Grid-Connected Renewable Energy Microgrids: A Systematic Review

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***Abstract*— A comprehensive review of the literature for the optimum design of microgrid is presented in this paper. This is aim at realistic evaluation of the current status, some existing research problems, and developed a future research topic in the area. Presently, the penetration of microgrid is increasing, ranging from developed to underdeveloped nations. Depending on the application, microgrids could be installed for specific applications, such as community-based and experimental microgrids. Examples of these situations are also highlighted in the paper.**

Keywords—Grid-Connected, Micro-grids, Optimum Design component

I. Introduction

Global warming has necessitated the need to decrease the amount of greenhouse gas into the atmosphere. This is contained in a Kyoto agreement which proposed the need to decrease the world gas emission by 50% by 2050. These efforts could be achieved by reducing the conventional power sources with green sources of energy. The proposal is critical as it can assist in reducing the number of people without access to electricity. Globally the number of people without electricity is about 1.5 billion and majority of them lives in developing countries. Therefore, according to statistics from the World Bank and International Energy Agency, there is a need to double the global installed energy for the next years to come. In order to achieve all these, researchers are proposing microgrids.

Microgrid is a new fast-growing concept which is refers to a small-scale power system with a cluster of loads and micro operating power sources together with energy management, control, protection devices, and associated software. All these are connected through power electronics interface. Microgrids can be classified according to the mode of operations. That means it can operate in grid-connected or standalone modes. In grid-connected mode, the system is connected to external main grid and it supplies the loads locally autonomously in island mode. However, due to the availability of wind and solar energy sources and dependence on the environmental factors, usually microgrids mostly consist of wind turbines (WT) and solar photovoltaic (PV). Unfortunately, some of the one of the concerns with these sources of energy is the reliability of the power supply. Therefore, there are some techniques available to improve the reliability of the power supply from these sources. Some of the methods include control of generation, demand, utilizing complementary characteristics of the renewable energy sources such as wind speed and solar radiation. On the other hand, the intermittent nature of the resources could be resolved by the use of a battery storage system. Unfortunately, these problems remained unsolved issues for grid-connected microgrids globally. Another problem of microgrids is cost of installations

Depending on the system configurations, microgrid could develop in standalone or grid-connected [3], [4]. On the other hand, microgrids can be classified according to the source of energy. That is wind, solar, hydro, and some cases in hybrid form. Another possibility is to classify microgrid according to power level. In all these, microgrids are site specifics. Some of the possible factors that could hinder the operations of renewable energy microgrids include weather, renewable energy potentials, hydrology, energy storage system demand to mentioned just a few [5]. Therefore, realistic sizing methodologies are still needed for higher penetrations of renewable energy resources globally [1], [6].

Microgrids provide an effective and a vital solution to the various issues facing the present-day electrical power systems and the need to reduce the greenhouse emissions and the carbon footprints and other challenges facing the present day and future generations. However, the structure of the microgrids is itself facing wide challenges considering the power system security and the power system reliability that is of prime importance to any country. Higher penetration of the renewables and the need to shift from conventional sources of energy to the non-conventional, the challenges facing the microgrids get even more complex. Renewables sources of energy, including the wind and the solar pose the vital issues of system security and the reliability due to their intermittent nature. Voltage control and generation dispatch are widely affected and as such stand-alone microgrids with deep penetration of these intermittent sources are highly unreliable. While battery storage devices in microgrids can provide potential alternatives, but their study and their utilization need to be understood before taking a step in this regard. Another issue of prime importance to microgrids is the low system inertia that exists in the microgrid structures.

One of the solutions to the above problems is to understand and study the optimum design of the microgrids. In view of these, this paper carried out a comprehensive review of recent happening in the area of optimum design of microgrid. In addition, existing microgrids across globe era reported globally. The next section reviews related literature in optimum design and methods for optimum design of microgrids.

