Literature Study on Hybrid Wind/Mini hydro Power Plants

Kruti Gupta, Kamal Kant Sharma

***Abstract*— In this paper, an in-depth study of hybrid system comprising of wind and hydro turbines connected to conventional generators is done. The turbines (wind and hydro) are connected mechanically with conventional generators such as PMSG, DFIG, fixed speed induction generator (FSIG), grid connected or self excited induction generator (GCIG or SEIG), full converter induction generator (FCIG) etc. depending on various controlling parameters. The turbines are electrically connected with grid through partial or full rated frequency pulse width modulated VSC converters (load side and grid side) in regenerative mode at DC bus. Various controlling strategies employed by two PWM using IGBT-VSC of rotor current, speed, voltage and frequency variations for standalone and grid connected hybrid systems are studied and analyzed in detail.**

***Index Terms*— Doubly fed induction generator (DFIG), hydro turbine, Maximum Power Tracking (MPT), Permanent Magnet Synchronous Generator (PMSG), Wind Turbine (WT)**

I. INTRODUCTION

Each RE have different present and future expected costs, present industrial base, availability, security of energy supply etc. and is in a stage of research, development and commercialization. They are gaining importance due to skyrocketing prices of fossil fuels and energy crisis. Being followed by Kyoto protocol signed in 1997, several countries have signed to reduce degree of GHG emissions responsible for climate change and global warming. RES are natural resources, thus inexhaustible such as wind, solar, geothermal, biomass, MHP etc [1]. Among these, wind and hydro have ability to complement each other. Hydro resource has great potential over the globe as they consume 94% of RE production and 20% of world power needs. Availability of hydro potential depends on water flow providing cheap, clean and reliable energy. The viability of isolated systems is dependent on regulations and stimulation measures. In today's world, many geographically isolated sites are available where hydro and wind resources avail simultaneously.

The various advantages of HRES are:

- Improved efficiency and high reliability
- Reduced consumption of fuels, GHG emissions, and optimum usage of components in DG
- Availability of cost effective solutions for fulfilling rural needs
- Improved power quality and availing of more generated power to deliver load
- Reduced transportation acquired and exemption from coal strikes

The disadvantages of HRES are:

- Installation costs of some plants such as solar, biomass etc. is expensive
- Extensive and in-depth geographical survey of site and availability of resources nearby
- Every technology is weather dependent such as sun, wind, tide, wave etc. available in different regions and of varying capacity
- Each technology has its own drawbacks such as:
    - Running cost of solar PV plant is high and it is not available in night or in cloudy days.
    - Wind turbine cannot operate in high or low wind speeds.
    - Collapse of biomass plant at low temperatures.

Ongoing R&D efforts are required in the field of wind, hydro and solar to:

- Improved performance
- Prediction of accurate and well-established strategies to evaluate output of system
- Synchronization of hybrid generation with other sources or grid reliably

The paper orientation is followed up as follows. Section I briefs out complementary nature of wind and mini-hydro plants. Section II presents detailed literature survey of hybrid wind/mini-hydro power systems. Section III and IV explains various methodologies adopted for the smooth functioning of standalone and grid connected hybrid wind/mini-hydro power systems respectively followed up by conclusion.

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II. Literature Survey

Now-a-days, IG (especially SCIG or DFIG) is more opted than conventional SG up to 1000 MW as they have to operate continuously in unattended sites. SCIG have certain merits:

- Rugged and simple in operation
- Brushless construction and absence of DC field excitation
- Low maintenance and cost

VAR drain of SCIG operated with MHP is met by shunt capacitors installed at stator terminals.

In standalone systems, if generation is more than demand, excess power from WT is diverted to dump load or stored in battery bank whereas deficit is supplied from battery to load in case demand is more than generation. In grid connected system, the total active power is fed to grid using RES.

Power generation by wind or MHP adopts SCIG for their functioning. The technology in WT has been shifted from FSWT to VSWT having merits such as reduced drive train gear ratio, counterbalancing of power and torque variations dynamically.

