Autonomous Wind–Hydro Hybrid System using cage Generators and Battery Storage

Stand- Alone Wind Hydro Hybrid System using Cage Generators and Battery Storage

[1]Sudhakar Durga, [2]Dr.N.Visali
[1]Student, [2]professor and head of the department
[1]PG scholar in power systems engineering , JNTUA College of Engineering , Pulivendula. A.P, India
[2]Professor, Head of the Department in EEE, JNTUA college of engineering, pulivendula, A.P, India

---

***Abstract* - This paper deals with the new autonomous wind hydro hybrid system using two squirrel cage generators. One cage generator driven by a variable speed wind turbine and another cage generator driven by constant power hydro turbine feeding three phase four wire local loads. The proposed system utilizes two back to back connected insulated-gate-bipolar–transistor- based voltage source converters controlled by pulse width modulation technique, and a battery energy storage system is kept in between them with the help of dc link. The main goal of the control algorithm is to achieve maximum power tracking through rotor speed control of wind turbine driven SCIG under varying wind speeds through machine side converter. And the proposed wind hydro hybrid system it has the capability of bi-directional active and reactive power flow, by which it controls the magnitude and the frequency of the load voltage through load side converter. The performance of the proposed hybrid system has been demonstrated under different electrical(consumer load variations) and mechanical(with wind speed variations) conditions. It also has the capability of harmonic elimination and reduction of peak oscillations of output voltage and current, neutral current compensation and load balancing.**

***Index Terms* - Battery energy storage system (BESS), small hydro, Wind Energy Conversion System (WECS), Squirrel Cage Induction Generator (SCIG).**

I. INTRODUCTION

The combination of different complementary energy generation systems based on renewable energies or mixed is known as hybrid system. Non- Conventional energy sources or renewable energy sources (wind, solar, hydro, geothermal, biomass) are the natural energy sources that are in-exhaustible and pollution free [1] .Among all the renewable energy sources , small hydro and wind energy have the ability to complement each other [2]. wind energy is the fastest growing and promising renewable energy source, Due to the high penetration of wind turbines in the power system from last two decades is due to increase in the advancement of wind turbine technology and the way of how to control. The viability of stand- alone systems using renewable energy sources depends largely on regulations and simulation measures. For power generation by small or micro hydro as well as wind systems, the use of squirrel-cage induction generators (SCIGs) has been reported in literature [3]–[18].

Although the potential for small hydro-electric power plants depends on the availability of suitable water flow and where the resource exists. Hydro- electric power plants provide cheap, clean and reliable electricity. Hydro-electric power plants converts the kinetic energy of water flow in to electric energy. The power available in a flow of water depends on the vertical distance of water fall (i.e., head) and the volume of flow of water in unit time(discharge). The water powers a turbine and its rotational movement is transferred through a shaft to an electric generator [1].

As regards wind turbine generators these can be classified in to many types based on their operation and application .These can be built either as the constant speed machines which rotate at fixed wind speed and in variable speed machines rotational speed varies in accordance with the wind speed. As compared to fixed speed wind turbines, variable speed wind turbines has many advantages [19]. They reduce mechanical stresses, dynamically compensate for torque and power pulsations, and improve power quality and increase in energy conversion efficiency.[12]-[13]

In the case of grid connected systems using renewable energy sources, the total active power can be fed to the grid. For stand-alone systems supplying local loads, if the extracted power is more than the local loads(losses), the excess power from the wind turbine is required to be diverted to a dump load or stored in the battery bank. Whenever the extracted power is less than the consumer load, the insufficient power to the load is supplied from a storage element e.g., battery bank[9]-[17].

L.L. Lai and T.F. Chan [1] describes the entire description of distributed generation of induction and permanent magnet generators. The general principle of phase balancing for a three-phase IG operating on a single-phase power system is investigated and several practical phase balancing schemes are proposed, including those that involve dissipative elements and current injection transformers. It also presents the analysis and performance of a three-phase synchronous generator with inset PM rotor. It is demonstrated that the voltage regulation is significantly improved as a result of the inverse saliency feature of the inset PM rotor construction. E.D. Castronuovo and J.A. Pecas [2] gives the description about bounding active power generation of a wind-hydro power plant. The usual operation, wind park production is strongly dependent on the instantaneously available wind power. When energy storage is accessible, the wind park operation can be improved, aiming to a better exploitation of the available wind power resource. It proposes an optimization approach to determinate the most probable range of the output production, to be used in the definition of production profiles that will help the participation of wind power in the market. Two production profiles strategies were analyzed and compared.B. Singh et.al [3] gives the description about an improved electronic load controller for self-excited induction generator in micro-hydel applications, The improved electronic load controller is a combination of a three-phase insulated gate bipolar transistor (IGBT) based current controlled voltage source inverter (CC-VSl) and a high frequency DC chopper which keeps the generated voltage and frequency constant in spite of change of balanced/unbalanced loads. A dynamic model of the SEIGIELC supplying different types of loads using stationary d-q axes reference frame is developed for predicting the behaviour of the system under transient conditions. The simulation is carried out for compensation of balanced/unbalanced loading conditions. J. B. Ekanayake [4] Induction generators for small hydro schemes discusses about the isolated power supply schemes for village electrification. It reduces the cost of single phase distribution lines. D. Joshi, et.al [14] discusses about the Constant voltage constant frequency operation for a self-excited induction generator. T. C. Yang [18] This paper discusses about initial study of using rechargeable batteries in wind power generation with variable speed induction generators.

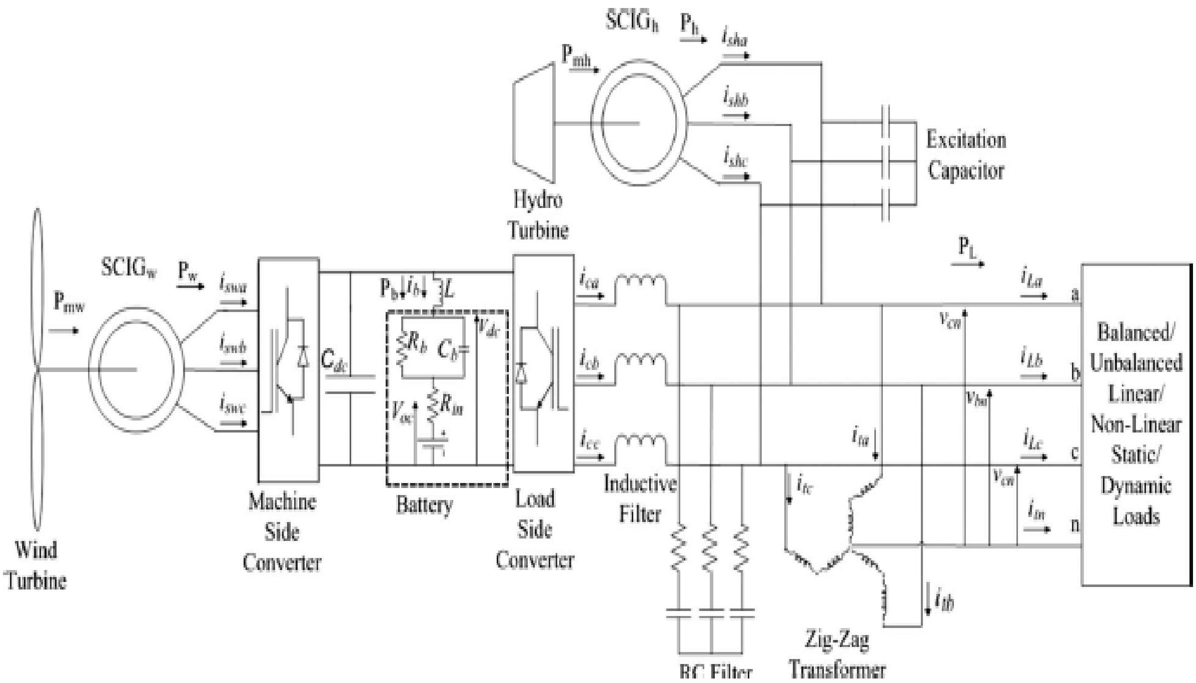

Fig.1 Schematic diagram of wind hydro hybrid system

II. PRINCIPLE OF OPERATION

As already stated, the proposed system uses two back to back connected PWM –controlled IGBT based voltage source converters .These voltage source converters are referred to as machine side converter and load side converter. The goal of the machine side converter are to provide the requisite magnetizing current to the SCIG and to achieve MPT, and the objective of the load side converter is VFC at the load terminals by maintaining active and reactive power balance

In order to achieve the maximum power tracking , $SCIG_w$ is required to be operate at optimum tip speed ratio as shown in the fig.2. The rotor speed set point for a given wind speed will be determined by the tip speed ratio. The maximum power generated depends on the maximum power line of the turbine as shown in fig 3. The operating principle of the controller of the machine 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 the rotor flux axis as shown in fig.4. the reference value for d-axis or reactive component of the $SCIG_w$ stator current is generated from the required magnetizing flux for the $SCIG_W$
.the reference value for the q-axis or active component of the $SCIG_W$ stator current is generated from the error of the desired speed and the sensed $SCIG_W$ rotor speed.

The sensed rotor speed changes in accordance with the wind speed, and the difference in the reference rotor speed and the sensed rotor speed is fed to the speed controller of the machine side converter. 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 with the help of clark's transformation and compared with the sensed three phase $SCIG_W$ stator currents to generate control signals for the machine side converter.

The load side converter control it regulates the load voltage magnitude and load frequency constant. It is essential that any excess power in the system is diverted to the battery and alternatively the battery system should be able to supply any deficit in the generated power. The magnitude of load voltage is maintained constant by balancing the reactive power requirement of the load through the load side converter.

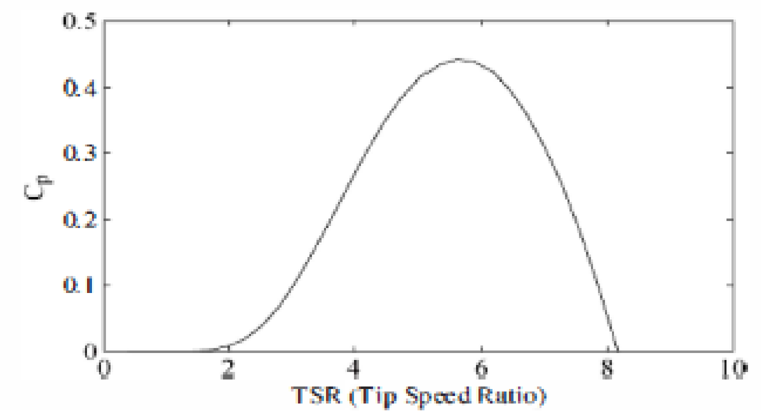

Fig2. Coefficient of performance(Cp) versus tip speed ratio (λ)

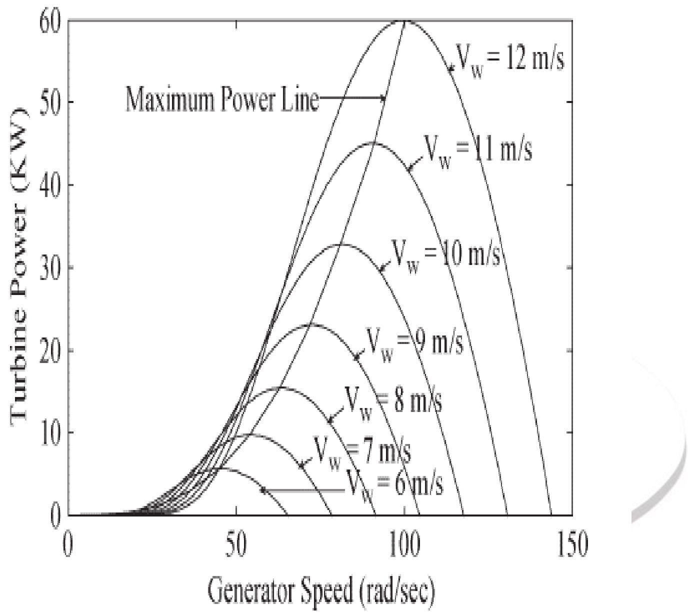

Fig.3. Mechanical power output of the wind turbine versus SCIGw speed for different wind speeds