II. CONTROL OF MICROGRIDS

The controller capabilities of a microgrid are one of the most crucial elements in determining the introduction of this new concept to the utility and its wide acceptance. Despite the recent efforts in the area of renewable energy, control capabilities issues still remained the most critical part of the expected stories of microgrids across the globe. Many factors determine the control of microgrids. Some of them include the types of microgrid, depth of renewable energy penetrations, distributed energy resources, load power quality et to mentioned just a few. The basic requirements of any control, in this case, to supply continuous power supply irrespective load changes. It can be seen that microgrids could be operating in grid-connected mode; however, it can go to island mode in case of a fault, or sometimes one or more DG could be connected or isolated from the grid. Generally, the requirements of control are to ensure that under all conditions, the microgrid control is expected to ensure power supply to the loads with acceptable voltage and frequency. When the system is operating in grid-connected mode, the system voltage and frequency are determined by the grid and distributed generation units.

On the other hand, the non-iterative methods always try to achieve maximum power point tracking mode or predetermined the amount of power. In addition, real and reactive powers are control by interactive control and depend on the type of microgrids system and demand. The former method is usually for unreliable and inconsistent sources such as solar and wind power sources. The latter option is for diesel generators and battery storage systems. In some cases, the same microgrid systems could hybridize the two control methods.

In the case of island microgrids, a dual approach is used. Moreover, voltage-frequency control is used to keep these parameters constant for some large DG networks. Once this is achieved, the rest of the DG will operate in the load sharing to ensure the load of the system is supplied and control as expected. By this technique, the microgrid can work within acceptable voltage and frequency limits while the loads are powered with expected stable power. Note that droop control is the widest control method for load sharing in the microgrid. This because it can operate automatically without the need for central control, mechanism, or communication between micro sources.

Most of the literature on the control of microgrid investigated either PV, wind standalone, or both with or without battery. Recent development in [19] proposed a coordinated strategy for DC microgrid with variable generation and storage. The same authors in [20] proposed a comprehensive control strategy of a DC voltage for a DC voltage control of a four-terminal microgrid consisting of variable generation and multiple slack terminals. The system consists of wind, AC, grid, DC load, and energy storage system. Authors in [21] investigated the DC voltage control of the strategy of a DC microgrid as a function of different terminals. Three-level of control were proposed according to the DC voltage variations. The proposed control strategy has been tested under different operating conditions, such as static and transient operations. Some authors in [22] have developed a control algorithm for both grids connected and standalone microgrid consisting of PV and storage batteries only. The algorithm demonstrated the capability of DC power flow between input and output terminals of the microgrid. Multi-loop algorithm capable of inverter control considering battery charge limit and state of charge for PV-storage microgrid has been devised [23]. The choice of control parameters for the stability of PV-storage microgrid has been investigated by [24]. [25] Used advanced power control techniques to satisfy the load demand, state of the battery, prevent blackout and extend the life of the battery of a PV/wind microgrid. This was achieved by the development of active–reactive power control of the microgrid. Similarly, another paper [26].

III. OPTIMUM DESIGN OF MICROGRIDS

An optimization model for the sizing of microgrids has been developed in [7]. The model takes fuel operational and environment cots into consideration. In the same paper, the authors proposed a non-dominated sorting genetic algorithm (NSGA II) for minimizing the cost of electricity and battery life. The proposed model was able to consider the characteristics of lead-acid battery storage. Another model was for the optimum design of PV/wind/diesel and battery storage. In the paper, the DIRECT algorithm was proposed in the design. However, the proposed model could not be realistic when a reliability figure is to be considered in the design [8]. Particle swamp optimization has been proposed for the optimum design of wind, solar microgrids. The model simultaneously optimized cost and reliability. The system was designed for Northern Iran, and it has a life span of about 20 years [6]. Unfortunately, the system may not be optimum for the target due to the intermittency of renewable energy sources. Simulated annealing has been used for the optimum design of microgrid, the developed method optimized system operational and system costs [9]. However, the developed model might not be optimum when uncertainties are incorporated into the design. In the same vein, the annual cost of microgrid has been obtained in [10]. Unfortunately, the attention of the developed model was on the economy. Other factors to be considered for a realistic optimum design were not considered. Therefore, the proposed model may not be optimum. Authors In [11] developed mixed-integer multi-objective particle swamp optimization. The model was used to minimized the system cost and maximized the reliability of microgrid [12]. It can be seen that the system may not be optimum when other components are added to the design. In a similar passion, it could not be optimum when the grid is added to the design. Other factors that could affect microgrid is the location of the distributed energy resources. Hence the design of such systems could be realistic when these factors are considered in the design could affect microgrid reliability.

