

# Integration, Power Management Control and Communication Technologies in Hybrid Energy Systems- A Review

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*Received: 18.04.2024 Accepted: 13.05.2024*

**Abstract:** Renewable energy systems are recent trends in power generation all over the world as it is environment friendly. Technical development of renewable energy technologies and socio-economic benefits are the other reasons of adopting these technologies. Integrating multiple numbers of alternate energy systems with suitable energy storage systems in an optimal way makes the power supply more reliable. As renewable sources are unpredictable and intermittent nature, suitable energy storage system is needed for an uninterrupted power supply acting as a stand-alone system. Hybrid renewable energy systems with or without storage systems can be connected to grid with grid interfacing inverters. Various technical issues like voltage, frequency control, islanding detection and corrective measures are needed to be taken in a right way. Efficient power management control is essential for an optimally sized hybrid system. Various controller-traditional as well as advanced controllers are implemented for power management. Communication technologies play an important role in management and control of hybrid system. This paper presents the different technical aspects of hybrid energy systems-configuration, power management control, role of communication technologies in power sharing control. Research challenges and future research directions are discussed.

**Keywords:** Hybrid energy systems; HRES optimal control; Wireless control; Power management control, Communication technology.

## 1. Introduction

Energy demand all over the world is increasing rapidly due to population growth in developed and developing countries. As there is a limited resource of fossil fuel-based energy, people are adopting the use of non-conventional based energy systems. It is environment friendly; resources are free and abundant throughout the world. It has various socio-economic benefits also. But renewable sources have limitations of its unpredictable and intermittent nature [1].

Application of non-conventional energy systems in isolated island or remote rural area becomes more popular. This is due

to the reason that expansion of conventional grid to the isolated place is not possible and it is not an economically viable solution. Inaccessibility of conventional grid and lack of rural electrification encourages people to exploit the non-traditional type energy resources [2].

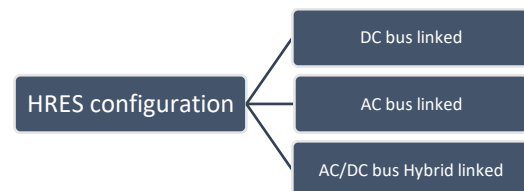
Renewable based hybrid energy systems are most promising technologies in remote rural communities to supply power because of some technical and economical benefits compare to

the single energy systems [3]. Combining alternate energy systems with energy backup systems is known as hybrid renewable based energy systems (HRES), which can operate independently of the grid or in conjunction with it [5]. In literature different combinations of renewable energy systems are available depending on the site-specific energy resources. Due to the intermittent nature of renewable sources, sizing optimization of HRES components is needed [115]. Oversizing or under sizing of HRES will affect the cost of HRES, cost of energy production as well as the power supply reliability. Different sizing methods-optimization based; software based are presented in literature [4]. Due to improvements of control technologies, interfacing power converters and renewable energy technologies, HRES is now an attractive solution in remote areas [6]. The hybrid systems may be linked with the stable power sources like diesel generator to make it more reliable. Because of the stochastic behavior of non-conventional energy systems, HRES is incapable to supply a stable and reliable power to load. Various stable power sources, such as batteries, pumped hydro storage, fuel cell, superconducting magnetic energy storage, super capacitors and diesel generators are to be integrated to create HRES, which can be operated independently or in conjunction with grid [7]. In spite of several advantages of using HRES, there are few power quality problems. Such problems are like fluctuation of power, voltage and frequency of power supply. The intermittent behavior of non-conventional energy resources and plug & play capabilities of HRES produce power fluctuation in power supply. In addition to that problem there are voltage and frequency fluctuation in the power supply due to shifting from stand-alone system to grid connected system or vice versa [8]. So, the HRES must be able to suppress the power fluctuation by using proper power management control approach for a high quality and reliable steady power supply [9]. Various control methods are integrated in the interfacing power converters for power management of HRES [10]. The utmost challenging issue is to make an effective controller for the power management of the HRES. Authors have reviewed in detail on sizing, power management and optimization of HRES. Details modelling of HRES have been reviewed [11-13]. A detailed power management strategies have been reviewed on PV-wind battery based HRES in literature [14]. It helps researchers very much for the further improvement of the designing and integrating of HRES. Authors have reviewed different configurations, control strategy, economic impacts analysis and social outcome of PV-wind based HRES applications in rural area [15,16]. To supply a good quality power to the load, power management of the HRES system is needed to balance the supply and demand. To do the power management, power sharing among the different HRES components is very essential. Power sharing is done effectively and efficiently by the use power converters control. Communication technologies acts a very significant role in modern clean energy systems power applications [17]. So, power converters control, control schemes and communication technologies are important parameters for the modern HRES systems power management control. In the previous study all these parameters are not reviewed in a merged way.