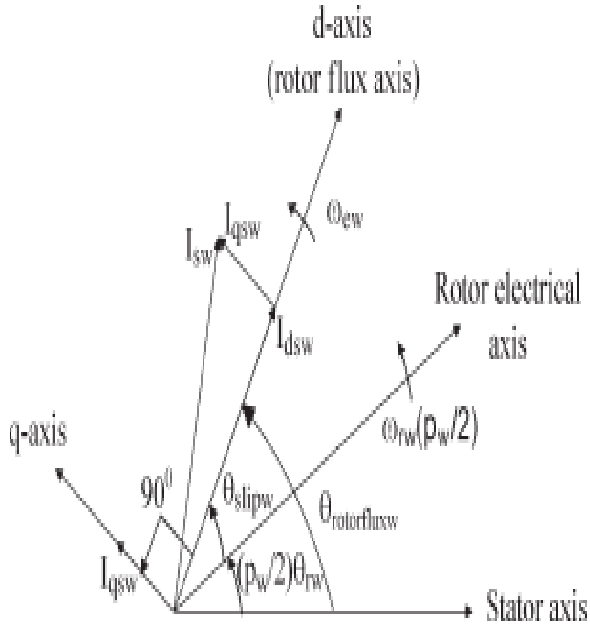

Fig 4. Phasor diagram of rotor flux oriented control of SCIG

III. CONTROL ALGORITHM

A. CONTROL OF MACHINE (SCIGw) SIDE CONVERTER:

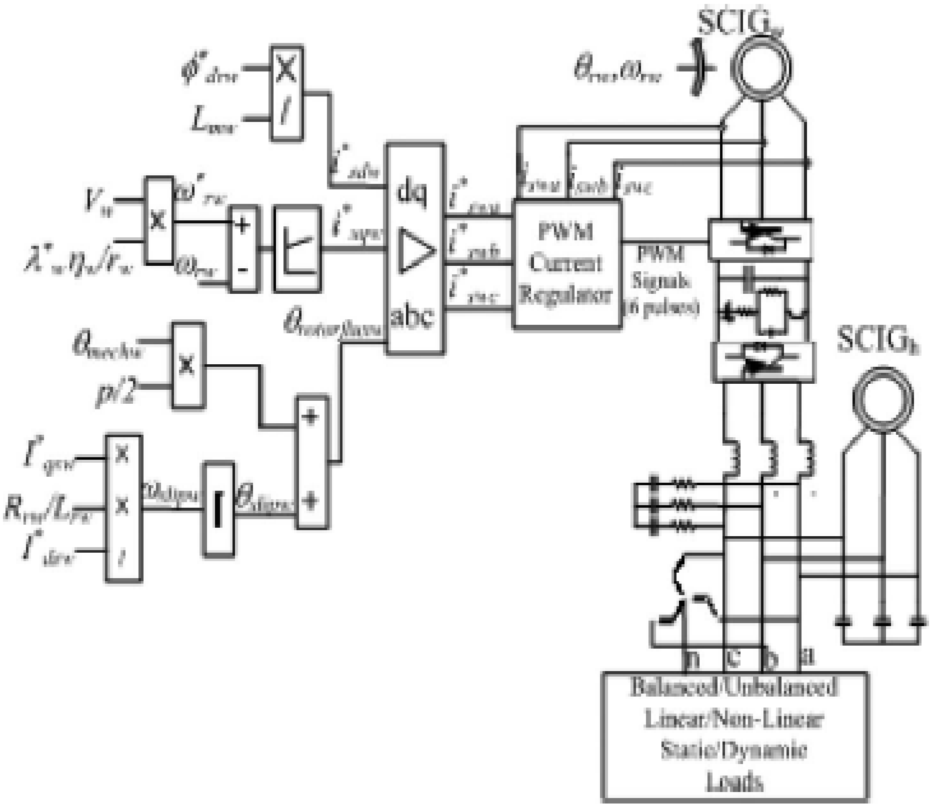

Fig.5. Control scheme of machine-side converter.

1) Speed-Control Loop for MPT and Reference q-axis SCIGw Stator-Current Generation:

The main objective of the machine side converter is to achieve optimum torque for the maximum power tracking (MPT) and to provide the requisite magnetizing current to the $SCIG_W$. In order to control the machine side converter we require the tip speed ratios (λw) and gear ratios (η_w) and wind speeds Vw are defined

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

$$\omega^*_{rw} = \lambda^*_w v_w \eta_w / r_w \qquad (2)$$

The rotor speed error is calculated with sensed rotor speed (ω_{rw}) of the $SCIG_W$ with the reference rotor speed ($\omega_{rw}{}^*$) at some sampling instant with integral gain $K_{iv=0.05}$ and proportional constant $k_{pv=15}$ gives reference q- axis $SCIG_W$ stator current ($I_{qsw}{}^*$) as

$$\omega_{rwer(n)} = \omega^*_{rw(n)} - \omega_{rw(n)} \qquad (3)$$

$$I^*_{qsw(n)} = I_{qsw(n-1)} + k_{pv}\left(\omega_{rwer(n)} - \omega_{rwer(n-1)}\right) + k_{iv}\omega_{rwer} \qquad (4)$$

2) Reference d-axis SCIGw Stator-Current Generation:

The reference d-axis $SCIG_w$ stator current generation is determined from the rotor flux set point (ϕ^*_{rw}) at some nth sampling instant as

$$I^*_{dsw} = \emptyset^*_{drw} / L_{mw} \qquad (5)$$

where $L_{mw=}0.0298\ H$ is the magnetizing inductance of SCIG and $\emptyset^*_{drw} = 0.053$ wb

3) Generation of PWM Signal for Machine-Side Converter:

The three phase reference $SCIG_W$ stator current ($I^*_{swa}, I^*_{swb}, I^*_{swc}$) are generated with the transformation angle $\theta_{rotor\ fluxw}$ where at some sampling instant ω_{slipw} is generated as

$$\omega_{slip\omega(n)} = R_{rw} I^*_{qsw(n)} / L_{rw} I^*_{dsw(n)} \qquad (6)$$

Where $L_{rw} = 0.867\ mH, R_{rw} = 0.0513'\Omega$ are the rotor self-inductance and the rotor resistance of $SCIG_w$ respectively

By integrating the slip frequency (ω_{slipw}), the slip angle in terms of mechanical angle ($\theta_{rotor\ fluxw}$) is obtained

$$\theta_{slip\omega(n)} = \int \omega_{slipw(n)}\, dt \qquad (7)$$

And the transformation angle which is in the mechanical angle is transformed in to electrical angle

$$\theta_{rotor\ flux} = \theta_{slip\ angle} + \left(\frac{p_w}{2}\right) \qquad (8)$$

The d-q reference components of the $SCIG_w$ stator currents (I^*_{dsw}, I^*_{qsw}) are converted to the three phase reference $SCIG_w$ currents as ($I^*_{swa}, I^*_{swb}\ I^*_{swc}$) from d-q to abc by $\theta_{rotor\ fluxw}$ transformation angle

$$I^*_{swa} = I^*_{dsw} \sin(\theta_{rotor\ fux\omega}) + I^*_{qsw} \cos(\theta_{rotor\ flux\omega}) \quad (9)$$

$$I^*_{swb} = I^*_{dsw} \sin\left(\theta_{rotor\ flux\omega} - \frac{2\pi}{3}\right) + I^*_{qsw} \cos\left(\theta_{rotor\ flux\omega} - \frac{2\pi}{3}\right) \quad (10)$$

$$I^*_{swc} = I^*_{dsw} \sin\left(\theta_{rotor\ flux\omega} + \frac{2\pi}{3}\right) + I^*_{qsw} \cos\left(\theta_{rotor\ flux\omega} + \frac{2\pi}{3}\right) \quad (11)$$

The three phase reference $SCIG_w$ stator currents (I^*_{swa} , I^*_{swb} , I^*_{swc}) are compared with the sensed stator currents I_{swa} , I_{swb} ,I_{swc}).these current errors are amplified with gain (k=5) and these amplified signals are compared with the fixed frequency 10 khz triangular carrier wave of unity amplitude in order to generate the signals for IGBT's at the machine side voltage source converter.50 µs is taken as sampling time constant for controller ,it is sufficient in order to complete typical calculations in DSP controller

B. CONTROL OF LOAD SIDE CONVERTER:

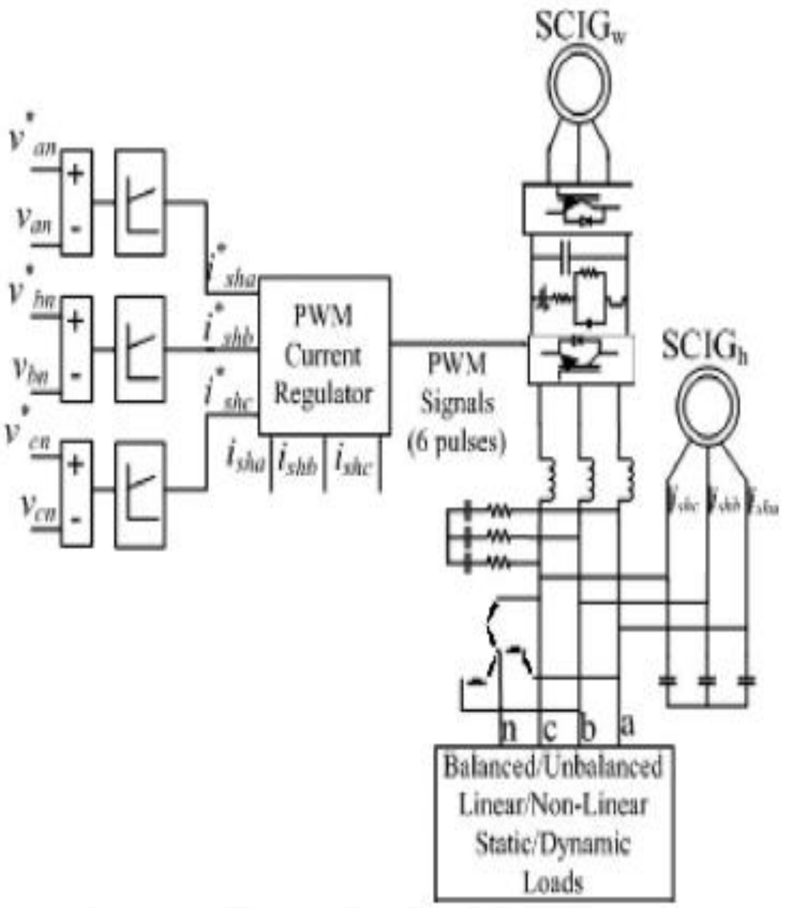

Fig.6. Control scheme of load-side converter.

