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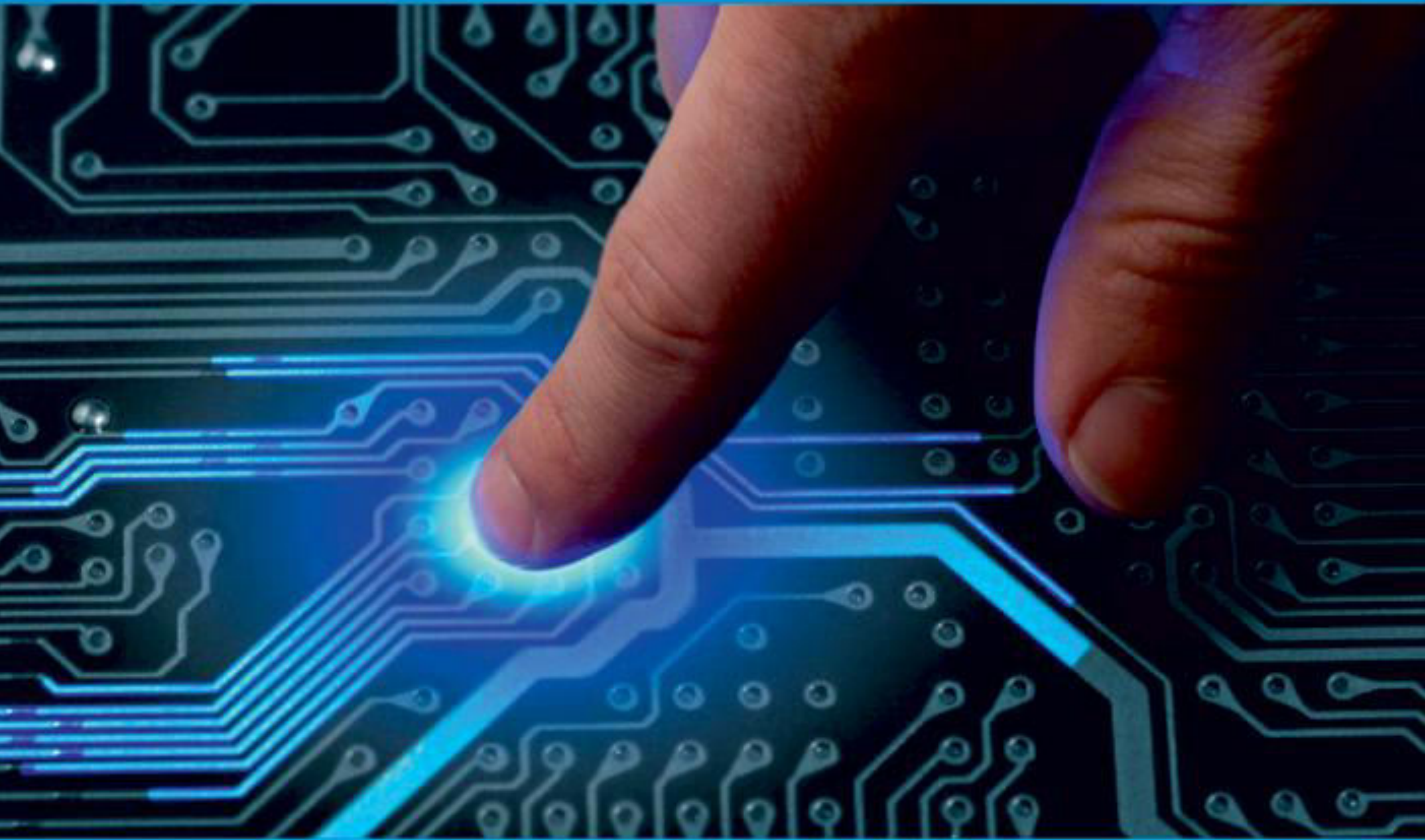

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Study and Design of AC and Hybrid AC-DC Microgrid: A Review

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ABSTRACT: The concept of smart grid and microgrid is a vast area of research now a days. In this paper, various control strategies are presented for AC and hybrid AC-DC microgrid. Basedon hierarchical control levels of microgrid, the different control strategies are discussed in local control, secondary control, and global control. Several research surveys are made for these methods. A proper control technique is required for constant generation of all units. Comparisons are done between different controltechniques.

