International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Solar/Wind Hybrid Renewable Energy System and Associated Control Issues – A Review

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ABSTRACT-

This paper reviews various configurations based on power electronics converters and their control issues in hybrid renewable energy systems (RES). The paper is focused on important control issues and challenges in the design and power utilization of hybrid RES. Different configurations of Wind/Solar system, generation side control and grid side control have been comprehensively covered and reviewed. The methods of using control concepts for enhancing hybrid renewable energy system performance in distributed grid system to meet the recent grid codes are discussed. Finally, future directions and important challenges related to this area are also presented.

Keywords- Hybrid energy system, Distributed grid, Grid code, Power electronics converters, renewable energy system, Wind/solar system.

I. INTRODUCTION

Due to the limited and depleting resources of conventional energy and environmental concerns, the hybrid renewable energy systems (HRES) are emerging as the sustainable and promising alternative to meet the growing demand of electricity which is environmentally friendly as well as competitive in terms of economy [1]. This is one of the active areas of research due to the fast development in power electronics converters which is increasing the possibilities of easy, efficient and cost-effective power transmission and utilization of RESs as compared to conventional energy sources [2].

But the RESs are by nature unpredictable due to changing weather conditions, therefore, the reliable and continuous power generation capability cannot be achieved only by one RES, however, the same can be achieved to a great extent by HRES using energy storage devices along with. Wind and Solar are the most significant renewable sources of energy available on daily and seasonal basis. HRES (Wind/solar) is becoming the most attractive and promising energy source which is practically feasible and provides continuous energy reliability [3].

Many researchers have proposed different configurations and control schemes on wind and solar energy systems and their hybrid combinations for improved performance [4]-[6]. But HRES are still in the development stage and are facing many challenges in which there is growing research on different prospects of HRES and their control issues to make them cost effective and efficient [7]-[9]. This review paper presents a recent perspective on the developments of HRES, their power electronics-based controls and future challenge. This paper is categorized as follows. In section II, the different configurations and future scope of change in HRES configurations are described. In section III, we discuss different types of generation side control of hybrid energy system to increase the efficiency of system by using Maximum power Point Tacking (MPPT) methods. There are different methods for MPPT tracking of wind and solar systems which have been discussed for Hybrid renewable energy systems. In section IV, grid side/load side control techniques have been discussed for hybrid renewable energy systems. Different Power electronics converters for off grid or grid interface and their control schemes are covered in this section. In Section V, recent challenges in the field of Hybrid energy systems and suitable enhancement in control schemes has been discussed. Future prospects of Hybrid renewable energy system are also discussed in this section. Lastly, section VI concludes this paper with highlighting some of the important issues and future trends of Hybrid renewable energy system.

II. DIFFERENT CONFIGURATIONS OF HRES

Every renewable energy system has different set of physical components and operating characteristics. Therefore, it is necessary to have in place a planned framework for interfacing them to make HRES. Renewable energy sources, loads and intermediate storage device should be integrated in such a way, so that they can operate and exercise control independently.

Renewable energy sources in HRES should have the capability to connect and disconnect from the grid smoothly and independently in the event of a fault or islanding conditions. There are different HRES configurations possible and for proper interfacing with the grid, power electronics converters are needed. Many researchers, in the past years, have proposed different configurations of HRES which have generally been categorized in three sub categories as: DC coupled, AC coupled and Hybrid coupled based on ac and dc load sharing. DC coupled category can further be divided into two sub categories namely: Residential DC and Bipolar DC network coupled, similarly AC coupled category is divided into two sub categories namely: High frequency AC (HFAC) coupled and power frequency AC (PFAC) coupled [10]-[15].