The main motive of the load side converter is to maintain the rated voltage and frequency irrespective of the connected load. The power balancing in the system is maintained by diverting the excess power generated to the battery and the deficit load power is supplied to the load from the battery

1)GENERATION OF REFERENCE THREE PHASE $SCIG_h$ CURRENTS:

The v_{an}^* ,v_{bn}^*,v_{cn}^* are the reference voltages for the control of the load voltages

$$v^*_{an} = \sqrt{2}V_t \sin(2\pi f t) \quad (12)$$

$$v^*_{bn} = \sqrt{2}V_t \sin(2\pi f t - 120°) \quad (13)$$

$$v^*_{cn} = \sqrt{2}V_t \sin(2\pi f t + 120°) \quad (14)$$

Where V_t is the rms phase to neutral load voltage which is considered as 240v.

The load voltages (V_{an} ,V_{bn},V_{cn}) are sensed voltages and it is compared with the reference voltages (v_{an}^* ,v_{bn}^*,v_{cn}^*).The error voltages (V_{anerr} ,V_{bnerr},V_{cnerr}) at some sampling instant are calculated as

$$v_{anerr(n)} = \{v^*_{an(n)} - v_{an(n)}\} \quad (15)$$

$$v_{bnerr(n)} = \{v^*_{bn(n)} - v_{bn(n)}\} \quad (16)$$

$$v_{cnerr(n)} = \{v^*_{an(n)} - v_{an(n)}\} \quad (17)$$

The reference three phase $SCIG_h$ currents (I^*_{sha},I^*_{shb}, I^*_{shc}) are generated by feeding the voltage error signals to PI voltage controller with proportionate gain K_{pv} and integral gain K_{iv} constants as 15 and 0.05

$$I^*_{sha(n)} = I_{sha(n-1)} + k_{pv}\left(v_{anerr(n)} - v_{anerr(n-1)}\right) + k_{iv}v_{anerr} \quad (18)$$

$$I^*_{shb(n)} = I_{shb(n-1)} + k_{pv}\left(v_{bnerr(n)} - v_{bnerr(n-1)}\right) + k_{iv}v_{bnerr} \quad (19)$$

$$I^*_{shc(n)} = I_{shc(n-1)} + k_{pv}\left(v_{cnerr(n)} - v_{cnerr(n-1)}\right) + k_{iv}v_{cnerr(n)} \quad (20)$$

The reference three phase $SCIG_h$ currents are then compared with the sensed $SCIG_h$ currents (I_{sha}, I_{shb}, I_{shc}) to compute the $SCIG_h$ currents errors as

$$I_{shaerr} = I^*{}_{sha} - i_{sha} \quad (21)$$
$$I_{shberr} = I^*{}_{shb} - i_{shb} \quad (22)$$
$$I_{shcerr} = I^*{}_{shc} - i_{shc} \quad (23)$$

These currents errors are amplified with gain k=5 and compared with fixed frequency (10khz) triangular carrier wave of unity amplitude and generate gating signals to the IGBT of the load side converter .where 50μs are the sufficient sampling time of a controller for the completion of the calculations

IV. SELECTION RATINGS OF SCIG BASED WIND- HYDRO HYBRID SYSTEM:

By making several assumptions and caluclations, for different wind speeds the mpt (maximum coefficient of performance) obtained is 0.441 for a tip speed ratio of 5.66 zero and gear ratio 12 and radius of turbine is 7.5m.The connected load to the system can be varying from 30 to 90kw at a lagging power factor of 0.8. The average load of the system is 60kw.The squirrel cage induction generator rating of wind and hydro is 55 kw and 35 kw .The machine side converter ratings of 1200V,200A and the load side converter rating capacity of 1200V, 300A. The battery capacity of 0.0431μF, inductive filter of 0.8 mh, RC filters of R=5Ω and C=5μF and three single phase transformer connected in zig-zag manner of 15KVA 138/138V are included in the system .

V. RESULTS AND DISCUSSION :

A.Performance of wind hydro hybrid system with balanced linear load at wind speed of 11 m/s:

This figure 7 represents the MATLAB simulink diagram in order to find the performance of wind hydro hybrid system with balanced linear load at wind speed of 11m/s. FIG. 8 represents the wind velocity (V_w), rotor speed of $SCIG_w$ (ω_{rw}) and maximum coefficient of power(C_p), stator frequency(f_s) and load frequency (f_l) , and rms phase voltage(v_t). Fig 9 .The stator current of $SCIG_w$ (I_{sw}), stator current of hydro $SCIG_h$(I_{sh}), load side converter current (I_c), three phase load voltage (v_l) and three phase load current (I_l) Fig .10 Battery voltage (v_{dc}), battery current (I_b), load power (p_l) , battery power (p_b), wind power (p_w) and hydro power (p_h) for wind speed 11m/s

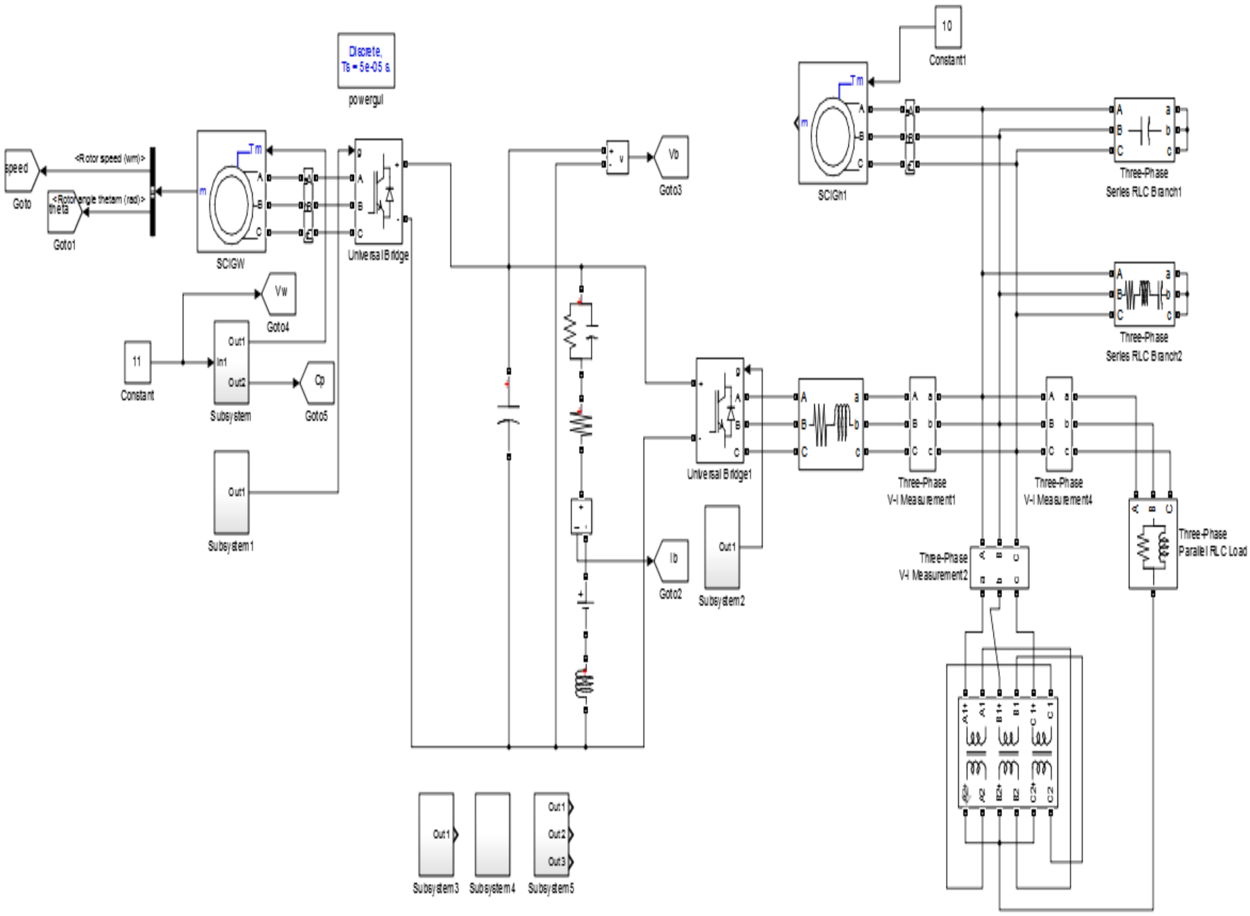

FIG 7. MATLAB simulation diagram of wind hydro hybrid system of balanced loads

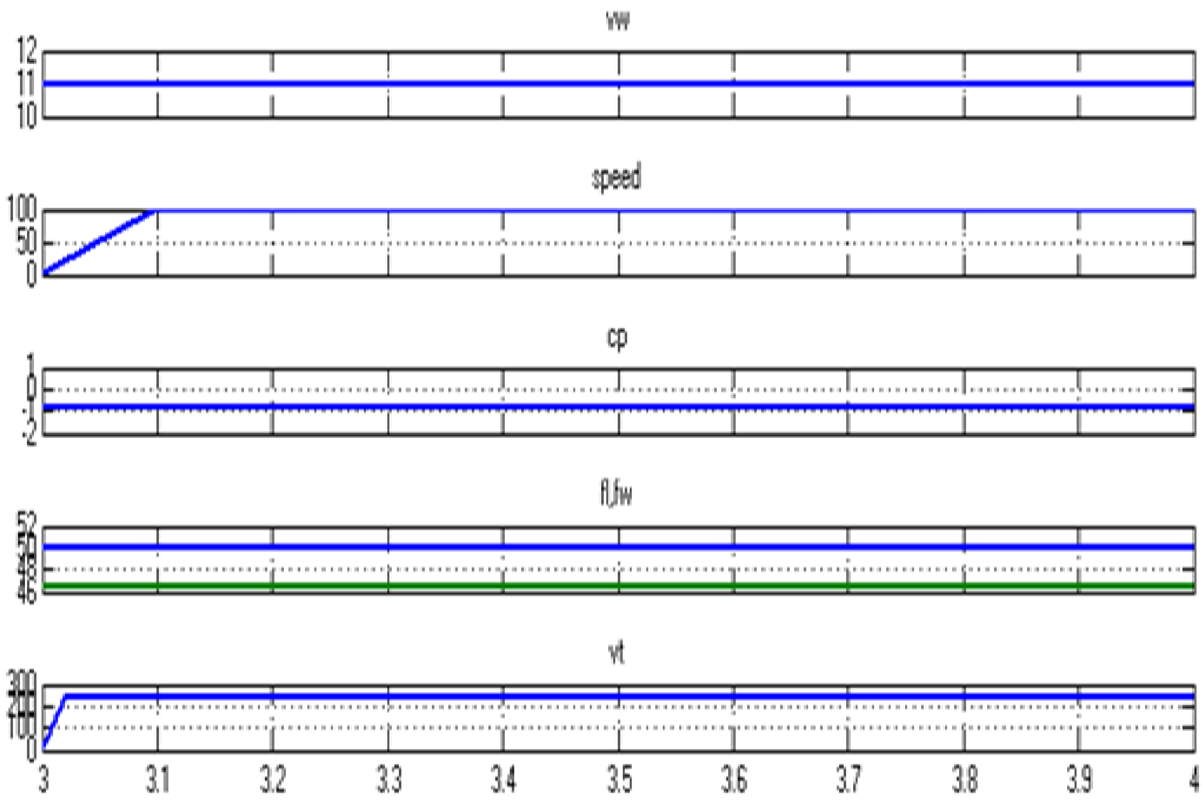

Fig 8. The wind velocity(V_w), rotor speed of $SCIG_w$ (ω_{rw}) and maximum coefficient of power(C_p), stator frequency(f_s) and load frequency (f_l) , and rms phase voltage(v_t)

