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AN ISOLATED WIND – HYDRO HYBRID SYSTEM WITH TWO BACK -TO- BACK POWER CONVERTERS AND A BATTERY

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ABSTRACT

This paper presents a voltage and frequency control of wind-hydro hybrid system in isolated locations in which one squirrel cage induction generator (SCIG) driven by a variable speed wind turbine and another SCIG driven by a constant power hydro turbine feeding three phase four wire local loads. The system mainly uses a rectifier and a pulse width modulation controlled insulated-gate-bipolar-transistor-based voltage-source converters (VSCs) with a battery energy storage system at their dc link. The main objectives of the rectifier is to convert the ac power generated by the wind system to dc and the control algorithm for the VSC is the control of the magnitude and the frequency of the load voltage. This system has the capability of bidirectional active- and reactive-power flow, by which it controls the magnitude and the frequency of the load voltage. Here pitch angle control is used to achieve maximum power tracking(MPT).In this paper wind turbine, hydro turbine, MPT controller, and a voltage and frequency controller are modeled and simulated in MATLAB using Simulink and Sim Power System set toolboxes, and different aspects of the proposed system are studied for various types of loads, and under varying wind-speed conditions. The performance of the proposed system is presented to demonstrate its capability of MPT, voltage and frequency control (VFC), harmonic elimination, and load balancing.

Keywords: Battery Energy Storage System (BESS) System; Small Hydro; Squirrel-Cage Induction Generator (SCIG); MPT.

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

IJARSE
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systems, the use of squirrel cage induction generators (SCIGs) has been reported in literature [5].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 terminal [3].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. They reduce mechanical stresses, dynamically compensate for torque and power pulsations, and improve power quality and system efficiency [4].Natural energy based power generation systems are commonly equipped with battery energy storage system (BESS) 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.

II. SOURCES OF POWER

2.1. Introduction

This Chapter deals with the sources of power regarding the wind – hydro hybrid power generation, i.e., wind energy and the hydro energy.

2.2. Wind Energy

Wind is defined as the movement of air from regions of high pressure to low pressure, and is primarily caused by uneven heating of earth’s surface, where an estimated 1% of the Sun’s energy is converted to wind. The second cause is the atmospheric circulation due to the rotation of the planet. The wind has associated kinetic energy which is converted to mechanical energy using wind mill or wind turbine, which slows down the passing wind; the energy conversion takes place by virtue of the law of conservation of energy.

2.3. Large and Small-Scale Wind Turbine Classifications

Turbine Properties	Small scale	Large scale
Blade Length	< 5 m	20-50 m
Rated Power	< 100 kW	1-3 MW
Turbine Speed	Several hundred RPM	15-30 RPM
Transmission Type	Directly Driven	Gearbox
Generator Types	DC , PM synchronous	Induction , Synchronous
Speed Control	Furling , Blade Stall, Power electronics Control	Blade pitch , Rotor Resistance , Power Electronics control
Applications	Stand alone , Grid connected	Directly , via full-scale converter
Stator Grid connected	Via full scale grid connected inverter	Directly , via full scale converter
Rotor Grid connected	-	Via partial –scale converter

Table.2.1. Comparison of small and large- scale wind turbine properties

IJARSE
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ISSN (P) 2319 - 8346

2.4. Wind Power Technologies

There are various types of the wind turbine. The follow table presents various types of classification. Modern wind turbines can be classified as either horizontal or vertical axis machines. Another classification is between wind turbines with different methods of controlling [15].

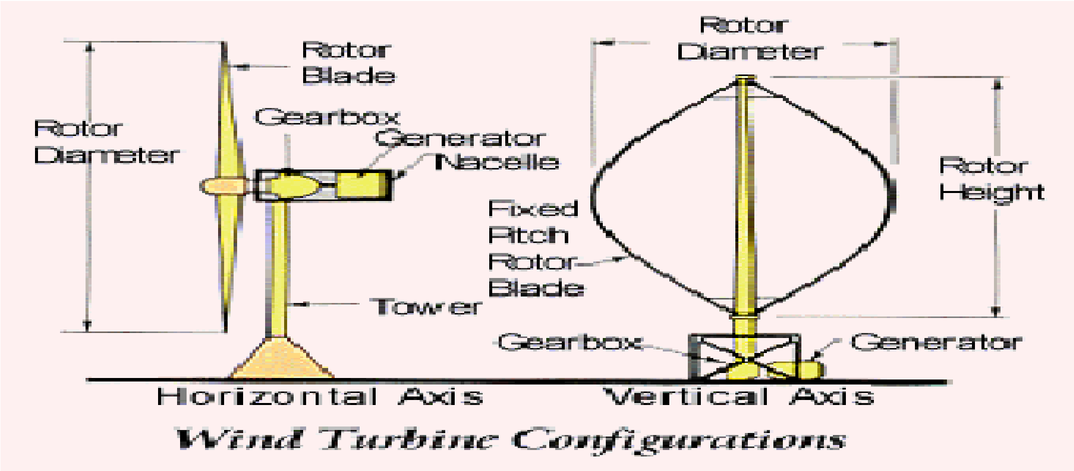

Fig.2.1 Horizontal and Vertical Wind Turbine configuration

2.5. Horizontal and Vertical Axis Wind Turbines

Horizontal axis wind turbines generally have either two or three blades or else a large number of blades. Wind turbines with large numbers of blades have what appears to be virtually a solid disc covered as high-solidity devices. In constant, the swept area of wind turbines with few blades is largely void and only a very small fraction appears to be solid. These are referred as low-solidity. Vertical axis wind turbines have an axis of rotation that is vertical, and so unlike the horizontal counterparts, they can harness winds from any direction without the need to reposition the rotor when the wind direction changes. These two technologies of wind turbines are shown in Fig.2.2.

Various Technologies in Wind Turbine		
Axis	Vertical	Horizontal
Direction	Upwind	Downwind
Blades	Three	Two
Speed	Constant	Variable
Regulation	Stall	Pitch
Generator Winding	Single	Double
Gear	With Gear	Gearless
Electronics	Direct A.C	A.C-D.C-A.C
Direction	Vertical	Horizontal

Table 2.2. Various technologies in wind turbines

IJARSE
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ISSN (P) 2319 - 8346

III. PROPOSED SYSTEM OPERATION, CONTROL STRATEGIES & DESIGN PARAMETERS

3.1. Introduction

This chapter deals with the block diagram of proposed wind hydro hybrid system principle of operation, its total control strategies (machine side converter & load side converter) and its design parameters.

3.2. Proposed System

A 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 [19]. 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.3.1.