These configurations are briefly discussed as under:

1) *DC coupled system*: These are categorized further in two sub categories as illustrated in the following subsections:

a) In DC residential coupled system, the hybrid renewable system sources are connected with DC bus through power electronics interfacing. DC or microgrid draws attention to innovate effective solution to meet our future energy distribution challenges. Fig. 1(a) shows a possible future DC coupled grid interface of hybrid renewable energy system sources. Allsources are connected with DC buses with suitable control technique of power conditioning through power electronics converters. This type of configuration is effective and useful where DC loads are in bulk as compared to AC loads. DC coupled system is also useful in off grid condition where load is only residential. HRES with DC coupled configuration have many advantages over AC coupled as discussed in [16].

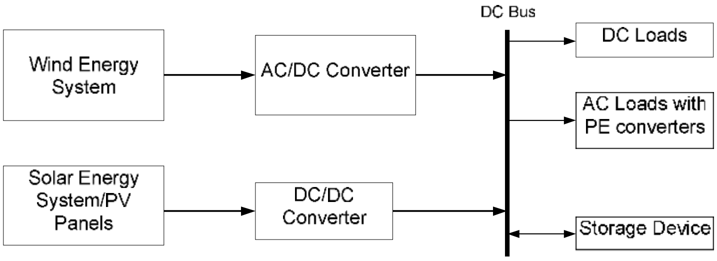


Fig. 1(a) DC residential coupled system

b) In DC Bipolar coupled configuration, shown in Fig. 1(b) [17], the hybrid renewable energy sources are linked with HVDC bipolar lines through proper power electronics interfacing and their associated control techniques. Some researchers suggest several advantages of Bipolar DC link over AC grid for future energy distribution systems, like high reliability, lower power losses, high power transfer capability, system stability etc. [17].

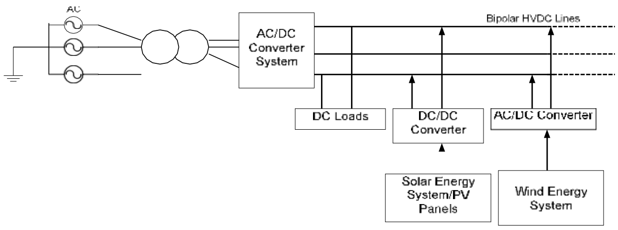
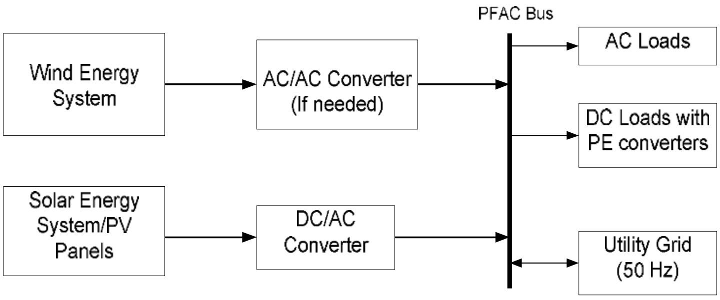


Fig. 1(b) DC Bipolar coupled configuration

2) *AC coupled system:* This configuration is based on AC bus coupling which also is further divided into two subcategories; PFAC and HFAC and is as shown in Fig.2 (a & b) [10].

a) In Configuration of PFAC, where, all sources are connected to power frequency AC bus through suitable power electronics converters and loads are connected to the PFAC bus for power utilization [18]-[20].



b) In HFAC configuration, all diverse energy sources are connected to HFAC bus where HFAC loads are also connected to get power from the bus. HFAC configurations are primarily used where HF loads are present like airplanes, space applications and submarines [21].

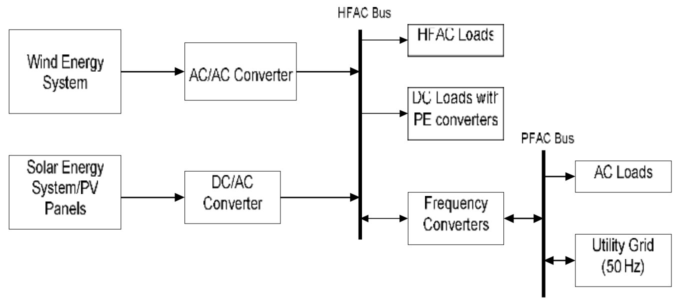


Fig. 2(b) HFAC configuration of AC coupled System

3) Hybrid coupled systems: In hybrid configuration, as shown in Fig. 3, diverse sources connected with different buses either DC coupled or AC coupled, depend on the output of the sources which results in reduction of the interfacing circuits (power electronics converters) and hence increases the overall efficiency of the system. By appropriate coupling of different sources, cost reduction is also possible in hybrid coupling [22].

