Standalone and Hybrid Systems: A Survey

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ABSTRACT
In this paper, a comparative study of various standalone and grid connected hybrid systems is done and analyzed. The hybrid system consists of wind, mini hydro, solar, fuel cell, biogas plants along with diesel generator as a backup source. The comparison between standalone and grid connected systems is done in detail. Various hybrid systems incorporate different controlling strategies for wind farms, hydro turbines, conventional generators etc. are also included. An in-depth study of hybrid system comprising of wind and hydro turbines connected to conventional generators is also done. Islanding operation is also considered a special concern in this paper, which also include various works by hydraulic turbine and controller of governor system in smart distribution systems.

Keywords
Distributed Generation (DG), Doubly Fed Induction Generator (DFIG), Hybrid Systems, Hydraulic Turbine and Governor (HTG), Renewable Energy Sources (RES), Small Hydro Power Plant (SHPP), Wind Turbine (WT)

1. INTRODUCTION
Due to depletion of fossil fuel resources and global warming giving rise to acid rain, use of RES such as wind, hydro, PV, tidal etc. has become necessary for sustainable development. Today, society pays much more attention towards more efficient, effective, sustainable RES due to ever increasing prices of fossil fuels, energy crisis, climate changes, acid rain, global warming followed by Kyoto protocol. As wind is omnipresent, free, clean, non-polluting and abundant in nature, it does not produce any by-products harmful to environment and reduces dependency on fossil fuels and GHG emissions. Thus, Ministry of New & Renewable Energy (MNRE) has devised provision of incentives to make wind energy competitive in India. As fossil fuel prices are skyrocketing, more and more homes, businesses, malls etc. started installation of rooftop panels and windmills to cut down electricity bills, gas emissions etc. and selling excess power back to grid [1]. Increased penetration of wind farms have following impacts:

- Modification in power line flows
- Change in capacity of transmission line
- Change in strength of grid
- Change in inertia of whole system
- Depends upon proximity of wind resource near to load centers
- Power quality in distribution systems
- Transmission congestion
- Energy pricing
- Large voltage and frequency variations in weak AC grids
- Control of energy balance line power flows

The world's most of the population living in rural areas has great chances of evolving. Due to isolation, to lighten up these areas is a challenging area. In hilly or mountainous regions where small tributaries of river are available, mini hydro power is the best option to generate electricity as they are non-polluting, inexhaustible, clean and environment friendly, thus, it is considered as green energy [25]. Small hydro power plants (SHPP) viz. run-off river plants have numerous advantages over large scale hydroelectric plants such as low administrative and execution cost, no evacuation of populated areas, availability of water for drinking and irrigation etc [2]. Due to low running cost of plants, hydro power plants have greater accessibility. SG is then used to convert this mechanical energy to electrical one in order to supply end consumers.

Electricity is the most versatile form of energy available and it can be accessed all over the globe through a series of tried and tested technologies. In India, demand of electrical power is very large as compared to generation. Power transferred from one end to other suffers greatly from power quality, voltage sag and swell problems, harmonic currents in supply lines etc. followed up by large voltage and frequency variations, power cuts and load shedding. The increased use of RES in hybrid system produces synergistic benefits. Hybrid systems are the combination of one, two or more renewable sources in an efficient and optimum way such that integration of two will overcome limitations of each other. 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. 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 [1].

The various advantages of hybrid systems are:

- Increased efficiency rather than individual technology
- Higher reliability with redundant technology and/or energy storage and affordable
- Improvement in power quality
- Availability of power
- Reduce fossil fuel consumption

- Optimal use of all components in Distributed Generation
- Provide cost effective solutions to rural electrification needs
- Reduction in transportation cost and freedom from coal strikes.
- Reduction in greenhouse gas emissions and particulate matter emitted in environmentThe disadvantages of hybrid systems are:
- Some technologies are too costly such as solar, biomass etc.
- Requires extensive survey of all geographical & meteorological parameters before practical implementation
- All technologies are weather dependent such as sun, wind, tide, wave etc.
- Depends upon region and capacity.
- Each technology has its own drawbacks such as:
  - Solar being not available in night or in cloudy days. Also, production cost is high.
  - Wind turbines do not operate in high or low wind speeds.
  - Collapse of biomass plant at low temperatures.