KEYWORDS: Microgrids, AC microgrid, hybrid AC-DC microgrid, hierarchical structure, control strategy, energy management system.

I. INTRODUCTION

Today, the world has exposed extraordinary importance and desire of incorporating RESs and DGs into the power system network (electrical network) on account of numerous improvements. These improvements integrate extra energy related advantages (peak load decrement, better security of supply, prevents overcapacity, decrement of grid losses). In addition, renewable energy sources can build the efficiency of the plantsignificantly. Microgrid (MG) is a combination of collecting DGs that works together and normallyoperates synchronously with the grid connected but can also be operated as disconnected to an islanded mode of operation [1]. The MGs consists of distributed energy resources (WTs, PV, and Fuel Cell), storage devices (flywheels, supercapacitors, and batteries), and loads for extensive control potential to the local loads. The MGs arrangement is linked to the low voltage distribution system. With the growth of distributed RESs, several creations should be conducted in field of improvement of power system like smart grid for combination of distributed RESs and MGs, transformation of the local loads and power source optimization, and operation of manageable and dependable generation (active generators) to control the irregular availability of renewable resources. Research progress has always led towards solution for fulfilling the increase energy requirement. In priority to provide a constant progress in a viable way, a substantial part of the electrical power should be developed bythe RESs. The major disadvantage is the intermittent character of the renewable energy sources (such as solar irradiation and wind variation). Therefore, the perception of renewable energy sources results in complicacy for operators in providing the same energy generation and demand which leads to poor power quality provided to the customers. The microgrids have the capability to enrich the consistency of electric power system if proper control techniques are implemented [2]. There are different distributedgenerations (DG) in microgrid that connects through the power electronic converters as the sources produces either AC or DC. The MG operation is managed by microgrid central controller(MGCC) through local controllers. In the grid-coupled operation mode, a synchronism energy layout is created between the DSO and the MGCC. The MGCC sets the power reference of system (micro turbine and diesel generator) instructing to satisfy the arrangement. In the islanded operation method, the microgrid should secure the regional supply and protection of energy [3].

The hierarchical control strategy is distributed with following levels:local control, secondary control, central and emergency control, and global control [2,3]. The voltage, frequency, active power, and reactive power are the key variables in microgrid. The need for microgrid control is to attain good power distribution in both mode of operation. The controllers are also responsible for participation with optimized fabrication of micro sources in energy market and optimized utilizing cost of production. An energy management system (EMS) is required for consistent and stable operation of microgrid. The grouping of control strategies depends on hierarchical control. This review paper is to classify the work done in ac, hybrid ac-dc microgrids hierarchically with control strategies. This paper is arranged as follows: I and II section consist of ac microgrid and control of ac microgrid, respectively. Section IIIandIVrepresentshybridacdcmicrogridandcontrolofhybrid acdcmicrogrid.

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1. ACMICROGRID

To accomplish the equilibrium between the generation and consumption,the MGCC should forecast the primary generation capability and the primary utilization requirement for the next interval. If the generation is more than the utilization, the power generation of the amenable DGs must be scale down. In the transient condition, thesurplus power is exhausted in substitute resistor loads when overvoltage occurs. If the generation is less than the utilization, then the stated DGs will be supplying the insufficient power or if necessary, t h e loads will be removed from the MG[4].

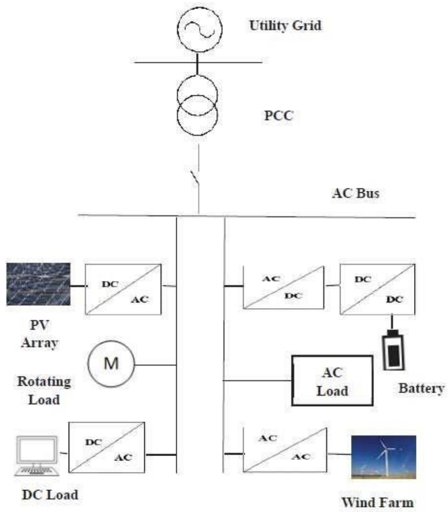

Fig. 1. An AC microgrid architecture.