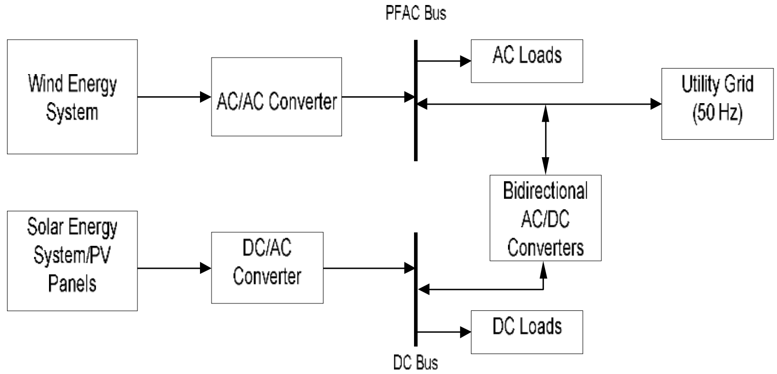


Fig. 3 Hybrid configuration system

Different types of coupling are used depending mainly on the sources, DC or AC load percentage and location of the load whether grid availability is present or not in that area

IV. GRENRATION SIDE CONTROL TECHNIQUES

To enhance the performance and maximize efficiency of HRES, Generation side control techniques are utilized which are generally called MPPT control. There are different controls meant for different RES which have different operating characteristics in HRES. This section is focused on Wind/Solar HRES with different MPPT control schemes. This paper presents, in the following subsections, critical review on MPPT control techniques for both the sources (wind/solar) based on comprehensive literature survey [23]-[27]. General block diagram of MPPT control is shown in Fig.4 with boost converter (any DC-DC converter can be used) for wind/solar and input variables of MPPT block depend on MPPT methods.

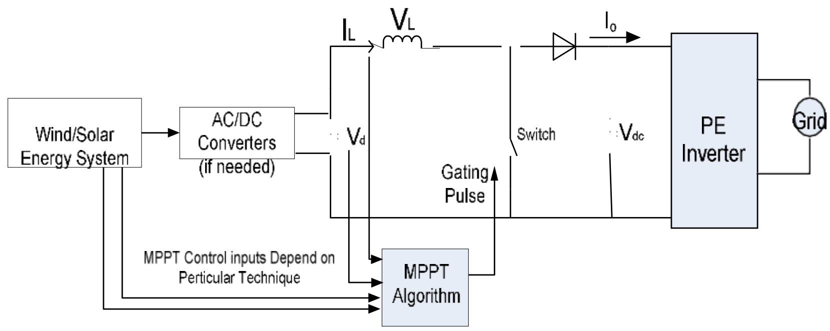


Fig. 4 Basic Diagram of MPPT control

1) *Perturbation and Observation (Hill-Climbing) method*: P&O methods are used for both sources to achieve MPPT for maximize the power output [28] [29]. Various derivatives of P&O have also been utilized as reported in literature for wind /solar energy sources using power electronics converter mainly boost converters [30]-[32]. It is simple MPPT method and only uses the current and voltage information of boost input to control by changing duty cycle of boost converter as per the information. P&O has many advantages like no need of a-priory information, no need to measure wind speed and quick response in steady variations etc. but there are some limitations also like adding extra power electronics converter, oscillations at maximum power point, and failure in sudden changes.