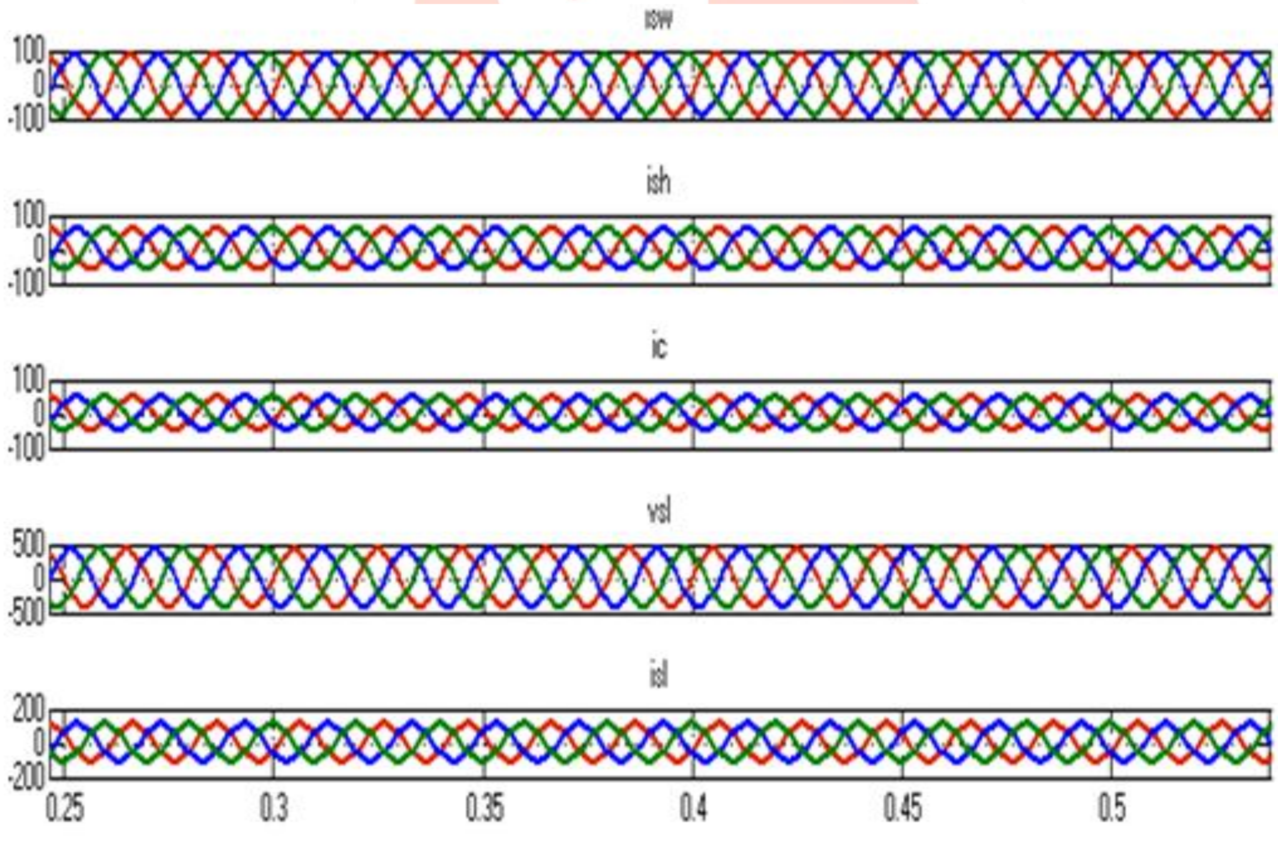

Fig 9 .The stator current of $SCIG_w$ (I_{sw}), stator current of hydro $SCIG_h$(I_{sh}), load side converter current (I_c), three phase load voltage (v_l) and three phase load current (I_l) for wind speed 11m/s

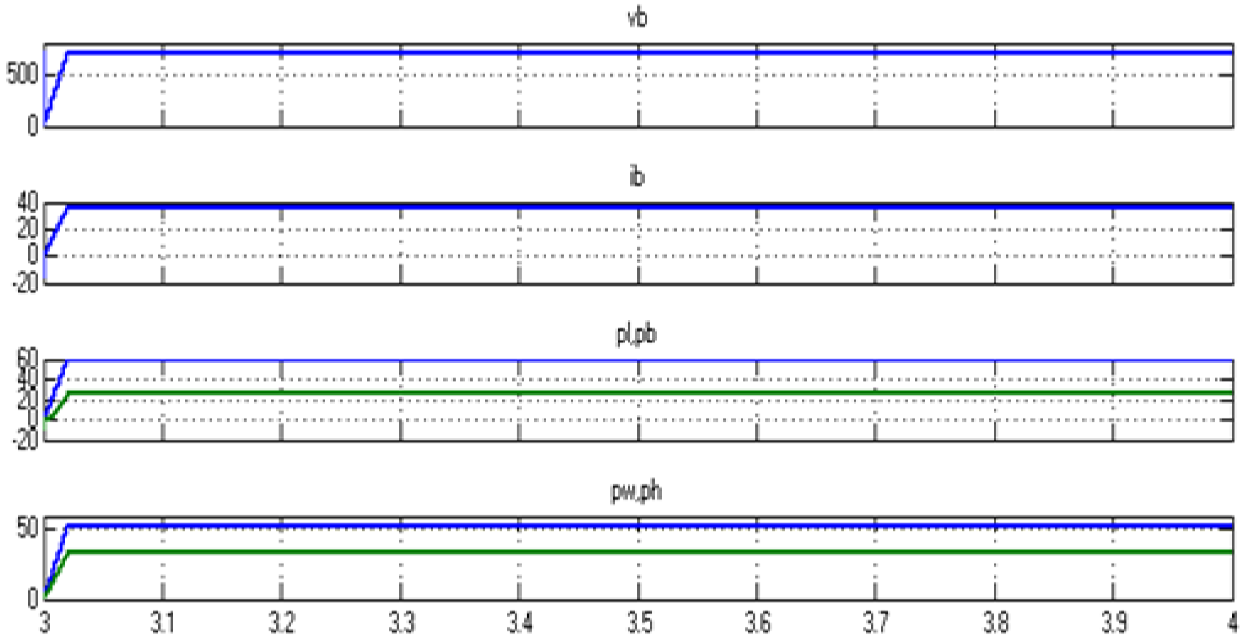

Fig .10 Battery voltage (v_{dc}), battery current (I_b), load power (p_l) , battery power (p_b), wind power (p_w) and hydro power (p_h)

For a wind speed of 11m/s, the corresponding rotor speed of $SCIG_w$ (ω_{rw}) and maximum coefficient of power (C_p) stator frequency (f_s) and load frequency (f_l) , and rms phase voltage(v_t) obtained is 99.6 rad/s, 0.4411, 47.08 Hz, 50 Hz, and 230 V and for the corresponding wind velocity the stator current of $SCIG_w$ (I_{sw}) = 86.21 A, The stator current of hydro $SCIG_h$ (I_{sh}) = 59.78 A, load side converter current (I_c) = 80.7 A, three phase load voltage (v_l) = 415 V and three phase load current (I_l) = 107.7 A .The mechanical power corresponding to maximum coefficient of performance is 52 KW for $SCIG_w$ and the mechanical input given to the $SCIG_h$ is taken as 35 KW and the power generated through the $SCIG_h$ is 33.3 KW, Thus the total power generated is (52+33.3) KW = 85.3 KW. The system is feeding three phase linear loads (each of 20 KW and 10 KVAR). Since the power generated by the system is more than the required active power for the electrical loads (60 kw) and therefore the remaining 25.3 KW is stored in the battery. In order to exchange of active and reactive power and to maintain the magnitude of load voltage and frequency constant, the dc link voltage or battery voltage is maintained to 700 V based on the calculations of selection of DC link voltage and battery design.

B. Performance of wind hydro hybrid system with unbalanced linear load at wind speed of 8m/s:

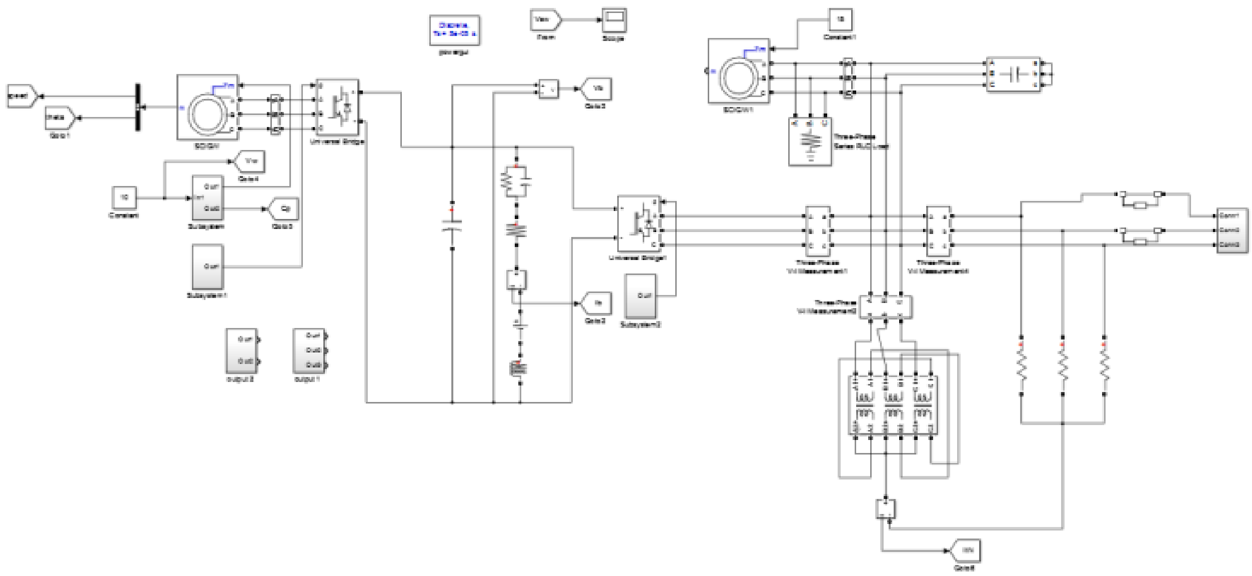

FIG 11. MATLAB simulation diagram of wind hydro hybrid system of unbalanced loads

This figure 11, represents the MATLAB simulink diagram in order to find the performance of wind hydro hybrid system with a wind speed of 8 m/s. Fig 12 . Rotor speed of $SCIG_w$, stator frequency(f_s) and load frequency(f_l), Stator current of $SCIG_w$,Stator current of $SCIG_h$,Load side converter current (I_c),Three phase load voltage(V_L), $SCIG_w$ Stator power (P_w) and

$SCIG_h$ Stator power (P_h).). Fig. 13. single phase load currents a, b and c (I_{la}, I_{lb}, I_{lc}) zig-zag transformers(I_{ta} , I_{tb}, I_{tc}) and neutral current (I_{tn}). Fig. 14. Battery current (I_b),Battery Voltage(V_{dc}), RMS value of phase load voltage (V_t), Load power(P_L), Battery power (P_b)

