Optimal Energy Management in Microgrids Equipped with Distributed Generation

Ali Esmaeel Nezhad

Abstract—**In recent years, the problem of optimal energy management has become a global concern all across the world. In this regard, this paper investigates the optimal scheduling of energy sources in microgrids taking into consideration distributed energy sources. In the presented paper Distributed Generation (DG) includes Micro-Turbines (MTs) as well as Fuel Cell (FC) generating units. This problem has been modeled as a single-objective optimization problem while the energy procurement cost is taken as the objective function. The model is implemented in General Algebraic Modeling System (GAMS) and solved using CONOPT solver, since the problem is proposed in a Non-Linear Programming (NLP) framework. Furthermore, simulation has been done on a 34-bus distribution test system to verify the performance of the proposed model.**

Keywords— **Microgrid, Distributed Generation, Fuel Cell, Micro-Turbine and GAMS**

I. INTRODUCTION

Nowdays, due to global concern on environmental issues and the problem of climate change, conventional energy generating units are intended to be replaced with those having less emission generation. Moreover, the increasing cost of transferring energy causes extra challenge in this area. In this regard, power system planners seek smaller generating units that are installed close to the consumers. For this purpose, DGs technologies have turned to be proper alternatives to replace conventional power plants with high emission generation. Some power sources, such as MTs, FCs, wind power and Photo-Voltaic (PV) systems are taken into consideration as possible and preferred solutions over other technologies [1-3]. These generating units generally connect to power systems at distribution level. Therefore, the conventional scheduling models must be replaced by new ones which are much more complicated due to DGs. It is noted that, the newly appeared distributions are no longer passive and now, they work as active distribution networks. It is worth mentioning that microgrids are defined as active distribution networks comprising both loads and DGs. Hence, they are able to operate in both grid-connected and stand-alone operating modes [4]. However, the concept of microgrids involves with severe challenges in their operation needing precise modeling of the network and DGs. In addition, such model requires and applicable and powerful load flow tool. For this purpose, an effective algorithm is suggested in refs [5, 6] for load flow analysis in distribution systems and microgrids. Refs [7, 8] have utilized frequency/voltage droop control scheme for optimal scheduling of active/reactive power in a microgrid. In microgrids, there is an entity called Microgrid Control Center (MGCC) having access to the data of load pattern, DGs' generation as well as any other necessary information through a communication system. This issue is more important in the case of smart grids. As MGCC knows the amount of system's load, It can use different Optimal Power Flow (OPF) forms [4]. A typical microgrid is depicted in Fig.1 [4]. In Microgrids, coordinating local controller installed in the system is the main role of MGCC in order to have a secure, stable and reliable operating mode. Refs [9, 10] proposed generalized formulation considering a variety of energy sources for optimal operation of a microgrid with respect to local requirements and environmental issues. Moreover, refs [11,12] present mathematical formulations on the problem of optimal scheduling of generating units esp. FC power plants. Among DGs existed in power systems, FCs cause very great interest for electricity and heat generation, as this energy source has low operating temperature, fast start-up characteristics as well as ecological constraints [13, 14]. FC is a type of energy source converting chemical energy of a reaction directly into electrical energy. Since, FCs have high efficiency and they have environmental-friendly operation, they will be one of the most promising energy sources [15]. Another advantage of FCs is their low emission generation due to utilizing electrochemical energy conversion system instead of a combustion process.

This paper proposes the problem of optimal scheduling in a microgrid equipped with FCs and MTs. The OPF model used is ACOPF. Furthermore, a 34-bus test system is used for simulation.

The remainder of this paper is organized as follows:

Section 2 includes the mathematical modeling of the proposed problem and section 3 represents the simulation results and finally, some relevant conclusions are drawn in section 4.

Manuscript received September 6, 2013. This work was supported in part by the Islamic Azad University, Najafabad, Iran

Ali Esmaeel Nezhad is with the Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran (Corresponding author to provide phone:+989388377658;

Email: Ali.Esmaeelnezhad@gmail.com).