Objectives of this paper is to review the advancement of various integration topologies of HRES, different power management control schemes, communication technologies used for power sharing control in HRES and droop-based power sharing control. In Section 2, it is discussed about the different integration technologies which are available in literature. Section 3 represents the power management control schemes for different types of HRES. Section 4 discussed about the different control structures of HRES power management. Also, their merits and demerits are presented in details in Table 3. In Section 5 and Section 6, it is presented about the different conventional and advanced controllers required for the efficient power sharing. Section 7 the various communication technologies used for the HRES power management. Wired and wireless technologies are presented with their merits and demerits. The difficulties and potential research directions of HRES research are discussed Section 8. Finally the conclusions derived from review work.

## 2. Integration Topologies of HRES Configuration

In the configuration of HRES, different alternate energy systems and DC/AC type load or both are connected through the AC/DC bus or both with the help of interfacing power electronics converters. There are different topologies of interfacing the different types of renewable energy systems and conventional systems within a HRES configuration. The most challenging task to configure a HRES is to reduce the numbers of energy conversion stages and to use an efficient control mechanism. This will make a more dependable and cost-effective configuration [18]. There may present energy backup devices in the HRES. The function of energy storage is to take excess energy generation and supplies energy during shortage of energy production. Thereby balancing the supply and demand. There are different types of HRES configurations: (i) DC bus linked, (ii) AC bus linked and (iii) AC/DC hybrid linked. The HRES may act as a standalone or may be connected to a traditional grid system [19]. The classification of various HRES is depicted in Fig.1.



**Fig. 1.** Classification of HRES configuration

### 2.1 DC Bus Linked Standalone/Grid Connected HRES

Figure 2 represents the DC bus linked HRES configuration. DC energy systems like solar, are connected to the DC bus via DC-DC converters. AC energy systems like wind power, hydro etc. are connected via AC-DC converter and the backup systems like battery, capacitors are connected through DC-DC bidirectional converters [18,20,21]. In stand-alone mode of operation, energy storage devices are used for supplying the shortage of power and excess power generation is used to charge the storage system. Thereby balancing the power

supply and power demand. For grid interfaced HRES systems, energy storage systems may be or may not be connected. The main advantage of this type of configuration is that synchronization among different energy systems is not required. Control mechanism is easier compare to the AC linked HRES. So, the power management of DC bus linked HRES is easier compare to the AC linked systems. This configuration may use multiport DC-DC converter instead of using several numbers of DC-DC converters to minimize the conversion losses [22]. This type of configuration is used when numbers of DC energy systems are more than numbers of AC energy systems.

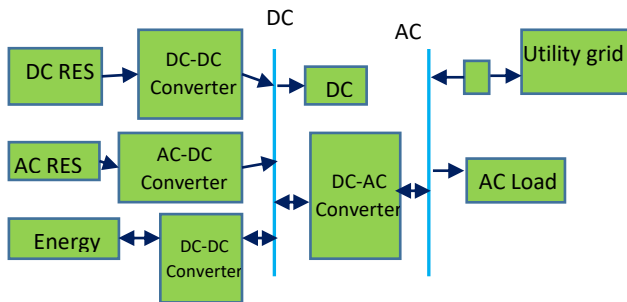


Fig. 2. DC bus linked HRES configuration

## 2.2 AC Bus Linked HRES

Figure 3 shows the AC linked HRES. Energy systems are connected to the common AC bus through interfacing power converters. DC energy systems are connected via DC-AC converters, AC energy systems are connected via AC-AC converters and DC/AC bidirectional converters are needed to connect the energy storage devices with the AC bus [20-22]. This type of configuration is used when numbers of AC energy systems are more than DC energy systems. As AC energy systems are connected, synchronization among them is essential for a good quality power supply. For this type of configuration also multiport converter may be used to reduce the power losses due to multiple numbers of converters [24].