1.1 CONTROL TECHNIQUES OF ACMICROGRID

The control hierarchy consists of the following three stages:
Distribution management system (DMS), Microgrid central controller (MGCC), Local controllers (LC) [5].

1.1.1) Local Hierarchical Control

The local control is the quickest among all stages. It consists of distributed generation (DG) internal voltage and current control loops. It is engaged in decentralized way and maintains DGs stability. The local controller works to manage DGs in usual operation. It also maintains controlling of local signals. The reference voltage for local controllers is provided b y droop controllers that operate as voltage source converter (VSC) [4]. The PI controllers are implemented in designing of control loops in it. The local controller takes care of inner control of DG. Usually, communication links are not required and thuslead to simple network and minimum cost. Local controllers are essential requirement for MG control. The important function of local controller is to manage DG to work in standard operation. The control of distribution of power between DGs couldbe added in this extent which is similarastheDG'soutputcommand.Itgenerally

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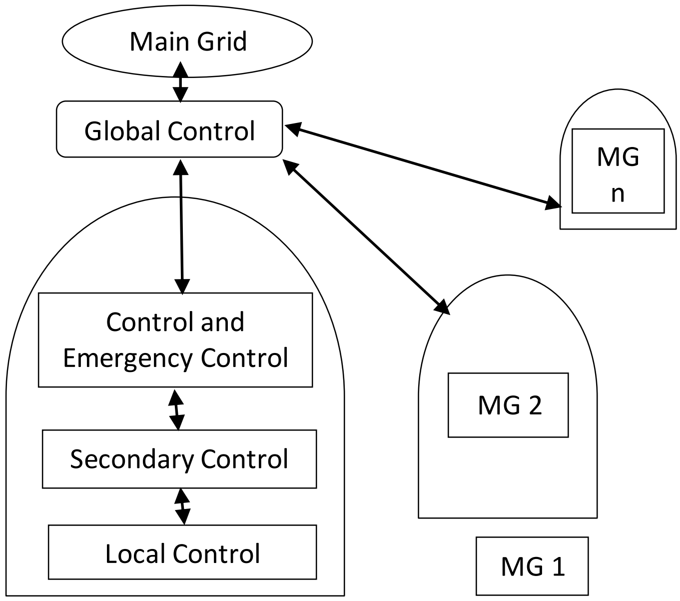

Fig. 2. Hierarchical control stages in MGs.

1.1.2) Conventional DroopMethods

The droop characteristics in conventional power system can be shown by P-f method which are implemented for management of voltage and frequency of the islanded microgrid [10]. If Vs, Vg are the source RMS voltage and grid RMS voltage, respectively, δ is rotor angle of the source and X is the total reactance of source and line, then electrical power Pe is given as

$$P_e = \frac{V_s V_g \sin \delta}{X} \qquad (1)$$

The P-f droop method acknowledges reduction in frequency of the output voltage as the output real power of the inverter is increased. The conventional droop methods are not effective for distribution network because of its highly resistive nature. The main cause of droop control is to design the inertial capacity of synchronous machines to modify the gap in generation and requirement by balancing the frequency [11]. According to [5,12, 13], the conventional droop method has many drawbacks which are described as that it has poor power sharing between DG units, poor voltage management of unfavorable loadsthroughthe approach of reactive power management, not suitable for nonlinear loads, droop equations are authentic simply for inductivelines.

1.1.3) Improved DroopMethods

There are lots of improvements to be needed in above droop control, so there are many control methods through which droop methods can be improved. They are listed as below.

1.1.4) Virtual ImpedanceMethod

This control method is implemented in [12,14]. The virtual impedance is used as a feedbackof the primarycontrol.