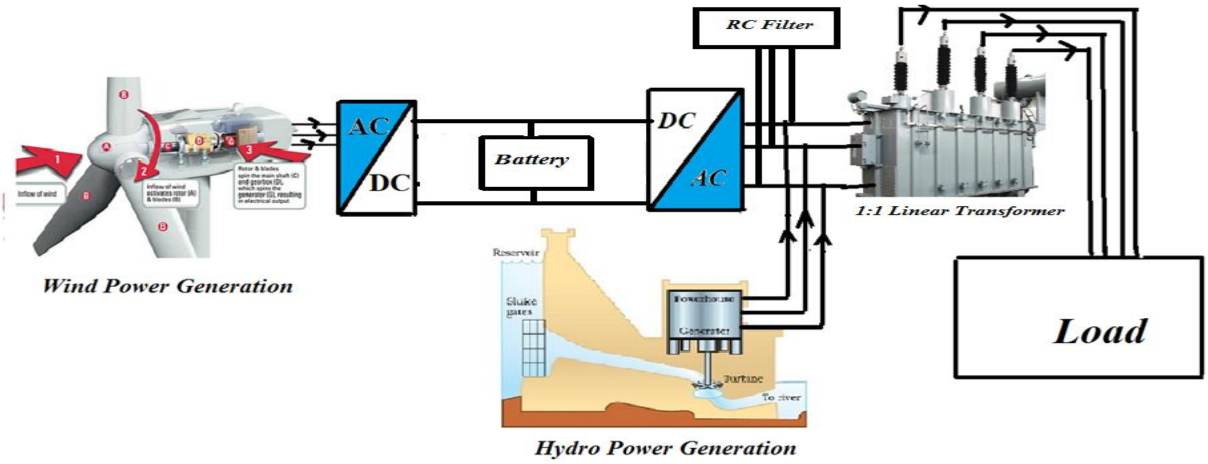

Fig:Single line diagram of wind-hydro hybrid system

Fig.3.1. Single line diagram of wind–hydro hybrid system

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 [22]. The proposed system uses two back to- back-connected PWM-controlled IGBT-based VSCs [23]. 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.

To achieve MPT, the $SCIG_w$ is required to be operated at optimal tip speed ratio as shown in Fig.3.3. 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.3.4. 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. 3.3[23].

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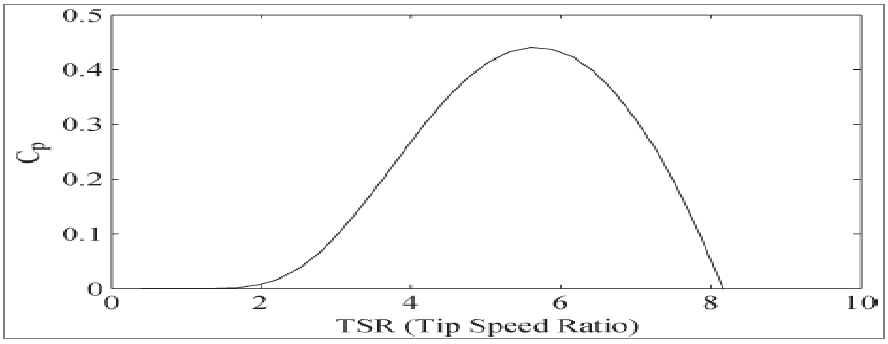

Fig.3.2. Coefficient of performance (*Cp*) versus tip speed ratio (λ) for wind turbine

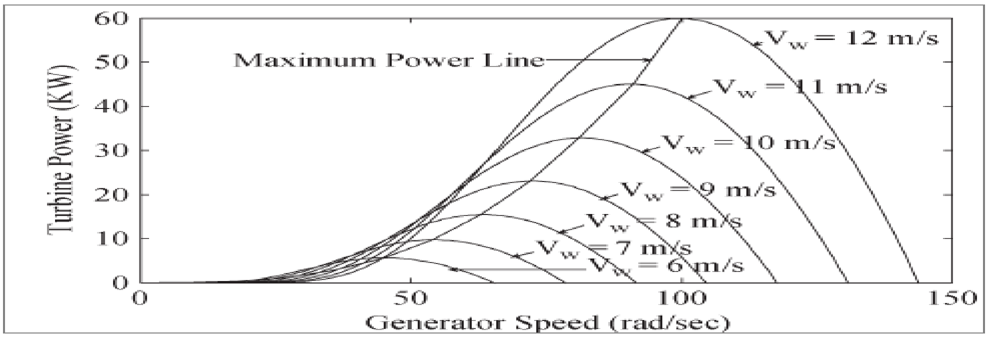

Fig.3.3. Mechanical power output of the wind turbine versus $SCIG_w$ speed for different wind speeds

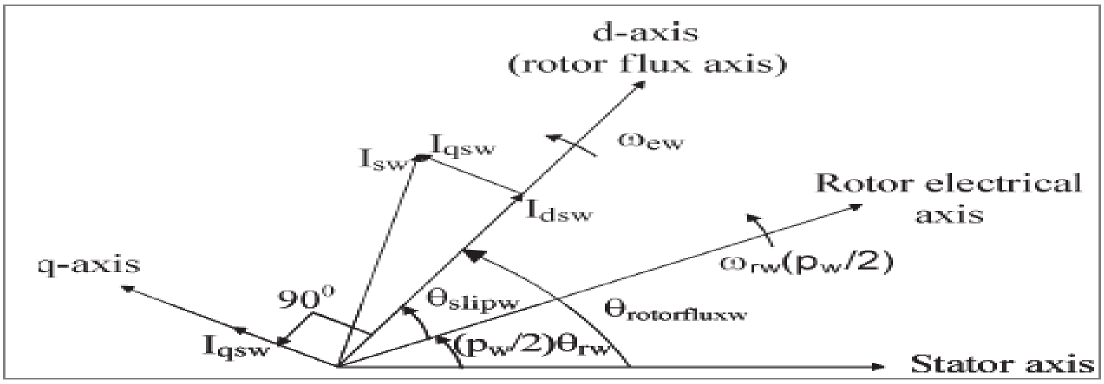

Fig.3.4. Phasor diagram of rotor flux oriented control of SCIG.

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[24].

A. Reference q-axis $SCIG_w$ Stator-Current Generation

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[24]

$$\omega_{rwer\,(n)} = \omega^*_{rw\,(n)} - \omega^*_{rw\,(n)} \qquad (3.3)$$

IJARSE
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ISSN (P) 2319 - 8346

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}).

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 [23]

$$I^*_{dsw\,(n)} = \frac{\varphi^*_{drw}}{L_{mw}} \quad (3.4)$$

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 $\theta_{rotorflux\ \ w}$ is[25]

$$\theta_{rotor\ \ flux\ \ w} = \theta_{slip\ \ w} + \left(\frac{pw}{2}\right)\theta_{rw} \quad (3.5)$$

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

$$i^*_{swa} = I^*_{dsw}\ \sin\left(\theta_{rotor\ \ flux\ \ w}\right) + I^*_{qsw}\ \cos\left(\theta_{rotor\ \ flux\ \ w}\right) \quad (3.6)$$

$$i^*_{swb} = I^*_{dsw}\ \sin\left(\theta_{rotor\ \ flux\ \ w} - {}^{2\pi}\!/_{3}\right) + I^*_{qsw}\ \cos\left(\theta_{rotor\ \ flux\ \ w} - {}^{2\pi}\!/_{3}\right) \quad (3.7)$$

$$i^*_{swc} = I^*_{dsw}\ \sin\left(\theta_{rotor\ \ flux\ \ w} + {}^{2\pi}\!/_{3}\right) + I^*_{qsw}\ \cos\left(\theta_{rotor\ \ flux\ \ w} + {}^{2\pi}\!/_{3}\right) \quad (3.8)$$

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 SCIGw 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. The total control mechanism of machine side converter is shown in Fig.3.6.