## 2.3 AC/DC Linked HRES

Figure 4 represents the AC/DC linked HRES. In this configuration both AC and DC buses are available. AC energy systems are interfaced with the AC bus and DC energy systems are interfaced with DC bus [20,23,113]. Here no of

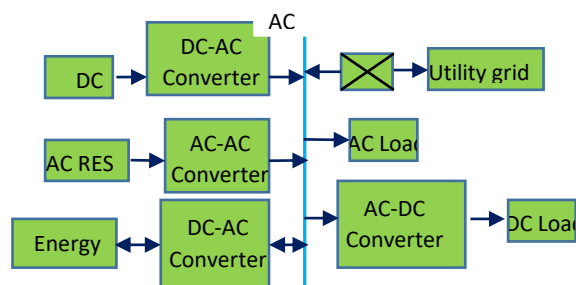


Fig. 3. AC coupled HRES configuration

converters stages are reduced compare to the previous two types of configurations. Due to the presence of two bus, control mechanism is more complex than the previous two topologies.

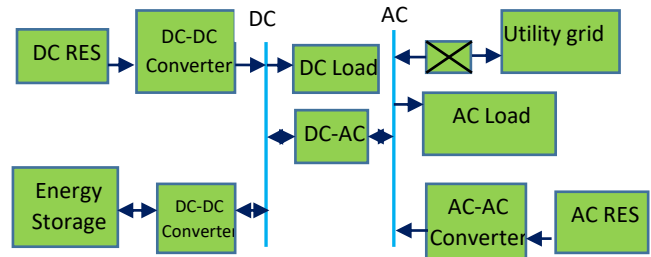


Fig. 4. AC/DC linked HRES configuration

These types of hybrid system may be operated as standalone or may be operated as grid connected mode. There may be a dummy load in a large standalone HRES which reduces the capacity of connected backup systems [23]. In the on-grid system, the size of storage devices may be reduced or omitted from the structure, thereby reducing the overall system cost. There may be excess power or deficit of power generation sometimes. In these situations, grid is used to balance the power supply and demand. By reducing systems cost and recovery of system cost by selling it to grid makes it more attractive configuration [22,25,26]. Table 1 shows the summary of HRES configurations along with their benefits and drawbacks. Table 2 shows the various HRES topologies presented in literatures in standalone/grid connected mode for various applications.

## 3. Power Management Control Concept in HRES

Power transfer among the various components in the HRES must be controlled properly through the interfacing converters. The interfacing converters are driven by an explicit power management control strategy to have a stable and good quality power supply in isolated/grid connected mode of operation. The power management control concept for a DC linked HRES is presented in Fig.5.

