

Review Article

A REVIEW ON HYBRID AC/DC MICROGRIDS: OPTIMAL SIZING, STABILITY CONTROL AND ENERGY MANAGEMENT APPROACHES

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Abstract

Electricity is the greatest gift of science to humanity reached for civilization where electricity is used for all purposes. However, in recent times a paradigm shift is evolving in the generation of electrical energy from the concept of using major generating plants to minor generating units allied to the distribution systems in the form of microgrids with alternative energy sources called renewables. Around the world renewable energy use is on the rise and these alternate energy sources can generate pollution-free electrical energy to the society. Although these are new centers and units with diminishing cost, there are still many challenges in operation and control of islanded and grid-connected microgrids configured in both AC and DC. Uniting the benefits of microgrids of AC and DC, Hybrid AC-DC Microgrids (HACDC) were developed. Thus, it is relatively imperative to investigate the optimal size, stability control, and strategies of economic efficiency operation of HACDC microgrid. Hence a great review on optimal sizing methods, stability control, and energy management strategies using various iterative and intelligence techniques published in different articles proposed by many authors were presented in this paper.

Keywords: MRenewable Energy Sources, Hybrid AC/DC Microgrid, Inter-Allied Converter, Energy Management System.

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INTRODUCTION

Recently From the survey, it has been identified that an average Indian consumes 1075kwh of electricity annually, and 85% of electricity is generated from fossil fuels as principal resources of energy, which causes large amount of CO₂ emissions to lead to global warming. But due to the growth of demand for electric power, the inadequate reserve and lifting worth of conservative sources such as firewood and petroleum, etc. renewable energy sources become a gifted substitute, available free of cost, atmosphere friendly and has a reduced amount of operational and maintenance cost. The higher penetration of various technologies of renewable energy sources such as solar, wind, tidal, biomass, and geothermal forms a distribution generation (DG). The vast scale incorporation of DG's will bring operational confronts to the power system network, and a vital solution to this predicament is a microgrid achieved much concentration globally [1].

At present, due to generation of electrical energy in both (AC and DC) forms with the use of various renewables; microgrids are classified as AC Microgrids, DC Microgrids, and HACDC Microgrids [2]. In AC microgrids, the DC generating sources such as PV, Fuel Cells are converted to AC with the use of DC/AC converters, while AC generating sources are directly allied using power electronic interfaces [3]. Whereas, in case of DC microgrids AC generating sources are converted to DC using AC/DC converters. However, these multiple conversions results in losses. An immediate solution to the problems mentioned above is hybrid microgrid, which minimizes multiple conversions and reduction in losses [4]. The two notable and key aspects bracketed together concerning hybrid systems are worth of electrical power and consistency of the system. The systems' best possible blueprint must be cost-effective and consistent, and it can be accomplished with the rally round of appropriate choice of apparatus of the system. Thus, an optimal sizing method is obligatory to propose a proficient and cost-effective HACDC microgrid system. The structure of hybrid microgrid consisting of renewables Photo-Voltaic (PV), Wind Turbine (WT) with Battery Energy Storage, and loads allied to utility grid is shown in Fig 1.

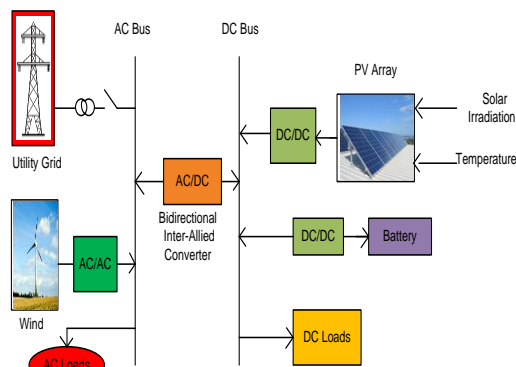


Figure.1 Layout of HACDC Microgrid

From Fig.1, the HACDC microgrid is allied to the service grid through an isolator switch [5], which helps to isolate the HACDC microgrid during faulty times. Under steady-state conditions, the HACDC microgrid can be functioned in two modes, such as grid allied mode and island mode. Maintenance of power balance between hybrid and utility grid is moderately easy in grid-connected mode [6] as compared to islanded mode because of infinite bus behaviour of utility grid [7] and be able to absorb or supply to the HACDC microgrid. In the case of islanded mode, the HACDC microgrid is no longer allied to the utility grid. Hence, the HACDC itself must supply the total load demand through Inter-Allied Converter (IAC). Therefore, a communication link is allied among the sources. A centralized method of control is applied between the sources, but it is a single point failure. A commonly known method called droop method, used for sensing of load demand by each source and regulates its production according to its rated capacity [8].