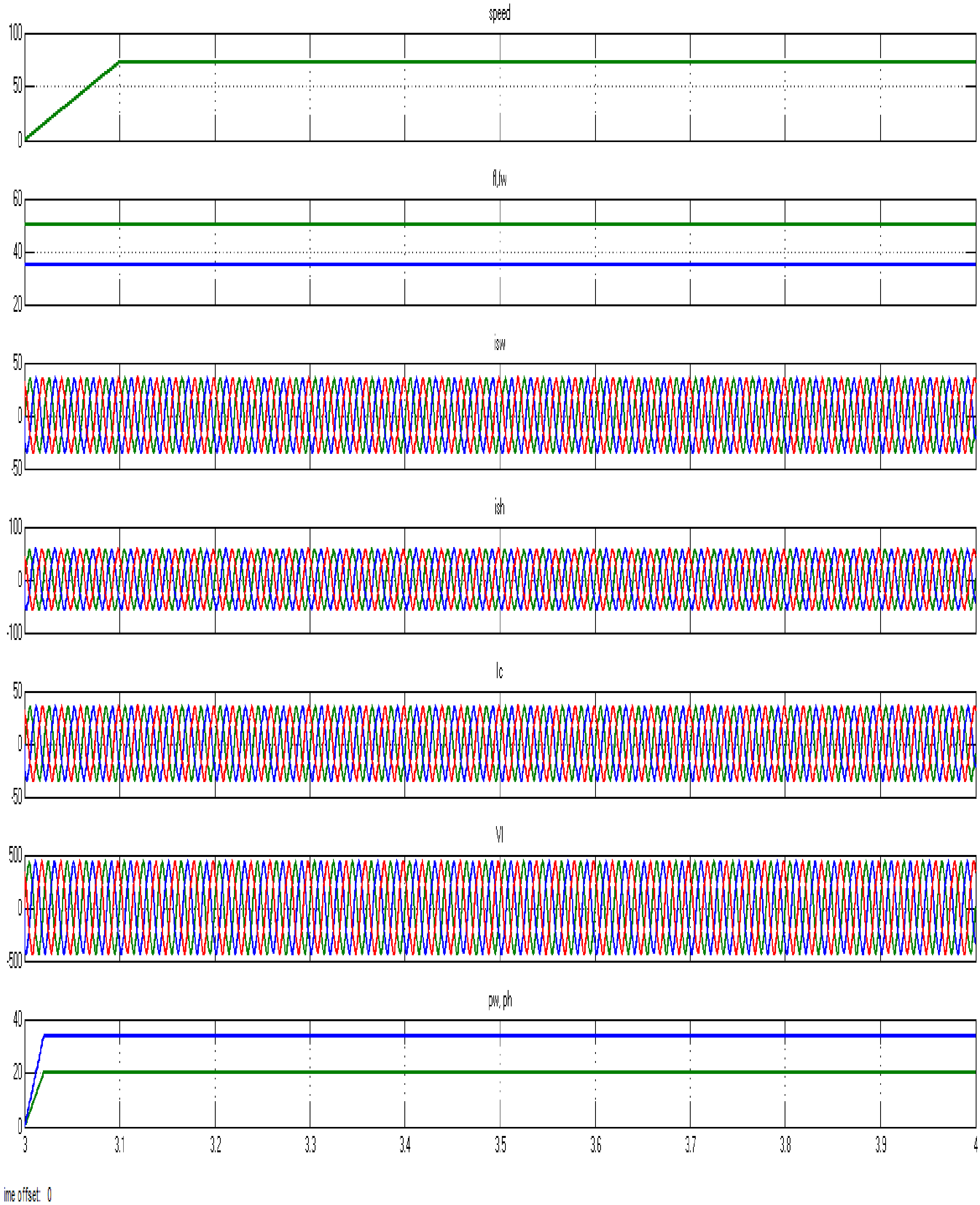

Fig 12 . Rotor speed of $SCIG_w$, stator frequency(f_s) and load frequency(f_l), Stator current of $SCIG_w$,Stator current of $SCIG_h$,Load side converter current (I_c),Three phase load voltage(V_L), $SCIG_w$ Stator power (P_w) and $SCIG_h$ Stator power (P_h)

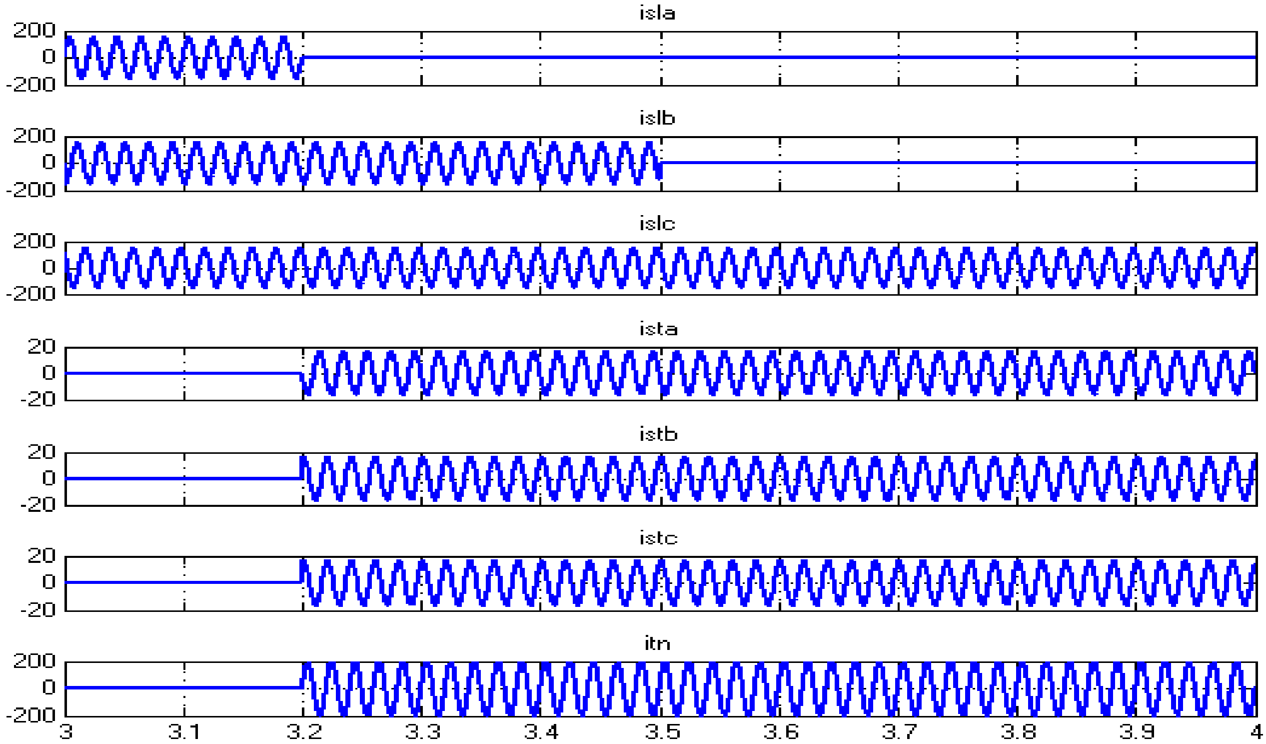

Fig. 13. single phase load currents a, b and c (I_{la}, I_{lb}, I_{lc}) zig-zag transformers(I_{ta} , I_{tb}, I_{tc}) and neutral current (I_{tn})

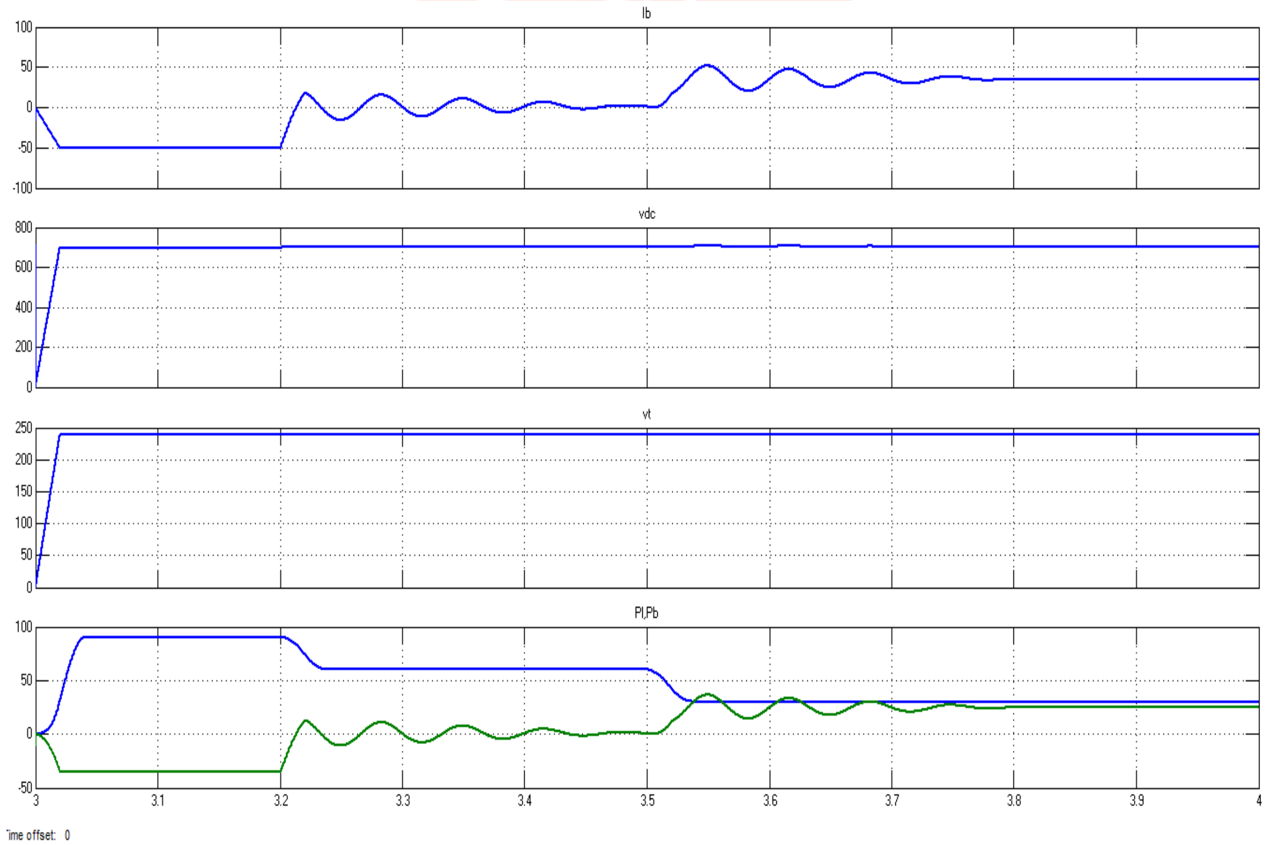

Fig. 14. Battery current (I_b),Battery Voltage(V_{dc}), RMS value of phase load voltage (V_t), Load power(P_L), Battery power (P_b)

Performance of wind hydro hybrid system with un balanced linear load at wind speed 8m/s

For an un balanced linear load at wind speed 8m/s with a capacity of (Each 30 KW) connected between each phase and neutral with a circuit breaker of breaker resistance ($R_{on=0.01\Omega}$), snubber resistance (1MΩ) and snubber capacitance of infinity with switching times at (3.2 s and 3.5 s) where as initial states are of 0 and 1 . Firstly 1 is selected so the breaker will be in closed condition. An external control mode, a simulink logic signal is used for the control of breaker operation. When the signal becomes greater than zero the breaker closes instantaneously. When it becomes zero the breaker opens at the next current zero crossing

For a given wind speed of 8m/s the corresponding rotor speed (ω_{rw}), stator frequency (f_s), Stator current of $SCIG_w$, and Stator power (P_w) generated with a maximum power coefficient (C_P) of 0.4411 is 72.45 rad/s, 34.17Hz, 33.1 A, and 20 KW . The Stator current and power of $SCIG_h$ obtained for a medium head of 15 m is 53.52A and 35 KW. Thus the total power generated is (20+33.33) KW = 53.3 KW. The system is started with the three phase electrically balanced three single phase linear loads (each of 30 KW) connected between each phase and neutral. Whereas the power generated by the system is less than the required power for the electrical loads (90 KW), the battery is supplying the insufficient 36.7 kw required power to the load. At 3.2 s, an un balance is created by disconnecting a load of 30 KW by opening phase A of load with circuit breaker initial state to zero at 3.2s and breaker opens and the active power of the load on the system is reduced from 90 kw to 60 KW and therefore the battery power discharging is decreased , that is 6.7 kw is supplied to the load, to maintain load frequency constant. A t 3.5 sec the phase "B" of load is opened now the total active power of the load on the system is reduced from 60 kw to 30 KW and the battery now receives the surplus power 23.3 KW to maintain the frequency of the load voltage constant. When the linear loads in three phases are balanced, the currents in the zig-zag windings are zero but during the unbalanced linear load condition , the currents in the zig-zag windings are non-zero, further the currents in the zig –zag windings are same indicating the zero sequence currents are flowing through the windings . Under the balanced/unbalanced linear load conditions the Stator current of $SCIG_w$,Stator current of $SCIG_h$ and the load voltages are balanced , even though the load currents and load side converter currents are unbalanced. Under these conditions, both the magnitude and frequency of the load voltage are maintained constant.