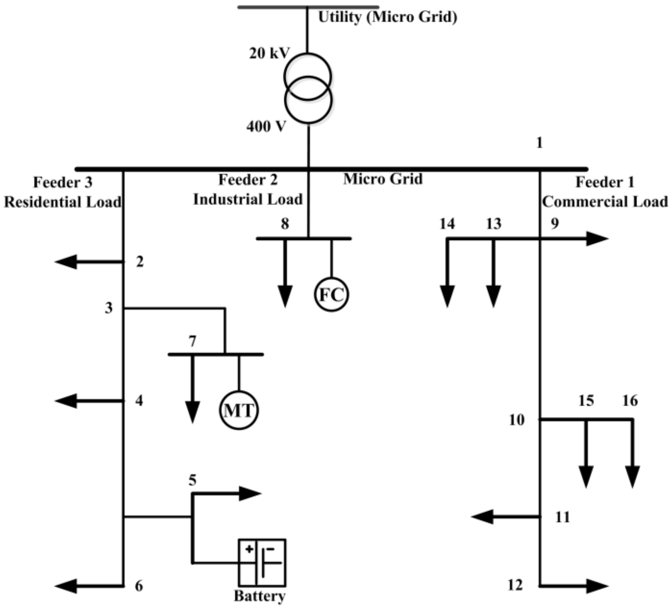

Fig. 1. A typical micro grid

II. MATHEMATICAL MODELING

In the proposed optimization problem, the objective function is cost minimization. This objective function can be stated as below:

$$Min \quad f_3(X)=\sum_{t=1}^{T}\left(C_g^t + \sum_{i=1}^{N_{FC}} C_{FC}^t + \sum_{j=1}^{N_{MT}} C_{MT}^t \right) \quad (1)$$

Where, C_g^t denotes the cost of energy procurement from the utility grid and it can be stated as eq. (2) [16].

$$C_g = \mathbf{Price}_g \times P_g \quad (2)$$

In above equation, $\mathbf{Price_g}$ is the price of supplying energy from the utility grid as shown in Fig.2 and P_g is the amount of power supplied from the utility grid. In addition, C_{FC}^t in the objective function indicates the cost of providing energy by FCs. C_{FC}^t takes the following form:

$$C_{FC} = (0.04)^{\frac{\$}{KWh}} \times \frac{P_{FC}}{\eta} \quad (3)$$

Where,

$$\eta = \begin{cases} 0.2716 & PLR = \frac{P_{FC}}{P_{\max}} < 0.05 \\ 0.9033PLR^5 - 2.9996PLR^4 + 3.6503PLR^3 \\ - 2.0704PLR^2 + 0.4623PLR + 0.3747 & PLR = \frac{P_{FC}}{P_{\max}} \geq 0.05 \end{cases} \quad (4)$$

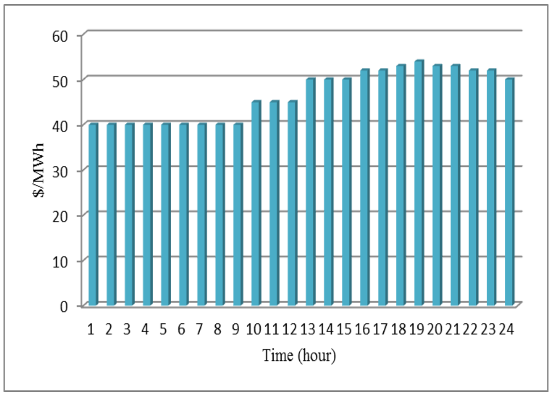

Fig. 2. Daily price of energy from the utility grid

Eq.(4) illustrates the cost of produced power by MTs [16]:

$$C_{MT}^t = a + b\,P_{MT} \quad (5)$$

Where,

$$a = \frac{\textbf{Capital cost(\$KW}^{-1}\textbf{)} \times \textbf{Capacity(KW)} \times Gr}{\textbf{Lifetime(Yr)} \times \textbf{365} \times \textbf{24} \times \textbf{LF}} \quad (6)$$

$$b = \textbf{Fuel cost(\$KWh}^{-1}\textbf{)} + \textbf{O \& M cost(\$KWh}^{-1}\textbf{)} \quad (7)$$

Note that, the cost of energy produced by MTs is calculated and it is equal to 0.07 (\$/KWh) [16].