In Malaysia, a similar microgrid for a building was designed. The system consists of Wind/PV and diesel generator, and the validity of the procedure has been confirmed in HOMER software [13]. In Jordan, the possibility of hybridizing wind and solar energy to form hybrid microgrid has been investigated in [14]. A similar microgrid has been developed for freezing and cooling systems in Algeria [15]. For a better understanding of the model, both emissions and economic factors were considered in the optimization. Another multi-objective model is developed in [16], which added customer outages and energy production costs into the cost function. The foregoing review has shown that renewable energy microgrids penetration level is rapidly increasing [17], [18]. Also, for a realistic and robust implementation of microgrids, regional, environmental differences are essential for system planners [19]. In a similar manner, a study in [20] developed a controlled strategy for active distribution networks. The study established that proposed controlled strategies could assist in reducing power loss, power consumption and achieved a double win situation between grid side and the user side. However, the method might not be optimum when other factors such as reliability and network structures are incorporated into the model. Recently large wind and solar penetrations have been analyzed in [21]. Unfortunately, the study was restricted to off-grid application. Therefore, grid-connected microgrid studies are limited.

IV. Renewable Energy Systems Optimization Methods

A. *Conventional Approach of Renewable*

Renewable energy microgrids systems can be designed from different approaches. In literatures, this ranges from theory to practical approaches. Some of the methods starts from trial and error method. This method results into issues that could be overlooked in the design and results into many undesirable situations after the procedure is completed. Some of the problems associated with this method include corrections, battery design corrections, and installations issues. Issues of battery usually are due to the lifespan of the battery is different from the lifespan of the system under considerations. Therefore, the system is too expensive for developing countries and low-income earners in society [22-24].

B. Ampere Hour Method

The ampere-hour method is a process usually develop for implementation in a spreadsheet. Therefore, it is term as a very simple process in the design of microgrids. Once the power rating of all proposed loads is obtained, it can be multiplied by the hourly of operation. Sometimes losses are also considered in the design. Finally, storage systems to be used in the design are determined by considering the autonomous days usually obtained arbitrarily. Hence, the method could be subjected to some inaccuracies and approximations that could results into over or under system design [25]. Implementation of this approach can be seen in various literatures example in [26], were PV system is used to supply energy for a particular load depending on some predetermined conditions. That is PV system will provide 605-80% of the needed energy if the load is under 2000mwh/day, or supply 5000 wh/day for a load in the range of 60% - 80% and finally 20%-40 for the demand in the range of 5000 and 1000 wh/day. Another similar paper was proposed in [27] for sizing of isolated PV microgrid. However, this method is time-consuming. Therefore, there are high possibilities of abuse in the sizing of system components. Generally, the method might not be economical and could lead to system error, especially when it results into sub-optimal results. This is possible due to the sessional nature of renewable energy supply sources that variability in the weather. Other factors that are not considered in the analysis are environmental factors.

C. Trade-Off Method

In a situation, whereby the system designer is interested in solving more than one objective, then a multi-objective optimization problem needs to be developed and solved. The method of trade-off is developed for solving such problems, especially due to the uncertainties of renewable energy resources. The advantage of the method is that it allows for solving all possible combinations that could lead to system design. However, the approach leads to a database that could determine all possible systems designs. Finally, the decisions are picked by the decision-makers [28]. Unfortunately, due to higher penetrations of renewable energy sources into world grids, available optimization techniques are becoming more critical. This is due to the fact that most of the techniques are nonlinear, and therefore results into nonlinear problems. Therefore, the operations of the systems become complex and highly inefficient. Therefore, classical optimization techniques could not handle them efficiently [30-31]

D. Classical Techniques

Classical optimization is usually employed in solving differential and continuous optimization problems. The methods are applicable in optimal sizing of hybrids systems and can be classified as Linear programming methods, dynamic programming, nonlinear programming method, and each of them can be used for optimizing renewable energy systems [32].

