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VOLTAGE STABILITY OF AC/DC MICROGRID SYSTEMS

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ABSTRACT

The attendance of distributed generators with DC production power and the progression in power electronics devices have provoked structure planners and grid worker to go towards mixing of DC microgrids into straight AC grid. In this paper, the optimal power flow (OPF) problem in AC-DC networks is tackled. The objective of the AC-DC OPF problem is to together reduce the total electricity production price of the system and the price of shift active power from the AC grid to the DC microgrids. The optimization problem is topic to the power flow constraints, voltage magnitude limits, the limits of the system power lines, and the limits forced by the power ratings of AC-DC power electronic converters. Since the prepared AC-DC OPF problem is shown to be nonlinear, a come up to reformulate the AC-DC OPF difficulty as an equivalent traditional AC OPF problem is planned. Due to the non-convexity of the AC OPF problem, a modified adaptive differential evolution algorithm is proposed. Simulation studies are performed on an IEEE 30-bus system connected to 6-bus under both normal operation and network contingency condition. Obtained results from the proposed approach for the test cases confirm the validity of the developed approach.

Keywords- *OPF, AC-DC networks, DE, MADE, Voltage stability, power system security*.

I. INTRODUCTION

Microgrids have established rising notice as a means of mixing distributed generation into the electricity grid [1], [2]. Usually explains as restricted bunch of loads, storage devices, and little generators, these independent systems connect as single entities to the community distribution grid. Microgrids consist of a diversity of technologies: renewable sources, such as photovoltaic and wind generators are operated beside traditional high-inertia synchronous generators, batteries and fuel-cells [3]. Thus, energy is produced near the loads, allow the use of small-scale generators that add to reliability, and decrease losses overlong power lines. But, the mixing of DC microgrids and straight AC grids makes power network management a difficult task for system planners and workers.

Optimal power flow (OPF) is a helpful tool for planning and decision building to make sure reliable process and to run power grids. The optimal power flow (OPF) consists of solving equations which differentiate an electrical power system (active and reactive power of each node) regulate the control variables values (voltages or powers) in order to optimize a exact system parameter, represented by one aim function [4]. A system typically includes state variables (unknown quantities) and independent variables (unknown data). Control variables can be any of the independent variables in the system, and are chosen depending on the function of the analysis.

When an AC grid is linked to one or more DC microgrids, the OPF problem of the AC-DC network takes the shape of a non-convex optimization problem consisting of the usual AC network and DC microgrid power flow equations, in addition to the constraints forced by the AC-DC converters equations [5]–[7]. The non-convexity of the problem arises from the nonlinear power flow equations and quadratic need on the set of bus voltages. The problem may have numerous local optimal solutions [8].Security constrained OPF (SCOPF) is an extensive form of OPF, which also includes security constraints of the power system. Due to significance of security, particularly in the modern power systems, more notice has been paid to SCOPF in new years. An appraisal of some SCOPF research works can be originated in [9-11].

Over the previous a number of years a lot of mathematical optimization techniques have been functioned to resolve the OPF problem such as; linear programming (LP), nonlinear programming (NLP), quadratic programming (QP), and interior point methods [12-15]. All these method rely on the initial situation and convexity to find the global optimum; the methods based on these assumptions do not assurance to find the global optimum solution when allowing for the various types of constraints. Reference [16] provides a valuable introduction and surveys the classical optimization techniques. Poor convergence, trapping in local optima and inability to offer great freedom for different objective functions and constraints are some of disadvantages of mathematical programming methods to solve OPF [9, 11]. For solving SCOPF, these disadvantages become more highlighted. To remedy these drawbacks, OPF and SCOPF solution approaches based on stochastic search techniques have been accessible in recent years.

To defeat the drawbacks of the mathematical methods related to the initial condition and to the shape of the aim function, a new group of global optimization techniques is developed, this category based on stochastic and heuristic aspect includes; Genetic algorithm (GA) [17, 18], Tabu search (TS) [19], Simulated annealing (SA) [20], Evolutionary programming (EP) [21], Particle swarm optimization (PSO) [22], Differential evolution (DE) [23], Harmony search (HS) [24], Artificial bee colony (ABC) [25], Biogeography based optimization method (BBO) [26, 27], A modified Artificial bee (MABCA) [28], Shuffled frog leaping algorithm (SFL) [29], and Gravitational search algorithm (GSA) [30], block-hole–based optimization (BHBO)[31] differential search algorithm (DSA)[32,33] electromagnetism-like mechanism (EM)[34] teaching-learning–based optimization (TLBO)[35] imperialist competitive algorithm (ICA)[36] invasive weed optimization (IWO)[37] and league championship algorithm (LCA)[38] honey bee mating optimization (HBMO)[39] and a new mutation based method called MHBMO have been used to solve OPF problems. All these methods applied with success to solving various problems related to power system operation and control. Reference [13] provides a significant and valuable introduction and surveys the non-deterministic and hybrid optimization methods that were used for solving the different optimal power flow problems.

