International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 4 Issue 1 (January 2014)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

Operations Analysis of Isolated And Connected Micro-Grid with CHP Using MIP

S. Mohammad Hasheminasab [1,1] , Mohammad Reza Besmi [2]

1 Faculty of Engineering, Shahed University, Tehran, Iran, Email: mohammad.hasheminasab@gmail.com
2 Faculty of Engineering, Shahed University, Tehran, Iran, Email: Besmi@shahed.ac.ir

Abstract. As energy demands around the world increase, the need for renewable energy sources, such as Micro-Grid (MG) that will not harm the environment has been increased. Micro-Grid has been extensively investigated as a promising solution to energy challenges in 21st century. The optimal generation is one of the important functions for the Micro-Grid operation. It should be noted that supplying thermal load with combined heat and power systems is one of the most evident features of the Micro-Grids which increase the efficiency of the system. In this study, the operation of Micro-Grids by considering two kinds of state i.e. isolated and connected is investigated and the results for these different states are compared together. In addition, the effect of CHP systems in a Micro-Grid and the possibility of collaboration of Micro-Grid in power supply marketing is studied. The results indicate that existences of CHP systems leads to reduction of operating cost; consequently, consumers pay less for energy. So this proposed model is used to reduce the total operating costs. The equations of Micro-Grids are solved using the mathematical analysis which is based on the application of Mixed Integer Programming (MIP).

Keywords: Micro-Grid, Isolated MG, Connected MG, Combined Heat and Power (CHP), MIP

1 Introduction

The deregulation in the electric power industry and pressing concerns about global environmental issues as well as the increasing energy consumption have led to an increase in installation capacity of distributed generation resources(DER) sources and energy storage system. Some benefits of the DER for consumers: Increase the

[1] Corresponding Author

reliability of electrical energy of distributed generation. Preparation of appropriate energy resource in an appropriate place can provided. Preparation of the needed high quality electrical energy satisfied. Increase the system efficiency for local applications by use of electricity and heat simultaneously. The possibility of energy costs reduction for special units.

Since the primary energy is lost as heat in the process of the electrical energy generation with the small scale generators, therefore the overall efficiency of system can be increased using this wasting thermal energy. CHP is defined as system that provides electrical and thermal energy for loads simultaneously. Thus some Small scaled generators are used as CHP systems can be defined as microturbins, fuel cells, internal combustion engines and thermal motors [2]. It should be mentioned that fuel cells and micro turbines are widely used in Micro-Grids. The generators' efficiency can be increased up to more than 80% by installing the thermal recycling equipment with these generators and using the wasting thermal energy.

It is evident that the transmission of electrical energy to far distances is much easier and more economical than the transmission of thermal energy, therefore installing micro CHP near the thermal loads is more suitable. Obtaining the highest thermal efficiency by Micro-Grids depends on the choosing appropriate location for installing CHP. In addition, if the using of generated heat in the CHP units properly is needed, the fuel cells can be applied.

By using a CHP set, the air pressure increases through the centrifugal compressor that leads to increase the temperature of the compressed air through the heat exchanger. By inserting the warm and compressed air into the combustion chamber and combining with fuel, it would be exploded. Thus the electrical power is generated in the turbine by expanding the ignited gas with high temperature. The shaft of synchronous machines with permanent magnet can be rotated by this energy, therefore high frequencies electrical power can be seen at the output of machine. By using the rectifier, high frequency output voltage is converted to a DC voltage and then by using a convertor it is converted to AC voltage with the frequency of 50/60 Hz.

The operation states of the system depend on the limitation of generating electricity and need to heat in the output. In general, four operation states can be assigned as below:

a) The consuming heat state:

In this state, for any time, the output heat of CHP system is equal to the needed heat and electricity that is produced proportional to this thermal energy. If the electricity is more than need of consumption, the surplus electricity is sold to the electricity company, but if it is less than need of consumption, this deficiency would compensate from the network.

b) The electric charge state:

The produced electricity is equal to the intake electric charge and the produced heat is proportional to this electrical power. If the mentioned generated heat was less than the needed amount, the auxiliary boiler can be applied to produce extra needed heat but if it is more, it is eliminated through gas outlet part.

c) The heat and power state:

For some hours, this state would follow the one with the consuming heat and for the remaining hours would follow the one with the electric charge. This state is proposed to reduce the expenses by summing up the electricity and fuel price and optimizing the consumption in different hours.

d) The separate modes state:

In this state, the desire electrical power and heat are generated simultaneously. This state is the most expensive generating method. Hence, this method is proposed to be independent from network and obtaining high reliability.