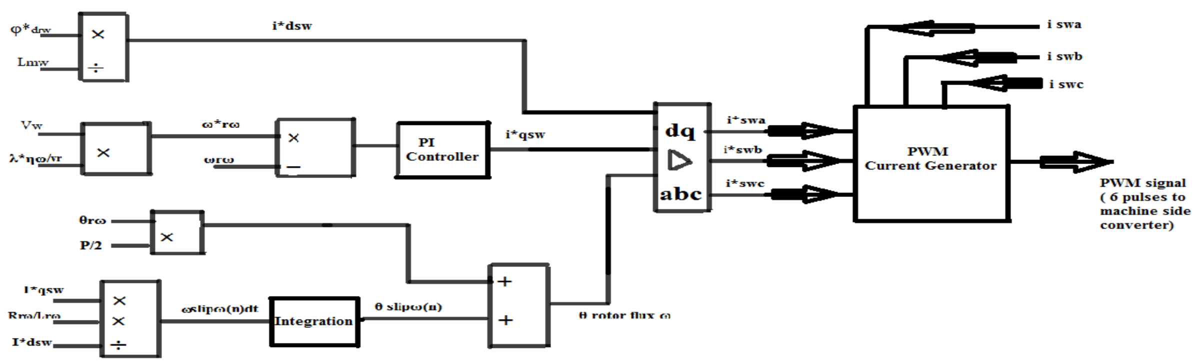

Fig.3.6.Control Scheme of Machine side converter.

IJARSE
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3.5. 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-poleSCIG$_w$:* 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, $C_{p\max}$ =0.04412, and λ^*=5.66.

4. *BESS specifications:* C_b=43156 F, R_b=10kΩ, R_{in}=0.2Ω, $V_{oc\ \max}$ = 750V, $V_{oc\ \text{mix}}$ = 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.

IV. MATLAB SIMULATION, RESULTS AND DISCUSSIONS

4.1. MATLAB-Based Hybrid System Model

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. 4.1

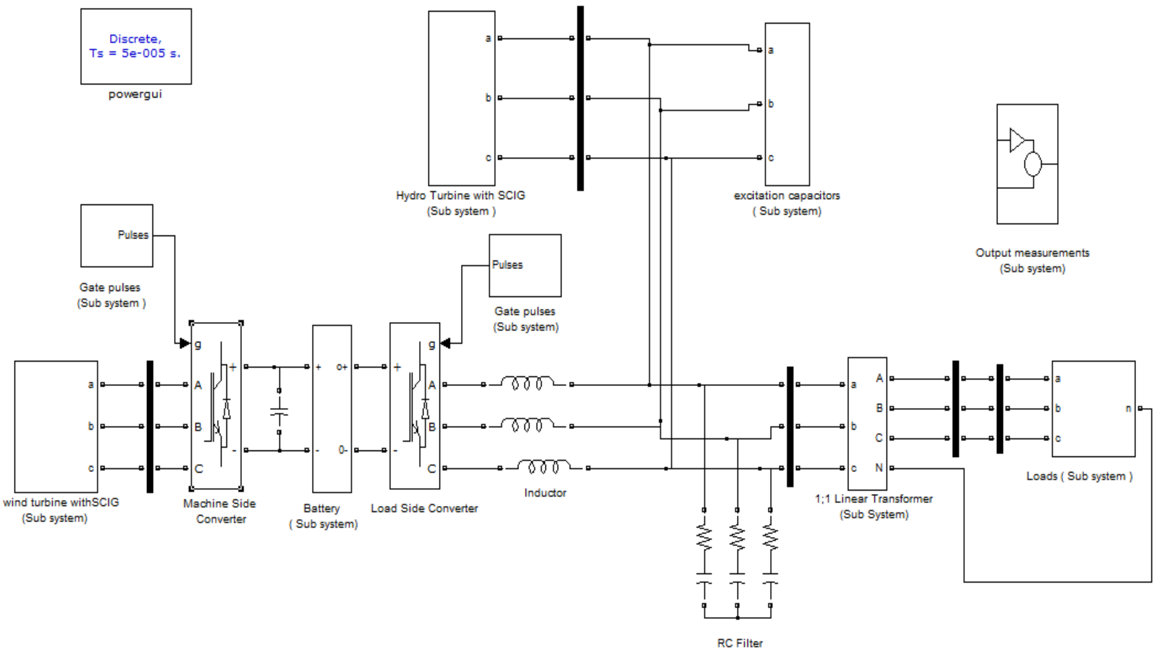

Fig.4.1. MATLAB Simulation diagram of wind-hydro hybrid system

IJARSE
ISSN (O) 2319 - 8354
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4.2. MATLAB Simulation Sub System Models