Differential Evolution (DE) is a population-based, direct stochastic search algorithm and one of the most prominent new generation EAs, proposed by Storn and Price [40], for optimization problems over a continuous domain. The main advantages of DE are: simple to program, few control parameters, high convergence characteristics. DE has been applied to several engineering problems in different areas.

In this paper, In order to enhance the local search ability and to accelerate the convergence of DE techniques, a new mutation scheme based on the weighted difference vector between the best and the worst individual at a particular generation is used. Further, the control parameters are adapted suitably to demonstrate a good performance property in the new method called modified adaptive differential evolution (MADE) algorithm. It is demonstrated that the proposed method results in superior performance in comparison with the existing methods and also numerically converges more quickly than the evolutionary methods reported in the literature.

II. AC-DC OPTIMAL POWER FLOW SOLUTION

In the AC-DC OPF problem, the aim is to reduce the price purpose of real power generation in both AC grid and DC microgrid and the price of linked power transfer from AC grid to DC grid subject to dissimilar equality and inequality constraints and the converters equations [41]. The OPF problem for AC-DC grids is nonlinear since the voltages of buses in the AC grid are joined with the voltage of the buses in the DC microgrids. Also, the converter variables are essential to be included in the traditional OPF problem formulation [42]. Hence, it is vital to find an appropriate model for the converters in the AC-DC OPF problem.

Consider a converter between AC bus r ∈ and DC bus s □ Ndh,c of the DC microgrid h ∈ H. First, merge the buses r and s to create a new bus in order to eliminate the dependency of the AC and DC voltage magnitudes. Then, add a generator with only reactive output power to the new buses to model the compensation ability of the converter. Finally, replace all lines in DC microgrid with only resistive elements (since there is no voltage drop across inductors in DC), and all DC sources and loads only with real power. Without loss of generality, we can assume that the DC microgrids are AC microgrids with resistive transmission lines, active output power generators, and active loads.

Let Oach denote an AC microgrid that corresponds to the DC microgrid h. After performing these steps for all the converters, the DC microgrids can be connected to the AC grid directly in the model. Hence, we have an equivalent AC grid consisting of the AC grid Oac and the AC microgrids Oach , for h ∈ H [43].

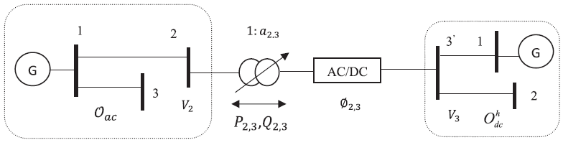

Figure 1: An AC-DC network consisting of AC grid and DC microgrid.

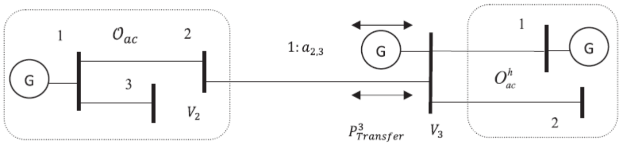

Figure 2: The equivalent AC grid of the original AC-DC network

III. AC-DC OPF PROBLEM FORMULATION

The main goal of the OPF is to optimize a certain objective subject to several equality and inequality constraints. The problem can be mathematically modeled as follows:

$$Min \;\; OPF(x, u) \tag{1}$$

subject to

$$g(x, u) = 0 \tag{2}$$

$$h_{\min} \leq h(x,u) \leq h_{\max} \tag{3}$$

where vector x denotes the state variables of a power system network that contains the slack bus real power output (PG1), voltage magnitudes and phase angles of the load buses (Vi , □ i) , and generator reactive power outputs (QG). Vector u represents control variables that consist of real power generation levels (PGN) and generator voltages magnitudes (VGN), transformer tap setting (TK), and reactive power injections (QCK) due to volt-amperes reactive (VAR) compensations;

i.e., u □ [PG2 ....PGN ,VG1..........VGN ,T1...........TNT ,QC1.....
QCS] (4)

where N = number of generator buses,

NT = number of tap changing transformers

CS = number of shunt reactive power injections.