1.1.5) Adaptive Droop Control

This improved adaptive droop control exhibits a goodperformance towards load fluctuationsby means of varying the load adaptively [15]. It provides the frequency stability with the changes in the load. It shows high robustness in making frequent changes in theload. The algorithm used in [15] conduct good coordination of power sharing of DG. It also avoids overload tripping. In [16], voltage regulation and reactive power sharing is improved by constant voltage strategy and conventional droop controlmethod.

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1.1.6) Angle Droop Control

In this strategy, for sharing the proportional load to DG, the output voltage of the converters is coordinated. The DG is injecting active and reactive power to the microgrid, which can be managed by voltage level and its angle [17]. The instantaneous real power p and reactive power q coming from DG to microgrid can be shown by theseequations:

$$p=\frac{\sin(\delta-\delta_t)}{X_f} \quad (2)$$

$$q=\frac{V^2-V*V_t\cos(\delta-\delta_t)}{X_f} \quad (3)$$

From these equations it can be found that if difference in angle is less, then active power can be determined by 6 and reactive power can be determined by voltage level. 6 controls the active power and V controls the reactive power respectively, so the angle droop control equations are shownas

$$\delta=\delta_{rated}-m*(P_{rated}-P) \quad (4)$$

$$V=V_{rated}-n*(Q_{rated}-Q) \quad (5)$$

Where Vrated is the rated voltage and 6rated is the rated angle respectively, P is the active power and Q is the reactive power of the converter, m and n are the constants representing angle drop and magnitude drop. This method has lowfrequency variation than the frequency droopmethod.

1.1.7) Virtual FrameTransformation

This approach implements MG frequency and voltage as the communication network and activates the DG to distribute the load requirement without physical interconnections. The analysis of the operational range for DG with thought of active andreactive power distribution are presented in [18]. This transformation implements a linear square matrix to mention the real and reactive power equations. These powers are transformed to the virtual frame and it is given by

$$\begin{bmatrix}P_v\\Q_v\end{bmatrix}=\begin{bmatrix}\sin\theta & -\cos\theta\\ \cos\theta & \sin\theta\end{bmatrix}\begin{bmatrix}P\\Q\end{bmatrix} \quad (6)$$

Similarly, frequency and magnitude of voltage source converter are also converted to the virtual frame given by the equations as

$$\begin{bmatrix}\omega_v\\E_v\end{bmatrix}=\begin{bmatrix}\sin\theta & \cos\theta\\ -\cos\theta & \sin\theta\end{bmatrix}\begin{bmatrix}\omega\\E\end{bmatrix} \quad (7)$$

This concludes that power output range is increased and improves microgrid stability.

1.1.8) Virtual Inertia Based Droop Control

This method is implemented for joining virtual inertia to the system. The virtual inertia is added to the system for preventing unfavorable triggering of relay because of over and under frequency. Despite the fact, the system stability is improved on virtual inertia-based sources, but effect is different [19]. The equivalence between virtual synchronous machine and frequency droop scheme of microgrid is referred in [20]. The zero-inertia virtual synchronous machines will be responded without low pass filter in power frequency droop control. It is concluded that the complicated structure does not alter the performance of the virtual synchronousmachine.

1.2) SecondaryControl

It is the second level control loop. This layer enhances the duty of inner control loops to upgrade the power quality in MGs and to boost arrangement efficiency by eliminating steady-state errors. This layer is firmly operating with local and central/ emergency control groups [6]. In grid connected mode, the grid signals are used by microgrid as references for regulation of voltage and frequency. However, in islanded mode,the main grid cannot supply the reference signal to MG. During this situation, they may synchronize to achieve a coinciding operation utilizing multi master operation strategies. It also includes controls required to enhance the parallel operation presentation for DGs and inverter. There are several procedures to form a strong parallel operation of

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DGs and inverter through current/power sharing, droop control and master slave control techniques. Low bandwidth communication may be needed to use in secondarycontrol.