The subsystem wind turbine with SCIG is shown in Fig.4.2

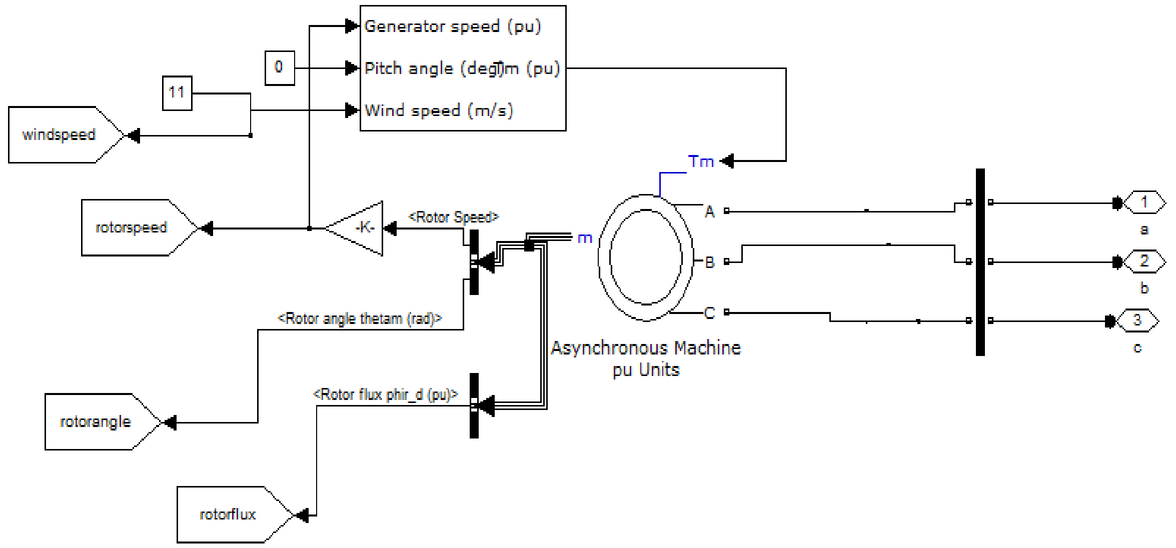

Fig.4.2. MATLAB Simulation diagram of wind turbine with SCIG

The subsystem of hydro turbine with SCIG is shown in Fig.4.3

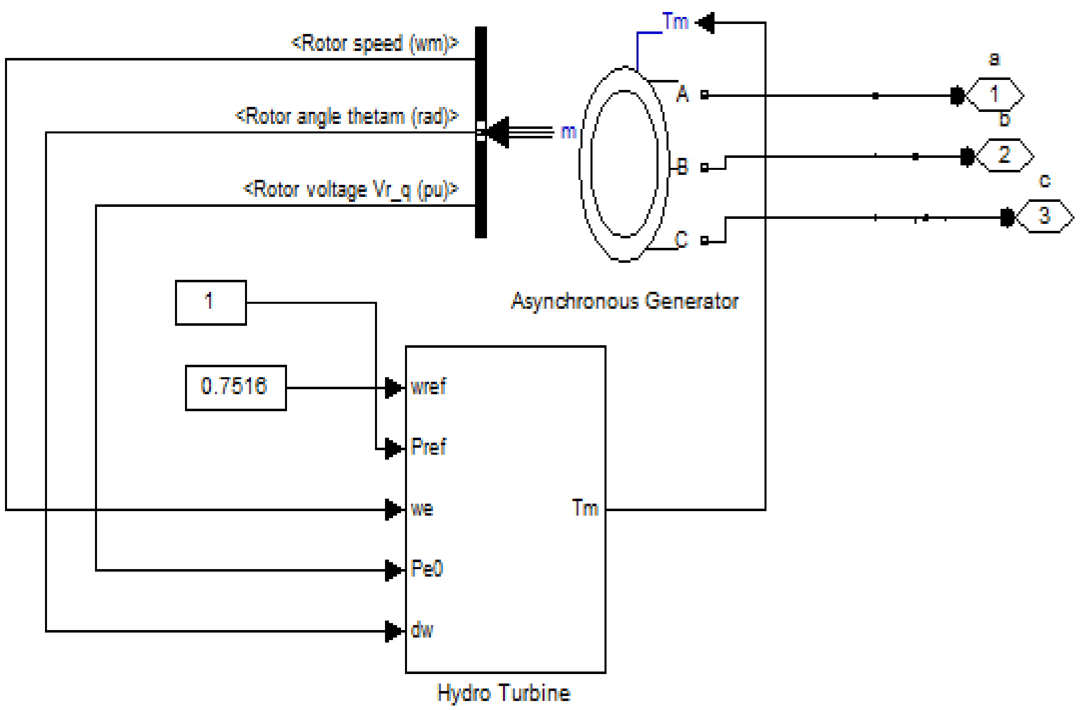

Fig.4.3. MATLAB Simulation diagram of hydro turbine with SCIG

4.3. MATLAB Based Results and Discussions

The performance of the wind-hydro hybrid system with the proposed control algorithm is demonstrated under different dynamic conditions. Moreover, performance of the wind-hydro hybrid system is studied with various electrical loads, i.e., balanced linear load, unbalanced linear load , balanced/unbalanced nonlinear load and

IJARSE
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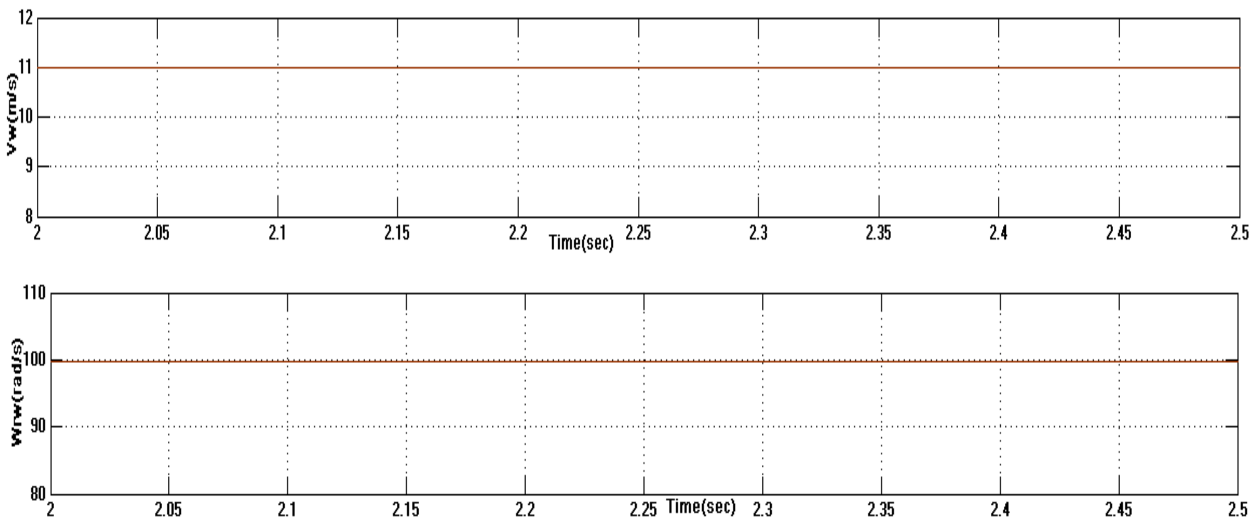
ISSN (P) 2319 - 8346

mixed load consisting of linear, nonlinear, and dynamic loads . The performance of the system is also studied under varying $SCIG_w$ rotor speeds due to wind speed variations. It is observed that under all these conditions, the wind-hydro hybrid system performs in the desirable manner. The $SCIG_w$ is able to run at speeds corresponding to the MPT with varying wind speeds. The simulated transient waveforms of the $SCIG_w$ stator current (*isw*), $SCIG_h$ stator current (*ish*), load-side converter current (i_c), three-phase load voltage (*vL*), three-phase load current (*iL*), single-phase load currents (*i*La, *i*Lb, and *i*Lc), zigzag transformer currents (*i*ta, *i*tb, *i*tc, and *i*tn), load frequency (*fL*), r.m.s value of phase load voltage (*Vt*), $SCIG_w$ stator frequency (*fw*), battery current (*Ib*), battery voltage (*V*dc), $SCIG_w$ stator power (*Pw*), $SCIG_h$ stator power (*Ph*), load power (*PL*), battery power (*Pb*), coefficient of power (*Cp*), $SCIG_w$ rotor speed (ω_{rw}), and wind velocity (V_w) are shown for different operating conditions.

A. MATLAB simulation results with balanced linear loads

In Fig. 4.4, the performance of the wind-hydro hybrid system is shown with balanced linear load at wind speed of 11 m/s. The corresponding rotor speed set point for $SCIG_w$ is at 99.6 rad/s, and its stator frequency is 47.08 Hz. At this speed, the mechanical power corresponding to maximum coefficient of performance is 52 kW. The input mechanical power to the $SCIG_h$ is taken as 35 kW, and the power generated through $SCIG_h$ is 33.3 kW. Thus, the total power generated is (52 + 33.3) kW = 85.3 kW. The system is feeding electrically balanced three single-phase linear loads (each of 20 kW and10 kvar). Since the power generated by the system is more than the required active power for the electrical loads (60 kW), the battery is absorbing the surplus power to maintain the frequency of the load voltage constant. Further the reactive power required by the load is supplied by the load-side converter to maintain the magnitude of the load voltage constant. Thus, under these conditions, both the magnitude and the frequency of the load voltage are maintained constant.