The objective function of the OPF problem in the equivalent AC grid includes the generation cost in AC grid and the DC grid and the cost of transferring power from AC grid to DC grid.

$$\text{Minimize: } \sum_{k=1}^{ng} f(P_{Gk}) + \sum_{r=1}^{nr} f(P_{Gr}) + \sum \omega_j v_j P_{transfer}^{j} \quad (5)$$

The minimization is performed over all voltage phases and magnitudes, active and reactive output powers of the generators, and the flowing active powers through the converters. Constraints (9) and (10) show the power balance equations in bus k ∈ . Constraint (11) shows that the input power to the equivalent converter bus is equal to the flowing power through that bus. Constraints (12)-(18) are the operation constraints.

Handling of Constraints: There are varied ways to handle constraints in evolutionary computation optimization algorithms. In this paper, the constraints are incorporated into fitness function by means of a penalty function method. In this method a penalty factor multiplied with the square of the violated value of variable is added to the objective function and any infeasible solution obtained is rejected. The extended objective function to handle the inequality constraints of state variables including load bus voltage magnitudes and output variables with real power generation output at slack bus, reactive power generation output, and line loading can be defined as:

$$OPF = \sum_{i=1}^{N} F_i(P_{Gi}) + K_p h(P_{G1}) + K_q \sum_{i=1}^{N} h(Q_{Gi}) + K_v \sum_{i=1}^{NL} h(|V_i|) + K_s \sum_{i=1}^{NL} h(|S_i|) \quad (6)$$

where K p , K q ,K v , K s and Kl are the penalty constants for the real power generation at slackbus, the reactive power generation of all generator buses or PV buses and slack bus, the voltage magnitude of all load buses or PQ buses and line or transformer loading respectively. h(PG1) , h(QGi) , h(Vi) , and h(Si) are the penalty function of the real power generation at slack bus, the reactive power generation of all PV buses and slack bus, the voltage magnitudes of all PQ buses, and line or transformer loading respectively. NL is the number of PQ buses.
The penalty function can be defined as:

$$h(x) = (x - x_{max})^2, \text{ if } x > x_{max}$$
$$= (x_{min} - x)^2, \text{ if } x < x_{min}$$
$$= 0, \text{ if } x_{min} \le x \le x_{max} \quad (7)$$

where $h(x)$ is the penalty function of variable x, and x^{max} and x^{min} are the upper limit and lower limit of variable x, respectively.

IV. SIMULATION RESULTS AND PERFORMANCE EVALUATION

IEEE 30-bus system results

In this section, we perform simulations on an IEEE 30-bus system connected to 6-bus and 9-bus DC microgrid systems as shown in Figs.3 and 4 respectively. The adapted IEEE 30-bus system consists of six generators, 41 lines and a total demand of 283.4MW and 126.2 MVAR. The fuel cost curves of the units are represented by quadratic cost functions. The lower voltage-magnitude limits at all buses are 0.95 p.u., and the upper limits are 1.1 p.u. for generator buses 2, 5, 8, 11, 13, and also for the remaining buses including the slack bus 1. Branches connected between buses 6-9, 6-10, 4-12 and 28-27 are off-nominal transformers with tap ranges of ±10%. The shunt injections are provided at buses 10, 12, 15, 17, 20, 21, 23, 24 and 29 as given in [47]. The cost coefficients and maximum and minimum limits of real power generations, line data, bus data and MVA line flow limits are taken from [48].

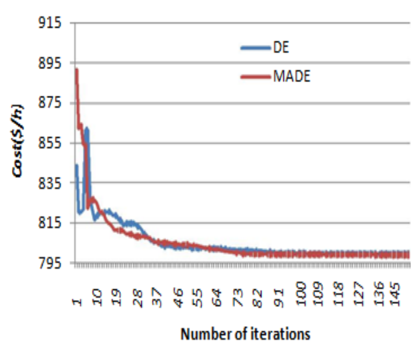

Figure 3: Best, worst, average results and standard deviation for DE and MADE algorithms