1.3) Central & Emergency HierarchicalControl

It is a highest-level control with important role in islanded operation mode. This system is responsible for secure and reliable duty of MG in both grid connected and islanded mode. The main purpose of this control is to search best unitcommitment, regulationof voltage and frequency, reactive power supply, black start renovation, transmitting of available RES in normal mode and provide protection in emergency conditions. Previously joining to the utility grid, this central control synchronizes MG to make easier transition from islanded togrid connected mode. A review of distributed and centralized control is further defined below.

1.3.1) DistributedApproach

This approach permits the communication between the units for incrementing security, intelligence, and reliability. This technique is used at secondary and global control levels. The local control has freedom to Similarly, frequency and magnitude of voltage source converter

2are also converted to the virtual frame given by the equations as take decisions by communicating with each other [21]. The local controllers of distinct units are in communication with each other in distributed system shown in Fig. 3.

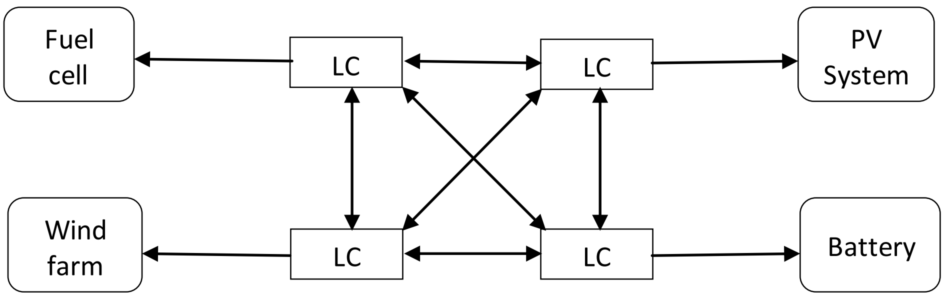

Fig 3. Typical distributed system microgrid

1.3.1.1) Multi-agent-basedtechniques

This technique uses an intelligent control system for interacting each other locally. The set points are determined that provide power quality and optimizesthe operation of the system. The multi agent-based techniques are investigated in [21,22,23]. There are various autonomous agents that keep control and monitoring of components, in addition, they also interact with other agents. This system uses the Java AgentDevelopment Environment (JADE), which simplifies the execution of agent systems [22]. Thedirectory of Agent Identifiers is maintained, and it is managed by Agent Management Service (AMS). This system has two-way communication for all the units in the microgrid. The agent has the ability to change its environment by themselves. The multi gent system has various advantages suchasrobustness,autonomy,limiteduseofdatachangeandcommunicationbetweenunits.

1.3.1.2) Model Predictivetechniques

This technique deals in an optimization problem whose solution is based on forecasts and demand [24]. The forecasting of the demand, generation of DG units is done to formulate the optimal plan. Assuming the forecasting is correct, the controllers make the decision by themselves. The branch and bound technique are implemented to optimize the problem of model predictive control [25]. The stochastic model predictive control algorithmis described in[24].Thedynamicprogramingmethodisusedtosolvetheproblemofoptimization.

1.3.1.3) Consensus basedtechniques

In this technique, the information is divided in distributive way. The consensus algorithm is presented in [26,27]. The process of updating information of agent i is shown as

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$$x_i[t+1] = \sum_{j=1}^{n} d_{ij} x_j\,[t] \qquad (8)$$

Where xi[t+1] is updated information of agent i, xj[t] is the local information of agent j. The dynamic consensus algorithm is discussed in [27]. The advantage of using this algorithm is communication is not required for all units; only neighboring units can communicate witheach other. Flexible and reliable operation can be obtained by plug and play functions. It also does not require a devotedcontroller.

1.3.2) Centralized Approach

This approach includes MGCC which establishes a communication between local controllers and it. The bidirectional communication exists between them.

Here, the MGCC defines the control set-points to LCs which helps in optimization [5]. To maintain reliability and optimality of microgrid, the energy management system interacts with distribution system and receives the control set- points from it. The typical centralizedmicrogrid system is shown in Fig. 4. The benefit of this approach is that the communication network is not too much engaged and provides online optimization.