Hydro turbine requires usage of constant speed, constant power generators whereas WT requires variable speed, variable power generator for MPT [2]. In autonomous systems, PMSG and in variable speed WECS system, PMSG are gaining popularity [3]. PMSG has lossless rotor and a small percent of copper losses are confined to stator core and windings [4]. Hydro turbines acquire variable speed SCIG or fixed speed synchronous machine construction and no use of power electronic devices is made. The operation of MHP depends on rate of water flow and variations are seasonal for small to medium intervals of time. The variable speed depends on shunt capacitor values or fluctuations in load impedance values if hydro turbine supplies power to isolated area and also on varied line flows if hydro turbine is utility connected. For both operations, control of frequency is required for turbine rate of flow regulation.

On the other hand, power from wind generators is variable in nature and is not predictable from one day to another.

The integration of generators with utility grid faces several challenges as it requires intensive control of voltage and frequency. When SG operates in parallel with IG, PMSG leads micro grid as it acts like a voltage regulator [5]. The frequency is maintained constant by energy balance in network. Variation in wind speed affects wind generator behavior and loads. On the other hand, power generated by MHP is constant and have variations in long term (seasonal). The grid supplies reactive power to both generator and load, however, shunt capacitors are connected in the line to reduce the same. Various fluctuations in voltage, frequency occurs due to grid failure or other faults, thus, it is necessary to investigate effects of variation in system conditions on performance of generator connected to grid.

III. Standalone Hybrid Wind/Mini Hydro Systems

An isolated hydro-wind hybrid system consisting of two PMSG impelled by hydraulic turbine and VSWT feeds three phase four wire linear/non-linear, balanced/unbalanced static loads. The modeling and simulation of all components of PMSG, MPT controller and VFC is done in MATLAB/Simulink and SimPower System toolbox.

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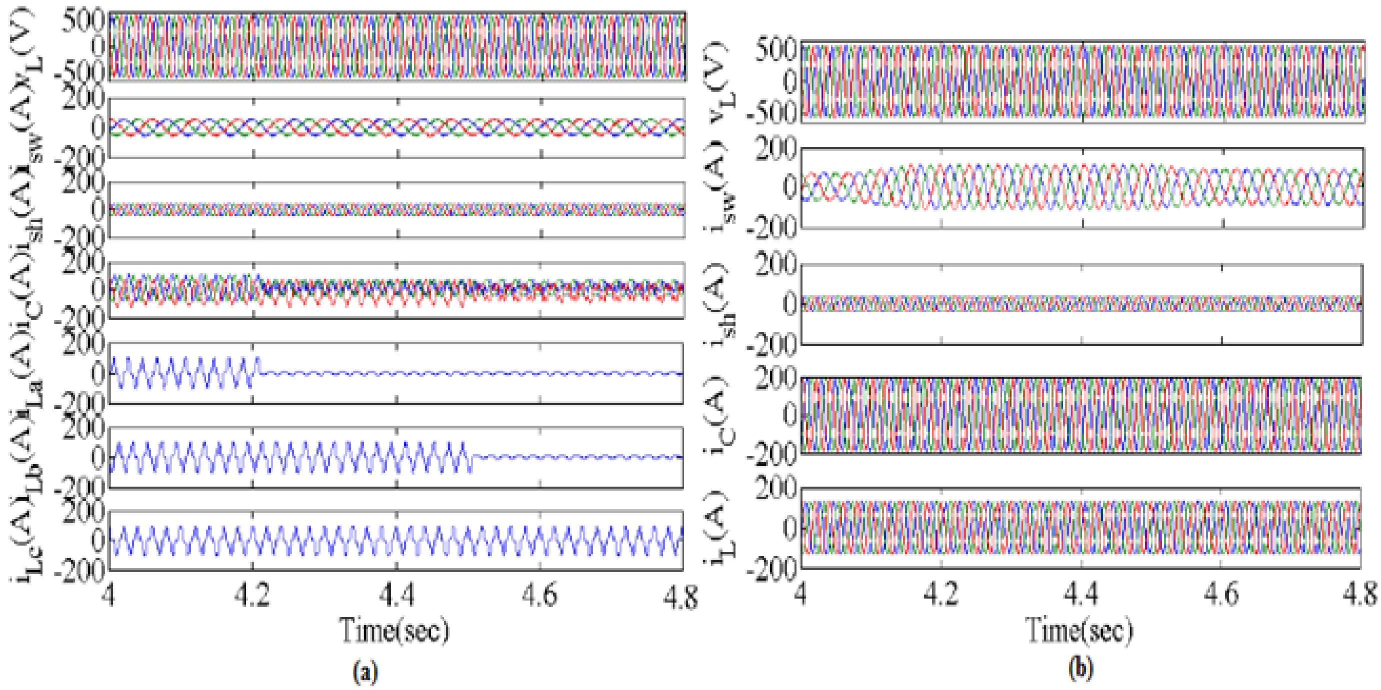