Some researchers studied optimized exploitation of Micro-Grid [3, 4]. Using the resources in the best way and also obtaining a plan to achieve a minimum exploitation cost are the objective of optimum exploitation. To reduce costs, proper use of batteries and a right time-scheduling for charging and discharging of batteries are two great help for obtaining this aim. The effects of intelligent energy managing system were studied by Alikhani et al [6]. Collaboration issue of a Micro-Grid in power supply marketing was investigated by Brooke et al in which the results reveal that participating of Micro-Grid in this market and power exchange with major network can reduce consumer’s energy expenses. Using CHP systems at hotels by scheduling charge and heat supplement in order to reduce the expenses was investigated by Marnay et al [9]. Renewable resources was not used in this article and some exploitation’s constrains were ignored.

In this study, the operation of Micro-Grids by considering two kinds of state i.e. isolated and connected is investigated and the results for these different states are compared together. In addition, the effect of CHP systems in a Micro-Grid and the possibility of collaboration of Micro-Grid in power supply marketing is studied. The results indicate that existences of CHP systems leads to reduction of operating cost; consequently, consumers pay less for energy. So this proposed model is used to reduce the total operating costs. In proposed model, CHP model are used for two states. As we know diesel engines are the most common type of MG technology in use today. The traditional roles of diesel generation have been the provision of standby power and peak shaving. So the effect of diesel in a micro gird with emission limits and without emission limits is considered. As well, constraints of small scale Micro-Grid's exploitation are fully considered by this paper. The possibility of selling electricity generated by Micro-Grid to the major network and gain profits in the power supply marketing are also considered in the suggested model. Finally, the equations of Micro-Grids considering the constraints are solved using the mathematical analysis which is based on the application of Mixed Integer Programming (MIP).

2 Relations for economic studies

In this article, both of the thermal and electrical loads are considered by Micro-Grid and supplying both kinds of loads is the aim of this study. To investigate the effect of CHP in Micro-Grid, first Micro-Grid without CHP units is studied and then resources are considered. Thermal loads which are produced by system can be used as heating system of buildings and to produce the needed heat for production process in the factories. Without CHP, the thermal loads of system are provided by boilers. By burning the fossil fuels in the boilers, the energy of these fuels are release and then this energy is transferred to water as heat. So, water plays a role as carrier and transfers the thermal energy in the boiler to loads.

3 Micro-Grid without CHP

The expenses of electrical and thermal energy are minimized by the objective function of this scheduling. Exploitation expenses include the unit production and launching costs. Also, objective function is included buying costs of energy from network, selling costs of energy to network and the cost of purchasing natural gas for boilers. The objective function of this scheduling is given as:

$$\begin{aligned}&\textit{Objective}\ \text{function:}\sum_{t=1}^{T}\sum_{i=1}^{I}[G(i,t).B(i,t)+SU(i,t)]+\\&\sum_{t=1}^{T}[P_{grid}^{pur}(t)\cdot C_{grid}^{pur}(t)-P_{grid}^{sol}(t)\cdot C_{grid}^{sol}(t)]+\\&\sum f_b(t).C_{gas}\end{aligned} \tag{1}$$

In which $B(i,t)$ is the offered price for generating power in i-th distributed generating unit and the t-th hour of exploitation. The amount of scheduled output power for that unit is defined as $G(i,t)$. The production cost per unit is depending on the amount and type of their fuel and also on their initial investment expenditure and their purchasing. As well, $SU(i,t)$ is the launching cost of the i-th unit and the t-th hour. Generally in Micro-Grids, fuel cell, micro turbine and some units such as diesel generator need fuel consumption and maintenances costs. The second term of objective function (second series in the second line of Eq. 1) is related to the exchange of power between Micro-Grid and utility network. Due to the deficiency or surplus of its domestic produced power, Micro-Grid can exchange power with major network. Normally when the price of network electricity is down, the Micro-Grid prefers to buy electricity from major network but when the price is high; the Micro-Grid to supply its loads uses its own internal resources and sells its extra power to the network. In second term of objective function (third series in the third line of Eq. 1), $P_{grid}^{pur}(t)$ and $C_{grid}^{pur}(t)$ are bought power and the value of major network's electricity at the t-th hour of exploitation, respectively. Also, $P_{grid}^{sol}(t)$ and $C_{grid}^{sol}(t)$ are respectively the amount of electrical energy that sold to the major network at the t-th hour of exploitation. The third term of objective function is related to the expenditure of thermal load which is supplied by boilers. Where, $f_b(t)$ and C_{gas} are the amount of boiler's used gas with m^3 dimension and gas's expenses with $\$/m^3$ dimension, respectively. Volume of generated thermal energy by boiler is calculated as follow:

$$P_{boiler}^{th}(t) = f_b(t).\eta_{bioler}.HHV \tag{2}$$

In which, $P_{boiler}^{th}(t)$ is the received thermal energy from boiler measured by KWh and η_{bioler} is the boiler's system efficiency. To convert m^3 (unit of natural gas) to Wh (unit of thermal energy), the HHV coefficient is used. This coefficient is defined as the maximum thermal value of the natural gas. The amount of thermal energy generated by boiler should provide the total thermal loads of Micro-Grid $P_{demand}^{th}(t)$ at all times. This constrain can be written as:

$$P_{bioler}^{th}(t) \geq P_{demand}^{th}(t) \tag{3}$$

The power balance is most important constrain of production scheduling relation in a Micro-Grid. This constrain indicates the importance of load providing by electricity generating resources. The frequency is deviated from its normal value by disturbing the balance of production and consumption of electrical energy in a Micro-Grid. For example, the frequency of network decreases when the demand of electrical energy is greater than its production. Then, the operator cuts some loads and give compulsory offs to them in order to maintain the frequency of grid and preventing from operation of relays under the frequency. In Eq. 3, $P^{el}_{demand}(t)$ is the hourly predicted load in the Micro-Grid which should be fed by distributed generating $G(i,t)$ and battery $P^{discharge}_{battery}(t)$ or with the bought energy from the grid $P^{pur}_{grid}(t)$.

$$\begin{aligned}&(\sum_{i=1}^{I} G(i,t)) + (P^{pur}_{grid}(t) - P^{sol}_{grid}(t)) \\ &+ (P^{discharge}_{battery}(t) - P^{charge}_{battery}(t)) \geq P^{el}_{demand}(t))\end{aligned} \tag{4}$$

Every distributed generating resource has its own exploitation constrain. One of these limitations is the maximum and minimum of allowed production amount for each generator which is specified by the manufacturer. This distributed generating resource and its own exploitation constrain can be defined as:

$$G_i^{\min} \leq G(i,t) \leq G_i^{\max} \tag{5}$$

It should be noted that the uncertainty of renewable energy get resolved by the supporting of storage resources. Batteries and energy storage capacitors which would be connected to them by power electronic devices can be used as storage resources. Battery constraints are included constraints of batteries charging and discharging:

1) Limitation of storage batteries generating power in each cycle of t:

$$P_{Storge}(t) \leq P_{Storgelimit}(t); \quad t \in \{1,\ldots,24\} \tag{6}$$

2) The maximum storage batteries limitation in the course of discharging the battery in each cycle of t:

$$P_{StorageBateryDischarge}(t) \leq P_{StorageBateryDischargelimit}(t); \quad t \in \{1,\ldots,24\} \tag{7}$$

The generating time scheduling for Micro-Grid in the presence of CHP is coded in the powerful software of GAMS and is solved with the solver of CPLEX [8].

International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 4 Issue 1 (January 2014)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

4 Case Study

Sample network which is used in this section is such as the Micro-Grid [3]. In the case without the participation of CHP units, the thermal load of the grid is provided by boiler. The boiler's fuel is the natural gas and its thermal efficiency is 80% [9]. The price of gas is $0.29 \$/m^3$ [9]. The thermal value of natural gas gets equal to $8.8\, KW/m^3$. Without the participation of CHP units, there is not absolutely any system for retrieval of heat from fuel cell generator and micro turbine of Micro-Grid, and these small scale generators are only used for generating electricity. So, total thermal loads of the grid are provided by the boiler. Table 1 contains the electric charge of a Micro-Grid in 24 hour. The Micro-Grid can exchange energy with the major grid because of its production capacity and energy price.

The hourly price of electricity of grid is derived and is shown in table 2 [3]. The purchasing price of electricity from Micro-Grid is considered such as these. In practice, it would be economical for grid to buy electricity from Micro-Grid with the selling price of generated electricity by its major power plants, and sell them to the other local loads or to the distribution network. Transportation cost and energy losses in transmission are neglected, so it causes the profitability of the project.

Table 1. Micro-Grid electrical load hourly

Time(h)	1	2	3	4	5	6	7	8
Load (KWh)	52	50	50	51	56	63	70	75
Time(h)	9	10	11	12	13	14	15	16
Load (KWh)	76	80	78	74	72	72	76	80
Time(h)	17	18	19	20	21	22	23	24
Load (KWh)	85	88	90	87	78	71	65	56

Table 2. Electrical market hourly price

Time(h)	1	2	3	4	5	6	7	8
$^{\$}/_{KWh}$	0.033	0.027	0.020	0.017	0.017	0.029	0.033	0.054
Time(h)	9	10	11	12	13	14	15	16
$^{\$}/_{KWh}$	0.215	0.572	0.572	0.572	0.215	0.572	0.286	0.279
Time(h)	17	18	19	20	21	22	23	24
$^{\$}/_{KWh}$	0.086	0.059	0.050	0.061	0.181	0.077	0.043	0.037

