Optimization Techniques for the Microgrid Framework: A Review

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Abstract— For the sustainable energy development, the microgrid technology emerges as a dominant alternative. One of the most important objectives of the smart grid is the optimal operation with satisfying the limits of the system. Intermittent nature of the renewable energy sources and continuously varying demand are major challenges in the development of microgrid. In this paper, various optimization techniques with different objective functions are investigated in microgrid context. This paper also addresses the technical as well as economical constraints for optimization.

Key words: Constraints, Microgrids, Objective Function, Optimization

I. INTRODUCTION

Fossil fuels are non-renewable energy sources that can only extract from finite sources that will eventually diminish. With the decelerating fossil fuels, the fuel prices growing abruptly this influences the cost of electricity generation. Microgrids can be a permanent solution to mitigate the electricity demand of such isolated regions in an economical manner. The microgrid requires optimization techniques in optimal sizing, allocation, scheduling, cost, and reliability analysis. The microgrid optimization problem is non-linear and non-convex. In this type of optimization problem, there is a high probability of solutions to fall in local optima because of numerous equality and inequality constraints. The microgrid optimization problem requires such an optimization technique which gives global results and free from local optima.

In [1], the authors reviewed the various tools and algorithms for optimization in the microgrid context. The optimization tools and algorithms are useful in sizing, allocation, scheduling, cost, and reliability analysis. The authors in [2] presented a comprehensive review of optimization techniques utilized to obtain various configurations and evaluation of SPV-wind based hybrid energy system. In [3], Deihimi proposed a multi-objective uniform water cycle algorithm to minimize the operational cost of the microgrid. In [4], the authors carried out a detailed review of optimization algorithms to achieve the optimal allocation of DES. To solve the optimization problem, the authors itemized the numerous classical and artificial intelligence based optimization algorithms. In [5], Pesaran performed an extensive review of optimization techniques for the optimal operation within the hybrid microgrid. In [6], proposed an optimization algorithm which works over a specific time horizon to meet the load demands at minimum cost.

With the integration of HRES, optimization problem transformed into non-linear non-smooth, which are complex and tricky to solve. Traditional methods such as MILP, linear programming, and some nature-inspired algorithms are trapped into local optima. The concept of hybrid techniques and optimization tools has evolved to obtain the optimal results with HRES. Nature-inspired algorithms do not guarantee the best solution but it imparts the optimally feasible solution based on situational awareness.

II. STATE OF ART

A. Microgrid Configuration with Hybrid Renewable Energy System

The microgrid functions as the localized distribution framework to supply the dynamic load demand. The controlling of the entire operation of the microgrid network is fully relying on load dynamics and power generation. For the reliable power system operation, it is essential that the generated power should be greater than the demanded power. The generation output from the RES is reliant on typical climatic variations and it is not possible to acquire the expected power production all the time. The speed of wind varies according to the season as well as location wise which acutely impact on power generation. Solar penetration is also affected due to rain and overcast conditions. Thus, the power extraction from individual DES is discontinuous as well as costly.

To compensate for the shortcomings of individual DES, the idea of HRES had proposed, which acquire their response according to overcast conditions and capabilities. For the electrification of geographically isolated areas, HRES should establish with a storage device or small hydro plant or small CHP to continue the microgrid operation. The components used in HRES are as follows:-

- DES (Such as wind plants, SPVs, biomass, tidal, and geothermal)
- Storage element (Battery, fuel cell, small hydro plant, small CHP)
- Charge controller
- Power conditioning devices
- Meters and instruments
- Protection equipment.

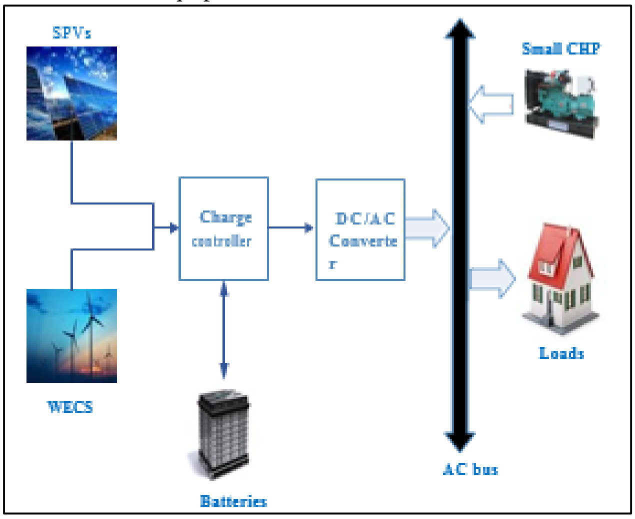

Fig. 1: Hybrid renewable energy system.

To ensure the reliable, stable, and secure operation of the microgrids, the optimization techniques plays vital role.

B. Concept of Optimal Solution

1) Global optima:-

It is the best solution for objective function among all the possible feasible solutions.