C. Performance of wind hydro hybrid system with un balanced non -linear load at wind speed of 10 m/s:

As shown in the figure 11, the MATLAB simulink diagram is same for unbalanced nonlinear load . In order to find the performance of wind hydro hybrid system with a wind speed of 10 m/s. Fig 15. Rotor speed of $SCIG_w$ (ω_{rw}) , stator frequency(f_s) and load frequency(f_l), Stator current of $SCIG_w$ (I_{sw}), Stator current of $SCIG_h$ (I_{sh}) , Load side converter current (I_c), Three phase load voltage(V_L), $SCIG_w$ Stator power (P_w) and $SCIG_h$ Stator power (P_h). Fig. 16 single phase load currents a, b and c (I_{la}, I_{lb}, I_{lc}) zig-zag transformers(I_{ta} , I_{tb}, I_{tc}) and neutral current (I_{tn}). Fig. 17 Battery current (I_b),Battery Voltage(V_{dc}), RMS value of phase load voltage (V_t), Load power(P_L), Battery power (P_b)

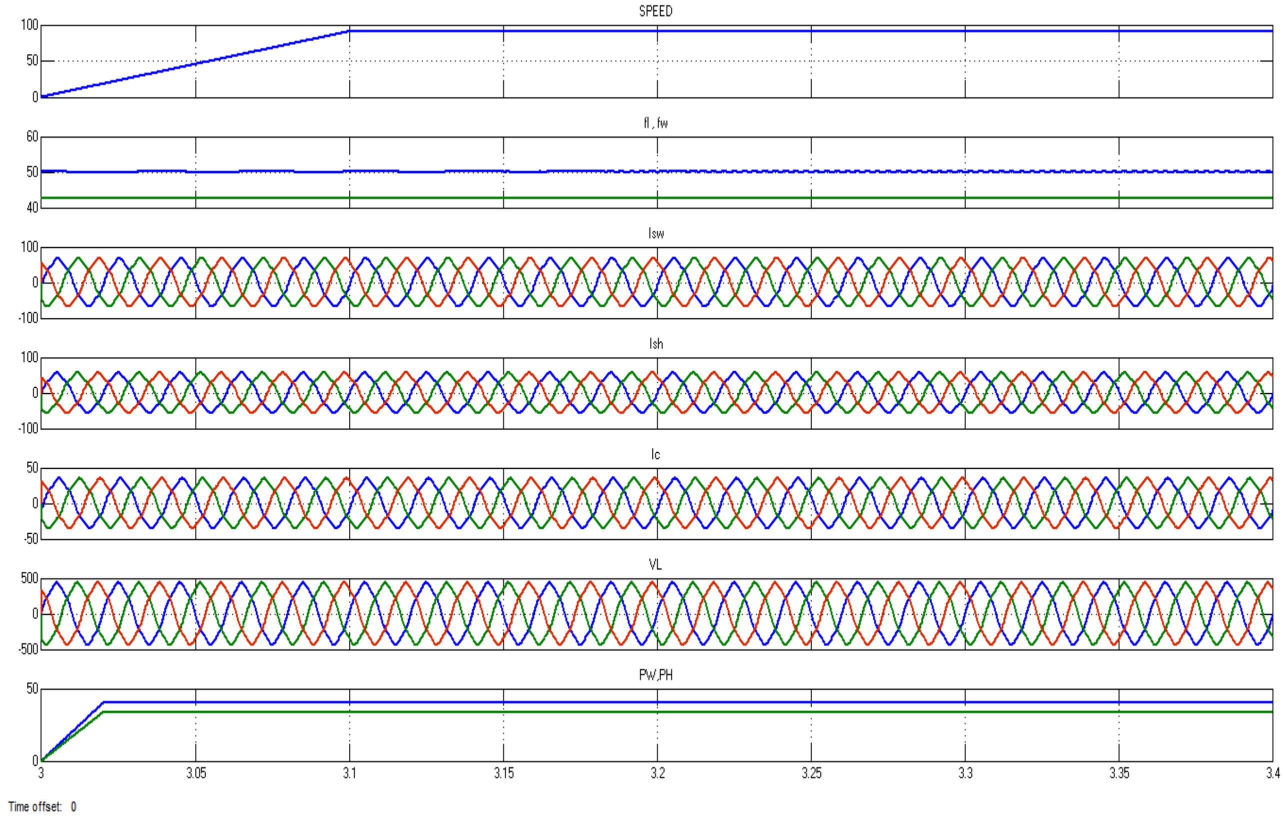

Fig 15. Rotor speed of $SCIG_w$ (ω_{rw}) , stator frequency(f_s) and load frequency(f_l), Stator current of $SCIG_w$ (I_{sw}), Stator current of $SCIG_h$ (I_{sh}) , Load side converter current (I_c), Three phase load voltage(V_L), $SCIG_w$ Stator power (P_w) and $SCIG_h$ Stator power (P_h)

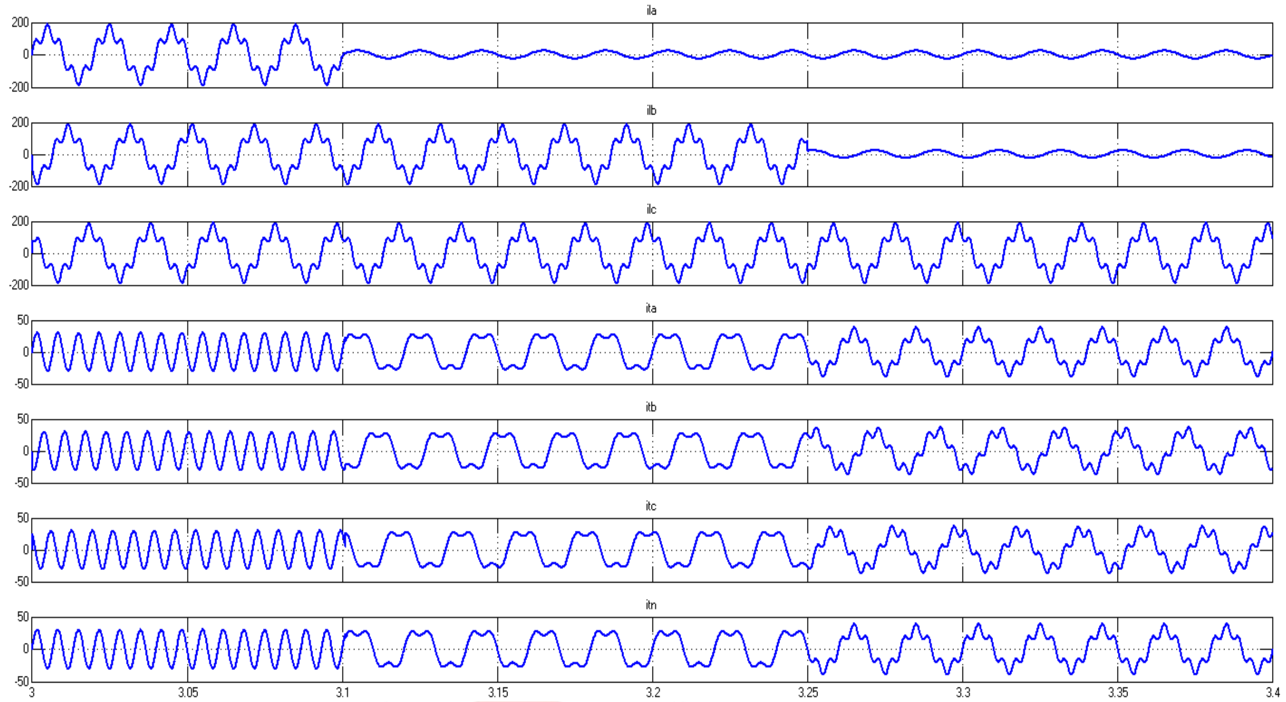

Fig. 16 single phase load currents a, b and c (I_{la}, I_{lb}, I_{lc}) zig-zag transformers(I_{ta} , I_{tb}, I_{tc}) and neutral current (I_{tn})

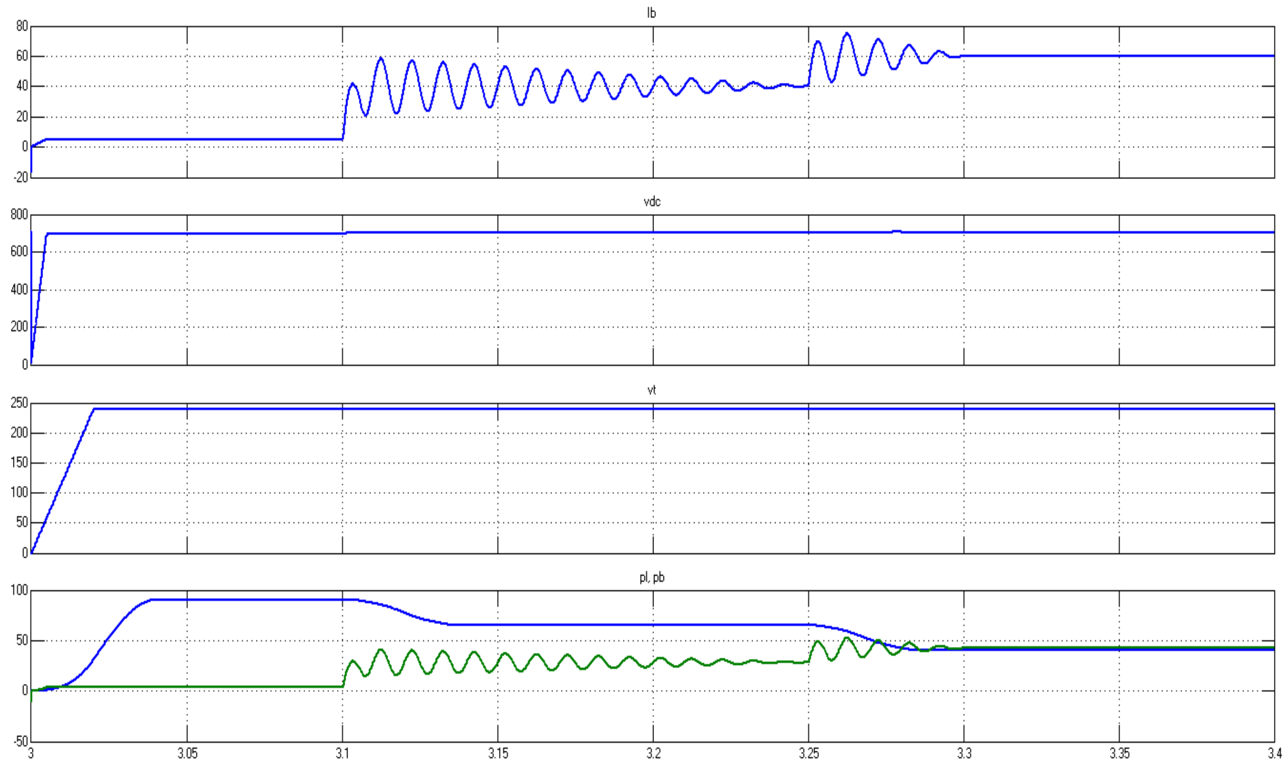

Fig. 17 Battery current (I_b),Battery Voltage(V_{dc}), RMS value of phase load voltage (V_t), Load power(P_L), Battery power (P_b)