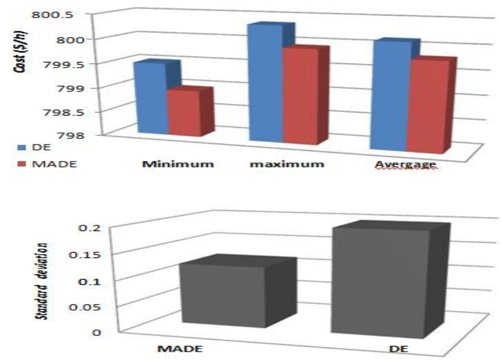

Figure 4: Best, worst, average results and standard deviation for DE and MADE algorithms

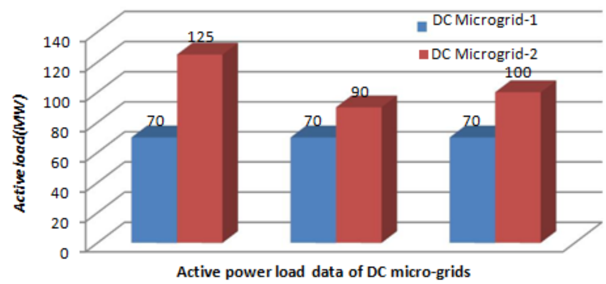

Figure 5: The active load data of DC Microgrids 1 and 2.

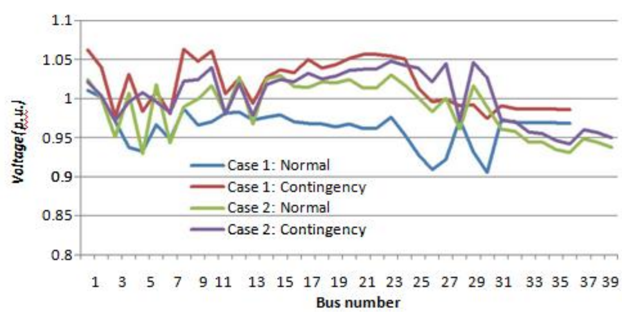

Figure 6: Voltage profiles of IEEE 30-bus system

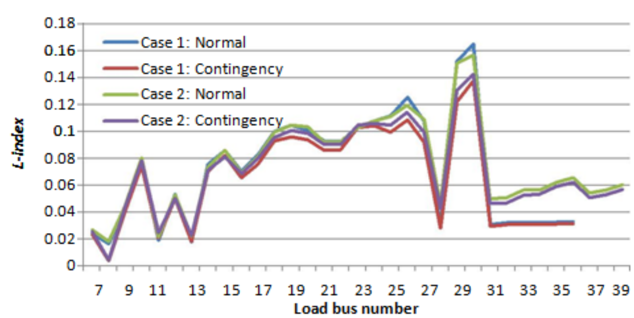

Figure 7: Voltage stability indices of IEEE 30-bus system

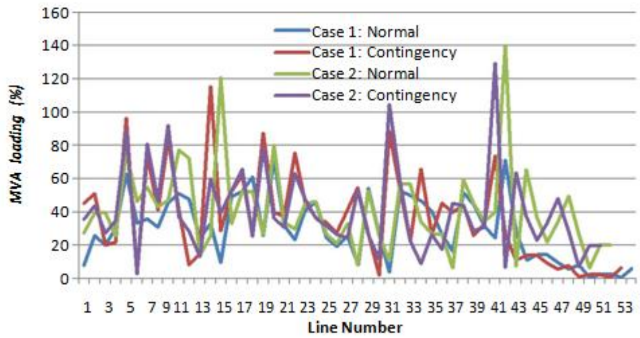

Figure 8: Percentage MVA line loadings of IEEE 30-bus system

V. CONCLUSION

The AC-DC microgrids offer a promising solution for grid integration of various types of distributed renewable energy sources. In this paper, the optimal power flow problem in the AC-DC system consisting of DC microgrids and AC network has been studied. The AC-DC converters have been represented by the corresponding real and reactive power conversion and power rating constraint equations in the OPF problem. As a result, the AC-DC OPF has been transformed to an AC OPF problem. A modified adaptive differential evolution algorithm has been employed successfully to solve the OPF in AC-DC micro-grid power systems. A new mutation and adaptive control parameters have been applied to improve the quality and efficiency of DE algorithm. Simulations were performed on an IEEE 30-bus connected to two sample 6-bus microgrids. By applying MADE approach, the generation output powers, cost of generations and transferred power between the DC microgrids and the AC grid have been determined. The numerical results reveal that the presented MADE algorithm can also be extended to solve AC-DC OPF by considering other power electronic devices such as flexible AC transmission system devices.

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