2) *Incremental conductance (IC) method*: This method can also be used for both wind and solar sources for MPPT. In this method, derivative of power with respect to voltage is used to search maxima point using P versus V characteristics of energy sources [33]. This method also does not require any prior information and has some advantages over P&O like damping out of the oscillations at maximum point, and simple in application but this method is not as fast as P&O and dynamic response of the system is also not proper in IC control method [34]-[36].

3) *Modified P&O method*: In this method, both P&O and IC techniques are mixed like hybrid MPPT control which removes the disadvantages of both techniques and thereby presents unique solution to get maximum power. This method uses P&O method for fast dynamics to achieve near maximum point then use IC method to damp out oscillations and get maximum point which results in increase in the power output and removal of the oscillations [37] [38].

Some techniques available for MPPT control depend on the type of source, like wind energy has some methods and solar energy have some other methods for MPPT control. A brief discussion is presented on such techniques in the following subsections:

In wind energy source, MPPT control can be achieved by Tip speed ratio (TSR) which uses wind speed and turbine speed for aching MPPT. TSR is based on turbine speed regulation according to given wind speed by using wind speed-turbine speed relation to get optimized value of TSR using regulation. But there are implementation difficulties in the TSR method due to the difficulties in measurement of wind speed [39]-[42]. Another method is optimum-relationship based (ORB) control technique which ensures MPPT with adequate solution of optimum relationship between system variables and parameters. Measurement of wind speed is not required in this technique and there is surety of fast response with changing wind speed. ORB has two methods, one based on power versus rotor speed relationship and the other on power versus rectified dc voltage relationship. This is an established technique which can be used for various power ratings and illustrated in literature [43]-[45].

Unlike wind, solar energy sources have several MPPT techniques and their derivatives which have been reported in literature. Some of them are briefly discussed below:

Curve fitting technique is used for solar panel MPP which is based on fitting the curve of third order polynomial offline mathematical model and P-V characteristics of the solar cell [46] [47].

Fractional Short-Circuit Current (FSCI) Technique is also used in solar energy to get maximum power point using the information of the short circuit current at which power is maximum at given conditions [48].

Look-up Table Technique uses memory device of MPPT control box to store the data of MPP of a PV system calculated before the use of system for each probable environmental condition. During the operation, control tool makes use of the stored data to achieve MPP condition for every particular environmental situation [49].

Feedback Voltage or Current Technique is applied on the system having no storage battery; a simple controller is needed to maintain the voltage constant without battery. Therefore, a simple MPPT method can be applied by getting feedback of panel voltage or current and compared with the reference voltage; boost converter tracks that reference using the adjustment of duty cycle and continuously operates near MPP region [50]. In some works reported in literature, discussion is available on *Feedback of Power Variation with Voltage Technique* which is similar to the feedback voltage or current technique and is simply a derivative of that [51].

Linearization-Based MPPT Technique is based on the linearization model of PV system and gets the locus of voltage and current at the MPP [52].

Intelligence MPPT Techniques have different derivatives based on the control tool like artificial neural network (ANN), particle swarm optimization (PSO), fuzzy logic based MPPTs [53]-[55].

To achieve generation side control of HRES, there are different methods depending on the sources of HRES. Some important works have been discussed which are important for generation side control to increase the efficiency and reduce the effective cost of HRES system.

V. GRID SIDE CONTROL TECHNIQUES

Grid side control techniques came into significance after the interface of different sources in HRES through common DC link. Therefore, grid side controls are common for both sources (wind and solar) in HRES using power electronics inverter. Inverter is used for interconnecting HRES and grid through proper LC or LCL filters and transformers (optional). The main purpose of grid side control is the following:

- Control of generated real power through HRES,
- Reactive power control transfer between grid and HRES,
- Grid synchronization.
- Keeping DC link voltage constant,
- Harmonic compensation.

All above mentioned controls are achieved by grid side control in HRES using different control techniques which have been proposed in literature using control of the switching sequence of power electronics inverter [56]-[58].

Grid side control techniques are mainly having two cascaded control loops called inner loop and outer loop. Inner loop is used for fast dynamics of system and controls the current injection into grid and harmonic compensation while outer loop control is used for keeping DC link voltage constant and system stability.

