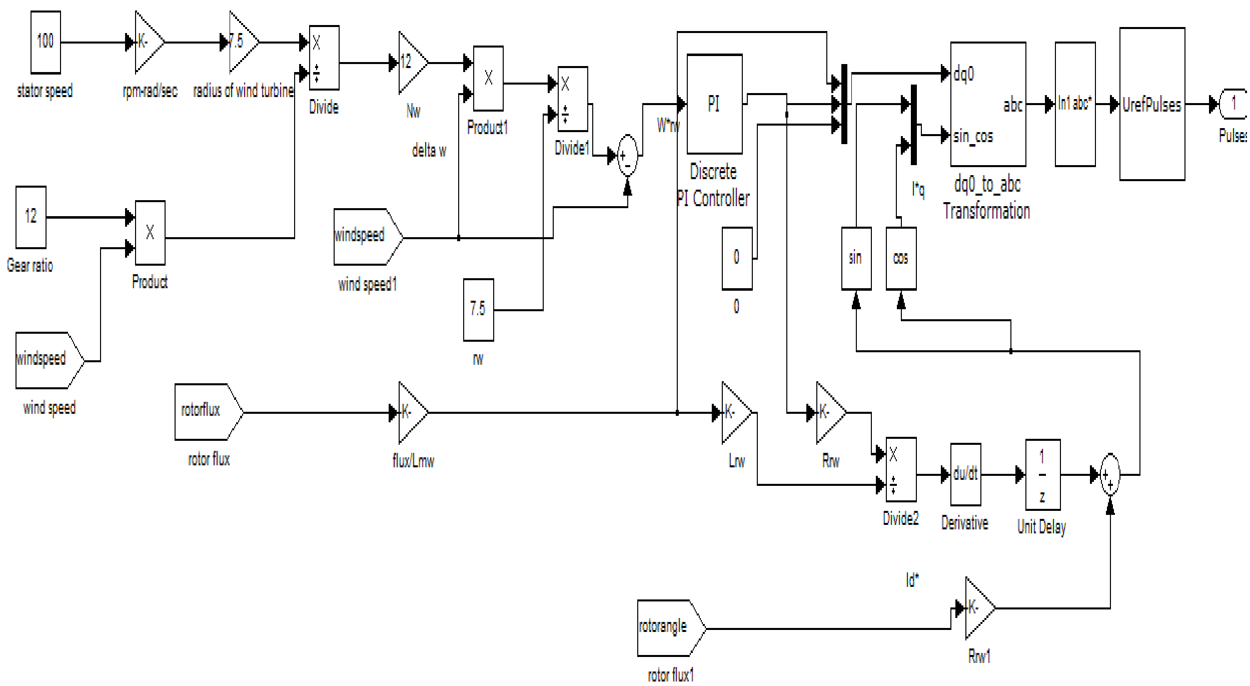

Fig.8. MATLAB Simulation diagram of machine side converter pulses

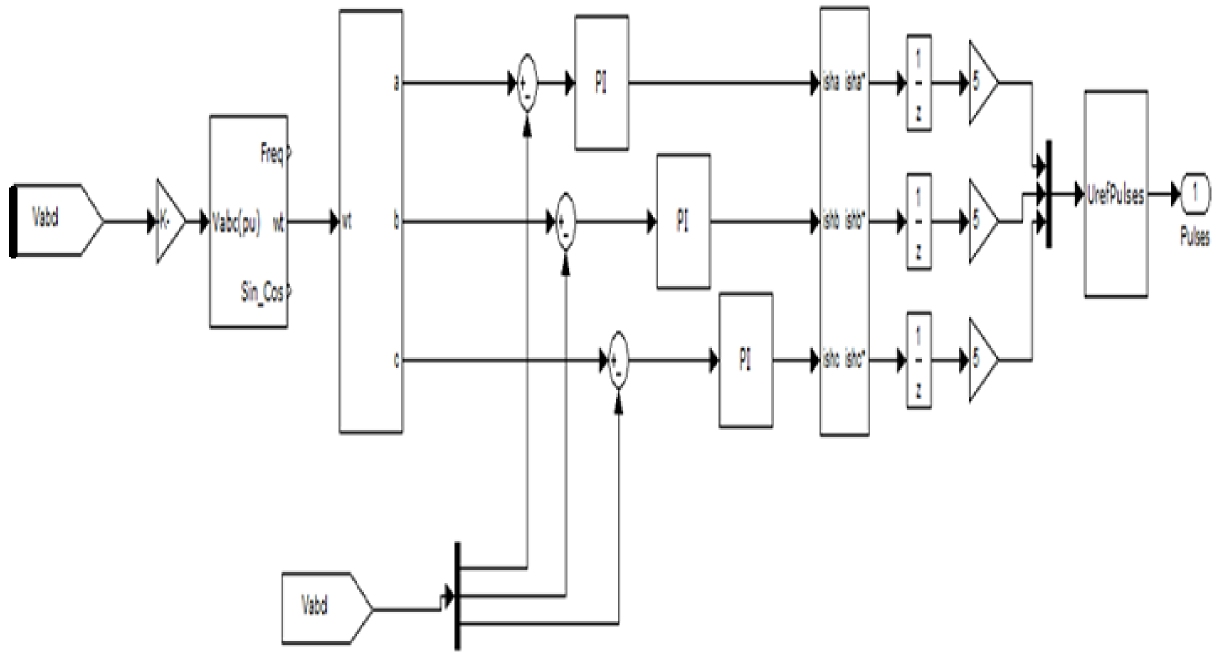

