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A Review on Design and Development of high Reliable Hybrid Energy Systems with Droop Control Techniques

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ABSTRACT

Hybrid Energy system is a combination of two or more different types of energy resources. Now a day this hybrid energy system plays key role in various remote area power applications. Hybrid energy system is more reliable than single energy system. This paper deals with high reliable hybrid energy system with solar, wind and micro hydro resources. The proposed hybrid system cable of multi mode operation and high reliable due to non communicated based controllers (Droop Characteristic Control) are used for optimal power sharing. Size of battery can be reduced because hydro used as back up source and Maximum power point Tracking also applied to solar and wind energy systems.

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1. INTRODUCTION

Today the world is mainly facing two problems. One is the power crisis that is fast depleting of fossil fuels and other one is pollution problem like carbon emission and global warming. The best solution for this problem is utilization of renewable energy resources. Renewable energy resources are abundant in nature, free of cost and non pollutant. Among the all renewable energy resources Solar and wind are more popular because of its huge potential in nature. In the process of Utilization of Renewable energy resources we have to face some challenges like reliability, cost, efficiency and Stability. The main drawback of renewable energy resources is they are inconsistency or more fluctuating in nature and depends upon weather atmospheric conditions. In order to provide continue power supply integrate two or more resources and provide storage system. Integrated system of two or more renewable energy systems, also known as Hybrid Renewable Energy System (HRES) [4], is gaining popularity because the sources can complement each other to provide higher quality and more reliable power to customer than single source System. A HRES can be standalone or grid connected. Standalone systems need to have generation and storage capacity large enough to handle the load. In a grid connected system, the size of storage device can be relatively smaller because deficient power can be obtained from the grid. Hybrid energy system that complements the drawbacks in each individual energy resources. Therefore, the design goals for hybrid power system are the minimization of power production cost, minimization of power purchase from grid (if it is connected to grid), reduction in emission, reduction of the total lifecycle cost and increase in reliability of the power generation of system. Wind and solar power generation are two of the most promising renewable power generation technologies. The growth of wind and photovoltaic (PV) power generation systems has exceeded the most optimistic estimation. Multi-source hybrid alternative energy systems (Figure 4) with proper control have great potential to provide higher quality and more reliable power to customers than a system based on a single resource. And because of this, hybrid energy systems have caught worldwide research attention.

A solar cell can be represented (Figure 1) by an equivalent circuit that indicate a current source in parallel depletion layer becomes wider so that the capacitance is reduced similar to stretching the electrodes of a plate capacitor. Thus solar cells represent variable capacitance whose magnitude depends on the present voltage. This effect is considered by the capacitor C located in parallel to the diode.

The diode indicates the I-V characteristics (Figure 2) of the PV cell. The output of the current source is depends upon the light falling on the solar cell. The open circuit voltage increases logarithmic according to Shockley equation which describes the interdependence of current and voltage in a solar cell. The characteristic of solar cell is dependent upon the level of insolation, cell temperature and array voltage. Thus it is necessary to implement MPPT in order to move the operating voltage close to maximum power point under changing atmospheric conditions. MPPT in solar is important because it reduces the solar array cost by decreasing the number of solar panels needed to obtain the desired output. V-I characteristics of the solar array are neglecting the internal shunt Resistance.

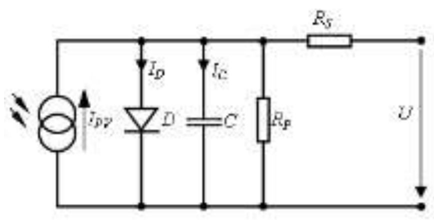

Figure 1. Equivalent circuit diagram of a solar cell

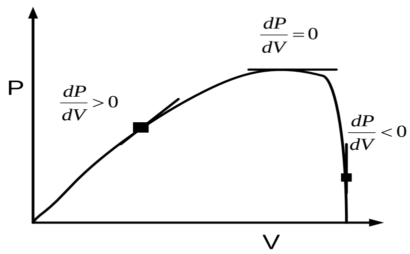

Figure 2. P-V characteristics of solar cell

1.1. Wind Power System

The fundamental equation governing the mechanical power of the wind turbine is given by

$$P_w = \frac{1}{2} C_p(\lambda, \beta) \rho A V^3$$

where ρ is air density (kg/m3), Cp is power coefficient, A is intercepting area of the rotor blades (m2), V is average wind speed (m/s), λ is tip speed ratio. The theoretical maximum value of the power coefficient Cp is 0.593, also known as Betz's Coefficient. The Tip Speed Ratio (TSR) for wind turbine is defined as the ratio of rotational speed of the tip of a blade to the wind velocity mathematically,

$$\lambda = \frac{R\omega}{V}$$

where R is radius of turbine (m), ω is angular speed (rad/s), V is average wind speed (m/s).