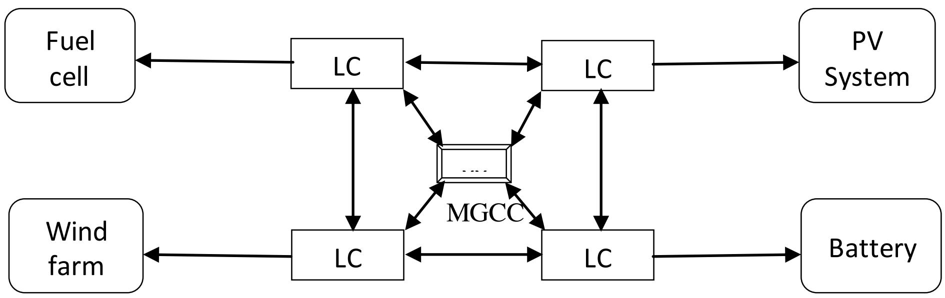

Fig 4. Typical centralized system microgrid

1.4) Global HierarchicalControl

It is the uppermost control level for synchronizing the operation of multiple interconnected MGs and communication necessity with the utility grid. The interchange of power can be done with the main grid in this control. This control is slowest among all. The compensators provide control set-points (voltage and frequency) to the secondary control [28]. The MGCC takes care of entire MG for control of fault level, power flow, load shedding, connection, and disconnection. The control of active and reactive set-points is essential to optimize the microgrid operation. The optimization is generally depending on economicaspects.

1.5) Intelligent ControlTechniques

This control technique has a vast research scope in smart grid area. The intelligence control includes artificial intelligence, fuzzy logic, and neuro- fuzzy systems. An online intelligent approach has been introduced in [31], which implements a mixture of fuzzy and particle swarm optimization. According to it, the parameters of proportional integral (PI) are automatically adjusted using online measurement fuzzy rules. The optimization problem can be solved using Genetic Algorithm, Ant and Bee colony shown in [31]. PSO is a way of direct search method and used to provide optimal solution inspecified search space. PSO algorithm was developed with an idea for finding food for birds. The process suggests that the bird's group is finding food in different area. The process can be explained as that each bit is found by two vectors X(t) and V(t). These two vectors represent the position and velocityof the bit at that time (t). The solution of the problem is the location of each bit Xi. All thebits rotate their places based on the experiences of the past. The algorithm concludes with following discussions as: easy to implement PSO online optimization, the PSO's result is high accuracy, optimal solution can be achieved easily, and more adaptable and robust structure can beattained.

A neural network-based approach is also an intelligent technique presented in [32]. This method is used for small wind turbine with gear box system. It is studied that the maximum power from wind turbine can be traced. It also

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gives the fast and accurate response. A supervised artificial neural network is used to evaluate wind velocity.

II. HYBRID AC-DCMICROGRID

A hybrid ac-dc microgrid is an arrangement of both ac and dc grids attached through bidirectional converters as shown in Fig. 5. In this architecture, the DC microgrid is connectedto an AC microgrid through bidirectional converter and an AC microgrid is connected to PCC. The role of power converter is very important in this type of structure. There are numerous challenges in hybrid AC-DC microgrid that are presented in [33- 37]. The main aim of hybrid microgrid is to control the power balance within the microgrid. It has distributed generation (DG) and energy storage devices on both sides of AC and DC bus.

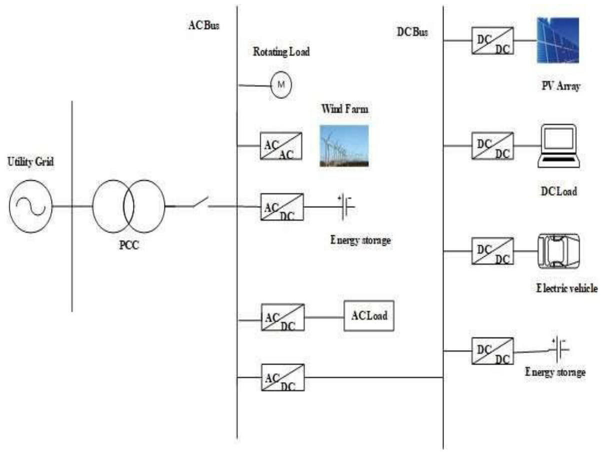

Fig 5. A typical hybrid AC-DC microgrid architecture.