Fig.9. MATLAB Simulation diagram of load side converter pulses

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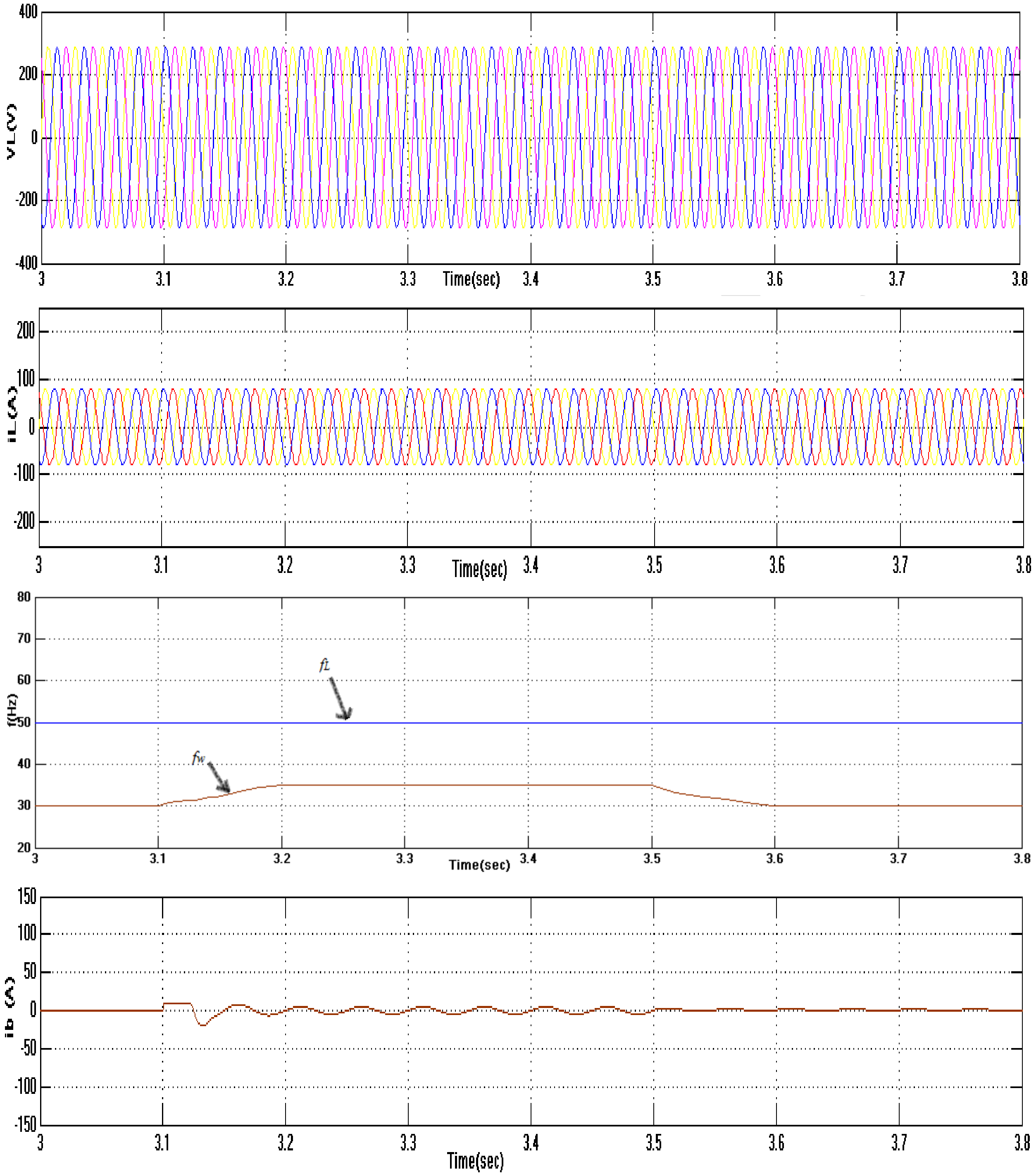