This optimization problem is constrained to load flow constraints as follows:

$$\sum_{u=1}^{NU_i} P_{Gi,u} - P_{Di} = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}| \cos(\delta_{ij} - \theta_{ij}) \quad i = 1,\ldots,NB \quad (8)$$

$$\sum_{u=1}^{NU_i} Q_{Gi,u} - Q_{Di} = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}| \sin(\delta_{ij} - \theta_{ij}) \quad i = 1,\ldots,NB \quad (9)$$

$$P_{G\min,i,u} \leq P_{Gi,u} \leq P_{G\min,i,u} \quad (10)$$

$$Q_{G\min,i,u} \leq Q_{Gi,u} \leq Q_{G\min,i,u} \quad (11)$$

$$|I_{ij}| \leq |I_{ij}^{\max}| \quad (12)$$

$$|V_{\min,i}| \leq |V_i| \leq |V_{\max,i}| \quad (13)$$

$$\sum_{i=1}^{NB}\sum_{u=1}^{NU_i} P_{Gi,u} = \sum_{i=1}^{NB} P_{Di} + PL \quad (14)$$

$$\sum_{i=1}^{NB}\sum_{u=1}^{NU_i} Q_{Gi,u} = \sum_{i=1}^{NB} Q_{Di} + QL \quad (15)$$

Eq. (8) and (9) relate to load flow. The maximum and minimum active and reactive power generation of generating units are stated through Eqs. (10) and (11). Furthermore, this optimization problem is constrained by security considerations. These security constraints can be stated as Eqs. (12) and (13). One of the most important constraints in power systems is power balance constraint ensuring that the generated power is equal to the power demand at each hour. Since, this paper implements ACOPF, this constraint is stated both for active and reactive power as Eqs. (14) and (15).

III. SIMULATION RESULTS

The proposed model is implemented on a 34-bus test system [17]. The data and the single-line diagram of the test system are shown in Table 1 and Fig.3, respectively. It is noted that the base MVA is 100.

Table 1. Data of the 34-bus test system

Bus NO.	Feeder length (km)	Feeder impedance X(Ω/km)	R(Ω/km)	Load Q (KVar)	P (KW)
1				0	0
2	0.60	0.080	0.195	142.5	230
3	0.55	0.080	0.195	0	0
4	0.55	0.083	0.299	142.5	230
5	0.50	0.083	0.299	142.5	230
6	0.50	0.083	0.299	0	0
7	0.60	0.090	0.524	0	0
8	0.40	0.090	0.524	142.5	230
9	0.60	0.090	0.524	142.5	230
10	0.40	0.090	0.524	0	0
11	0.25	0.090	0.524	142.5	230
12	0.20	0.090	0.524	84	137
13	0.30	0.090	0.524	45	72
14	0.40	0.090	0.524	45	72
15	0.20	0.090	0.524	45	72
16	0.10	0.090	0.524	7.5	13.5
17	0.60	0.083	0.299	142.5	230
18	0.55	0.083	0.299	142.5	230
19	0.55	0.086	0.387	142.5	230
20	0.50	0.086	0.387	142.5	230
21	0.50	0.086	0.387	142.5	230
22	0.50	0.090	0.524	142.5	230
23	0.50	0.090	0.524	142.5	230
24	0.60	0.090	0.524	142.5	230
25	0.40	0.090	0.524	142.5	230
26	0.25	0.090	0.524	142.5	230
27	0.20	0.090	0.524	85	137
28	0.30	0.090	0.524	48	75
29	0.30	0.090	0.524	48	75
30	0.30	0.090	0.524	48	57
31	0.30	0.090	0.524	34.5	57
32	0.40	0.090	0.524	34.5	57
33	0.30	0.090	0.524	34.5	57
34	0.20	0.090	0.524	34.5	57

It is worth-mentioning that, the computer system used to solve the presented NLP problem has an Intel Core i5 processor with 2.27 GHz clock speed and 4 GB RAM. Moreover, the problem is implemented in GAMS environment and solved using CONOPT solver under Windows 7 operating

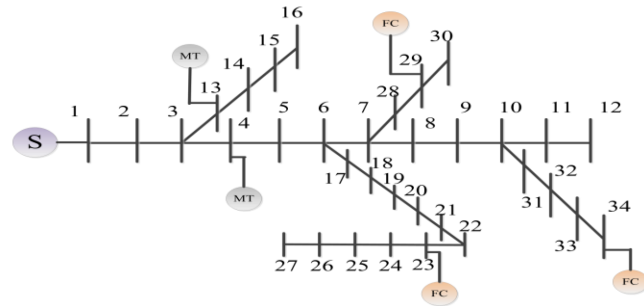

Fig. 3. Single-line diagram of the 34-bus test system

system. The data of DGs and their locations are represented in Table 2. Additionally, instead of fixed load, dynamic load is considered in this paper with 24-hour variations that is shown in Fig.4.

