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Optimization Techniques for Hybrid AC-DC Grid: A Review

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Abstract- With the advancement of Distributed Energy Re- sources (DERs) Hybrid AC/DC grid have got the importance due to its simple configuration where AC sub grids, DC sub grids and storage systems are grouped into several clusters. Component sizing and cost minimization, power quality, power management and load shedding are important objectives in control and management of Hybrid AC/DC grid. Hybrid AC/DC grid operates in two modes grid connected and off grid (Islanded mode), disturbances occur during transition from one mode to other which are to be addressed. Optimization techniques are applied in several fields to get the best or most favorable solutions, this paper reviews the basic configurations of Hybrid AC/DC grid, modes of operation and control techniques, optimization techniques with their objectives that are applied to Hybrid AC/DC grid.

Keywords- Distributed Energy Resources (DERs),Hybrid AC/DC grid, microgrid, optimization techniques, grid connected and off grid(Islanded mode)

I. INTRODUCTION

Renewable Energy Technologies with fractional power ratings can be installed in many number and anywhere which led to penetration of Renewable Energy sources in to existing system, these creates disturbances in system; here comes the necessity of smart grid which uses communication techniques viz. phasor measurement units(PMUs), wide area monitoring system (WAMS), Internet of Things (IoT) these make the system smart grid. In design and control of smart grid optimization techniques play a key role, this paper reviews the basic smart grid topologies of micro grid and hybrid AC/DC grid, control techniques and optimization algorithms for hybrid AC/DC grid .This paper is divided in to five sections Section I briefs about necessity of smart grid and its comparison with traditional grid, it also emphasizes smart grid configurations, micro grids and hybrid electric grids. Section II presents types of micro grid structures present in literature and principles that should be followed in structure design. Section III discusses the modes of operation and control techniques of Hybrid Electric Grid. While section IV introduces necessity of optimization techniques and its basic types with comparison and Section V reviews optimization techniques that are applied to hybrid electric grid with objectives of planning cost minimization, optimal sizing and configure, power flow and control.

Fig 1: Components of Smart Grid

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II. SMART GRIDS

The utility industry across the world is trying to address numerous challenges, including generation diversification, optimal deployment of expensive assets, demand response, energy conservation, and reduction of the industry's overall carbon footprint. It is evident that such critical issues cannot be addressed within the confines of the existing electricity grid [1].Existing grid is unidirectional in nature, which converts only one third of fuel in to electricity by which load demand cannot be met, in addition to any failure in system results in cascaded failure of system. The next-generation electricity grid, known as the "smart grid" or "intelligent grid," will ad- dress the problems associated with the existing grid. Affordable and reliable electric power is fundamental to modern society and the economy, with the pervasive application of electronics and microprocessors, reliable and high quality electric power is becoming increasingly important [2], the figure2 shows the important components of smart grid which requires communication between systems.

1. Micro Grids

Micro grids are part of smart grids, with the advancement of renewable energy technologies they are deployed at several locations near to the customer premises, by which customer becomes prosumer (producer of electricity). Renewable energy sources such as solar power, wind energy, geothermal energy, direct energy conversion systems (DEC) etc, can be installed in customer premises or near local loads are termed as distributed energy sources (DERs). While the application of DERs can potentially reduce the need for traditional system expansion, controlling a potentially huge number of DERs creates a daunting new challenge for operating and controlling the network safely and efficiently. This challenge can be partially addressed by microgrids, which are entities that coordinate DERs in a consistently more decentralized way, thereby reducing the control burden on the grid and permitting them to provide their full benefits [3].Microgrids can operate and controlled safely in grid connected mode and islanding mode with centralized, decentralized and hierarchical control modes. The author in [3] has detailed several real time projects on micro grid operation and control.