During transition from grid allied mode to islanded mode or vice-versa, unstable harmonic currents and voltages are of crucial concern. In addition to this, proper synchronization of voltage and phase between HACDC microgrid and utility grid is necessary. To increase the generation and to meet the load demand, renewable sources, together with storage devices, are

integrated into the utility grid, causing challenges and impacts on microgrid operation. The organization of paper is as follows. A rigorous literature review on different methods of optimal sizing of HACDC microgrid is presented in section II, followed by stability control strategies in section III, and section IV presents energy management strategies for HACDC microgrids. Finally, the conclusion of the review is presented in section V.

OPTIMAL SIZING METHODS

Nowadays, a paradigm shift for exploit of HACDC microgrids due to radical transformations like load due to the advancement in electronically based distribution generation. The vital aspect of HACDC microgrids is the high operational cost of renewables and the large size of Battery Energy Storage Systems (BESS). For optimization of capacities of Photo Voltaic (PV), Wind Turbines (WT), and BESS, various iterative and intelligent methods were developed and discussed briefly.

In [9], to congregate the load demand and for minimization of total annual cost, hybrid systems generation and storage units are sized by a numerical study based on hourly load demand. By considering economic factors, a simple arithmetical algorithm was built up to gratify the available load demand and to determine the optimal configuration of WT/PV. In [10], the optimal design of hybrid microgrid system is obtained by employing linear programming methods for minimization of the annual price of generation while meeting the prerequisites of load in a consistent approach. Environmental factors are also considered in both design and operation phases.

In addition to the determination of annual cost, balanced generation, and demand by a simple numerical algorithm, an economic analysis is also presented to justify the use of renewable energy. Comparison by configuration cost and break-even distance is also made among the solar alone, wind alone, and hybrid systems [11]. Different components of hybrid solar-wind system with the existence of battery banks are sized optimally to minimize the capacity by using Loss of Power Supply Probability (LPSP) approach to level the cost of energy [12]. The system configuration is obtained in terms of power supply reliability.

The crucial aspects considered in the optimization problem are cost, reliability and pollutant emissions. In [3], a technique was proposed called multi-objective Particle Swarm Optimization (PSO) to obtain the optimal configuration of the grid-connected hybrid system using multiple renewable energy sources. [14] determined the optimal sizing of PV/WT grid-connected system among different configurations using multi-criteria decision analysis. The sensitivity of these algorithms is also analysed with various techniques of weighting criteria in different scenarios like wind speed and radiation profiles of solar.

An improved optimal sizing method for a hybrid generating system consisting of PV/WT and battery was proposed in [15], by considering the principles such as high reliability of power supply, characteristics of utilization of PV/WT, battery charge and discharge state optimization and finally system's total cost minimization. According to [16], the characteristics of load changes using various renewable generation sources because of their different geographic regions during a year. Due to this reason, collective capacity optimization is proposed for the reduction in generation cost and storage by considering investment and operational cost.

[17] proposed an optimization framework to assess the capacity of distributed generation and focus on maximum profit with utilization of renewables, minimization of pollution in the environment, and the increase in reliability level, forming a master objective function. The optimal design can be

determined using PSO algorithms. With the consideration of the integration of renewables, the stage of design can be complicated. In [18], the optimal model can be designed based on mixed-integer linear programming, which includes the stochastic behaviour of renewables and uncertainty in the prediction of electric load.

In [19], optimal sizing of hybrid PV/WT and battery systems is based on two constraint search algorithms and aimed at avoiding of over and under sizing. This paper also considered the forced outage rates of solar, wind and utilization factor of battery energy storage systems to make the design more realistic. [20] determined the energy sources unit location and optimal power of a hybrid AC/DC system by formulating as a mixed-integer linear programming and solved by using CPLEX optimization studio includes total cost minimization. The proposed work in [21] determines not only the optimal configuration of renewable sources but also the power electronic converters needed in the hybrid microgrid. The effectiveness of the proposed work can be obtained by using "deterministic branch-and-bound non linear solver."