Fig.1 Performance of the system with (a) non linear load at wind speed of 7 m/s and (b) balanced linear load at variable wind speeds

Fig. 1(a) shows performance of balanced/unbalanced non-linear load with 7 m/s wind speed. The static load consists of single phase diode bridge rectifier and three single phase linear loads. As active demand is more than generation, battery supplies shortfall to keep constant frequency on load side. Then, the loads are made unbalanced by switching non linear loads from phase A to B. Thus, active demand decreases and battery current increases to keep constant frequency on load side. Fig. 1(b) shows operation of hydro-wind hybrid system with deviating wind speeds. The system starts with 8 m/s wind speed and three single phase load. Here also, battery supplies shortfall as generation is less than active demand to keep constant frequency. Then, wind speed is increased and then decreased to see the performance of system [3].

Another isolated hydro-wind hybrid system considered consists of one PMSG impelled by fixed speed hydraulic turbine and other SCIG driven VSWT to feed three phase four wire static loads. Simulation of PMSG, SCIG is done in MATLAB/Simulink and SPS toolbox. Indirect current control method for load side converter is used to make SCIG currents sinusoidally distributed and balanced at power frequency. The performance of proposed hybrid system is found satisfactory for linear loads maintaining constant voltage and frequency. The speed control of WT rotor impelled by PMSG [3] and SCIG [6] with varying wind speed, control of amplitude of load voltage and frequency; a control algorithm for achieving MPT is prepared which is main objective of VSC. The system utilizes two PWM controlled IGBTs based VSC connected back to back with BESS (performing function of load leveling) at their dc link connected back to back. Control of amplitude of load voltage and frequency is done through two-way active and reactive power flow [3, 6-7]. Another off-grid hydro-wind hybrid system consisting of one SCIG driven by VSWT and other SCIG impelled by fixed speed hydraulic turbine feeds three phase four wire local load. Modeling and simulation of all components is demonstrated under different mechanical (deviated wind speed) and electrical (fluctuations in end users' load) dynamic conditions. The main objective of load side controller is to maintain energy power balance at load terminals and of machine side converter is to provide sufficient magnetizing current to achieve MPT. The potentiality of MPT, VFC, neutral current compensation, harmonic suppression and load management is demonstrated through the performance of proposed system [3, 6].

As MPT technique (based on SCIG running at fixed speed) is not efficient in an isolated WECS plant, for the control of voltage and frequency, a battery based controller is proposed [3]. When demand is less than generation, electronic load controller (ELC) supplies extra power from supply to variable resistive loads [2]. Certain demerits of gearbox required to connect low speed WT shaft to high speed generator shaft are:

- Increased weight to cost ratio
- Incremental losses and maintenance

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Thus, gear box is omitted for wind power generation to achieve better and efficient solution. The efficiency of PMSG is found to be greater than VSWT based WECS [3]. HPS grounded on RES is proposed consisting of micro-hydro plant including SG and WT based IG in stand-alone mode. These two generators supply AC micro grid (such as ELC or dump load) and capacitor bank delivering VAR to reactive loads. The power balance in system is ensured by common voltage regulator and frequency controller based on dump load of SG and IG. SG incorporates Banki (cross flow) construction whose output is constant, thus omitting need of HTG whereas WG delivers electric power depending on variable wind speed. Simulations are carried out based on following issues:

- Power quality for varying load shapes
- Operation of micro grid under unstable conditions
- Response of system at unforeseen SG's failure

The capacitor bank acts as filter for high frequency dump load current harmonics and do not affect generators. Analysis shows that rated value of voltage unbalance factor exceeds for unbalanced loads greater than 30% which produce torque oscillations and machine shaft vibrations. Also, failure of SG causes unbalance system as both voltage and frequency deviates from rated value. Follow ups regarding disconnection of unimportant loads should be prioritized.

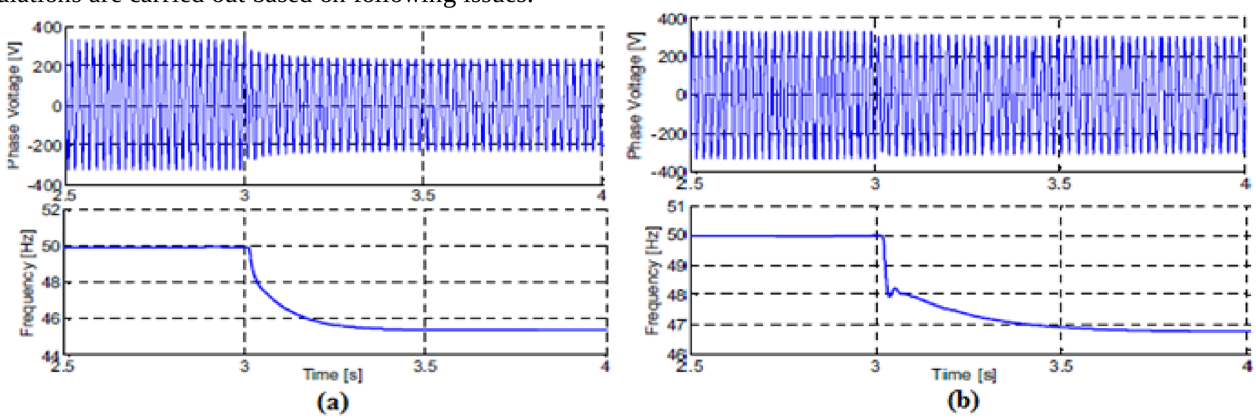

Fig. 2 Phase voltage and frequency for (a) average load and (b) small load

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Wind and hydro hybrid system works suitable under steady state conditions. However, when one machine fails, micro grid parameters are affected based on machine's inertia. The worst condition exists when SG is disconnected which delivers 2/3 of total active power, some amount of reactive power also and performs voltage regulation. Hence, IG sustains and neither performs function of voltage regulation nor produce reactive power. If active power of load is more than IG, frequency will stabilize below 50 Hz. Fig. 2(a) shows simulation for average load being connected with SG initially and followed by IG after fault supplying load. Fig. 2(b) shows simulations of small load where load is reduced due to increased wind speed (10 m/s) and generator produced only 70% power. Thus, if IG gets disconnected, then SG supplies power under voltage regulation mode and the system becomes more stable.
Regulatory issues for standalone systems using SG and IG are also studied in detail [5].

IV. Grid Connected Hybrid Wind/Mini Hydro Systems

Computer simulation of GCIG driven by two prime movers (viz. 220 kW hydro and 55/11 kW & 22 kW horizontal axis WT systems) is done to predict performance of system containing an IG connected to 11 kV grid via transformer and line of certain impedance (realistic values are considered for representation). A suitable algorithm is developed to determine system response at constant and variable power input. Terminal capacitors are also included to compensate reactive power. Study analysis is focused on:

- Fluctuations in grid voltage and frequency
- Power input
- Terminal capacitance
- Self excitation criteria on failure of supply

Following aspects of GCIG are considered for study in this paper:

- IG is feeding power to a weak distribution network with variation in voltage and frequency depending on system and load conditions.
- For hydro system, the input power to IG is constant and for wind, it is variable depending on wind speed.
- Appropriate capacitor size or rating should be calculated connected at generator terminals to improve power factor or for reactive power compensation.
- Terminal capacitors provide self excitation during disconnection of grid which results in over-speeding of WT and high voltages. To avoid this, minimum capacitor size to cause self excitation should be calculated at different wind speeds to check whether these PFCC is larger than this value. The variation of self excitation voltage with speed should also be done [8-9].