The performance of the wind hydro hybrid system for un balanced non linear load at wind speed of 10m/s to the unbalanced linear load at 8m/s, these changes that are encountered . The corresponding rotor speed (ω_{rw}), stator frequency (f_s), Stator current of $SCIG_w$, and Stator power (P_w) generated for a maximum power coefficient (C_P) of 0.4411 is 90.57 rad/s, 42.58 Hz A, 86.21 A and 40 KW . The Stator current and power of $SCIG_h$ obtained for a medium head of 15 m is 59.78 A and 33.33 KW. Thus the total power generated is (40+33.33) KW = 73.3 KW. The system is started with the three single phase diode bridge rectifier loads (each of 16 KW) and three single phase linear loads, each of 5 KW, hence the total capacity of the load is 63 KW . The total power generated is greater than the load then the remaining 10.33 kw is stored in battery and the loads are made un balanced by disconnecting non- linear load from phase “A” at 3.1 s then the load capacity is 47 kw which is less than power generated by the system (73.33-47) kw= 26.33 kw is stored in battery, the battery charging current is increased from 40 to 60 A at 3.1 s and disconnecting the nonlinear load from phase “b” at 3.2 s then load capacity is (16+15) kw = 31 KW then remaining 42.33 KW is stored in the battery and the battery charging current is increased from 60 to 80 A. In order to maintain the magnitude of load voltage and frequency constant by exchanging active and reactive power through VFC by maintaining the DC link voltage to 700V. During the balanced/ unbalanced non- linear load condition , the currents in the zig-zag windings are non-zero, further the currents in the zig –zag windings are same indicating the zero sequence currents are flowing through the windings. Due to the usage of non- linear loads the Total harmonic distortion (THD) of load currents are on the order of 35% but by using the RC filters, inductive filters and zig-zag transformers the THD of load voltages, $\mathrm{SCIG_w}$ stator currents and SCIG_h currents are well with in the limits of 5%.

D. Performance of wind hydro hybrid system with balanced mixed load consisting of linear, non linear and dynamic loads at wind speed of 9 m/s:

The MATLAB simulink diagram is shown in Fig.18 is used for the balanced mixed load consisting of linear, nonlinear and dynamic loads. Fig .19 The rotor speed of $\mathrm{SCIG_w}$, torque (T), maximum coefficient of power(,cp,)stator frequency(fs) and load frequency(fl) and rms phase voltage (vt). Fig .20 The stator currents of $\mathrm{SCIG_w}$, stator current of $\mathrm{SCIG_h}$, load side converter current ($\mathrm{I_c}$), three phase load voltage ($\mathrm{v_l}$) and three phase load current ($\mathrm{I_l}$) for wind speed 9m/s. Fig.21 Battery voltage ($\mathrm{v_{dc}}$), battery current ($\mathrm{I_b}$), load power ($\mathrm{p_l}$) , battery power ($\mathrm{p_b}$), wind power ($\mathrm{p_w}$) and hydro power ($\mathrm{p_h}$). Fig.21 Battery voltage (v_{dc}), battery current (I_b), load power (p_l) , battery power (p_b), wind power (p_w) and hydro power (p_h)

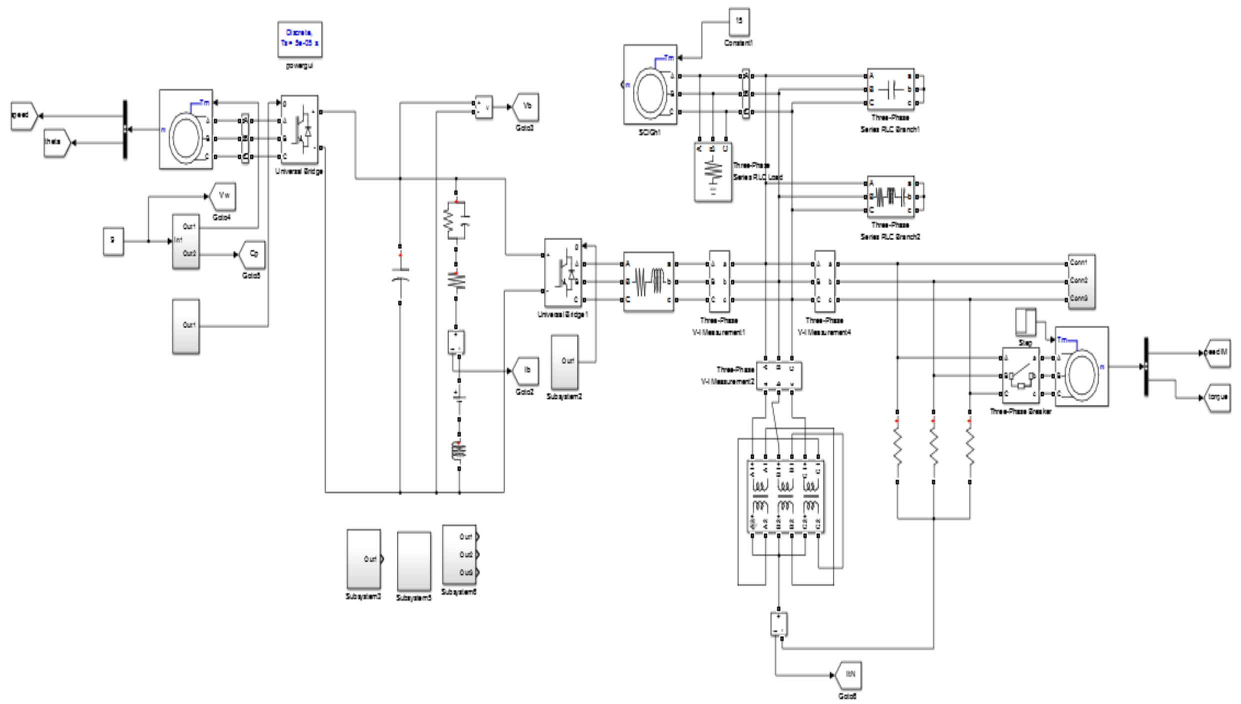

FIG.18 MATLAB simulation diagram of wind hydro hybrid system of balanced loads

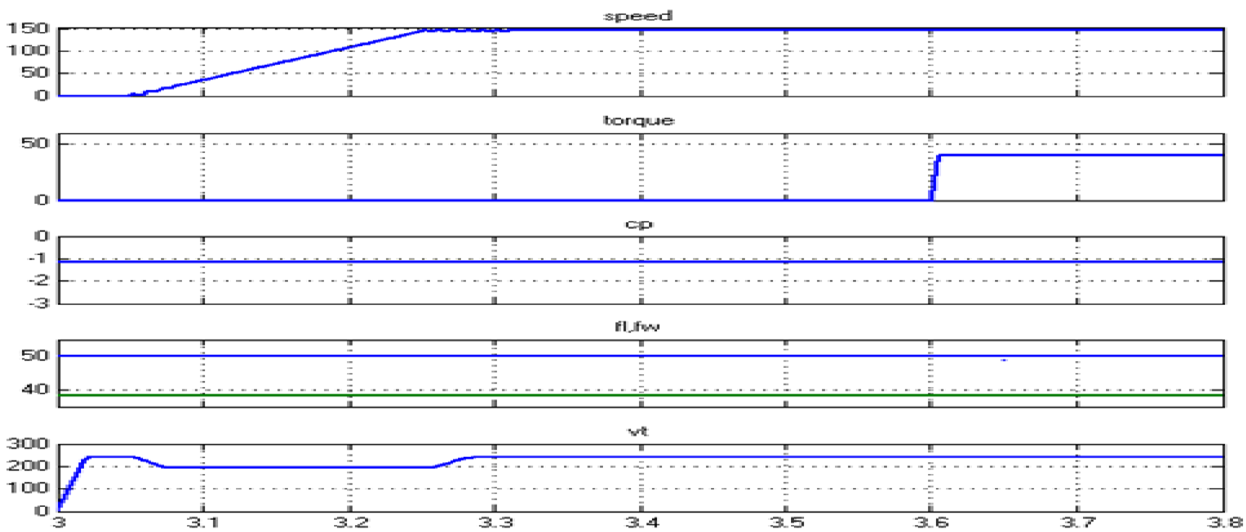

Fig .19 The rotor speed of $SCIG_w$, torque (T), maximum coefficient of power(,cp,)stator frequency(fs) and load frequency(fl) and rms phase voltage (vt)

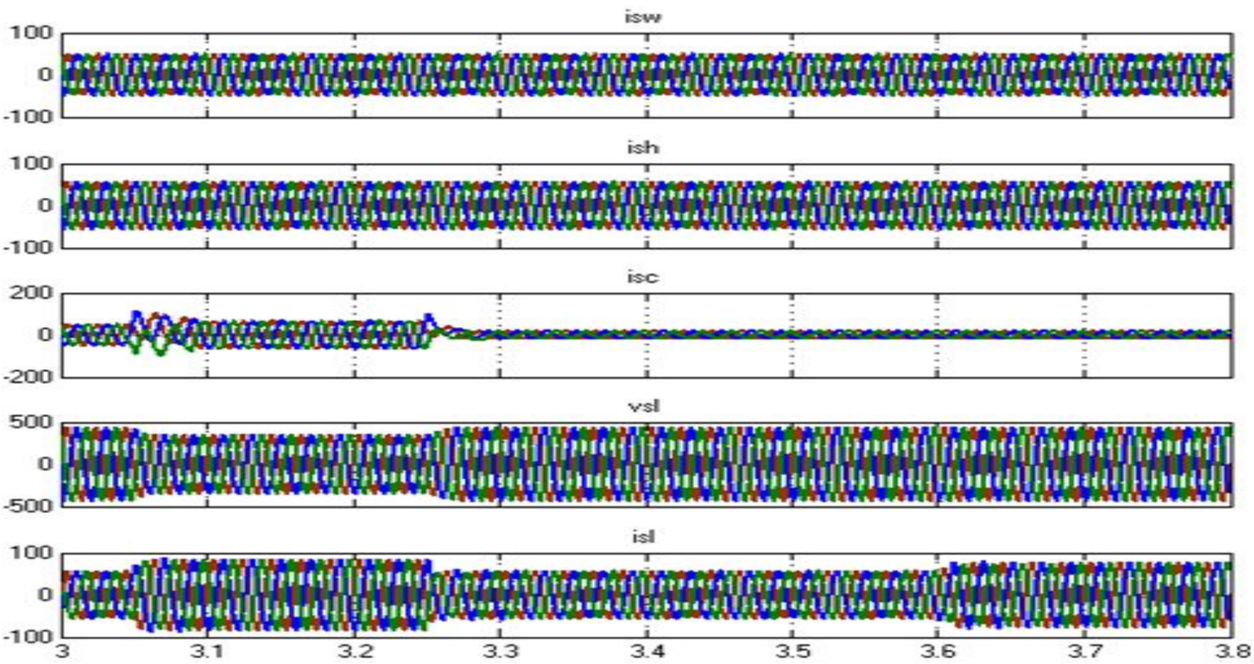

Fig .20 The stator currents of $SCIG_w$, stator current of $SCIG_h$, load side converter current (I_c), three phase load voltage (v_l) and three phase load current (I_l) for wind speed 9m/s