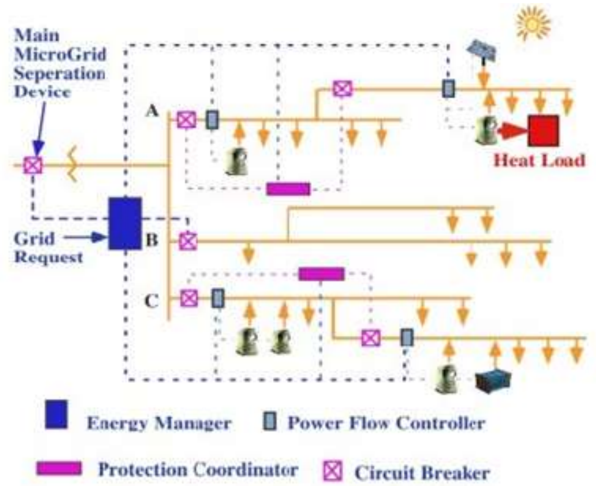

Fig 2: Architecture of Micro Grids

2. Hybrid AC/DC Grid

Conventional electric grid is an AC based; where as micro grid consists of AC or DC DERs which operate independently. In hybrid electric grid both AC and DC sources are connected to DC bus bar, in [5] authors proposed hybrid electric grid which have advantages of both AC and DC grids, power consumption is controlled by droop control method, AC grid is controlled by frequency and voltage and DC grid is controlled by controlled loads, however authors addressed only independent control of sources and loads. The hybrid grid eliminates multiple DC-AC-DCAC-DC-AC conversions in an individual ACDC grid. The hybrid grid increases system efficiency, eliminates the embedded AC/DC and DC/DC converters in various home, office and industry facilities which can reduce size and cost of those facilities [6].The figure3 shows the basic architecture of hybrid electric grid, the DC and AC micrograds are interlinked through the four quadrant operating thyristors, all the AC and DC sources and loads are connected to AC and DC bus respectively, AC grid is connected to utility through transformer, wind turbines are connected by AC/DC/AC converters. Fly wheel and AC loads are controlled by DC/AC converter and breaker respectively. Whereas DC sources and loads are connected by DC/DC converters, DC loads are used to control the power in the DC bus bar. Ref. [7] has elaborated various hybrid electric grid structures by taking consideration some principles of the structure design.

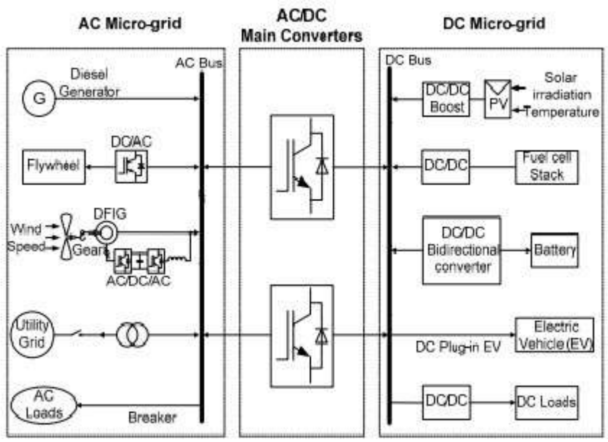

Fig 3: Architecture of Hybrid AC/DC Grid

3. Principles of the Structure Design

Following principles are important principles to be followed in designing hybrid electric grids

- The principle of partition
- The principle of hierarchy
- Fully use of the resources
- Power quality assurance principles

Principles of partition segregates the power lines by which complexity is reduced and losses are minimized. By using principle of hierarchy voltage levels are set for both DC and AC systems for these load capacities are required to compute in advance. Power quality assurance principles are useful to maintain reliability in system such as ESS, reactive power compensation. The above difficulties and advantages can be met by advanced micro grid structures such as multi-ring structure, single ring structure and the complementary ring structure.

III. CONTROL TECHNIQUES FOR HYBRID AC/DC GRID

Micro grid operates in Three modes that are AC grid mode, DC grid mode and combination of AC and DC, table I shows three modes of operation for power flow and control variables. Control schemes for hybrid AC/DC grid can be broadly categorized as centralized control and Decentralized control. Centralized control requires communication devices where as decentralized control is an autonomous control without communication example droop scheme of control. Further control techniques of hybrid grid classified based on hierarchical of parallel AC/DC converters for grid connected and stand alone modes [9][10].