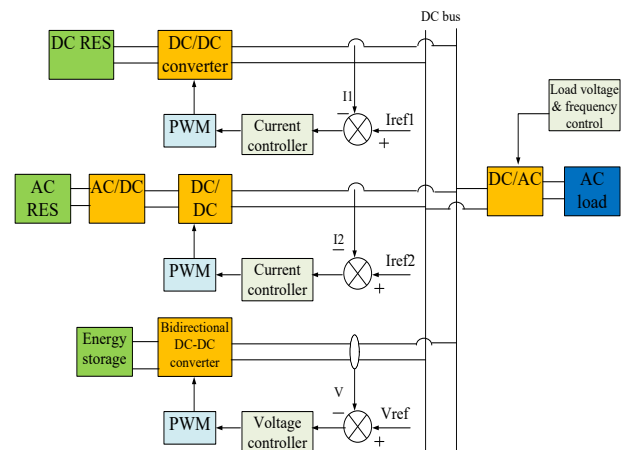


Fig. 5. Control concept of DC linked HRES

**Table 1.** Various HRES configuration topology

| Type of HRES   | Types of RESs | Mode of operation          | Storage                                                           | Benefits                                                                           | Drawbacks                                                      | References |
|----------------|---------------|----------------------------|-------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------|------------|
| DC coupled     | DC/AC or both | Standalone                 | Required                                                          | Simple, synchronization not required, power management control complexity is less. | If DC bus fails the entire system will stop working            | [26-28]    |
| DC coupled     | DC/AC or both | Grid connected             | May be omitted/Reduced size                                       | synchronization not required, DC bus fails then the system will work,              | Grid synchronization is required.                              | [29-31]    |
| AC coupled     | DC/AC Or both | Standalone                 | Required                                                          | Less numbers of converters                                                         | Synchronization is required; control complexity is more.       | [20-22]    |
| AC coupled     | DC/AC or both | Grid connected             | May be omitted                                                    | Less numbers of converters                                                         | Systems synchronization is needed                              | [32-34]    |
| Hybrid coupled | DC and AC     | Standalone /grid connected | May be omitted/reduced size for grid connected mode of operation. | Less numbers of converters than other types, high system efficiency                | Systems synchronization needed, complex power sharing control. | [35-41]    |

**Table 2.** HRES at various locations for different applications

| Region/Country                       | RES & Configuration         | Application                       | Technology/Software used in the work | Reference |
|--------------------------------------|-----------------------------|-----------------------------------|--------------------------------------|-----------|
| Rajasthan, India                     | PV-WECS-BGS                 | Agriculture                       | Goal programming                     | [42]      |
| Northern Australian community        | PV-BESS-DG standalone       | Domestic                          | Dynamic modeling, ANN technique      | [43]      |
| Remote hilly area Uttarakhand, India | PV-BG-WECS-BESS standalone  | Agriculture, domestic             | LPSP IREM                            | [44]      |
| Indonesia                            | PV-MHP-BESS                 | Domestic                          | LCOE based method                    | [45]      |
| Abu Dhabi                            | PV-WECS standalone          | Domestic                          | HOMER                                | [46]      |
| 3 Villages in Chennai, India         | PV-WECS-BGS-BESS            | Domestic                          | HOMER                                | [47]      |
| Villages in Kerala                   | PV-MHP-WECS-DG              | Others                            | Nonlinear programming                | [48]      |
| Madhya Pradesh, India                | PV-WECS-BECS                | Domestic                          | Power Pinch Analysis                 | [49]      |
| Jaunpur block in Uttaranchal         | PV-BGS-WECS standalone      | Domestic, Agriculture, Commercial | LP/LINDO 6.10                        | [50]      |
| Gokceada, Turkey                     | PV-WECS-BESS-FC standalone  | Domestic, commercial              | HOMER                                | [51]      |
| Khvaf, Khorasane-Razavi, Iran        | PV-FC grid connected        | Residential                       | PSOAIW & PSOCF                       | [52]      |
| Kavaratti, Lakshadweep               | PV-WECS-BESS grid connected | Domestic,                         | HOMER, DigSILENT                     | [53]      |
| Gothenburg, Sweden                   | PV-BESS grid connected      | Residential                       | Multi objective GA                   | [54]      |
| South African area                   | PV-WECS-BESS grid connected | Residential                       | MPC                                  | [55]      |
| Canada                               | PV-Hydrogen-Diesel          | Stand alone House hold            | HOMER                                | [116]     |

During islanded mode of HRES operation, the reliable power source must be operated as controlled voltage source to adjust the voltage of DC bus and the other sources must be operated as a controlled current source to handle power sharing among the power sources in accordance with the load demand [56]. The load side inverter must be controlled properly so that it can supply stable voltage and frequency to the load. Therefore, to regulate the voltage & frequency of power supply, a voltage & frequency (V/f) control scheme is required for inverter [57-59]. To control the active and reactive power supplied to the grid, the inverter at grid side must be act as a controlled current source in the grid connected HRES system [60]. So, an active & reactive power (PQ) control mechanism must be available for the grid side inverter [58,59]. Figure 6 represents the AC bus interfaced HRES control schemes. In this system the alternate energy systems and storage systems are linked with the AC bus parallelly. The required load power is shared by the different RESs and storage systems as per their power ratings. The interfaced converters are controlled to share the power properly among the sources [61]. The AC bus voltage is maintained at a steady value, by operating at least one of the stable power sources as controlled voltage source [62]. All other sources must be operated as controlled current source owing to their parallel connection to the AC bus [56]. Therefore, the stable power source must be operated by voltage & frequency (V/f) control and the rest of the sources are to be operated by one of the two control mode-(i) PQ control, (ii) Active power & voltage (PV) control. For a grid connected AC coupled HRES, AC bus voltage & frequency is kept at a stable value by the grid side power converter control. So, the power converters may adopt any one of the PQ, PV or V/f control scheme [63].