Linear programming is an optimization method in which a function is to minimize or maximize subject to linear constraints. The general linear programming problem can be defined in mathematically in matrix form as [33]:

$$\min_{x} f^{T}_{x} \tag{1}$$

Subject to:

$$Ax \le B$$

$$A_{eq} x = B_{eq}$$

$$L_b \le x \le U_b$$

where,

f, x, B, B_{eq}, L_b And U_b are vectors and A, A_{eq} are matrices.

On the other hand, when all or some of the decision variables are restricted to an integer, then an integer optimization technique is used, and it has the following standard form that is; [34]

$$p(x) = \sum_{j=1}^{n} c_j x_i \tag{2}$$

Subject to constraints defined as follows that is:

$$\sum_{i=1}^{n}\left(\sum_{i=1}^{n}a_{ij}x_{j}\leq b_{i}\right)$$

$x_j \geq 0 \quad \forall j \in \{1,n\}$ and x_j is an integer $\forall i \in \{1,I\}$

In addition, there are situations whereby the objective function or any of the defined constraints is no-linear. In this situation, the problem can be formulated as a non-linear optimization problem. Also, the solution can be obtained by using a non-linear programming technique model. Unfortunately, there are issues with this optimization technique. These include non-convexity and complexity. Usually, Nonlinear programming (NLP) employs Lagrangian or Newtonian techniques for solving constrained and unconstrained optimization problems. Generally, this optimization problem has a structure as follows [35]:

Minf(x) (3)

Subject to:

$$g_i(x) \leq b_i \qquad \forall i \in \{1,2,-----,N\}$$

where some terms in the constraints $g_i(x)$ or **f(x)** are non-linear.

In literature, many works have applied linear programming for the optimal sizing of renewable energy systems. Example of such works includes [36] in which a technique for sizing storage system sizing of renewable energy microgrids has been proposed. The storage system designed is for energy storage at all times and dispatch for another time. In the same paper, unit commitment for microgrids with scanning reserved is considered. Therefore, the problem was formulated as a mixed nonlinear integer problem (MNIP) that was eventually solved a mathematical programming language.

Further analysis shows that optimized energy storage decreased the total cost of microgrids. Another paper [37] authors have developed a method for selecting and sizing of more one renewable energy source and battery storage using mixed integer programming problem. In a similar work, [38] authors have designed a microgrid considering reliability issues. The proposed method designed a microgrid using dynamic programming, also the method was able to determine the optimal power line layout between micro-sources and load points, given their locations and the rights of way for possible interconnections. Both Cooling and Heating Power model of a rural micro-grid is built-in [39] and optimized by using mixed integer linear programming optimization model. This is for energy improvement in order to improve system efficiency. Also, in similar paper [40], MINLP is used to minimized fuel consumption of microgrid while satisfying system constraints that fulfill the local energy demand and provide a certain minimum power reserve. Authors in [41] proposed a dynamic optimal schedule management method for optimal sizing of isolated or grid-connected microgrid systems. In the design, factors such as forecast errors with uncertainties of renewable energy sources and user demand were considered. The same authors used the same optimization technique, in [42] in order to maximize the profit due to energy trading either in isolated or grid-connected micro-grids. Reference [43] developed a linear problem for optimal energy mix using real data in order to size residential microgrid considering weather variability. Another development was in [44], whereby two linear techniques are proposed for the optimal design of energy supply systems. The first model minimized deviation from the electric load requirements of the system. The second optimization is one that minimizes the system costs per annum. Recently, due to the nature and requirements of future grid, biological optimization techniques have gained popularity in future energy systems optimization.

V. BIOLOGICAL BASED APPROACHES

Biological approaches of sizing renewable energy systems can be categorized into three, including which are artificial neural networks (ANNs), evolutionary algorithms (EAs), and swarm intelligence [45].