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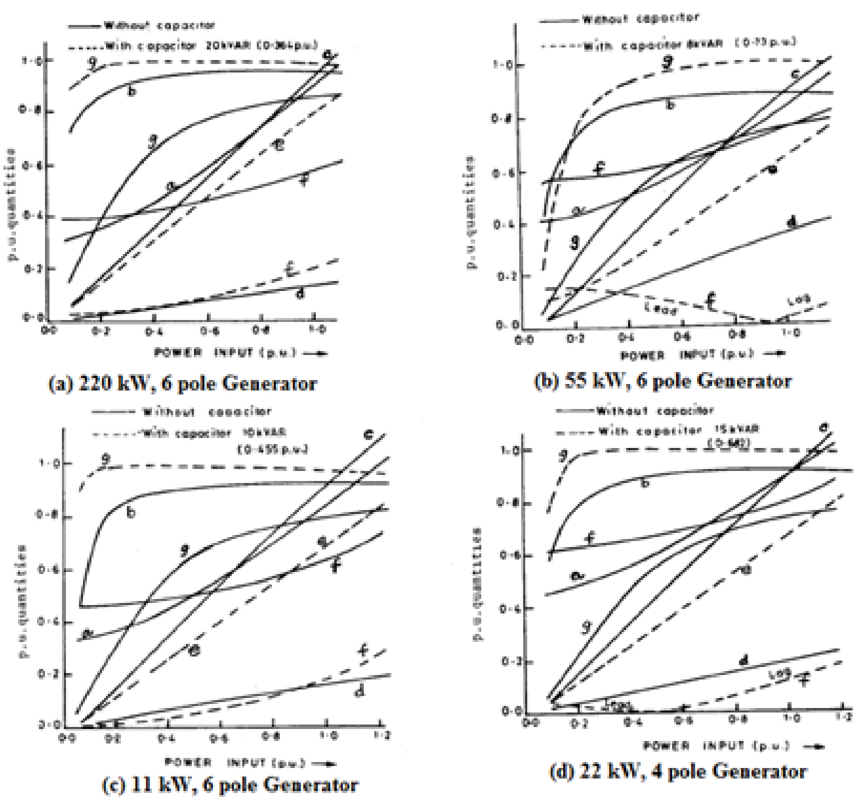

Fig. 3 Characteristics of wind driven IG at varying power input
a: Machine current; b: Machine efficiency; c: Power fed to grid; d: P.U. slip * 10; e: System current; f: VAR drawn from grid; g: PF at grid

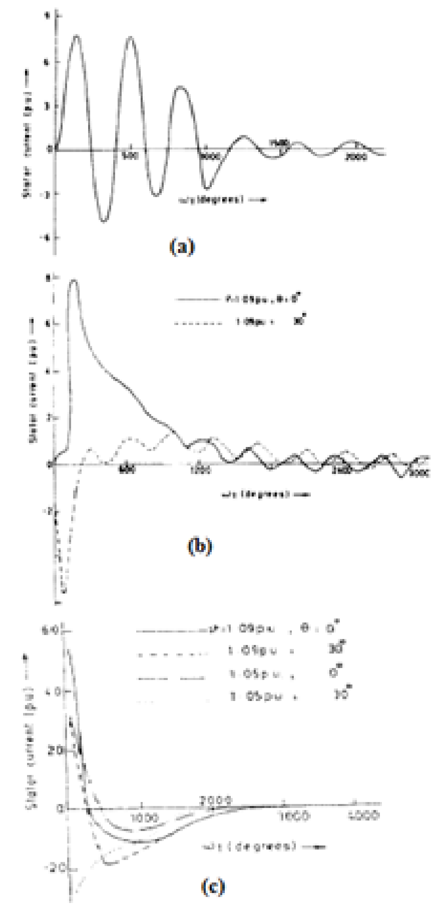

Fig. 4(a) Run-up transient (b) Re-switching transient and (c) Short circuit transient