Table 1: Modes of Micro Grid Operation

Operation of modes	AC Subgrid Micro sources	DC Subgrid Micro Sources	Power flow	Control system
Mode(a)	yes	no	AC microgrid sources to AC loads and grid	control of AC voltage/AC current for AC load sharing
Mode(b)	no	yes	DC microgrid sources to DC loads and grid	control of DC voltage/DC current for DC load sharing
Mode(c)	yes	yes	AC and DC microgrid sources to AC and DC gridS	Control of AC and DC voltage for AC and DC load sharing

With the development of smart hybrid AC/DC grid Distributed Energy Resources (DERs) can be either AC or DC type. The objective of any microgrids is to share power proportionally among its DERs.v Design of control schemes for Interlinking Converters (ICs), different rated DERs can create uncertainties in control schemes for these an interlinking converter scheme with Droop control technique is proposed in [8]. In power management for hybrid AC/DC grid centralized control is superior to decentralized control technique. It has shown that autonomous controlled VSI is subjected to false signal in large scale hybrid systems, this problem is addressed in [11] with an improved control technique. In grid connected mode micro grid is balanced by grid voltage and frequency, in Island mode voltage and frequency are controlled locally. During transition from grid connected to island mode or vice-versa a mode adaptive control technique is employed [13]. Further frequency and voltage stabilization in standalone (Island) microgrids can be controlled by Battery Energy Storage System or inserting a super capacitor apart from centralized droop control schemes [12]. In transition from grid connected to island mode uncertainties in demand and supply are present these are addressed by multi agent based on control scheme for these objectives are to be formed for centralized and decentralized control. Centralized control objectives are power scheduling, energy management, operating cost and load scheduling. In decentralized control DERs are controlled and has their own objectives. Multi agent based control scheme objectives are objectives of DERs that are power agent, photovoltaic power agent, wind power generation agent; battery agent etc, by these objectives multi agent based control scheme gives optimal solution for island mode operation [14]. Another important issue in hybrid electric grids is circulating current and power sharing issue deviation in among converters. Circulating current issue can be addressed by Isolation transformers which is uneconomical these issues are eliminated by virtual impedance control method [15].

IV. OPTIMIZATION TECHNIQUES

To solve and design a problem in real time world it is difficult to do experiment multiple times to get a acceptable one which involves time consuming, human involvement, which is a tedious and expensive. This conventional design method are replaced with computer simulation models which have fast modeling capacity but these computer simulation models have got the disadvantages of slow design process, medium human involvement and they give the error prone results. Drawbacks of simulation models can be overcome by optimization techniques, which are optimization algorithms with benefits of fast modeling, fast design and minimum human involvement, and solutions are with low error. These optimizations have disadvantages of complex optimization algorithm, difficulties of solving the real world problems.

Table 2: Comparison of Optimization Techniques

Deterministic optimization	Stochastic Optimization
Popular methods: Branch-and-Bound methods, Primal- Dual Decomposition methods, Inner Approximation methods, Difference of Convex methods, Reverse Convex methods, Lipschitzian methods, Trajectory and Homotopy methods, Interval Analysis methods, etc.	Popular methods: Genetic Algorithm, Tabu Search, Particle Swarm Optimization, Cuckoo Search, Ant Colony Optimization, Simulated Annealing, Hill Climbing, Downhill Simplex, Artificial Bee Colony Algorithm, Swarm Intelligence, Differential Evolutionary Algorithm ,etc.
Global optimal Solution: 100 percent guaranteed	Global optimal Solution: Not 100 percent guaranteed (probabilistic guarantee and it will become percent in infinite computing time)
Problem type: LP, MILP, NLP, MINLP Problem size: (usually) small	Problem type: Any types Problem size: (usually) small, medium and large
Computing time: Long and extremely long for medium and large–scale problems(not controllable)	Computing time: can be short for medium and large scale problems(controllable)