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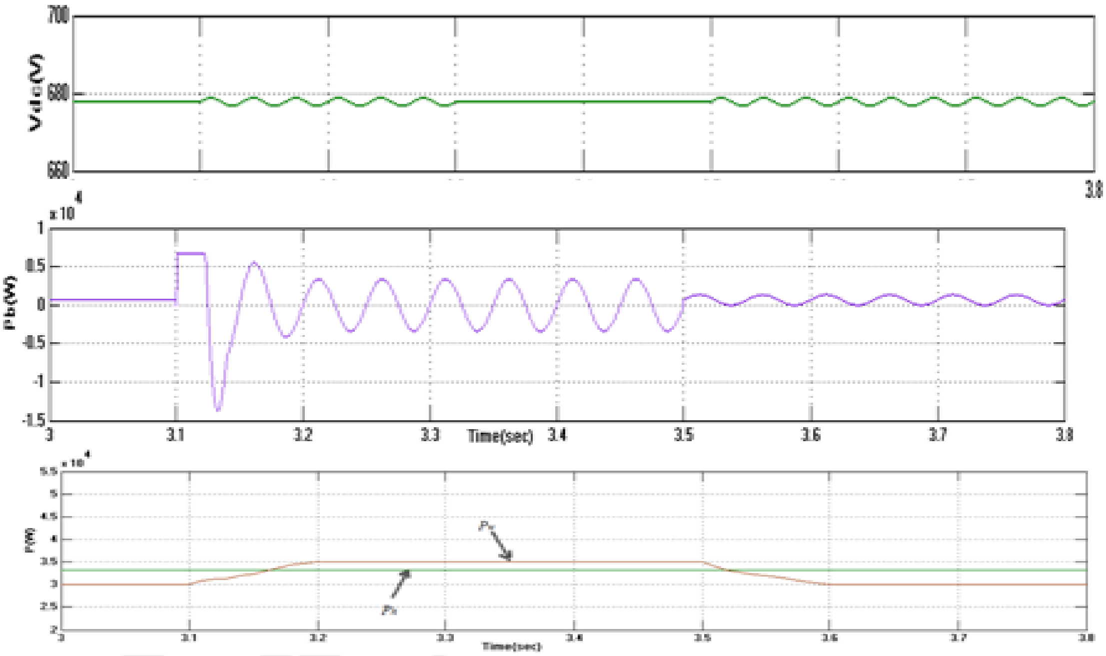

Fig.10. MATLAB results of the hybrid system under mixed load consisting of Linear, Nonlinear and Dynamic loads at wind speed of 9 m/s.

VI.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 and load balancing.

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