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IJARSE
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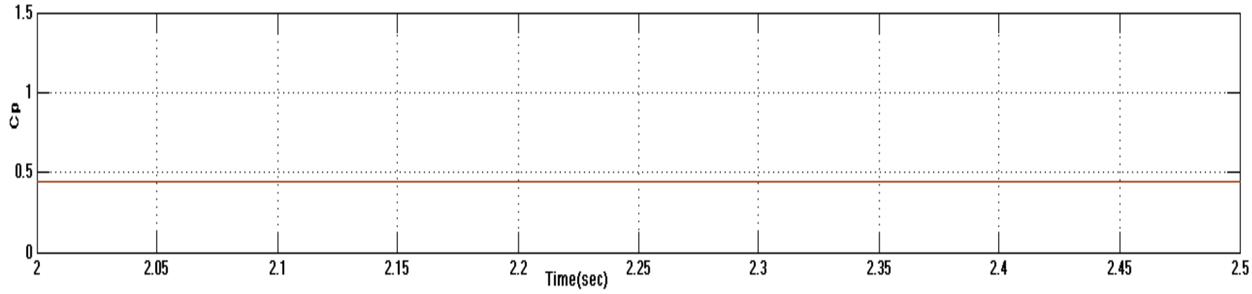

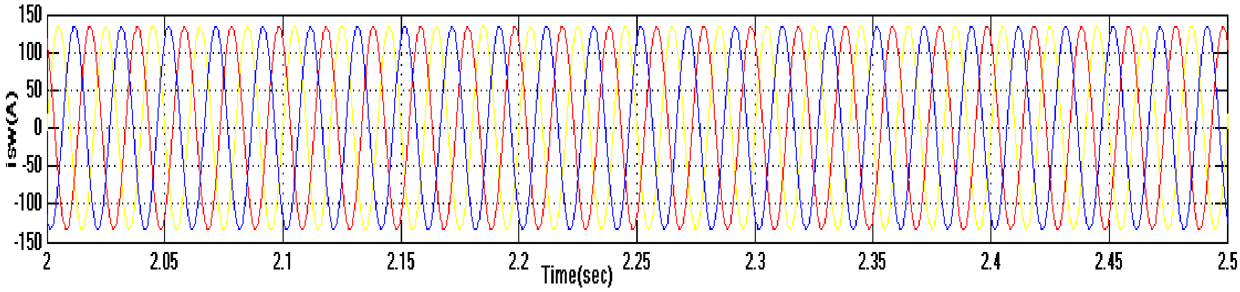

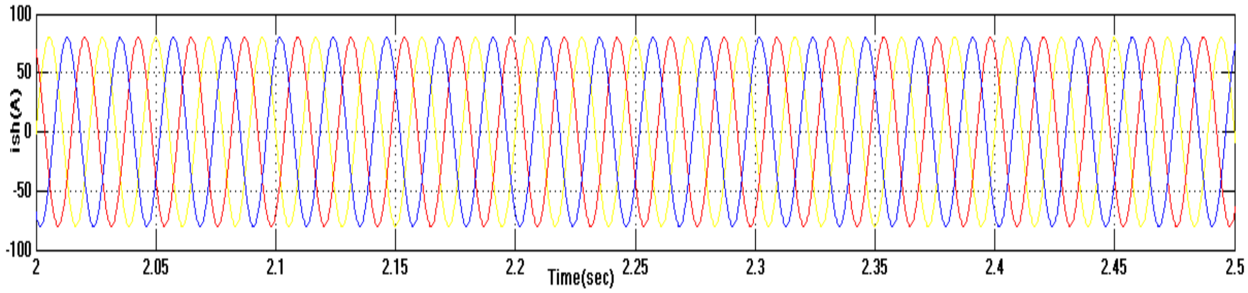

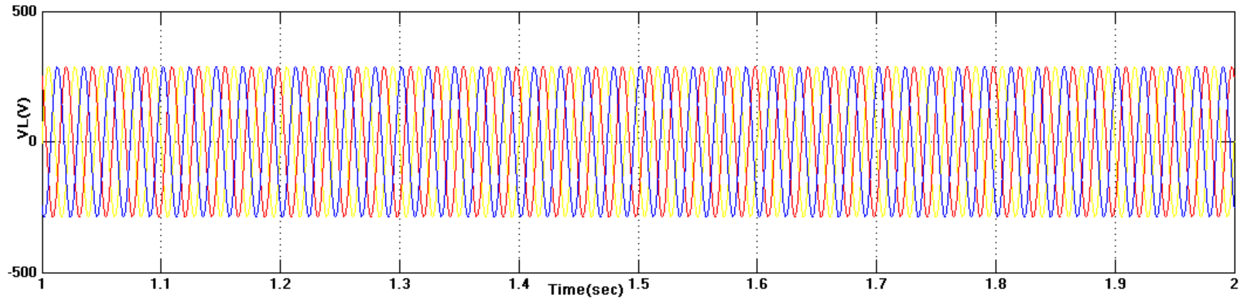

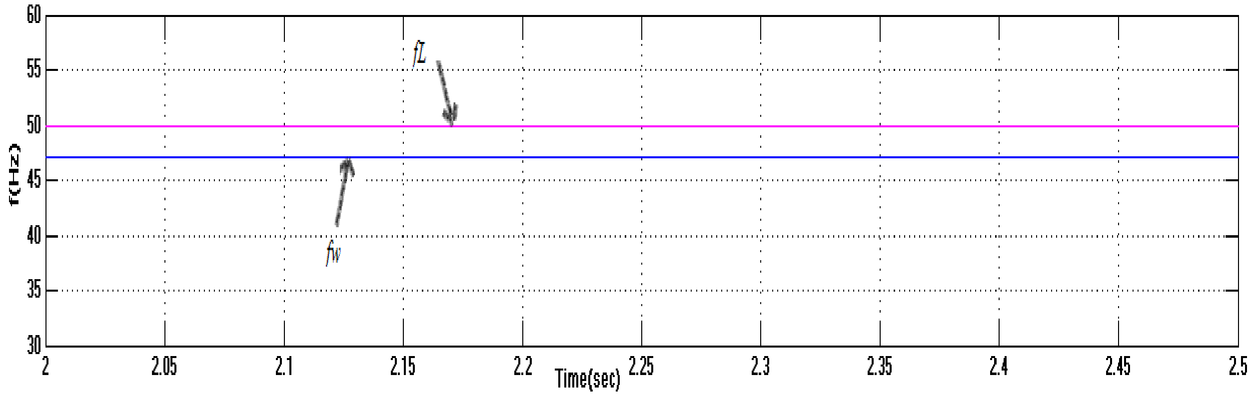

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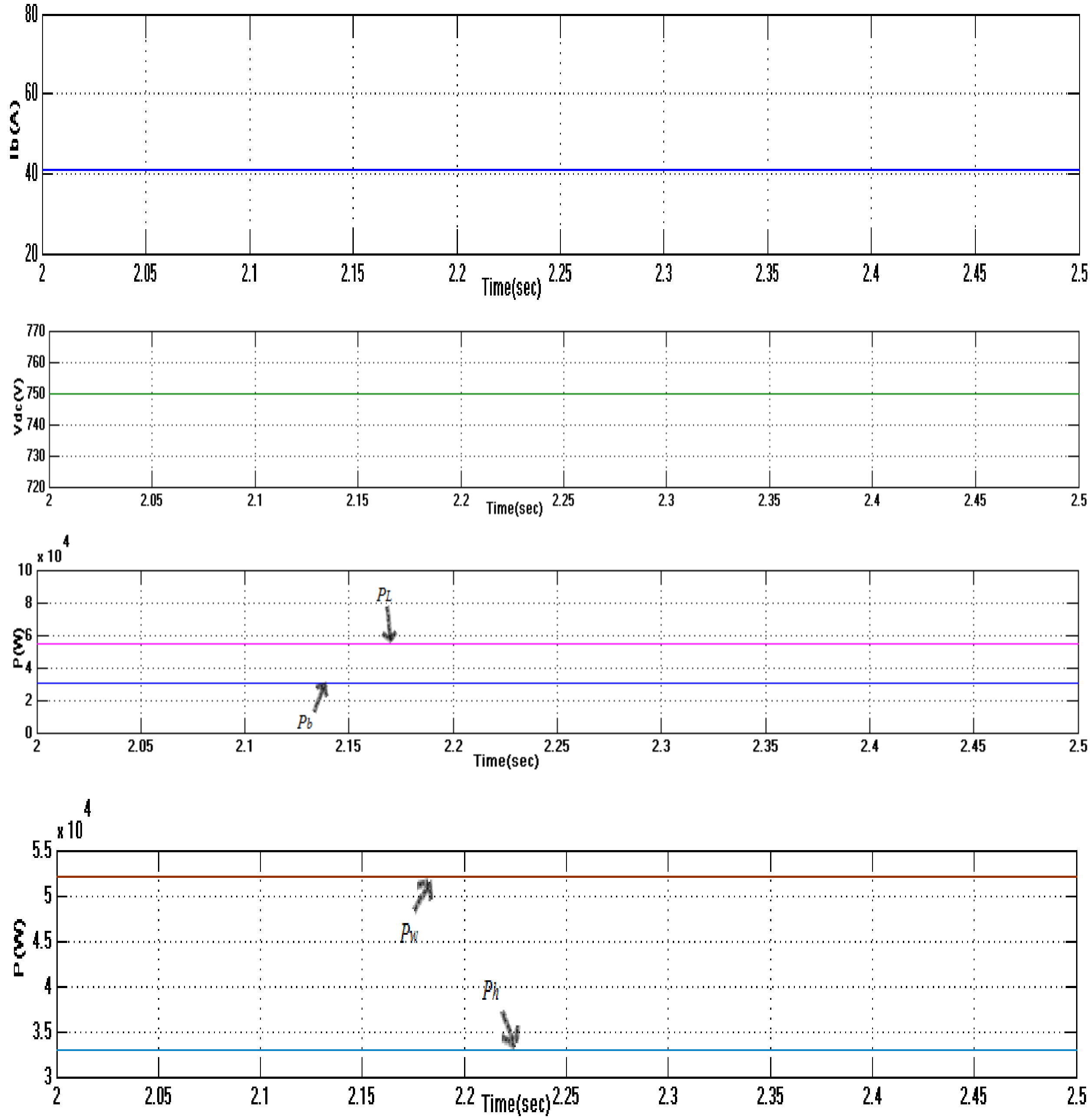

Fig.4.4. MATLAB Results of hybrid system with balanced linear load at wind speed of 11m/s

B.MATLAB simulation results with unbalanced linear loads:

In Fig. 4.5, the performance of the wind-hydro hybrid system is shown with unbalanced linear load at wind speed of 8 m/s. The corresponding rotor-speed set point for $SCIG_w$ is at 72.45 rad/s and the stator frequency is 34.17 Hz. At this speed, the mechanical power corresponding