A. Genetic Algorithm

John Holland developed a Genetic Algorithm (GA) between 1960–1970 [46] in order to search the process that could mimic the process of natural selection. The method usually developed a solution using techniques inspired by natural evolution such as mutation, inheritance, selection, and crossover. The procedure consists of five main components: a random number generator, a fitness function, a reproduction process, a crossover, and a mutation. The reproduction selects the fittest candidates of the population. At the same time, Crossover is the procedure of combining the fittest chromosomes and passing superior genes to the next generation, and mutation alters some of the genes in a chromosome [47].

An optimal number of components that make up microgrid was obtained using GA in [48]. The optimization problem developed to ensure that the system load requirements are met. The same method was for sizing a power unit of a typical base station in [49]. A similar study was carried out in [50] for the optimal design of hybrid microgrid in which the first solution was obtained by application of the exhaustive enumerative method. Sensitivity analyses were carried out to investigate the effects of the number of generations, population size, and crossing and mutation rates on optimal sizing of the developed microgrid system. In another study, authors in [51] investigate the effects of PV array slope and WT installation height on the optimum design of microgrids. Also, the optimization considered reliability parameters in the model. In another paper [52], authors were able to minimize annual cost and Loss of power supply probability of hybrid PV-wind energy microgrid. The optimization was achieved with the help of Pareto-based multi-method. An extension of similar microgrid was designed in [53]. The authors were able to minimize LCE and emissions by applying Parato-base GA. Authors in [54] the design standalone hybrid microgrid by minimizing the total cost of the system considering the useful life of the system and carbon emission taking load profile into consideration. [55] The capability of elitist GA was shown in which the method was able to optimize three objective functions of a hybrid microgrid. In this optimization, a new variable was introduced these include life cycle cost, LPSP, and an ecological model. In this case, the decision variables are areas of PV and WT and the capacity of the storage systems.

[56] designed a microgrid system for the water treatment plant of a community with the help of Genetic Algorithm.

B. Artificial Neural Network (ANN)

Due to variability in wind and solar radiation, it has become almost impossible to accurately forecast these resources without error. These needs necessitate the development of smarter techniques, such as artificial intelligence techniques. In similar passion forecasting of these renewable energy sources is needed for realistic planning of the smart grid and future energy systems. It also allows system planners the ability to make changes expected to the baseload power plant in order to minimize peak power plant utilization. These forecasts are better handled by artificial neural networks (ANNs) because it can allow multiple and variable data to estimates power ahead in advance at different times intervals. There are many efforts in optimization problems that relate to energy in general, which deal with optimization techniques. such as the prediction of energy demands using ANN. Authors in [57] developed a simulator for renewable energy system. The developed module is suitable for grid-connect and stand-alone microgrid. It can also determine the energy flows and optimize the scheduling plants in grid-connected or standalone modes. In another development in [58], it was shown that a recurrent neural network is cable of determining of battery state of charge and output voltage of the system when connected to a microgrid. Similar research has shown the ability of different types of neural networks in the wind speed prediction. The techniques employed for the predictions were the Self-Organizing Map (SOM) and a Radial Basis Function (RBF) [59]. The methods were able to reduce prediction error compared to conventional techniques. Efforts to minimized input data in sizing renewable energy microgrid were demonstrated by authors in [60] ANN, and the results have shown tremendous improvement in decreasing the number of inputs parameters. A similar investigation was carried out in [61] to size PV energy microgrid using ANN. The results have shown the ability of the sized battery system to meet system demand with very high availability of about 99%. Energy management system was developed in [62]. The developed method used Multi-Layer Perceptron Neural Network in order to achieve optimal scheduling of generators for industrial applications. The neural network used many inputs parameters such as weather factors, load demand, thermal constraint of the system, to mention a few. In [63] method of prediction was to optimally size PV microgrid by using a large data set with the help of ANN. The optimal combination was determined by considering different loss of power supply probability and yearly cleanness index. The possibility of sizing hybrid PV-wind-battery microgrid using ANFIS model has been proposed in [64]. The objective of the optimization was to minimize the energy production cost. Similarly, authors in [65] used the backpropagation neural network model to predict the hybrid renewable energy microgrids. The same authors used FLC for energy management of the same system. Hybridization of ANN and fuzzy logic was done in order to control the flow of power between hybrid energy systems and battery storage system. The overall results were higher storage state of charge [66].