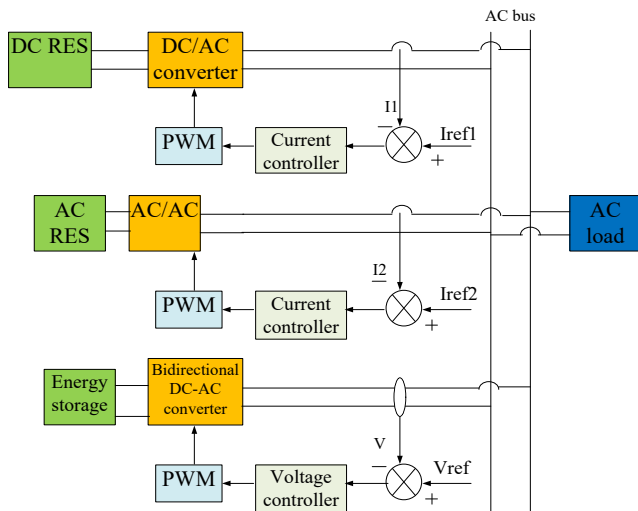


Fig. 6. Control concept of AC linked HRES

#### 4. Control Structures of HRES

For executing an efficient and reliable power management strategy, the interfacing converters must be perfectly controlled. For HRES power management control considering different constraints, a multi-level control structure has been extensively applied as a standard solution [64-66]. It combines

three control levels which is presented in Fig.7 – namely-(i) primary, (ii) secondary, (iii) tertiary control.

- In the primary level local controllers control local voltage, current and power. These are driven by the set point decided by secondary level.
- The secondary control level is located above the primary level. It is used for the regulation of power quality, coordination in HRES and synchronization of HRES with external grid.
- Tertiary level deals with the system overall economic, environmental optimization, fault management, coordination of multiple systems, islanding and interconnection management.

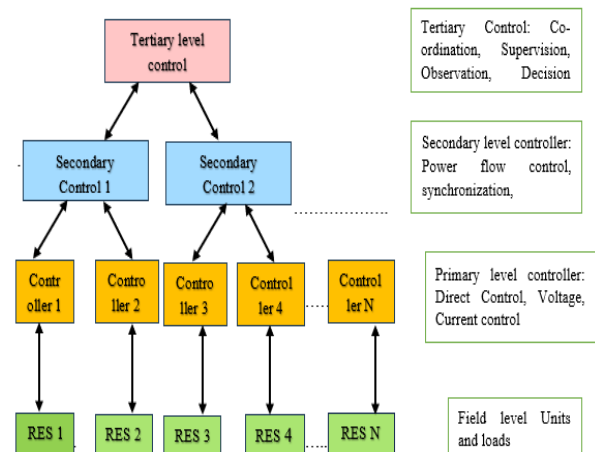


Fig. 7. Hierarchical structure of HRES power management control

As the hierarchy presented in Figure 7 above, the implementation of the control levels are done in four different ways-(i) Centralized, (ii) Decentralized, (iii) Distributed and (iv) Hierarchical way as shown in Fig.8. Depending on the various application i.e., residential, commercial or agriculture or army etc. and depending on the legal and physical parameters like sizing of systems, place for the installation and configuration etc. the suitable control structure is selected. In the centralized control, the central controller gathers the numerous data's and gives instructions to the local RESs as shown in Fig. 8 (i) [67,68]. But in decentralized control structure as shown in Fig. 8 (ii), no central controller is present. The local controllers work separately in a decentralized way [69]. No dedicated communication lines are required for both centralized and decentralized control. The power lines are used for both transferring power and communicating signals. The distributed control structure is depicted in Fig. 8 (iii). There is no central controller but the local controllers are interconnected with each other through communication link [70,71]. For the hierarchical control structure, control tasks are distributed among the local controllers and the upper-level controller [70]. The different control structures and their merits and drawbacks are given in Table 3.