Table 2. Data of DGs

Energy Source	Location	Capacity (p.u.)	Type
Utility Grid	1	....	. . . .
DG1	23,29,34	0.01345	FC
DG2	4,13	0.01345	MT

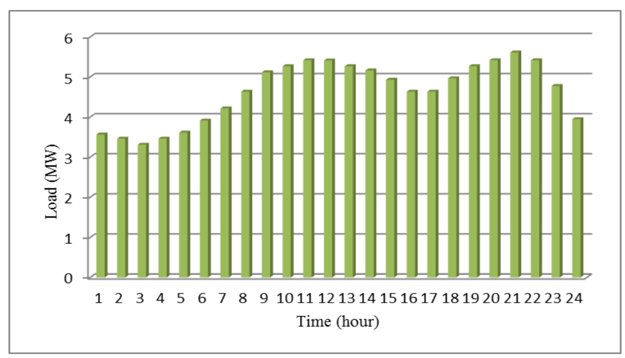

Fig. 4. Daily load of the 34-bus test system

The results obtained from active and reactive power dispatch are represented in Tables 3 in terms of p.u.

IV. CONCLUSION

The problem of optimal scheduling of DG units in a microgrid has been studied in the presented paper. This microgrid is based on MTs and FCs while it has the ability to operate in stand-alone mode or it can connect to the utility grid via Point of Common Connection (PCC). The obtained results from solving the NLP model verify the performance and efficiency of the proposed model. The ongoing research work by authors is to propose multi-objective framework for optimal scheduling of DG units while considering other objectives as maximization of Voltage Stability Margin (VSM), minimization of total power loss as well as minimization of emission generation.

Table 3. Results of active and reactive power dispatch

Hour	Q_{DG34}	Q_{DG29}	Q_{DG23}	Q_{DG13}	Q_{DG4}	P_{DG34}	P_{DG29}	P_{DG23}	P_{DG13}	P_{DG4}
1	0.012	0.026	0.027	0	-0.046	0.003	0	0.010	0.003	0.021
2	0.013	0.025	0.027	0	-0.046	0.003	0	0.009	0.003	0.021
3	0.013	0.024	0.027	0	-0.046	0.003	0	0.009	0.002	0.021
4	0.013	0.025	0.027	0	-0.046	0.003	0	0.009	0.003	0.021
5	0.012	0.026	0.027	0	-0.046	0.003	0	0.010	0.003	0.022
6	0.012	0.029	0.026	0	-0.046	0.004	0	0.012	0.003	0.022
7	0.012	0.030	0.026	0	-0.045	0.004	0.0002373	0.013	0.003	0.023
8	0.012	0.031	0.027	0	-0.045	0.005	0.0008306	0.015	0.003	0.024
9	0.012	0.031	0.028	0	-0.045	0.005	0.002	0.017	0.004	0.025
10	0.012	0.032	0.029	0	-0.045	0.006	0.002	0.017	0.004	0.026
11	0.013	0.032	0.029	0	-0.044	0.006	0.002	0.018	0.004	0.026
12	0.013	0.032	0.029	0	-0.044	0.006	0.002	0.018	0.004	0.026
13	0.012	0.032	0.029	0	-0.045	0.006	0.002	0.017	0.004	0.026
14	0.012	0.031	0.029	0	-0.045	0.006	0.002	0.017	0.004	0.025
15	0.012	0.031	0.028	0	-0.045	0.005	0.001	0.016	0.004	0.025
16	0.012	0.031	0.027	0	-0.045	0.005	0.0008294	0.015	0.003	0.024
17	0.012	0.031	0.027	0	-0.045	0.005	0.0008308	0.015	0.003	0.024
18	0.012	0.031	0.028	0	-0.045	0.005	0.001	0.016	0.004	0.025
19	0.012	0.032	0.029	0	-0.045	0.006	0.002	0.017	0.004	0.026
20	0.013	0.032	0.029	0	-0.044	0.006	0.002	0.018	0.004	0.026
21	0.013	0.032	0.030	0	-0.044	0.006	0.002	0.019	0.004	0.027
22	0.013	0.032	0.029	0	-0.044	0.006	0.002	0.018	0.004	0.026
23	0.012	0.031	0.028	0	-0.045	0.005	0.001	0.015	0.004	0.024
24	0.012	0.029	0.026	0	-0.046	0.004	0	0.012	0.003	0.022
Cost ($)										
12035.9626										

REFERENCES

[1] R. J. Braun, S. A. Klein and D. T. Reindl, "Evaluation of system configurations for solid oxide fuel cell-based micro-combined heat and power generators in residential applications," *Journal of Power Sources*, vol. 158, pp. 1290-1305, 2006.