The energy generated by wind can be obtained by

$$Q_w = P \times (Time)[kWh]$$

The wind speed Vs power characteristics curve of wind turbine is represented in Figure 3.

2. MPPT TRACKING

Maximum power point tracking (MPPT) is a software algorithm which is used to operate the PV/Wind energy system at maximum power point electrical power generated by PV array depends upon solar insolation and temperature of the cell. The amount of power extracted from the solar depends upon the P-V characteristics. At a particular voltage only it can generate maximum power and beyond that point, it can't generate the maximum power. In order to track that particular point, maximum power point tracking is used. In the same way Electrical power generated by Wind depends upon Tip Speed Ratio (TSR) Vs power coefficient (Cp) characteristics. At a particular Tip speed ratio only it can generate maximum power and beyond that point, it can't generate the maximum power. In order to track that particular point, maximum power point tracking is used which can the vary speed of the turbine according to wind speed variation and finally it provides optimal tip speed ratio at maximum power coefficient. Maximum power point tracking not only increases the system's efficiency but also decreases the payback period of the total installation cost. Since the variable parameters for MPPT of wind and solar system is different, individual tracking system should be applied for each system [16].

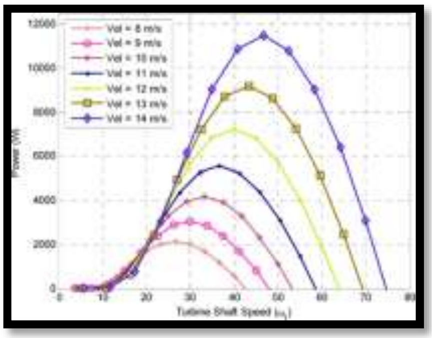

Figure 3. Wind Turbine power curve

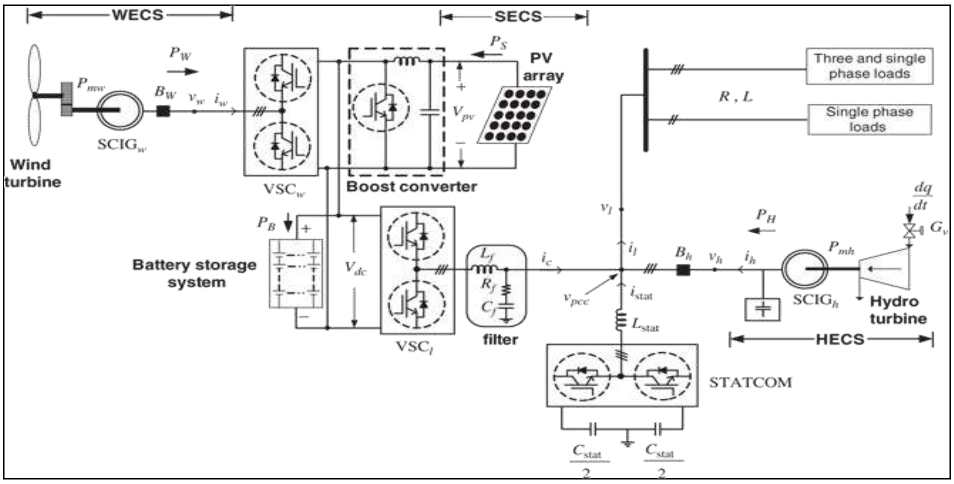

Figure 4. Proposed model for hybrid energy system with solar, wind and small hydro resources

3. DROOP CONTROL SYSTEMS FOR POWER SHARING OF HYBRID SYSTEMS

Communication-based control techniques require communication lines between the modules which can increase cost of the system. Long distance communication lines will be easier to get interfered, thus reducing system expandability and reliability. The developing trend toward a More/All Electronic Power System highlights the importance of coordinative control of multiple power converter interfacing different energy sources. It can control both frequency and bus voltage to be within required range and Adequate power sharing among energy sources. The control methods that operate without inter unit communications for power sharing control are based on droop concept Operation is often essential to connect remote inverters. It can reduce complexity operation and high cost, and improve reliability. Communication lines are often avoided especially for long distances, high-investment cost.

And such a system is easier to expand because of the plug-and-play feature of the modules which allows replacing one unit without stopping the whole system. To overcome these drawbacks several droop control methods are developed: 1 conventional and variants of droop control; 2 construct and compensate-based methods; 3 virtual structure-based methods; and 4 hybrid droop/signal-injection-based methods. Comparison of various communication system based control systems with its disadvantages is explained in the following Table.1.