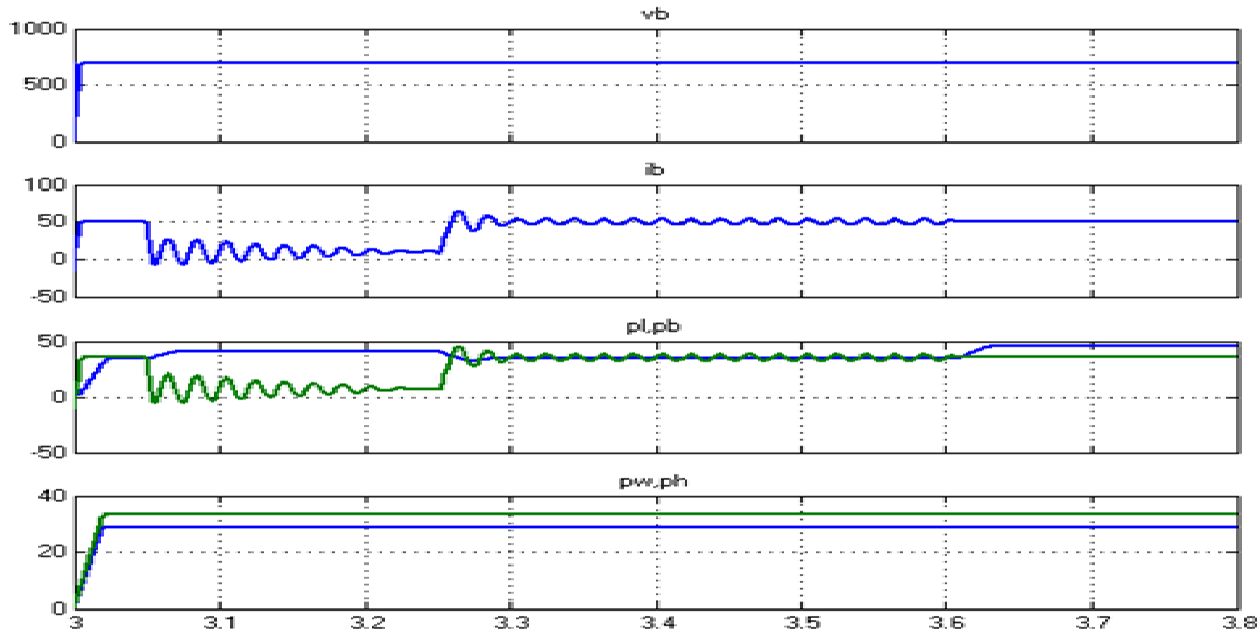

Fig.21 Battery voltage (v_{dc}), battery current (I_b), load power (p_l) , battery power (p_b), wind power (p_w) and hydro power (p_h)

Performance of wind hydro hybrid system with a mixed load consisting of linear, nonlinear, and dynamic loads

. The wind hydro hybrid system is performed with the balanced mixed load with a wind velocity of 9m/s. For the corresponding wind velocity , the rotor speed obtained for $SCIG_W$ is at 82 rad/s, and its stator frequency is 38.36 Hz. At that wind speed the mechanical power obtained for the maximum coefficient of performance is 29kw. The input mechanical power to the $SCIG_h$ is 35kw and the power generated is 33.33kw. The total power generated is (29+33.33) kw = 62.3kw. The system is supplying the three single phase nonlinear loads (each of 3.3 kw i.e; 9.9kw) and three single phase linear loads each of 8 kw (ie; 24kw). The total load capacity is (33.9)kw, where as the power generated by the system (62.3kw) is more than the required active power of the load (33.9kw) and the remaining 28.4kw is stored in the battery.so the battery will be in charging condition. The battery power increases with the increase in the charging current. At 3.05 sec an induction motor of 15 kw is started, which takes large starting current after a few cycles the transients will be settled down.at 3.6 s a mechanical load of 40N.m is applied to the motor shaft, and the motor starts drawing current to meet the requirements of the mechanical load. As a result the battery charging current reduces to maintain the frequency of the load voltage constant

VI. TOTAL HARMONIC DISTORTION PERCENTAGE IN PROPOSED SYSTEM WITH FILTERS.

The demonstration of the total harmonic distortion percentages in $SCIG_w$ current, $SCIG_h$ current, Load current and Load voltage. without filters the THD will be in the range of 35%, , where by using the RC filters and zig zag transformers the THD is reduced in the range of close to the limit of 5%

TABLE I
PERCENTAGE THD OF GENERATOR VOLTAGE, CURRENT, AND CONSUMER LOAD CURRENT

	Balanced linear load	Un balanced linear load	Un balanced nonlinear load	Mixed load (linear, nonlinear and dynamic loads)
Load current THD	6.4	6.0	6.4	11.41
Load voltage THD	5.0	5.0	5.0	5.0
$SCIG_w$ current THD	6.22	6.21	6.22	6.10
$SCIG_h$ current THD	6.4	6.0	6.4	6.0

VII.CONCLUSION

Due to the increase in the cost of fossil fuel and increase in the security of energy supplies the renewable energy sources attained attraction over worldwide. Among all of the renewable energy sources wind and hydro complement to each other. The isolated locations where the grid is not accessible, there these type of hybrid system can be implemented. A new three phase four wire autonomous wind hydro hybrid system using one cage generator driven by variable speed wind turbine and other cage generator driven by constant power hydro turbine along with BESS, has been modelled and simulated in the sim power systems tool boxes. The performance of the proposed hybrid system has been demonstrated under different electrical (consumer load variation) and mechanical (with wind-speed variation) and it works satisfactorily under different dynamic conditions. by maintaining constant voltage and frequency. Moreover, it has shown capability of MPT, neutral-current compensation, harmonics elimination, and load balancing

VIII. REFERENCES

[1] L. L. Lai and T. F. Chan, Distributed Generation: Induction and Permanent Magnet Generators. West Sussex, U.K. Wiley, 2007, ch. 1.

[2] E. D. Castronuovo and J. A. Pecas, "Bounding active power generation of a wind-hydro power plant," in Proc. 8th Conf. Probabilistic Methods Appl. Power Syst., Ames, IA, 2004, pp. 705–710

[3] B. Singh, S. S. Murthy, and S. Gupta, "An improved electronic load controller for self-excited induction generator in micro- Hydel applications," in Proc. IEEE Annu. Conf. Ind. Electron. Soc., Nov. 2003, vol. 3, pp. 2741–2746.

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

[5] J. G. Slootweg, S. W. H. Haan, H. Polinder, and W. L. Kling, "General model for representing variable speed wind turbines in power system dynamics simulations," IEEE Trans. Power Syst., vol. 18, no. 1, pp. 144–151, Feb. 2003

[6] M. Molinas, J. A. Suul, and T. Undeland, "Low voltage ride through of wind farms with cage generators: STATCOM versus SVC," IEEE Trans, Power Electron., vol. 23, no. 3, pp. 1104–1117, May 2008.

[7] S. Ganesh Kumar, S. Abdul Rahman, and G. Uma, "Operation of selfexcited induction generator through matrix converter," in Proc. 23rd Annu. IEEE APEC, Feb. 24–28, 2008, pp. 999–1002.

[8] G. Quinonez-Varela and A. Cruden, "Modelling and validation of a squirrel cage induction generator wind turbine during connection to the local grid," IET Gener., Transmiss. Distrib., vol. 2, no. 2, pp. 301–309, Mar. 2008.

[9] E. Diaz-Dorado, C. Carrillo, and J. Cidras, "Control algorithm for coordinated reactive power compensation in a wind park," IEEE Trans. Energy Convers., vol. 23, no. 4, pp. 1064–1072, Dec. 2008.

[10] 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.

[11] M. Elnashar, M. Kazerani, R. El Shatshat, and M. M. A. Salama, "Comparative evaluation of reactive power compensation methods for a standalone wind energy conversion system," in *Proc. IEEE Power Electron. Spec. Conf.*, Jun. 15–19, 2008, pp. 4539–4544

[12] S. S. Murthy, B. Singh, P. K. Goel, and S. K. Tiwari, "A comparative study of fixed speed and variable speed wind energy conversion systems feeding the grid," in *Proc. IEEE PEDS*, Nov. 2007, pp. 736–743

[13] G. Poddar, A. Joseph, and A. K. Unnikrishnan, "Sensorless variablespeed controller for existing fixed-speed wind power generator with unity-power-factor operation," *IEEE Trans. Ind. Electron.*, vol. 50, no. 5, pp. 1007–1015, Oct. 2003

[14] D. Joshi, K. S. Sindhu, and M. K. Soni, "Constant voltage constant frequency operation for a self-excited induction generator," *IEEE Trans. Energy Convers.*, vol. 21, no. 1, pp. 228–234, Mar. 2006

[15] L. A. C. Lopes and R. G. Almeida, "Wind-driven induction generator with voltage and frequency regulated by a reduced rating voltage source inverter," *IEEE Trans. Energy Convers.*, vol. 21, no. 2, pp. 297–304, Jun. 2006.

[16] 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.
[17] L.-R. Chen, R. C. Hsu, and C.-S. Liu, "A design of a grey-predicted Li-ion battery charge system," *IEEE Trans. Ind. Electron.*, vol. 55, no. 10, pp. 3692–3701, Oct. 2008. 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.
[18] T. C. Yang, "Initial study of using rechargeable batteries in wind power generation with variable speed induction generators," *IET Renewable Power Gener.*, vol. 2, no. 2, pp. 89–101, Jun. 2008.
[19] J. G. Slootweg, S. W. H. Haan, H. Polinder, and W. L. Kling, "General model for representing variable speed wind turbines in power system dynamics simulations," *IEEE Trans. Power Syst.*, vol. 18, no. 1, pp. 144– 151, Feb. 2003.

IX. AUTHORS PROFILE

Sudhakar Durga received B.tech degree in Electrical and Electronics Engineering Department from Sree Vidyanikethan Engineering college Rangampet, Tirupathi in 2012 and currently pursuing M.tech at JNTUA college of engineering pulivendula. Her research interests includes HVDC and FACTS, power systems, Green energy storage and power quality .

Dr. N. Visali, Professor and Head of Electrical & Electronics Engineering department, JNTUA College of engineering, Pulivendula, Y.S.R. Dt. She has completed M. Tech. from Karnataka Regional Engineering College in the year 1998 and Ph. D. from JNTU Ananthapur in the year 2013. Her research area is electrical distribution systems. Area of interest is electrical power and energy systems. She has published 20 technical papers in various international and national journals. She has presented many papers in national and international conferences in India and abroad.