Optimization techniques or algorithms are single objective or multi objectives with multiple number of inputs, in these output depends on inputs and system constraints which are to be strictly followed, the output of system is feedback to system under 'n' number of iterations. Depending on tools of computation optimization methods are classified in to mathematical optimization model and computer programming optimization model as in figure4 In mathematical and computer model numerical, metaheuristic respectively are popular, based on nature inspiration metaheuristic are classified in to Swarm intelligence (SI) based algorithms, Non-Swarm intelligence (SI) based algorithms and Physics or chemistry inspired algorithms [16]. Optimization methods are broadly classified in to Deterministic and stochastic types, in deterministic output of the model is investigated by the initial conditions and parameter values, a unique output is produced due to a unique input for a well defined linear models and multiple outputs are possible for non linear models. Whereas stochastic model posses some inherent randomness so that same set of initial values and parameter produce different outputs. Stochastic model accounts uncertainties caused due to the varying behavioral characteristics, so stochastic is more informative than deterministic. Deterministic model can guarantee the global optimal solution for certain solutions with specific position structures but fail in problems like black box, ill behavior functions or complex large scale problems. On other hand stochastic model can work with any type of optimization problems but weak in guaranteed global optimum solution. Table II shows the comparisons between stochastic and optimization methods in terms of global optimum solution, types of problems, problem type and size, and computing time.