VOLTAGE AND FREQUENCY CONTROL METHODS

Various control approaches were implemented for both AC and DC microgrids individually [22] to uphold the voltage and frequency in synchronous with utility grid during fault conditions. The same control strategies were implemented to HACDC microgrid also, but a little attention has received towards HACDC microgrid because of Inter-Allied converter (IAC) present in the HACDC microgrid. By considering the significance of hybrid microgrid, the paper presents a synopsis of different control approaches of Interlinking Converter (IC) based on droop or communication control methods[23], [24] for voltage and frequency control of hybrid microgrid in standalone and transition mode. But the most dynamic control can be acquired by exploiting amalgamation of these two control methods. The aspiration is to comprehend the functionality of projected schemes. So that better control approaches may be enlarged for the future grid.

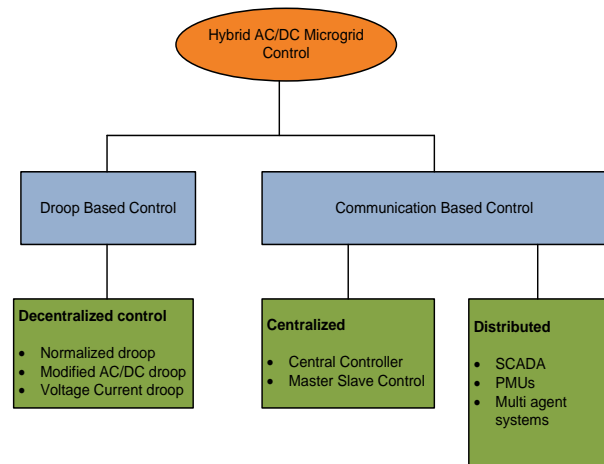


Figure.2 An outline of different control methods of voltage and frequency of IAC in HACDC Microgrid

The first step of controlling voltage and frequency in a HACDC microgrid is to manage the flow of power within the grid separately then secondly, IAC comes into play to supervise the power flow from underloaded grid to the overloaded grid. An outline of various control methods of voltage and frequency for IAC in detached mode is depicted in Fig.2.

DECENTRALIZED OR DROOP BASED CONTROL METHODS

Before reviewing the essential aspects of decentralized control methods for IAC of HACDC microgrid, some of the conventional droop control methods for each microgrid are explained. The various conventional droop methods are DC droop control, Angle droops control method, a voltage and current droop control. Generally, methods of droop control are used to determine the voltage V and frequency f of HACDC microgrids and are given by the (1) and (2)

$$f_y = f_x + m_x P_x \tag{1}$$

$$V_y = V_x + n_x Q_x \tag{2}$$

Where V_x, f_x are no-load upper limit values of voltage and frequency, m_x, n_x are negative droop coefficients.

DC DROOP CONTROL

For DC bus voltage control [25], proposed a droop control method in which the control algorithm of voltage at each converter is implemented to share the load equally among source converters and selection of capacitance dc bus at each converter is also presented for two converters and five converter ring bus. Stability is also investigated using method of root locus for varying dc bus capable parameters. Location of sources with long distances using droop control, high bandwidth data lines is not required, and voltage, current harmonics are not considered for non-linear loads using this method. In the DC droop control method, steady state error exists, and it is the main drawback. To overcome the drawback of steady state error, an additional control scheme is required as a secondary control [26].

DROOP CONTROL METHOD OF ANGLE

In the Angle droop method, the real and reactive power flow is controlled using the voltage angle. Its droop characteristics can be set by the ratings of Distribution Generation (DG), and for each converter, a reference time signal is used for synchronization based on Global Positioning System (GPS) [27]. The existence of any mismatch in the system tends to system instability. For the regulation of voltage, voltage current droop is implemented only in DC grids. Where the converter DC current through the virtual resistance is measured and applied at the input to give output voltage as DC. The DC output voltage is controlled by designing a proportional controller with gain equal to virtual resistance, and this proposal has a drawback of deviation in load voltage. The minimization of these deviations can be done using a controller called the Proportional plus Integral (PI) controller [28].

DROOP CONTROL METHOD OF VOLTAGE AND CURRENT

In [29], the voltage and frequency droop control methods were proposed for microgrid operating in unconnected mode or connected to an infinite bus. A comparison is made between the existing techniques and concluded that droop control of microgrid through the finite output impedance method exhibits superior behaviour in the reduction of harmonics. A strategy of control and sharing of power was anticipated by [30] consisting of virtual inductance at the output of interfaced inverter for accurate control of real and reactive power in both allied and unconnected mode with no physical communication among the units of DG.