[2] M. Tanrioven, "Reliability and cost–benefits of adding alternate power sources to an independent micro-grid community," *Journal of Power Sources*, vol. 150, pp. 136-149, 2005.

[3] P. Thounthong, V. Chunkag, P. Sethakul, S. Sikkabut, S. Pierfederici and B. Davat, "Energy management of fuel cell/solar cell/supercapacitor hybrid power source," *Journal of Power Sources*, vol. 196, pp. 313-324, 2011.

[4] S. Chowdhury, S. Chowdhury and P. Crossley, *Microgrids and active distribution networks*: Institution of Engineering and Technology, 2009.

[5] G. Chang, S. Chu and H. Wang, "An improved backward/forward sweep load flow algorithm for radial distribution systems," *Power Systems, IEEE Transactions on*, vol. 22, pp. 882-884, 2007.

[6] S. Khushalani, J. M. Solanki and N. N. Schulz, "Development of three-phase unbalanced power flow using PV and PQ models for distributed generation and study of the impact of DG models," *Power Systems, IEEE Transactions on*, vol. 22, pp. 1019-1025, 2007.

[7] S.-J. Ahn, J.-W. Park, I.-Y. Chung, S.-I. Moon, S.-H. Kang and S.-R. Nam, "Power-sharing method of multiple distributed generators considering control modes and configurations of a microgrid," *Power Delivery, IEEE Transactions on*, vol. 25, pp. 2007-2016, 2010.

[8] R. Majumder, G. Ledwich, A. Ghosh, S. Chakrabarti and F. Zare, "Droop control of converter-interfaced microsources in rural distributed generation," *Power Delivery, IEEE Transactions on*, vol. 25, pp. 2768-2778, 2010.

[9] F. A. Mohamed and H. N. Koivo, "System modelling and online optimal management of MicroGrid using Mesh Adaptive Direct Search," *International Journal of Electrical Power & Energy Systems*, vol. 32, pp. 398-407, 2010.

[10] M. Mohammadi, S. Hosseinian and G. Gharehpetian, "GA-based optimal sizing of microgrid and DG units under pool and hybrid electricity markets," *International Journal of Electrical Power & Energy Systems*, vol. 35, pp. 83-92, 2012.

[11] M. El-Sharkh, A. Rahman and M. Alam, "Short term scheduling of multiple grid-parallel PEM fuel cells for microgrid applications," *International Journal of Hydrogen Energy*, vol. 35, pp. 11099-11106, 2010.

[12] T. Niknam, H. Z. Meymand and H. D. Mojarrad, "An efficient algorithm for multi-objective optimal operation management of distribution network considering fuel cell power plants," *Energy*, vol. 36, pp. 119-132, 2011.

[13] M. T. Gencoglu and Z. Ural, "Design of a PEM fuel cell system for residential application," *International Journal of Hydrogen Energy*, vol. 34, pp. 5242-5248, 2009.

[14] J. Larminie, A. Dicks and M. S. McDonald, *Fuel cell systems explained* vol. 2: Wiley Chichester, 2003.

[15] M. Uzunoglu, O. Onar and M. Alam, "Dynamic behavior of PEM FCPPs under various load conditions and voltage stability analysis for stand-alone residential applications," *Journal of Power Sources*, vol. 168, pp. 240-250, 2007.

[16] T. Niknam, H. Zeinoddini Meymand and H. Doagou Mojarrad, "A novel Multi-objective Fuzzy Adaptive Chaotic PSO algorithm for Optimal Operation Management of distribution network with regard to fuel cell power plants," *European Transactions on Electrical Power*, vol. 21, pp. 1954-1983, 2011.

[17] M. Chis, M. Salama and S. Jayaram, "Capacitor placement in distribution systems using heuristic search strategies," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 144, pp. 225-230, 1997.