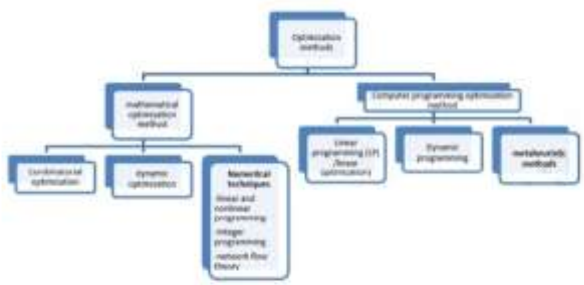

Fig 4: Classification of Optimization Techniques

Fig 5: Evolution of Optimization Techniques

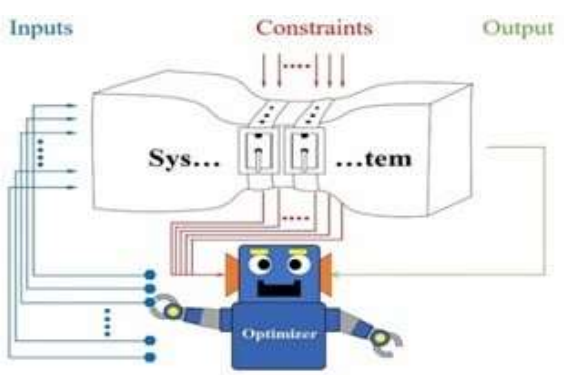

Fig 6: Basic Optimization System Components

V. OPTIMIZATION TECHNIQUES FOR HYBRID AC/DC GRID

Compared with deterministic optimization, stochastic model can compete with real time problems due to thiis extensively used for hybrid AC/DC grids. Table III presents popular optimization techniques and their objectives in hybrid AC/DC grids.To meet local loads in the system a hybrid power system is designed by using DERs by considering cost of system as an objective function of PSO[16], further to find the optimal system configuration and optimal component size for each location is predicted by applying multi objective PSO [17][21][22].Hybrid Energy Storage Systems[HESS] plays a key role in suppressing the power fluctuations in the grid transmission mode from grid tied mode to islanded mode, optimal sizing of the HESS is evaluated with PSO algo-rithm[24]. Power quality of system is improved by power electronic devices such as D-FACT, Filters, and Compensators PSO is used to design control gains of D-FACTS controllers [18, 19]. According to hierarchy a hybrid AC/DC grid can be controlled by master slave controller method, interlinking converters is master and sub grids are slaves, PSO is used to design optimal controller strategy. The real and reactive power (PQ) control scheme regulates the DC bus voltage and power flow between the AC/DC sub grids. Genetic algorithm (GA), artificial bee colony (ABC) optimization, particle swarm optimization (PSO) and the PSO with new update mechanism (PSOd) are used to compute the optimum gain values of proportional-integral (PI) controller in the PQ control scheme [24]. Several techniques exist in the literature to control the power flow; however, most of these techniques use proportional-integral (PI) controllers which are difficult to tune and exhibit slow response. To eliminate the drawback of existing control solutions, Hill climbing (HC) algorithm proposed [25] to exchange active power among DC and AC microgrids which uses perturbations of power angle and observes the corresponding changes in the active power. To exchange power between DC and AC grids of the hybrid system, it should have a good collaboration for exchanging power and energy during the day to minimize the total cost of the hybrid grid. A powerful optimizer based on crow search algorithm (CSA) is designed to search the problem space; the proposed method uses a new two stage modification method to increase the search ability of CSA when avoiding premature convergence [26]. A Pareto optimality concept was used [27] to minimize system costs and maximizing system reliabil- ity, the model features a Monte-Carlo simulation (MCS) for addressing stochastic variations related to load demands and DERs. Quasi-oppositional harmony search algorithm is a novel improved version of music inspired harmony search algorithm for obtaining best solution vectors and faster convergence rate; it is applied to load frequency control technique followed by disturbances in islanded mode of operation [28]. To get reliable power through micro grid energy storage system plays a crucial role for which batteries are used, these has got environmental issues with low capacity; [30] applied fuel cell in conjunction with electrolyzer for generating hydrogen fuel, for optimal sizing and placing harmony search and simulation annealing is used.While in [31] authors used Robot soccer Algorithm for solving coordinated operation issues between islanded mode grids.

VI. CONCLUSION

There is a continues penetration of DERs in to existing system, maximum loads and DERs are of DC type, which are prone to less disturbances for this DC grid becomes advantageous compared with AC grid but these creates disturbances to existing grid. In addition to conventional control schemes, optimal solution is obtained with help of computerized computational methods for selecting optimal sizing and configure of components, power management and control. Particle swarm optimization (PSO) is widely used for various issues in hybrid AC/DC grid, apart from this Genetic Algorithm and Harmony Search Algorithm are used for selecting component size and configuration. While Robot soccer Algorithm is best for coordinated control between different microgrids. Further there is a need to evaluate various abnormal conditions that occur in micro grids and hybrid AC/DC grid in transforming traditional grid into hybrid AC/DC grid with reliability.

Table 3: Optimization Techniques For Hybrid Electric Ac-Dc Grid

Ref.	Optimization Algorithm	Objective
[17],[24]	particle swarm optimization (PSO)	optimal sizing and operation of grid
[18]	particle swarm optimization (PSO)	power flow control
[19]	particle swarm optimization (PSO)	Power quality
[20]	particle swarm optimization (PSO)	System configuration and size of component
[21]	particle swarm optimization (PSO)	minimizing system investment cost
[22]	particle swarm optimization (PSO)	Centralized and De-centralized control
[23]	particle swarm optimization (PSO)	planning of HESS Capacity
[25],[33]	Genetic algorithm (GA) artificial bee colony (ABC) optimization particle swarm optimization (PSO) Hill climbing (HC) algorithm	power control
[26]	crow search algorithm (CSA)	optimal operation and management of the hybrid AC-DC MG
[27],[29]	Genetic Algorithm and PSO	Planning for micro-grids, Optimal planning
[28]	minimizing system costs and maximizing system reliability	Pareto optimality concept
[30]	quasi-oppositional harmony search algorithm	Load frequency control
[31]	Alternating direction of multipliers method (ADMM), Alternating direction inexact Newton (ALADIN)	optimal power flow
[32]	Harmony Search	Simulated Annealing, sizing of standalone grid,
[34]	Robot soccer Algorithm	coordinated operation of islanded microgrids

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