## 5. Controllers in DC Linked HRES

The HRES performs in an efficient and reliable manner by the interfacing converters control. For a precise power management control of the HRES, all the interfacing converters must have the features of local current control, voltage control. In addition to that a proper power sharing control is incorporated in the control mechanism as per the rating of HRES units. For the DC bus linked HRES, local control is performed by PI controller which gives zero steady state errors. It can be tuned easily for the robust performance of the HRES [83]. There are others controllers like PD, boundary control, fuzzy, neuro fuzzy and hybrid controller like fuzzy-PID [84-87,114]. For a complex system model, Fuzzy controller design is simple as it does not depend on the model. Fuzzy control can be used as main power regulator or may be used in a series with feedback type controller to regulate the power flow in HRES. State dependent switching's may be implemented as a boundary control technique for robustness and fast convergence of the HRES control [85].

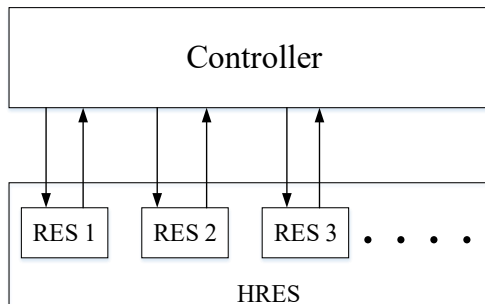


Fig. 8 (i). Centralized Control

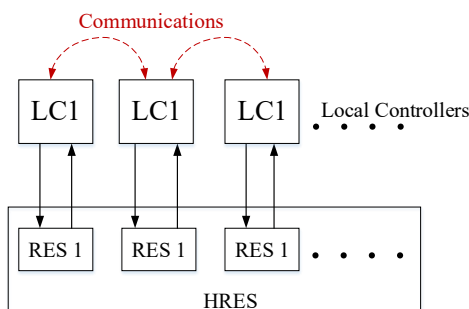


Fig. 8(iii). Distribute control

## 6. Controllers in AC Linked HRES

In AC bus coupled HRES, inverters are attached to the common AC bus parallelly. For power management control of AC HRES, local voltage and current control are implemented by various controllers like PID, Proportional resonant controller, deadbeat controller, model predictive control, hysteresis, neural network, fuzzy logic, sliding mode control etc. Every controller has their merits and demerits. The conventional PID controller has simple control structure and implementation is simple. In dq reference frame it has zero

error but it suffers from state error in unbalance conditions [84]. The proportional resonant controller is improved by inner current controller but it cannot suppress the problem of frequency variation. An accurate tuning is required for this type of controller [89]. The hysteresis controller is easy to implement but resonance problem is there [90]. The neural network-based method has good current control capability but it suffers from slow dynamic response [91]. The benefit of fuzzy logic control design is that it does not depend on parameters variation and operational points but the control method is slow [92]. The sliding mode control is reliable during transient, having good disturbance rejection capability but the design is complicated [93].

## 7. Communication Technologies in Power Management of HRES

The various power sharing control methods among the different RES units can be categorized in two types-(i) communication-based control and (ii) communication less

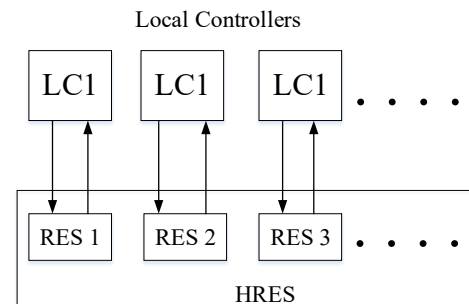


Fig. 8 (ii). Decentralized control

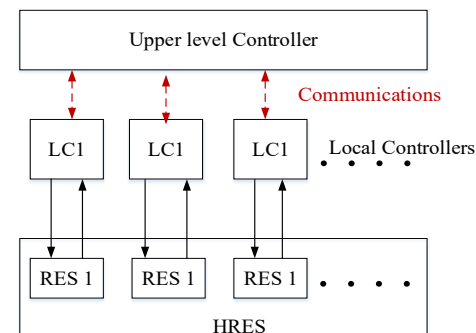


Fig. 8 (iv). Hierarchical control

control as shown in Fig.9. The communication-based control performs good in regulating the voltage and power sharing among different RESs in HRES. An ethernet based wired communication system has been presented for energy