According to [31], a hierarchical method of control was proposed for both AC and DC microgrids consisting of three levels. The primary control is based on the droop method including virtual loop of output impedance, the secondary

control loop restores the variations produced by primary control, and tertiary control loop manages the power flow between the microgrid and the external electrical distribution systems. Even though the conventional droop control methods achieve a higher reliability level, this method faces a disadvantage of slow transient response, deviation in voltage, sharing of unbalanced harmonic current, and highly dependent on the output impedance of inverter. To conquer the above drawbacks, modified method of droop control was proposed in [32] to enhance the dynamic performance.

INTER ALLIED CONVERTER DROOP CONTROL METHODS

After the implementation of droop methods individually to each microgrid, the subsequent task is to manage the flow of power among sub grids for the regulation of voltage and frequency. This can be achieved using IAC, but due to continuous operation of IAC, loss in energy occurs. To minimize these energy losses, IAC is designed based on power flow of energy storage tuning between the sub grids of AC and DC [33]. This scheme utilizes a stationary reference frame with multiple PI controllers for generation pulse width modulation. For the determination of loading inside each grid, the measurement of DC grid voltage and AC grid frequency is required. Hence, a modified method of the ac-dc droop control scheme is presented in [34]. This method has a direct impact on AC sub grid frequency; hence multiple IACs can be used. A double loop control scheme shown in Fig.3 [35] involving three-level controls is used for the regulation of voltage and frequency, which increases system cost, complexity, and accurate tuning of PI controller is also required.

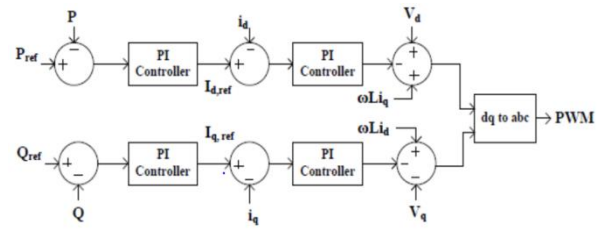


Figure. 3 Double loop control scheme with proper tuning of PI Controller

For the cost-effective operation of the system, another method called voltage-current droop control method is implemented using a proportional resonant controller, including a PI controller. In this scheme, the value of virtual resistance should be appropriately selected when working with parallel converters.

CONTROL BASED ON COMMUNICATION

As the name itself says that, this method of control is based on continuous information exchange among the variety of microgrid resources. In this approach, microgrid control can be centralized or fully distributed with high accuracy because of less communication delay during information exchange [36]. But if there exists a loss of communication link security and reliability issues raises affecting system stability. To overcome the problem of stability and reliability issues, a hierarchical control scheme is proposed with a combination of droop and communication methods. The underlying implementation of centralized control for HACDC microgrid is shown in Fig.4.

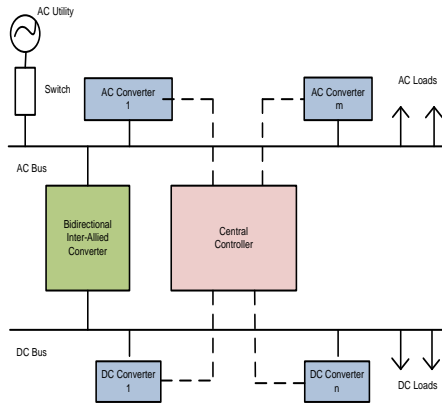


Figure.4 General Structure of Centralized control of HACDC microgrid

In this configuration, AC and DC subgrids are allied utilizing a bidirectional inter-allied converter with one centralized controller. In centralized communication-based control, all the data from local distributed energy resources controllers are transmitted to the microgrid central controller in real-time. Hence this approach is a single point failure but has better response compared to droop control. Using power regulators, a control strategy based on communication is applied [37] at each source in the microgrid. For synchronization of phase and frequency, including reference signal, current modules with phasor lock loop (PLL) are proposed in [38]. A simple and effective approach named master-slave control was described by [39], which can be applied in both grid connection mode and island mode. In this method of control, one converter works as a master and other works as a slave for the existence of data transmission between master and slave controllers. Even though this method is not much complicated from technical point of view, but the failure of the master controller affects the total system operation, and its reliability also decreased.

To avoid communication links and to provide good capability of expansion, an alternate method of control was proposed in [40] called peer to peer control. In this scheme, the existence of oscillations in power and decrease in energy usage occurs with increment in renewable energy sources number. Generally, master-slave approach is employed in island mode of operation, whereas peer to peer method is applicable in the grid allied mode of operation. So, there exists a problem of stability in switching. To resolve this problem, a hierarchical method is developed in [41] and suitable for sophisticated microgrids.