2) Local optima:-

Non-linear, non-smooth optimization problems have a number of possible feasible solutions which is known as local optimum. In this region, it is possible to get no feasible solution in the right next of founded previous solution.

3) Suboptimum:-

It can be illustrated as a saddle point effect (neither minimum nor maximum). Minima and maxima are depended upon their specific path trajectory.

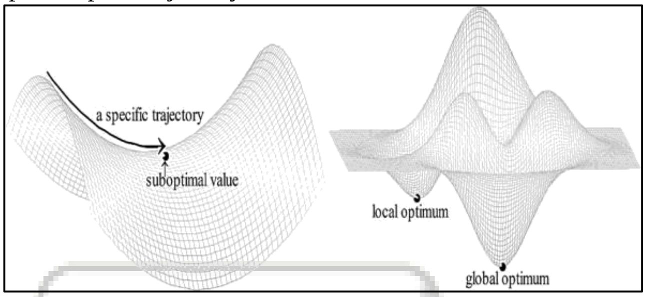

Fig. 2: Concept of optimal solution.

C. Objective Functions

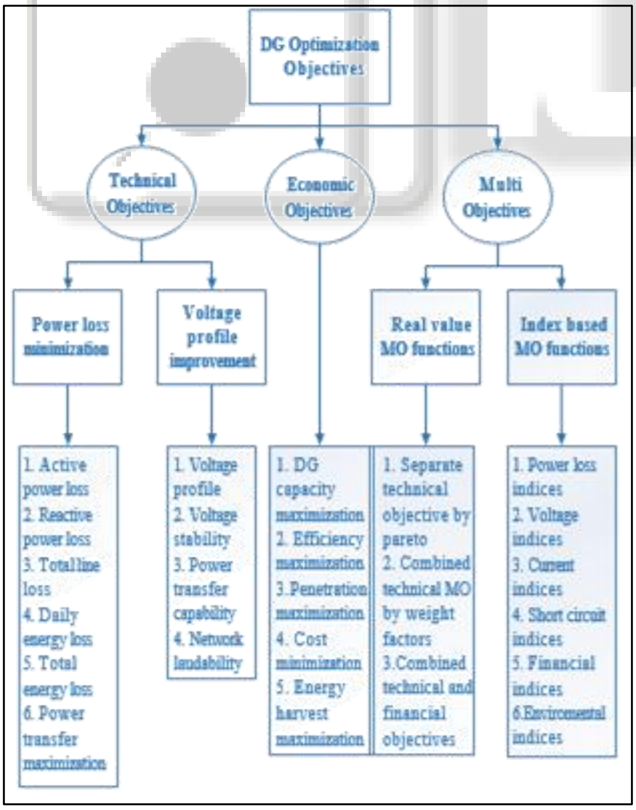

Fig. 3: Objective functions for the microgrid.

For the microgrid designing, capacity enlargement, construction, operation, and maintenance, engineers should have to make decisions and requires problem solving approaches. All of these decisions are aimed to either minimize cost or maximize generation productivity, which is reliant on a number of decision variables as well as constraint sets. With the presence of numerous constraints, the power system decisions turn into a complex and non-linear optimization problem. The objective functions are classified into technical economical and multi-objective functions.

1) Technical Objectives

Technical objectives are formulated to evaluate the real-time technical performance of the system. Most important technical objective is the real-power loss reduction and the other issues are maximization of power generation, voltage profile, and congestion management.

2) Economic Objectives

Net operational cost minimization and to decide the optimal size of generating units are the major economic objectives for the microgrid optimization. The other objectives are the maximization of renewable energy extraction and static cost minimization.

3) Multi-objectives

It is the combination of both technical and economic objectives. These are formulated to solve the real-time operational issues of the microgrid.

D. Constraint Limits

Microgrid optimization problems are non-linear, non- smooth optimization problems. It constitutes both equality and inequality constraints. Handling of equality constraints is more complex and it requires robust optimizer. Figure 4 shows the various constraints for reliable operation of the microgrid.

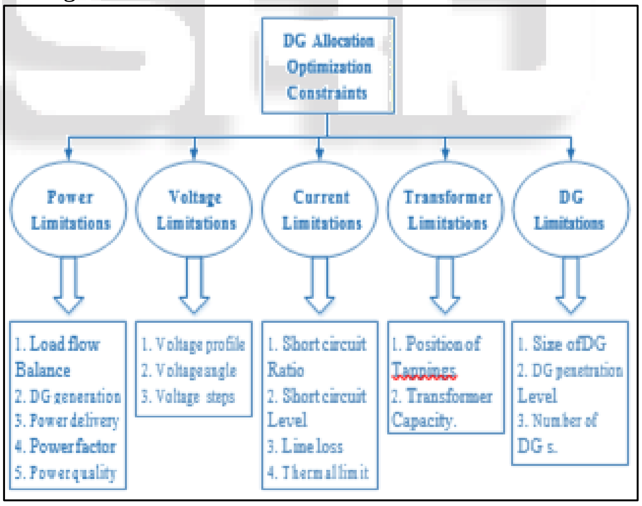

Fig. 4: Constraints for the microgrid optimization.