2. STANDALONE SYSTEMS

Wind Farms: There are three control strategies viz. pitch control, rotor resistance control and vector control of DFIG which are compared to verify control of fluctuated power output taking place due to variable wind speed within specified limits. Above three methods are tested for variations in wind velocity on input side and fixed preset power on output side. WECS consists of following sub-systems:

1. Aerodynamic model of turbine rotor blades
2. Wind turbine model
3. Drive train model
4. Wind turbine generator model and
5. Command control signal model

The first three model forms mechanical sub-system of WTG, generator establishes electro-mechanical connection between turbine and grid and lastly, control system controls generator output. It is found that DFIG has least output power variation at high velocities, 20% at low wind velocity and 10% for fast response of three control techniques. Thus, it is found to be a better option for controlling power with reduced losses, improved operation at unity p.f. operation [3].The mathematical modeling of WPP with wound rotor asynchronous generator is explained by building Simulink models from mathematical descriptions, knowledge of basic parts etc. and finally whole system is represented. Simulation requires good knowledge of system being considered as it is abstraction of real object. The real object is simplified, assumptions are made such that they don't have any impact on its characteristics, and mathematical equations are formulated and solved by two approaches viz. analytical method and numerical method. Simulink forms an integral part of MATLAB which enables use of blocks of basic mathematical functions to more complicated ones. This model of WPP can be connected to mathematical model of LV grid or more complicated model of variable speed DFIG for large power plants [4].A new control scheme for improving voltage and transient stability of system through integration of large wind farms to grid is proposed. Transient stability of system is improved by incorporating WT coupled to PMSG with reactive support ability connected close to generators. During steady state, PMSG delivers active power and in faulty state, it delivers reactive power which improves short circuit level. However, the voltage stability is improved by using full power PMSG together with STATCOM to deliver reactive power at constant speed during fault. FSIG supplies active power and a small VAR drain taken from grid enhancing wind farms to remain connected with grid during LVRT or fault [5].The impacts on WT and power system are analyzed when three phase fault happens on grid. Two case studies are done viz. when wind farms of different capacity are coupled at PCC and when wind farms with varying capacities are coupled at different points. In first case, transient stability is given by critical clearing time and ability of LVRT. In second case, voltage stability is improved by providing sufficient reactive power if the grid is strong enough. Bus voltage waveforms are studied when wind farm and grid are disconnected [6].The impact of wind farm on distribution network is studied by estimating maximum power within voltage stability transfer limits using ABCD parameters of line at various power factors to draw PV curves. Thus, maximum line power flows connected to load bus until voltage collapse point reaches is evaluated. Limited VAR power and relation between active power and voltage at load bus is studied to evaluate voltage stability limit. Thus, a study is conducted for evaluating impact of priority placed WGs in these systems with reference to critical voltage variations and voltage collapse limits. Bus bar, generator and field protection settings should be adjusted carefully within statutory limits, network voltages and machine ratings [7].

2.1 Mini/Micro Hydro Plants

To operate hydro turbines, optimum value of head and discharge is required in order to attain fixed speed. Under fixed speed operation, head and discharge should have minimum deviations. Variable speed operation offers several advantages such as large tractability of turbine performance in cases of flow or head deviations from original values [8].SHP utilizes Squirrel Cage IG with short circuited rotor as they are cheap and robust. For variable speed, stator is connected to grid of fixed frequency through back to back converter or used Wound rotor having full capacity as that of generator power [9].Capacities up to 100 kW or less are referred to as micro/pico hydro plants which can supply both off-grid and on-grid areas [10]. Micro-pico hydro plants supplying off-grid areas are not commercial as load factor for these plants is very low in the range of 10-30%. While, generations in an on-grid area are performed through two modes viz. standalone and grid connected. Standalone mode is somewhat similar to off-grid functions so they are becoming obsolete while in grid connected mode, all energy generated is utilized by grid and can be operated commercially. The merits of micro-pico hydro plants operating in grid connected mode are the efficient use of hydro generation via economical prices and maintenance and a qualified standard of electricity [25]. A new technique of islanding is emerging due to large penetration of DG. It is not beneficial to disconnect DG during islanding instead, utility presumes to acquire full capacity of DG for supplying loads in islanding mode. This requires right timing and control of islanding as islanded area and grid both are endangered. It calls for designing smart distribution grid such that it performs the function of supervising, control, analysis and communication to obtain synchronized islanded operation. Islanding occurs due to fault occurrence at PCC leading to opening of associated circuit breaker and/or opening of CB due to fault at load feeder. Thus, several islanding areas are formed with numerous amounts of load being connected to it. [11].A small hydro power plant (SHPP) is modeled through MATLAB simulation to indicate that RES will soon obsolete the existence of conventional sources in near future and generation through RES in standalone areas is a feasible solution to supply power at remote and distant locations. The simulation of various sub-systems comprising of penstock, turbine, electro-hydraulic or PID governor, exciter etc. is carried out and a suitable dynamic behavior is achieved through change in load, speed, voltage etc [25]. Different designs of penstock viz. non-elastic water column and water column travelling effect theory, governor viz. electro-hydraulic and PID governor design, exciter of AC1A are considered [2].The potential of micro/pico hydro driven by SCIG power can be better utilized in an on-grid area by optimizing it and connecting it to utility grid. The modeling and simulation of IG driven micro/pico hydro turbine in self excitation mode and grid excitation mode is done in MATLAB/Simulink software. [10]. A general model using MATLAB/Simulink is built to simulate hydro power plant consisting of SG driven hydro turbine connected to grid. A digital computer solution is achieved through schematic model of HTG and synchronous machine for modeling the dynamics by using basic function blocks of Simulink. The dynamic analysis of HTG, penstock etc. and their mathematical representation is carried out in time and frequency domains [25]. A three phase fault case is applied on this non-linear system for dynamic analysis and several other operating conditions such as overload etc. can also be tested upon [11].