C. Particle Swarm Optimization (PSO)

PSO is initially developed for social interaction to problem-solving [67] and was designed by Kennedy and Eberhart in 1995. However, presently Particle Swarm Optimization (PSO) could be categorized as one of the most successful optimization techniques that have achieved great success in computational intelligence. The technique has been robust and finds many applications in solving may optimization problems in microgrids. Some of the attributes of this technique that make it great include simplicity, flexibility less convergence time. Therefore, it becomes one of the most frequently used methods for microgrid optimization problems. Some of the optimization problems resolved with the help of PSO include offline and online optimization problems. These areas enhanced microgrid applications in many areas such as power demand, economic aspect and renewable energy resources related problems. Also, offline problems are formulated based on the prior knowledge of weather conditions and pre-determined load profiles. On the other hand, online optimization problems, sometimes called real-time problems, are tuned to find the optimal system solution irrespective of the variations of system parameters. These parameters might include weather condition, fuel cost that changes over time, and load profile to motioned a few. Objective functions formulation in microgrid that is well handled by the used PSO include both single and multi-objective function optimizations problems. In the same vein, it could handle both minimization and maximizing of the resources for successful and realistic implementations of microgrids globally.

Minimization problem is formulated to minimized many variables. Example includes life cycle cost of the system, gas emission including (carbon dioxide, nitrogen oxide, Sulphur oxide to mention just a few,), power losses including reactive and active power losses), lifetime degradation.

When formulating an optimization as a maximizing problem, usually parameters to maximize include benefits such as profit, reliability by minimizing some system parameters such as loss of load probability, loss of power supply probability, power generation, and network present value.

Generally, PSO depends on the swarm of N particles. The particles are in search space randomly D. in each case, each of them can be defined by its position Xij and velocity Vij. The system operation is that particles are moving at each iteration, taking their best position and the best position of their immediate neighbor. This shows that at each iteration, the particle moves towards an optimal solution. The velocity and position are defined mathematically as :

$$V_{ij}^{k+1} = w.V_{ij}^{k} + c_1 * r_1 * (P_{best} - X_{ij}^{k}) + c_2 * r_2 * (G_{best} - X_{ij}^{k}) \quad (4)$$

Position is defined,

$$X_{ij}^{k+1} = X_{ij}^{k} + V_{ij}^{k+1} \quad (5)$$

where c1 and c2 are acceleration coefficient,
r1 and r2 are random numbers between 0 and 1
w is the inertia
Pbest is the particle best position and
Gbest is the particle global best position

$$W = W_{max} - \frac{(W_{max} - W_{min})iter}{iter\_max} \quad (6)$$

Where

W_{max} Is the final inertia weight

W_{min} Initial inertia weight

Iter is the current iteration number

Iter_max is the maximum iteration number

Note that the choice of parameters and stopping criteria has a great influence on the performance of the algorithm. That means if the correct parameters are selected, the result expected is always the best. More details about the PSO can be seen in the figure in figure 1 that is,

Binary Version of PSO

Another version is called BPSO, in which a particle is represented by a binary space. In addition, the particle position velocity is a binary value between 0 and 1.. the same equation is used in order to update the velocity of a particle, that is [68]:

$$x_{ij}^{k} = \begin{cases} 1 & \text{if} \quad u_{ij}^{k} < s_{ij}^{k} \\ 0 & \text{if} \quad u_{ij}^{k} \geq s_{ij}^{k} \end{cases},$$

Where, where U^{K}_{ij} is a random number in the range of 0 and 1

$S^{K}_{ij}$the sigmoid function defined as

$$s_{ij}^{k} = \frac{1}{1 + e^{-v_{ij}^{k}}}.$$

PSO was used in [69] in order to determine the leverlized cost of energy produced by hybrid renewable energy microgrid. This paper shows how sensitive the optimization procedure is in solving such type of problems. In a similar paper, [70], system cost was minimized by satisfying system demand while taking all the defined constraints into consideration. In the same paper, the authors have shown how parallel optimization is better than serial optimization. Experimental microgrid has been developed in [71]. It was clear from the result that the system minimized investment cost and fuel cost with the help of the PSO technique.