to a maximum coefficient of performance is 20 kW. The input mechanical power to the $SCIG_h$ is taken as 35 kW, and the power generated through $SCIG_h$ is 33.3 kW. Thus, the total power generated is (20.0 + 33.3) kW = 53.3 kW. The system is started with electrically balanced three single-phase linear loads (each of 30 kW) connected between each phase and neutral terminal. Because the power generated by the system is less than the required power for the electrical loads (90 kW), the battery is supplying the deficit power. At 2.2 s, an unbalance is created by disconnecting a load of 30 kW by

IJARSE
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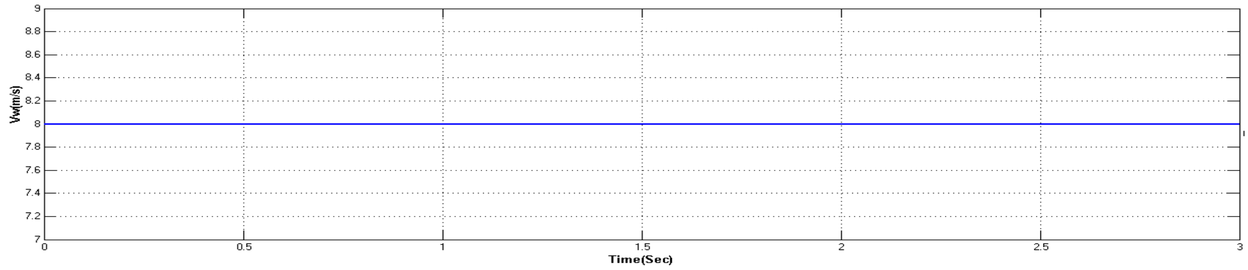
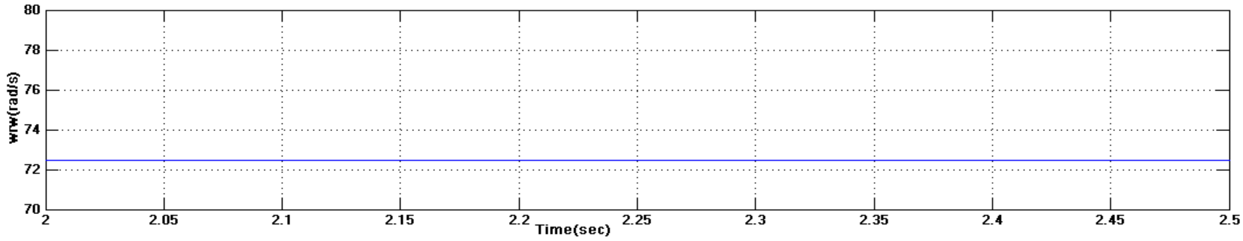
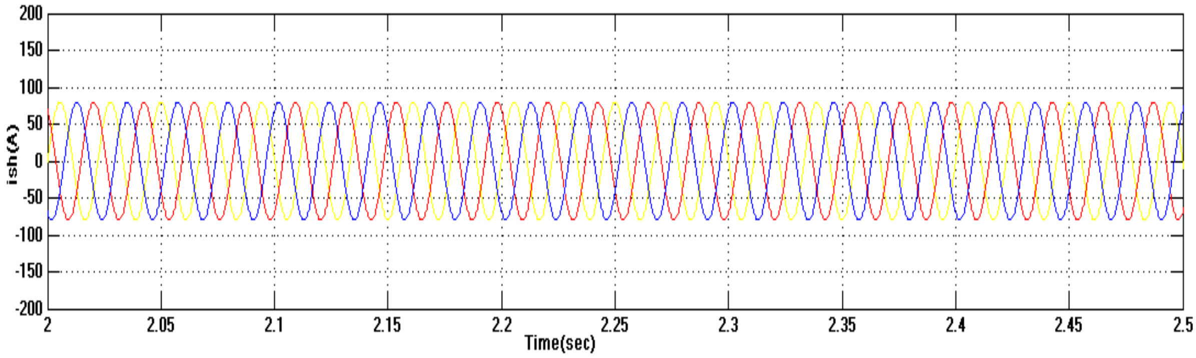
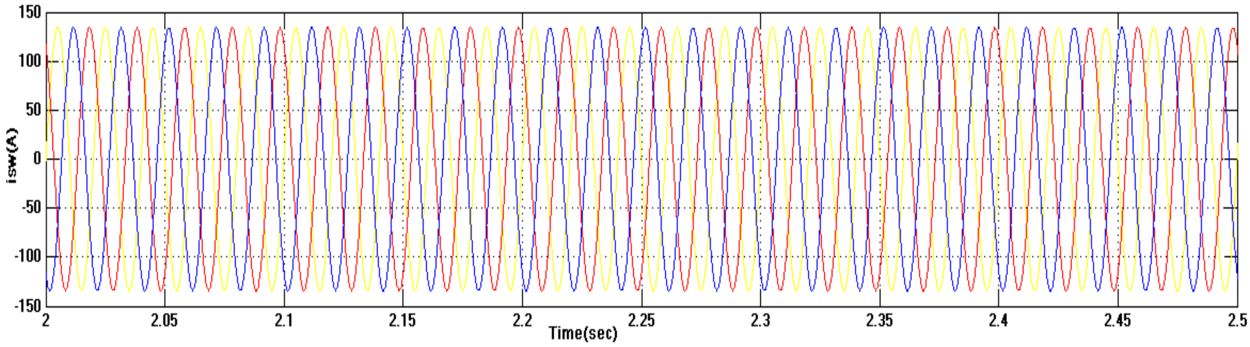
ISSN (P) 2319 - 8346