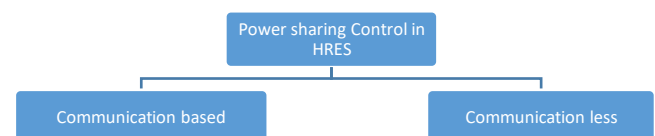
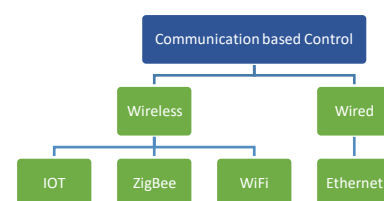


Fig. 9. Classification of communication technologies in HRES

**Table 3.** Various control structures

| Control Structure     | Summary                                                                                                                                                                           | Merits                                                                                                                                                                                                                                     | Demerits                                                                                                                               | Reference |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Centralized control   | Measured parameters are sent to the central controller and accordingly it operates the local RESs.                                                                                | Its design is simple and it has the robust observability and controllability.                                                                                                                                                              | It suffers from the problem of single point failure and improper working of central controller will stop working of the whole systems. | [67,68]   |
| Decentralized control | Individual controllers work separately. No requirement of information interchange among the controllers.                                                                          | It does not suffer from single point failure. Expansion of the systems can be possible without changing parameters of other controllers, no dedicated communication link is needed, the power line act as channel for communication        | Along with control and electrical parameters, system configuration also impacts on accuracy.                                           | [74-77]   |
| Distributed control   | The information's are sent to the respective local controllers and the local controllers exchanges their information's.                                                           | Single point failure is resolved in this control method and the computation requirements is less.                                                                                                                                          | Additional burden of communication complexity.                                                                                         | [78-81]   |
| Hierarchical control  | Optimal operation of local controllers are achieved by the centralized controller and the distributed control paradigm ensures the global optimal operation among various groups. | Single point failure problem is solved and computational complexity of each controller is reduced. It also performs supervisor controller roles. In order to carry out decisions, there is two-way communication among the various levels. | Requires a complicated communication                                                                                                   | [82]      |

system has been presented for energy management of HRES in literature [90,95]. The communication infrastructure design becomes complex for the HRES located in extreme environmental condition or having massive sensors network. To standardize the communication infrastructure used for integrated energy system, a framework has been issued by the National Institute of Standards and Technology, USA in 2010 [95]. Due to several demerits of wired communication as mentioned above various types of wireless communication can be implemented for power management of integrated energy systems such as IEEE 802.11n, GSM, 4G/3G/HSPA, IOT, ZigBee, Wi-Fi etc. [96,98]. An IOT based HRES has been developed for isolated small power system application based on IEC 61850 standard [101]. This IOT based system solve the problem of end-to-end delaying in ethernet based communication. An optimized energy management scheme using IOT based SCADA for PV, bio-gas, battery-based grid interactive HRES has been presented in literature [100,110]. It performs efficiently for both on grid and off grid conditions. Another useful technology for energy management in HRES is ZigBee which provides less maintenance, flexible, robust operation for a long time [97,101,111]. Various types of communication-based control have been shown in Fig.10.



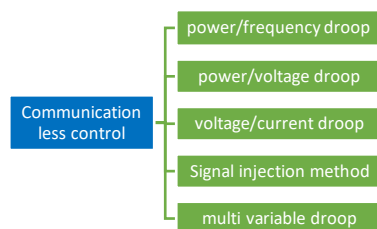
**Fig. 10.** Communication based control

The communication-based control uses high band width communication lines which causes a high cost of the systems used for the remote/rural area applications of HRES. In that cases **communication less control** methods are implemented as shown in Fig.11. There are numerous techniques that do not require a communication link, including power/frequency (P/f) droop, power/voltage (P/V) droop, Signal-Injection based techniques, voltage/current (V/I) droop, reactive power/voltage (Q/V) droop, multi-variable droop, and synchronous current converter control techniques [103-105,112, 117]. In the P/f droop approach, frequency is used to regulate active power in spite of phase angle because the initial phase angle is unknown and the power angle is related to changes in frequency. Active power measurement is easier in