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Fig. 3 shows different motor designs assorted as NEMA A, B, C and D on the basis of starting and operation. Different SCIM rotor designs are available such as brazed, single or dual cage, deep bar etc. and we have to select any one design for generator operation. Minimum VAR requirement, improved efficiency and output at rated current are some good measures to be achieved. Generally, class A designs meet these criteria and class B is also suitable. Graphs are plotted for 220, 55 and 11 kW for class A in Fig. 3 (a), (b) and (c). Fig. 3(d) shows results for 22 kW of class B employing double cage rotor design and reduced VAR drain is seen [8]. Steady state and transient stability studies and simulations of IG driven 220 kW micro-hydro plant and varying wind speed 55 kW wind turbine system under grid failures are carried out. Dynamic modeling of wind driven IG also analyzes run up, re-switching and short circuit transients of wind driven IG. Some operational problems are identified in order to develop techniques to study behavior of such systems. Transient performance of IG is very important. Run up transients occur when IG operates as motor and switching from standstill condition. Re-switching transients occur when IG operates at fixed speed and switched to grid to feed power. Short circuit transients occur when there is short circuit on IG terminal during normal operation.

Fig. 4 shows results of 55 kW wind electric system and various transient patterns are obtained. Fig. 4(a) shows run-up transients (depending on system inertia) of stator currents which continues for 0.07 sec after which steady state is achieved for current and speed. Fig. 4(b) shows re-switching transients for different values of speed and phase angle of switching. The stator current varies with this phase angle but speed does not affect it. Time required to reach steady state position is found to be 0.3 sec. Fig. 4(c) shows short circuit currents at different instants and results are obtained at different speeds of IG. At each instant, the peak values of current changes with operating speed. At each speed, initial transient depends on instant of short circuit though the time taken for current to decay to zero is same [9]. Several literatures employ variable speed WECS based on PMSG connected to grid utilizing regenerative converters. PMSG operates at constant wind speed if grid connected [3]. Several HPS incorporating different RES connected to energy provider system is available in literature [5].

A hybrid wind/mini-hydro system associated with grid is experimented which consists on one side DFIG connected mechanically and electrically to PMSG via regenerative converter in rotor circuit connected to DC bus and on other side FSWG driven by SCIG. Variable speed MHP functions out smoothing of fluctuated wind power connected to grid. The performance of system is improved by using short term storage device smoothing power variations and maximizing power delivered to grid [10]. This system is tested experimentally on 3 kW laboratory test bench able to imitate grid connected hybrid wind/hydro system. The hydro system consists of Kaplan turbine and is a run-off river plant used for low heads which drives DFIG via gearbox whose excitation is supplied by PMSM mounted on same shaft. The rotor side PWM controls DC bus voltage and grid side PWM controls DFIG to have efficient operation of DFIG on isolated loads and connection to grid [10]. The structured model of hybrid wind/hydro system connected to grid which controls DFIG active and reactive power independently is presented in [10]. Simulations for these two sub-systems are carried out in Matlab/Simulink. Extensive survey is done for this hybrid system [10].

V. CONCLUSION

A hybrid system incorporating wind and hydro turbines in stand alone or grid connected mode is studied in detail and analyzed. Various control strategies for controlling various parameters such as rotor current, speed, voltage and frequency variations, VAR drain compensation etc. are also studies in-depth. The study can be broadened by carrying out transient and dynamic modeling of various components of wind and hydro hybrid systems in different software’s in future. The results of these modeling can then be used for practical implementation at various sites over the globe where wind and hydro exist simultaneously.

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