Several authors have proposed different methods to achieve proper functioning of cascaded loops for grid interface, some of those techniques are briefly reviewed in the following subsections:

1) *Voltage Oriented Control (VOC):* VOC method is used by many researchers as reported in literature for grid side control. This method is mainly based on power balancing equation of inverter to grid through LCL or LC filter. By sensing DC link voltage, grid voltage and current into stationary frame (ABC to DQ transform), reference current for inner loop and outer loop are generated. Active power control is achieved by d-axis current and reactive power control by q-axis current in VOC [59] [60]. Several derivative methods of VOC have also been discussed in many research papers like VOC using PI controller, VOC using PR controller, VOC using hysteresis control etc. elaborating on their advantages and disadvantages [61] [62].

2) *Current Control method (CCM)*: With the use of different power electronics inverters some research papers have proposed CCM which depends on the dc link current and line currents of the grid to generate reference d and q axis current for switching control of inverters. CCM also has different derivatives like instantaneous current method, Lyapunov based CCM, current vector control method etc. to achieve control objective of grid side [63]-[65].

3) *Feedback Linearization Control (FLC)*: FLC method is based on the transformation of nonlinear HRES into linear system through feedback linearization to control all variables independently. Using lie derivatives in FLC, output and input can be related to develop the controller of the system. FLC has got many advantages like no need of PI gain values, better control in fault and islanding condition and fast dynamic response [66] [67].

All control methods for grid side control are mainly derived from the above methods with different tools like ANN, Fuzzy and power electronics inverters such as current source inverter, Dual inverter, Matrix converter, Multilevel matrix converters etc. [68]-[70].

In this subsection some grid side control schemes, which are standard control methods, have been reviewed besides all other controls as are proposed under current research, mainly derivatives to achieve better performance, quality of power, reduction in complexity of control, reduction of effective cost and reduce disadvantages of above discussed methods.

VI. FUTURE CHALLENGES

Hybrid renewable energy system is an emerging area of research in electrical energy sector which is still not an established area and needs much attention to improve efficiency, reduce cost and match the growing demand of electricity. There are challenges to achieve quality power at cheaper cost with better efficiency. Some of the challenges in hybrid renewable energy systems are mentioned below:

1) Scope of improvement in control aspects of transition between grid interfaced HRES and islanded mode or vice-versa.

2) There is need to improve the control and reduce the adverse effect due to the penetration of different renewable sources in HRES on grid.

3) Issues in re-synchronization capability to connect the autonomous islanding to the grid without any disturbance or interruption.

4) Need to develop new MPPT control which satisfy fast Dynamic response and stable steady state of the response for HRES.

5) Need to find a way for MPPT control using single DC-DC converter in HRES which can simplify control and reduce the effective cost of the overall system.

6) Power quality enhancement for specific loads during operation is needed which is important and significant in case of HRES systems.

7) HRES should have some control mechanism in place to improve the grid stability during abnormal as well as normal conditions.

VII. CONCLUSION

The paper presents a critical review of the works reported on hybrid renewable energy systems and their associated controls based on the survey of available literature. Due attention has also been paid to recent developments, such as control schemes based on the concepts of neural networks and fuzzy logic and the incorporation of other evolutionary algorithms like PSO. Emphasis has been given to categorizing various configurations of hybrid renewable energy systems highlighting their salient features and control methods used therein for efficient and cost-effective operation of these systems. Control techniques of both generation side control as well as grid side control and role of power electronics converters in it has been discussed.

Finally, some of the challenges in different areas of hybrid renewable energy systems are discussed to improve overall system performance in future.

Although the authors have sincerely attempted to present the comprehensive set of references on hybrid renewable energy systems and their associated controls, they would like to apologize for exclusion of many good papers because the literature is voluminous and hope that additional references will be advanced as discussion to this publication. It is envisaged that this paper will serve as a valuable resource to any future researcher in this important area of research.

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