A method of determining the capacity of PV, wind, and battery storage were developed in [72]. The method was able to be optimized system parameters by taking uncertainty in renewable energy resources into consideration. The developed hybrid system consists of PV, wind, battery, and diesel generator. The optimization problem was able to determine optimal system cost considering the reliability parameters of the network. A modified version of microgrid was developed in [73] by adding tidal energy; the objective of the design was minimizing the annualized cost of energy. The design was based on PV specific availability. Other parameters optimized in sizing microgrid include net present value [74]. In this paper, the authors determined different designs of microgrid consisting of PV, wind, storage and energy storage system. Fuel cell microgrid annual cost was optimized in [75]. The optimization considered other probability parameters; this was to ensure that the system demand was meat at all times. The probability parameters were outage probability wind turbine, PV array and converter.

More complex optimization problems were developed to solve. Example authors [76] developed a triple objective optimization problem. A similar problem was developed and the results were compared with improvement in total system cost while having the same gaseous emissions. This shows that sometimes, system cost depends on the method and mathematical model developed in microgrid design. This was further confirmed by authors in [78] and implement in different parts of the Iranian electricity network. The authors used different optimization techniques tabu search, simulated annealing, harmony search algorithm, and modified PSO. The conclusion from work shows that different PSOs can perform differently in a different part of the country.

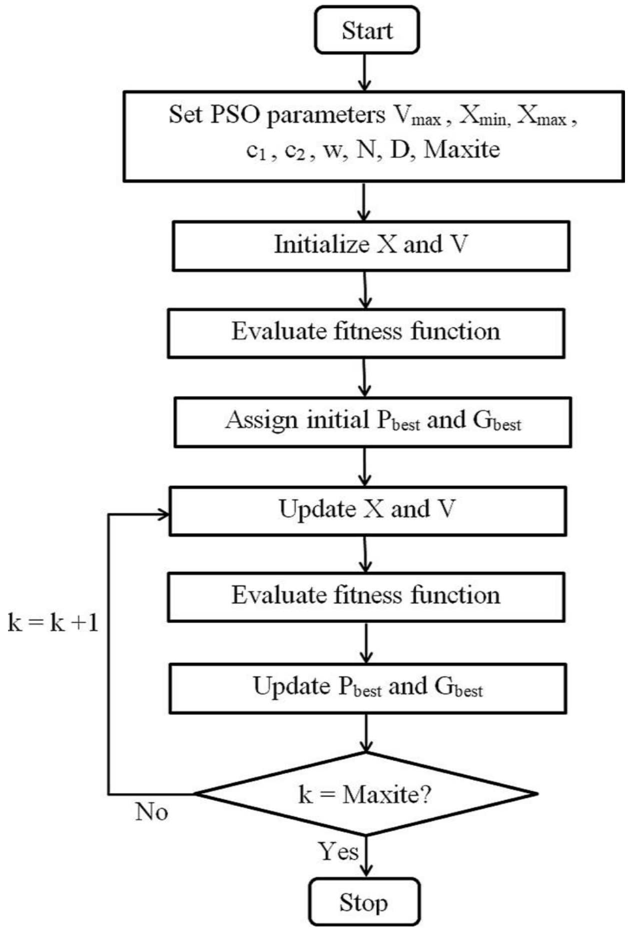

Fig: Flowchart for PSO implementation

VI. Existing Grid-connected Microgrids

In this section, some existing microgrids are shown in Table I. It can be observed that microgrid ranges from experimental to community scale. In addition, looking at the locations of installation.