case of converter-based hybrid system so a droop is proposed where frequency is the function of active power [102,106]. The P/f method suffers from the poor reactive power control and it is applicable to high voltage (HV) distribution systems only. Due to the resistive behavior of low voltage (LV) distribution systems, active power is correlated with voltage whereas reactive power is correlated with frequency. So, for the LV distribution network P/V droop control method is applicable [107]. Although the signal injection approach is independent of line impedance, it has the drawback of being unable to guarantee voltage regulation [108]. Reactive power sharing is controlled through the signal injection approach. This method can cause harmonics and resonance problems which is corrected by the virtual impedance method. To improve reactive power sharing, dynamic response, and stability of AC linked HRES, a V/I droop control mechanism considering voltage/current characteristics is developed [109]. It is run by the direct and quadrature axis voltage components drooping, with the associated current having a piecewise linear droop characteristic. However, it experiences oscillation problems for low droop coefficients and voltage quality issues under high load conditions.

## 8. Challenges and Future Research Trends

Each control method used for power management of HRES has its own merits and demerits. So, it is difficult to get one control method which will overcome the drawback of all



**Fig. 11.** Various communication less control

methods. More investigations on this control method will further enhance the system stability and reliability. The various future trends which have been found out from the review are given as follows:

- [1] As the standalone or grid connected HRES is a complex model, intelligent controllers can be implemented for the active integrated coordination among the RESs, Energy storage devices, consumers and also with the grid.
- [2] Plug and play feature is the important aspect of any advanced integrated energy systems. The device level control and the system level control should have such features to provide a flexible handling of the whole system. The devices must be able to connect or disconnect from the HRES. The system should have the capability of connect or disconnect from the conventional grid or the RESs based micro grid. Considering this plug & play features of the integrated system a flexible control coordination is needed.
- [3] Energy storage is required for supporting the intermittent RESs to suppress the fluctuation in power generation. It also improves the system reliability of power supply

during unavailability of renewable sources. A recent trend in hybrid energy storage systems which can be applied to the HRES is to check the economical impact as well as environmental impact.

- [4] Multiple HRES systems can be integrated with each other and which may be connected to the conventional grid. So, there are scope of future work on energy storage management, optimal power flow, sizing optimization of the multiple HRES, energy management of the integrated HRESs.
- [5] The multi agent-based control methods with advanced communication technologies are the attractive research area applicable to the integrated energy systems.
- [6] As the renewable system has low inertia there may be serious voltage and frequency variation during the disturbances in the hybrid systems. Some researchers have used various types of storage devices or synchronous generators to improve the response time. So, there is an opportunity in analyzing the HRES performance by improving the inertia.
- [7] Power sharing among the RESs is an important aspect of power management control. Wireless communication is to be used for integrated energy system placed in a severe environmental condition or having a large sensor network. The efficient and reliable communication technologies are to be implemented for the power management control of integrated energy systems.
- [8] Economical impacts of using wireless communication technologies in power management control of HRES is also a good scope for the future researchers.

## 9. Conclusion

This review study focuses on the different issues of power management control for different types of HRES configurations. The DC linked structure is applied where numbers of DC type energy systems are more than numbers of AC energy systems. The merits, demerits of the DC linked HRES and AC linked HRES structures is presented. So which types of HRES is to be chosen that is depending on the resource's availability at the projected location. This paper presents the different HRES integration topologies of the HRES, control methods-communication based and communication less methods for power management control of HRES. From the literature review it is found the communication play a significant role in reliable and flexible operation of the HRES. Different types of communication technologies used for the integrated energy systems have been presented which will help the future researchers to apply new technology to the HRES. The communication-based systems are again classified into wire and wireless technologies. The wire communication is more reliable than the wireless but increases the installation complexities and cost. Reliability issues are to be taken care for selecting the right communication technologies for HRES control. There are droop based methods which are communication less methods. It improves the system's reliability and flexibility but it suffers from some drawbacks of poor transient response, inability to provide accurate power sharing. Signal injection-based method has overcome the drawbacks of

droop-based method. So, to design an optimal power management control for HRES, different criteria's like-integration topologies, control structures, application of communication technologies are to be selected properly. The future research directions in the field of integrated energy systems have been presented finally in the article. These challenges and the future trends will assist the researchers to open new dimension of research in that field.

## Acknowledgements

N/A

## Author Contributions

Authors were responsible for the conceptualization, validation, resources, data curation, software development, and project administration. They jointly contributed to the methodology, formal analysis, investigation, original draft preparation, review and editing, visualization, supervision, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

## Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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