3. HYBRID SYSTEMS

Hybrid system consisting of solar-hydro plant providing continuous electrical energy to consumers is studied and analyzed [12]. An analysis of measured wind speed and solar insolation data is done through MATLAB software by simulating different cases on the basis of energy balance calculations (hourly basis). For this, two sites in Palestine viz. Ramallah and Nablus are used. Almost all cases viz. wind-diesel hybrid, PV-diesel hybrid, wind standalone, PV standalone or diesel standalone have COE greater than COE of optimum case resulting in zero replacement of purchasing of power from grid [13]. Another hybrid system consisting of solar, wind farm coupled to DFIG, pumped storage hydro with residential and industrial loads is analyzed under an islanded and grid connected mode. In an islanded mode, stabilization of system without central master controller is done through designing proper control strategy. Load shedding is adopted for low frequency control. In grid connected mode, wind farm, solar power and load helps stabilizing hybrid system contributing to voltage and frequency control [14]. The modeling of solar PV, wind energy, hydro-electric systems and storage devices such as battery is done. Storage device carries out three functions: System stability, LVRT capability and load management [15]. The modeling of hybrid system in MATLAB/Simulink is proposed for simulating, optimizing and trajectory analysis of small hybrid systems based on RES. MATLAB is expanded with RegenSim library which is designed to implement various functions of HRES and also interfacing of their components from other libraries such as SimPower systems etc. The modeling of both single and three phase consumers can be done with different powers, nature and types. The two tri-hybridization processes are proposed and implemented for rural electrification which includes hydro-wind and PV modules [16]. An ant colony algorithm for optimization of hydro-wind-solar-fuel cell hybrid system is prepared. PV, wind and fuel cell are connected to DC bus and hydro system to AC bus supplying load via DC/AC bus through DC/AC transducer. Loss of power supply probability (LPSP) is used to evaluate system reliability [17]. An 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 speed control of WT rotor impelled by PMSG [18] and SCIG [19] 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. Control of amplitude of load voltage and frequency is done through two-way active and reactive power flow [18-20]. 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. Regulatory issues for standalone systems using SG and IG are also studied in detail [21]. Computer simulation of GCIG driven by two prime movers is done to predict performance of system containing an IG connected to 11 kV grid via transformer and line of certain impedance. A suitable algorithm is developed to determine system response at constant and variable power input. Terminal capacitors are also included to compensate reactive power [22]. 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 [23].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 [24].

4. CONCLUSION

Different standalone and grid connected hybrid systems are compared and analyzed on the basis of various strategies, optimization techniques etc. In future, we can extend the study for detailed transient and dynamic modeling of various components of hybrid systems incorporating wind, mini hydro, fuel cell, solar PV panels etc. Due to increased integration of wind parks in power systems, stability issues are arising specially voltage and transient stability. In present era also, there are still some unsolved challenging problems which needs careful attention and fast controlling such as large reactive power support, LVRT capability etc. The future scope lies with developing the dynamic models of WECS system in MATLAB/Simulink or PSCAD/EMTDC considering every minute detail of its sub-systems. An emerging field of islanding detection is also included. 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 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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