Table I: example of some existing Microgrids globally

S/No	Location	Details
1	Boston, USA microgrid	MW peak and consist of two hydropower plants and Autonomous control

2	Quebec hydro USA	7MW peak & it has connected about 700 customers, is Autonomous control system
3	Bronsbergen, Netherland	Agent-based controlled of Mesh connection of PC, DG CHP & battery
4	Kythnos, Greece	PV, and battery & diesel generator, central controlled
5	National Technical University, Greece	PV generators, wind turbine, & Battery, agent-based controlled
6	University of Manchester, UK	20 kVA microgrid that is driven by induction and synchronous generators, it uses SCADA
7	Aich, Japan	1.4 MW, 330 kW, and battery storage, radial controlled
8	Demotec, Germany	Wind turbine, battery and diesel generator
9	KERI, Korea	120kW, consisting of PV, wind turbine and battery storage

VII. Future Research Problems of Grid-connected Microgrids

In this section, some of the major critical issues associated with the development of microgrid across the globe are discussed. It can be observed that the problems can be divided into technical and non-technical problems. Tables 1I and III presented no-technical and technical challenges that hinder the implementation of the microgrid. Follow by elaborates discussions of some of them immediately.

Table II: General Future research areas for grid microgrids:

S/No	Issues	Comment
1	Legal	There is a need for a clear identity for a microgrid in order to achieve a realistic implementation and penetrations of microgrid. This because the initial costs are high, looking at time constraints.
2	Interconnectivity policy	Another fundamental issue is the need for legislation to regulate the connections of distributed e energy resources to the grid.
3	Utility Regulation	In order to achieve the objectives of microgrids penetration, there is a need for restructuring and deregulation. This could define a clear jurisdiction between generation, transmission, and distribution globally. This shows that more work needed to be done to incorporate them into regulatory legal structure.
4	Utility opposition	In order to achieve a better grid base microgrid, there is the need to move from the traditional cost-effective service to a performance-based microgrid

Table I1I: General Future technical research areas for microgrids

S/ No	Area	Requirements
1	Energy management concept	More realistic energy management strategies need to be developed. Also, there is a need for implementation and or simulations of the proposed model
2	Fault current protection issues and new microgrids protection schemes	Due to the nature of future energy grids, there is a need for design and development of high, accurate and sensitive protection schemes that could be absorbing the requirements of future sophisticated grids
3	Incorporation of high-speed equipment within the microgrids networks	ICT is needed for smart- metering, and network controls applied to microgrids. For example, wireless communication, power line communications, bus signaling, etc. There is still difficulty on how to implements some of the proposed models.
4	Policy and Standards	Standard procedures and policies are needed in order to achieve higher penetration of microgrid across the globe.
5	Optimization schemes	Since future grids are expected to be available at all times, there is a need for the development of both offline and online optimization strategies in order to enhance the performance, availability, reliability, decrease losses and optimum economical operation of the microgrids.
6	AC Microgrids	Isolated loads and rural communities are most vulnerable to non-availability of electricity, therefore; there is need for conventional island microgrid in order to take care of these loads.
7	DC Microgrids	Recent improvement in the area of DC power supply utilizations and transmission show that, the DC systems are gaining momentum at distribution level. Therefore, the expectations from DC microgrids are high.
8	Model development	There is need for new modelling techniques due to complexity of the future microgrids. This is as a result of emergence of new generators, energy storage systems, loads, power electronic interfaces, distribution network's needs, frequency ranges and time.
9	Energy storage systems	Looking at Rogen diagram of energy storage systems, it can confirm that, there is a need for trade-off in order to achieved high power and energy densities for future energy microgrids especially when large scale is becoming critical

VIII. Conclusion

This paper has carried out a comprehensive review of the recent development in microgrids. A survey of different optimization techniques has been reported in detail. Most of the used techniques been used in practice and theoretically are also reviewed. In addition, some of the existing microgrids, together with their technical details, have been analyzed realistically. In addition, for microgrids to achieve the global desired objective of more penetration in providing clean and reliable energy to more communities, some problems that have not solved are also reported. The paper has shown that there is a clear demarcation between technical and nontechnical problems affecting the implementation of microgrid across the globe. Finally, some techniques performed differently in the same environment when an optimization problem is to be solved. Therefore, the choice of optimization technique has a serious implication on the optimum design of microgrid systems.

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