3.1. A Simple Review on Disadvantages of the Communication-Based Control Systems

Table 1. Comparison of Various Communication System Based Control Systems with its Disadvantages

Communication based control type	Disadvantages
Distributed control system	Communication bus is required Modularity of the system will be degraded
Master or slave control system	Low redundancy high bandwidth is required during transients high current over shoot
Concentrated control system	Very low reliability and less size high bandwidth is required

3.2. Conventional Droop Control

The droop control method for the parallel connected inverters can avoid the dependency on communications. It is sometimes named as “wireless” control with no interconnection between the inverters. The droop control system mainly divide into three parts [8].

1. Primary control (Voltage and current regulation and Droop based power sharing)
2. Secondary control (Voltage restoration and Synchronization)
3. Tertiary control (Optimal operation of micro grid and Power management in grid-tied mode)

When droop control is applied, compromise exists between the accuracy of power sharing and the regulation rate of the output voltage. Low droop gain results in a bad accuracy of power sharing, while high droop gain results in a bad voltage regulation rate. In AC power system, if the impedance of distribution line has a large resistive component, then there will be coupling with Droop Control, which can reduce the response speed and the stability of the system. If the impedance of distribution line has a large resistive component, then there will be coupling with Droop Control, which can reduce the response speed and the stability of the system. When the line impedance increases (larger resistive component) to a threshold value, the system will become unstable. Different secondary control methods are discussed in the following Table.2.

Table 2. Different Secondary Control Methods are Discussed

Solutions	Limitations
Centralized secondary control	Low reliability Communication is required
Distributed secondary control	Parameter mismatch may cause power sharing inaccuracy Communication is required
Adaptive inverse control	Lack of synchronization may cause different operation status for parallel inverters

When the inverter output impedance is highly inductive, hence the active and reactive powers drawn to the bus can be expressed

$$Pi = VEi / X \sin\phi$$
$$Qi = VEi\cos\phi - V_2 / X$$

where X is the output reactance of an inverter, φ is the phase angle between the output voltage of the inverter and the voltage of the common bus, and Ei and V are the amplitude of the output voltage of the inverter and the grid voltage, respectively. It can be found that the active power is predominately dependent on the power angle, while the reactive power mostly depends on the output voltage amplitude. This principle can be integrated in voltage source inverters (VSIs) by using the well-known P/Q droop method which can be expressed as

$$FI = FRATED - MP \cdot (PI - PRATED)$$
$$EI = ERATED - NQ \cdot (QI - QRATED)$$

where i is the index representing each converter, *f*rated and *E*rated are the nominal frequency and voltage of the microsource, respectively, Pi and Qi are the average active and reactive power, *P*rated and *Q*rated are the nominal active and reactive power, respectively, and mP and nQ are the active and reactive droop slopes, respectively. The choice of *mP* and *nQ* impacts the network stability, so they must be carefully and appropriately designed. Usually, the droops are coordinated to make each DG system supply apparent power proportional to its capacity

$$Mp = FI - FMIN$$
$$PI - PI, \text{MAX}$$
$$NQ = EI, \text{MAX} - EI, \text{MIN}$$
$$QI, \text{MIN} - QI, \text{MAX}$$

The control algorithm with conventional droop control is illustrated in Figure 5. The power stage consists of VSI with a LC filter and a coupling line inductor. The controller consists of three control loops.

a. A power sharing controller is used to generate the magnitude and frequency of the fundamental output voltage of the inverter according to the droop characteristic.
b. A voltage controller is used to synthesize the reference filter inductor current vector.
c. A current controller is adopted to generate the command voltage by a pulse width modulation module.

As discussed above, the conventional droop method can be implemented without communication between modules, and therefore is more reliable.