The control and power management strategies are important for hybrid microgrid system [35]. It finds active and reactive power of storage devices and DG and therefore maintains frequency and voltage of microgrid. In autonomous mode of control of hybrid microgrid, it is difficult to attain power sharing by P-F and Q-V droop control methods.

2.1) CONTROL TECHNIQUES OF AC-DC HYBRIDMICROGRID

The centralized, decentralized and distributed primary and secondary control strategies are discussed in [36].

2.1.1) Centralized Primary and Secondarycontrol

In centralized control, each unit is controlled from a single controller using a communication medium. The controller collects the data from various agents to achieve the optimization. A hybrid system with solar and wind energy source, a power control strategy is discussed in [39]. The MPPT control algorithm is used to attain maximum power by perturbation and observation method. The wind energy control design is an important aspect for it. Under a variable environment, voltage and power can be good managed in a hybrid system. More efficiency is obtained by a power sharingtechnique.

A centralized secondary control has various techniques described as further. An intelligent supervisory control is used in [40] to provide demand of load power for hybrid system. The SOC of the storage devices is maintained with the help of Fuzzy control. When the demands from the solar and wind does not meet the requirement thenDG willbe used. Fuzzy controller is used to determine the SOC of energy storage devices. An optimization based supervisory control is implemented for maximum use ofenergy sources [37]. To obtain optimal solution, a robust strategy is implemented. To find the chargingand discharging of energy storage device, two-way control scheme isimplemented. A coordination control of hybrid microgrid for autonomous and grid connected mode is described in [33]. The converters have to make a proper coordination with the grid for an uninterrupted supply. In grid connected mode, the important control is converter which maintains a dc voltage for variable loads. A coordination control algorithm is proposed for stable operation of microgrid. In isolated mode, the converter plays an important role for supplying voltage and frequency for ac grid. Here also, two level coordination control is implemented for stable operation. The hybrid system reduces the number of converters used in the system and the efficiency can be increased as the converter losses are less. A hybrid ac dcsystemcanbelocatedindividuallyforhomesandindustries.

2.1.2) Decentralized Primary and SecondaryControl

In Primary control, the two-control loop is used for voltage and current control. The current control is done

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through PR controller and dc voltage control is done through PI controller. For proper load sharing, droop control method is required. By using equal virtual resistance,dc load sharing can be done [36]. The frequency of both the grids are normalized as represented byequations

$$f_{pu} = \frac{f - 0.5 * (f_{mx} + f_{mn})}{0.5 * (f_{mx} - f_{mn})} \quad (9)$$

$$V_{pu} = \frac{V - 0.5 * (v_{mx} + v_{mn})}{0.5 * (v_{mx} - v_{mn})} \quad (10)$$

Where fmx and fmn are the frequencies on ac side and Vmx and Vmn are the voltage on dc side. In secondary control, decentralized method for autonomous hybrid structure for local and global power sharing is implemented [41]. Global power sharing (GPS) removes overstressed in DG. It is used when the sub grids are in symmetrical position. A distributed secondary control permits the communication between local controllers in microgrid.

III. CONCLUSION

This paper exhibits an outline of control techniques in microgrid. The MG's hierarchical control system consists of four control levels:local or primary, secondary, central/emergency, and global controls. The primary control accommodates with each DG's internal voltage/ frequency and current control loops, whereas thesecondary control extends upper level control loops i.e. the voltage and frequency control surrounded by a bus connecting MGs, supporting a load deviation. The central/emergency control deals as a microgrid EMS, and it is answerable for emergency control and overall protection plans. Lastly, the global control maintains the flow of power among the microgrid and the main grid, in gainful optimal operation. The drawback of decentralized secondary control can be solved by implementing distributed control where each local controller connects together and sends particulars to the smartgrid.

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