Power balance should formulate as the equality constraint and voltage limits, current limits, and short circuit current limits are formulated as the inequality constraints.

E. Optimization Techniques

Many optimization algorithms have good extrapolation incorporation, lend results in global optima and free from local optima. Global optimum is indicated for global search space for the algorithm. Algorithms which have good extrapolation can be implemented for HRES optimization. Most of the metaheuristic techniques are greatly depends upon the initial fitness values so the selection of initial sets plays a vital role to obtain optimal results. Mainly four approaches are utilized for the microgrid optimization:-

1) GA

GA was first introduced by the scientist Holland in 1975. It resembles the principle of natural selection, which is inspired by Darwin's survival theory. It can be applied for both constrained and unconstrained optimization problem. It encodes the population matrix into a fitness function and then manipulates the solution by assimilating the rules of natural selection, crossover, and mutation. The accuracy of GA requires more parameter settings which increases complexity in algorithm processing.

In 2012, Liao imposing GA with a chaotic quantum theory where search accuracy and sensitivity of GA was enhanced using quantum models and chaotic algorithms. In 2017, Askarzadeh applied memory based genetic algorithm (MGA) for HRES scheduling. MGA has a faster convergence rate and better search capability.

2) PSO

PSO was developed by J. Kennedy (a social psychologist) and R. Eberhart (an engineer) in 1995. PSO is an evolutionary algorithm which emulates the civic response of swarm in food foraging with dynamic environmental conditions. Each particle with a certain velocity is considered as the solution. The particles are a move towards the P_{best} and then track path in the direction of g_{best}.

There are lots of PSO variants are available such as binary PSO, MOPSO, PSO trelea Vectorized, PSO with constriction factor and many more that's why PSO is explicitly used in microgrid optimization.

3) SA

SA was invented by Kirkpatrick, Vecchi, and Galatt in 1983. SA is an arbitrary search approach which mocks the functioning of a metal cooled by an annealing process to enhance its inner strength. The annealing process is modeled as

$$P_r\{E = E\} = \frac{1}{Z(T).\exp(-E/k.T)} \tag{1}$$

Where,

$Z(T)$ = Normalization factor (temperature dependent)

T = Temperature

New state probability is expressed as

$P_r\,(accepted) = \exp(-\Delta E \,/\, k.T\,)$

Where ΔE = Energy difference

$$P_r(configuration = i) = \frac{1}{Q\,(c).\exp\left(\frac{-c_i}{c}\right)} \tag{2}$$

C = Cost function.

4) Ant colony algorithm:-

Since 1992 research on ant's behavior was pioneered and it is observed that ant drops a pheromone substance to track their paths in food foraging. Ant searches their food at 1230 angle from their previous searching location, which provides excellent extrapolation and covers the whole area. When the path is not used for a long time the searching probability automatically decreases. State transition rule for path tracking is modeled as

$$P_{ij}^k = \left\{ \frac{[\tau_{ij}^k]^\alpha . [\eta_{ij}]^\beta}{\sum_{u \in J_{k(i)}} [\tau_{iu}]^\alpha [\eta_{iu}]^\beta} \; if J \in J_{k(i)} \right\} \tag{3}$$

Where,

τ = Pheromone

η = Inverse edge distance

The pheromone deposition equation is expressed as

$$\tau_{ij} = (1-\rho_h).\tau_{ij} \tag{4}$$

Where ρ_h = heuristically defined parameters.

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F. Optimization Tools

1) HOMER

NREL, USA developed the HOMER tool to execute HRES (SPVs, wind battery, and EVs) with PEC and loads in an optimal manner. The most impressive characteristics of this tool are its compatibility to track inconstancies and parameter fluctuations. Simulation can be carried out between the ranges of a few minutes to the entire year.

2) GAMS:-

This tool is used for linear and non-linear optimization. It allows complex situational changes which are significant for smart grid design planning and security assessment. It also provides access to tools with another language. Likewise, WILMER planning tool is developed by IEA incorporating GAMS.

3) HYBRID2:-

It is developed by University of Massachusetts Renewable Energy Research Laboratory (RERL). It is frequently used to model power conditioning devices and loads with higher accuracy in flexible time frames.

4) RETSCREEN:-

RETSCREEN is based on the Microsoft (MS) Excel and provides the exposure of technical and economic viability of RES with conventional sources. It is the most downloaded simulation tool across 222 countries.

III. CONCLUSION

This paper presents an overview of objective functions, constraints, and various optimization approaches for the microgrid optimization. The optimal operation of the microgrid depends upon the selection of the constraints and applied optimization technique. This is very useful in power scheduling, generation forecasting, and other operational issues. The presented study can be impactful for the selection of constraints and suitable technique to ensure the optimal operation of the grid.

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