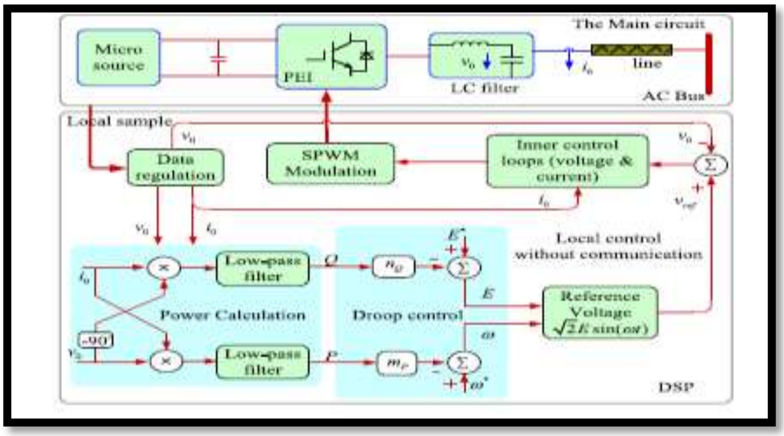

Figure 5. Control structure of conventional *P*/*f* and *Q*/*V* droop control

3.3. Proposed Hybrid Droop/Signal-Injection-Based Method

A small ac voltage signal is injected into the system as a control signal. The real power due to the control signal is drooped with the voltage amplitude or the bandwidth. Therefore, the reactive power or the distortion power can be regulated by controlling the frequency of the injected control signal (Figure 6). Conventional droop control cannot ensure a constant voltage and frequency, neither an exact power sharing. But an advantage of the control can avoid communication among the DGs. Communication-based control is a simple and stable strategy providing a good current sharing, yet a low reliability and redundancy. Therefore, to take advantage of their respective advantages, a hybrid scheme combining two control methods. The sharing of real and reactive powers between the DGs is easily implemented by two independent control variables: 1) power angle; and 2) voltage amplitude. However, adding external communication is still not desired. Such communications increase the complexity and reduce the reliability, since power balance and system stability rely on these signals. Several current sharing techniques based on frequency encoding of the current sharing information The power lines are used for the communication for the power sharing. Most importantly, this technique does not require extra control interconnections and automatically compensates for inverter parameter variations and line impedance imbalances. Each DG injects a small ac voltage signal to the micro grid. Frequency signal *wq* is determined by the reactive power *Q* of the DG.

$$\omega Q = \omega Q0 + dQq$$

where w_{q0} is the nominal frequency of injected ac signals and D_Q is the boost coefficient. The small real power transmitted through the signal injection is then calculated. And the value of the output voltage, E, is adjusted as

$$E = E_* - Dp.Pq$$

In this way, a Q/V droop is achieved, through the frequency component w_q. In the presence of nonlinear loads, the harmonic distortion D caused by nonlinear loads is shared in similar way. A control signal with a frequency that is drooped with D is injected. The power in this injected control signal used to adjust the bandwidth of the voltage loop

$$\omega d = \omega d0 - mD$$

$$D = \sqrt{(S2 - P2 - Q2)}$$

$$BW = BW0 - Db\omega Pd$$

where BW_0 is the nominal bandwidth of the voltage loop and D_{bw} is the droop coefficient. The block diagram of the signal injection method is shown in Figure 6. Signal injection method properly controls the reactive power sharing and is not sensitive to variations in the line impedances. It is also suited for linear and nonlinear loads.

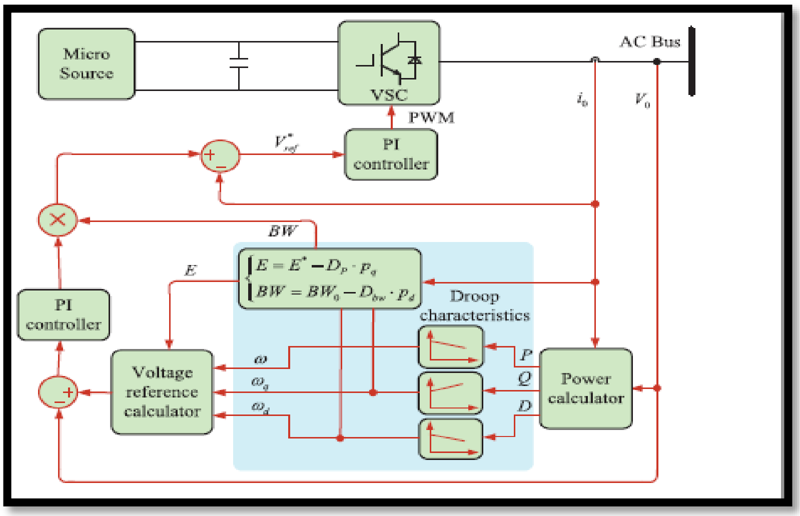

Figure 6. Proposed Block diagram of the frequency signal injection method

3.4. A Review on Comparison of Our Proposed Method (Hybrid Droop/Signal Injection Method) with Conventional Method is Explained in Table 3

Table 3. A Review on Comparison of Our Proposed Method (Hybrid Droop/Signal Injection Method) with Conventional Method

Droop characteristic based control	Advantages	Disadvantages
Conventional frequent droop control	High expandability and flexibility Easy implementation without communication	dynamic response is low poor voltage and frequency regulation physical parameter will be effected
Hybrid droop/signal injection method	High reliable It can handle linear & non linear loads and not effected by physical parameters. Effect of line impedance imbalance can be compensated	Cause harmonic distortion voltage

4. CONCLUSION

This paper has presented an overview of the hybrid energy systems and different power sharing control strategies of off grid hybrid system. Detailed description of maximum power point tracking of PV, wind energy system and the conventional and signal injection control schemes has been given. The communication-based methods of concentrated control, master/slave control, and distributed control perform a good current sharing, yet a low reliability and redundancy. Based on review work done, the droop characteristic-based control method has been presented to avoid communication lines/cables; optimal power sharing and which can help increase the system reliability, modularity, and flexibility.

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