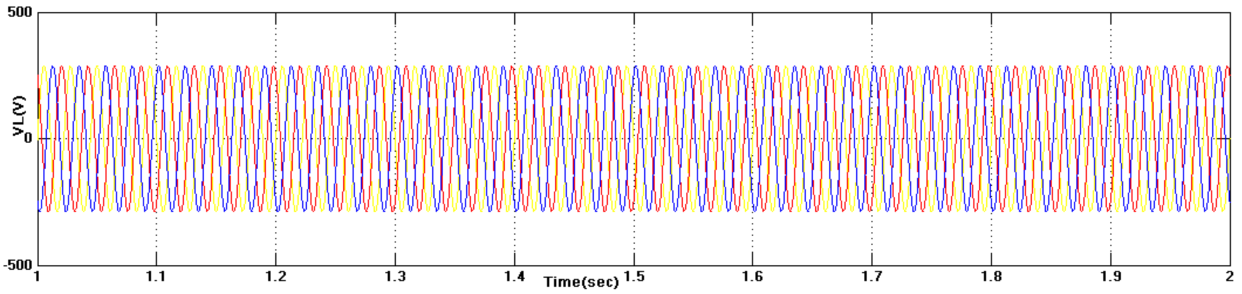
opening phase "*a*" of the load. Now, the total active power of the load on the system is reduced from 90 to 60 kW, and, therefore, the battery power (discharging) is decreased to maintain the load frequency constant. At 2.5 s, the phase "*b*" of the load is also opened. Now, the total active power of the load on the system is reduced from 60 to 30 kW, and the battery now absorbs the surplus power to maintain the frequency of the load voltage constant.











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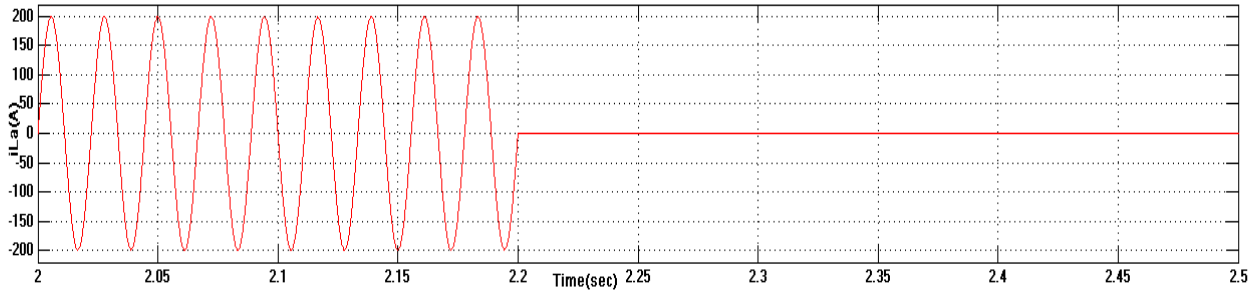