Overcoming the single point failure with centralized control, an alternate form of control based on communication is designed without a central controller called distributed control. In this control mechanism, a control action is designed at the local converters within the microgrid. The operational information of each source is communicated with neighbour ones, and the concluded information is gathered at the IAC. In this process, the information is communicated to the IAC which produces the necessary control actions to control voltage and frequency. This method can be implemented both in grid allied and island mode. Loss of any unit may cause system instability [42].

In [43], a Supervisory Control and Data Acquisition (SCADA) were proposed to supervise and control the devices or equipment present in microgrid based on the technology of the computer. For reliable control and communication of microgrid [44] proposed a device called Phasor measurement Unit (PMU), a microprocessor-based intelligent device that gathers data with high resolution and records disturbances. Even though

SCADA and PMUs provide timely and detailed monitoring of microgrid, it contains some hidden information. The engineer requires additional analysis, and it is a time consuming process. To overcome such limitations, Multi-Agent Systems (MAS) were replaced for the autonomous operation of microgrids with high intelligence to improve the reliability of voltage and frequency. MAS can be implemented using different frame works such as JADE, JANUS, ZEUS, and VOLTRON. Comparing the various properties of MAS, the suitable frame work for implementation of MAS is JADE. In [45] a multi-agent control has developed to enhance the voltage and to increase the speed and accuracy in decision making.

4. ENERGY MANAGEMENT STRATEGIES

Presence of more than two distribution energy resources (DERs) in the system, the existence of Energy Management System (EMS) is necessary for the allocation of power among DERs, the production cost of energy, and emission. According to International Electro-technical Commission (IEC) standard 61970 EMS is defined as “a computer system comprising a software platform providing basic support services and a set of applications providing the functionality needed for the effective operation of electrical generation and transmission facilities to assure adequate security of energy supply at minimum cost.” The various categories of energy management strategies were depicted in Fig.5.

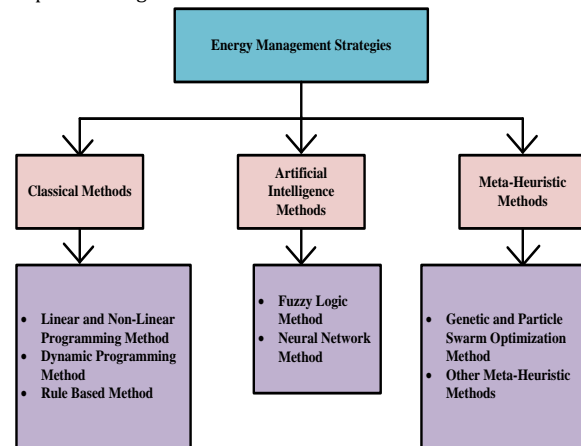


Figure.5 Energy Management Strategies

To predict hourly outputs in a high-frequency AC microgrid, an intelligent energy management system called fuzzy ARTMAP neural network was proposed in [46] using adaptive resonance theory. Based on developed rules, an energy management strategy named as Rule-Based Method was proposed by [47] for stand-alone Wind-PV-Fuel Cell system. In [48], an expert and predictive system using mix integer linear programming method were proposed for optimal energy management.

A real-time EMS using particle swarm optimization (PSO) technique was developed by [49] to minimize the operating cost. To balance the power among the sources, power control and management strategy was implemented by [50] in simulation PSCAD/EMTDC software. For effective energy management of HACDC microgrids, a two-stage method called crow search method was proposed in [51] to increase the search ability.

CONCLUSIONS

An attempt is made to portray the information available in the literature presented by different authors. This paper gives knowledge on the current status of HACDC microgrids by knowing the importance of renewables and challenges facing

the generation of electrical energy of the developing world. To enlighten the researchers in the area of HACDC microgrids, this paper presents various optimal sizing methods, stability control techniques, and energy management strategies implemented in both island and grid allied mode of HACDC microgrid with their advantages and disadvantages. For optimal operation of HACDC microgrid, various optimization strategies include iterative methods, intelligent methods, and software tools are also presented. A rigorous literature survey is also presented on various control strategies starting from well-known droop methods to communication methods include centralized and distributed. For providing proper energy distribution among various sources in island mode of operation and to obtain the balanced flow of power between utility grid and HACDC microgrid in a grid allied mode different energy management strategies of HACDC microgrid presented in the literature are also reviewed in the paper. Furthermore, this paper supports the researcher to quickly understand the present scenario in the field of HACDC microgrid overall performance in both islanded and grid-connected mode.

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