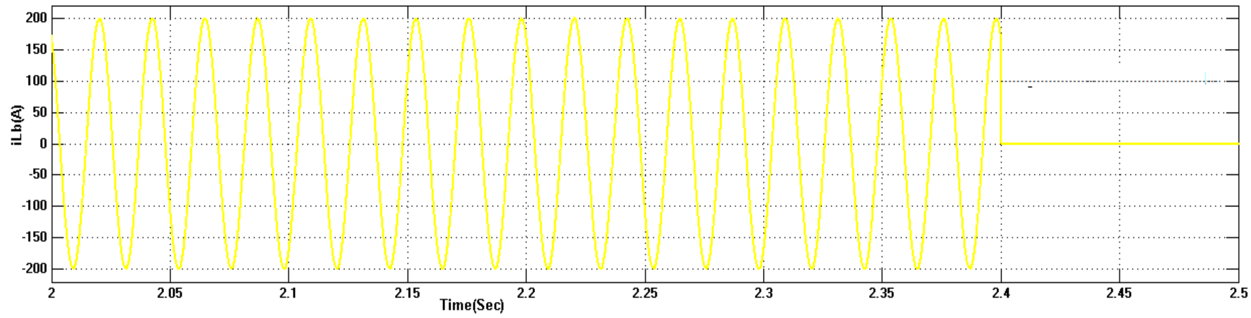

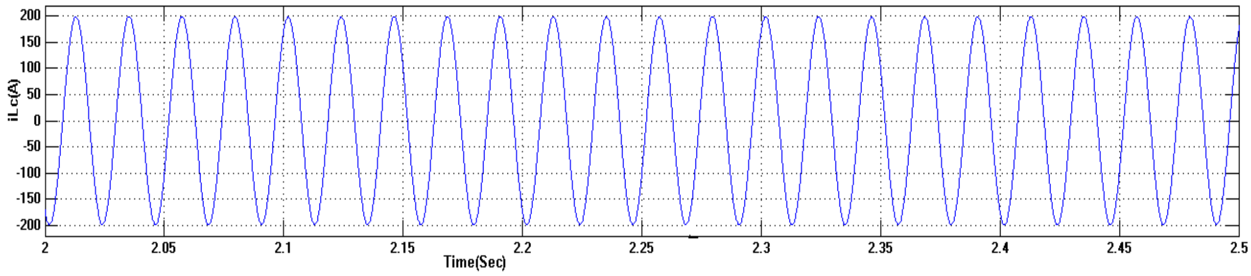

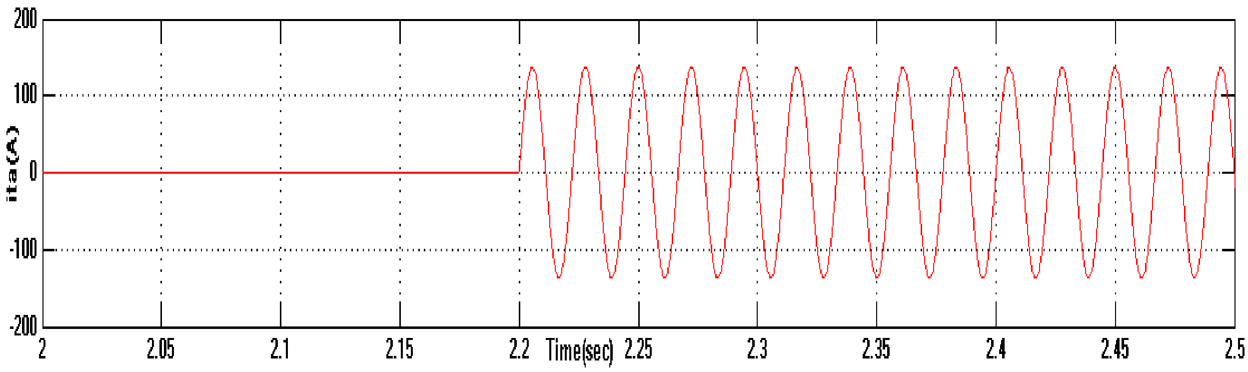

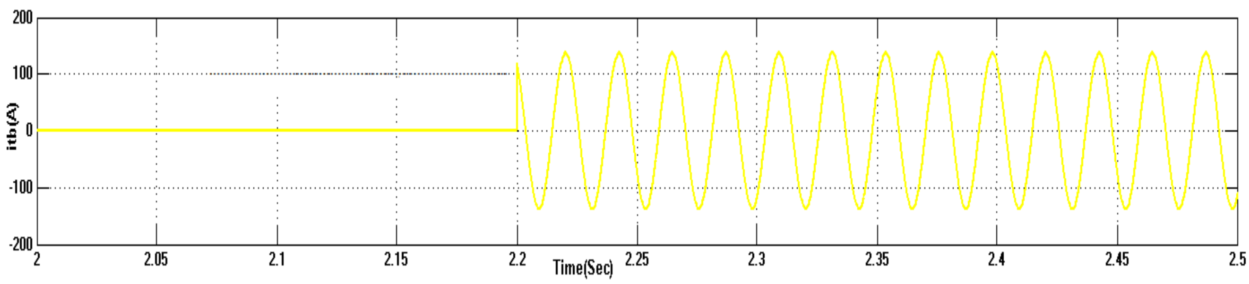

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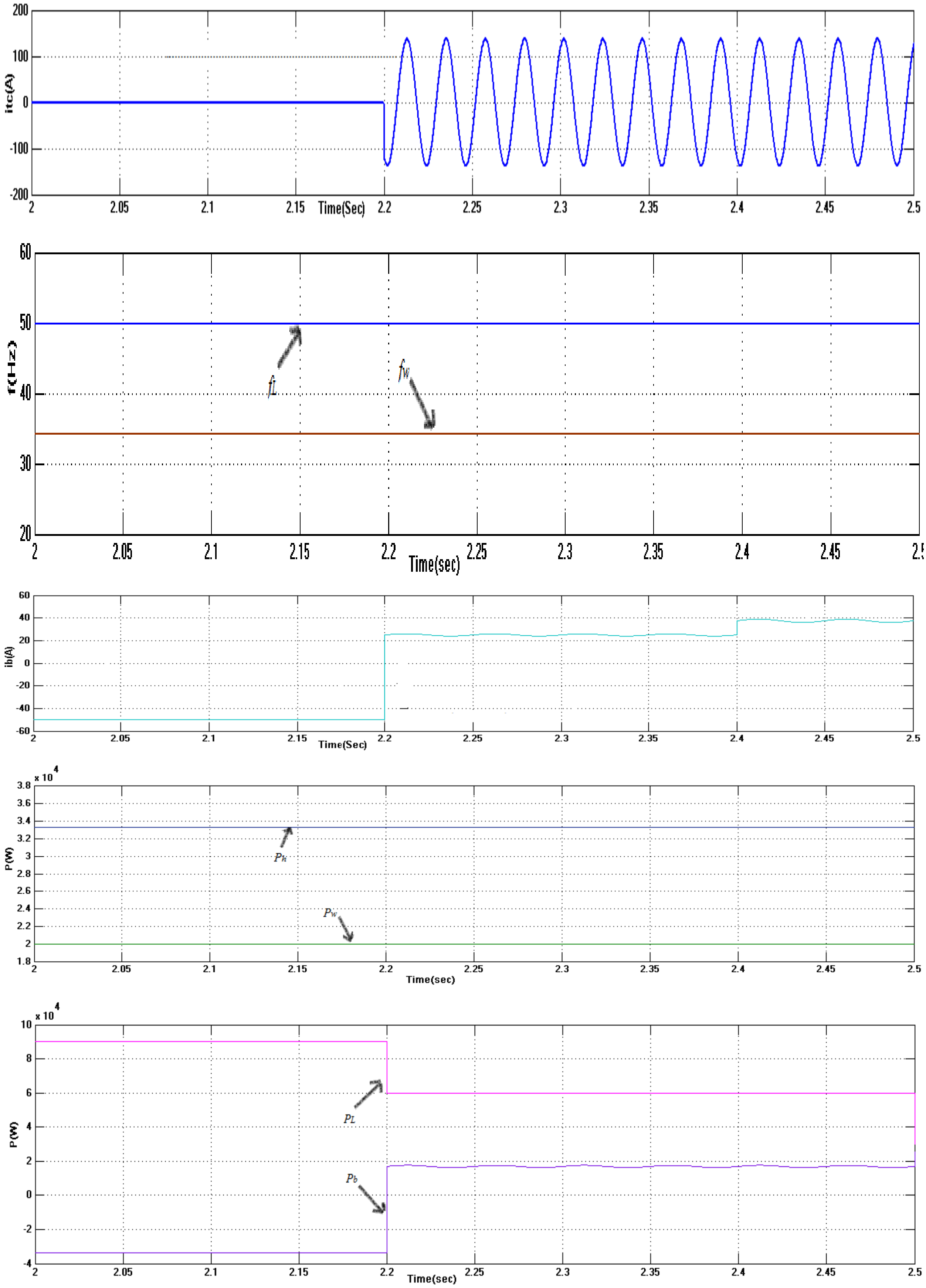

Fig.4.5. MATLAB Results of hybrid system with unbalanced linear load at wind speed of 8m/s.

V. CONCLUSION & FUTURE SCOPE

5.1. 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 under different load conditions at various wind speed conditions . Moreover, it has shown capability of MPT at wind turbine side (Machine side converter) and load balancing, harmonic elimination at different wind speed and load conditions.

5.2. Scope for Future work

In order to increase reliability few more sources such as solar and biomass can be added.

An AI technique can be adopted in the fine tuning of system variables to get optimal performance of the proposed model.

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