Table 3. DERs' Limitation & Startup Cost

No.	**Type**	**Minimum power**(KW)	**Maximum power**(KW)	**Startup cost**($\$$)
1	Micro Turbine	6	30	0.14
2	Fuel cell 1	3	30	0.24
3	Fuel cell 2	2	20	0.18
4	Photo Voltaic	0	20	0
5	Wind Turbine	0	10	0
6	Diesel Generator	2	20	0.29

The characterization of grid's small scaled generator is shown in table 3. These data are derived from Ref. [7]; only the features of the wind turbine have been inserted. The energy storage capacity of battery which use in Micro-Grid is 33kwh. The proposed energy sale price by each small scaled generators of Micro-Grid is taken from Ref. [7]. The proposed sale price of each generator is calculated based on its purchase, fuel, Operator and maintenance expenses. Also, time and economical parameters such as interest and inflation that are used in efficient of generator are involved in the calculation. Some examples of this calculation have mentioned in Ref. [9]

International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 4 Issue 1 (January 2014)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

In Figure (1), the scheduled power of isolated small scale generators is presented. Also in this figure the results with using CHP and without using CHP are obtained. It is observed that using and no using CHP do not varied the obtained scheduled power.

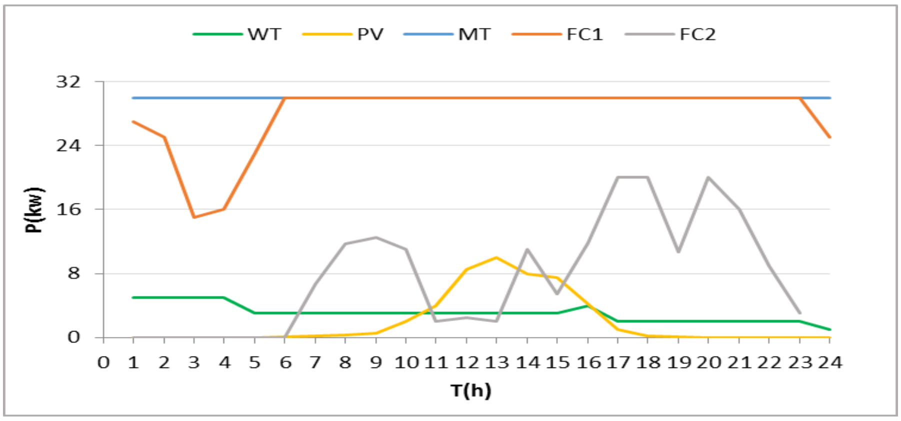

Fig. 1. The scheduled power of isolated small scale generators

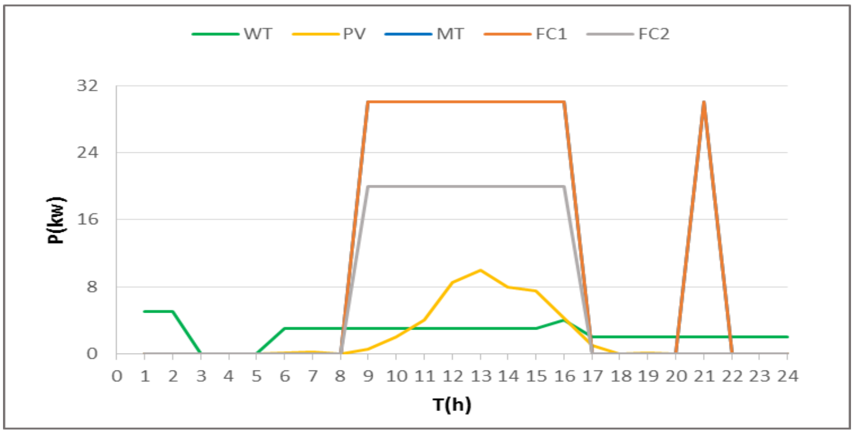

Fig. 2. The scheduled power of small scale generators without CHP

In this section, first it’s assumed that the CHP units do not participate in supplying the thermal load and the boiler is the only part that provides the thermal load of Micro-

International Journal of Electronics Communications and Electrical Engineering
ISSN : 2277-7040 Volume 4 Issue 1 (January 2014)
http://www.ijecee.com/ https://sites.google.com/site/ijeceejournal/

Grid. The results of small scale units and the rate of exchanged power with the grid are shown in Figure (2).

Figure (3) indicates the scheduled power of small scale generators when the CHP units are participate. By comparison between figure (2) and (3), it can be seen that by acting micro turbine as CHP, it has strongly role for generating power. This is partly because of reducing the total costs of electricity and gas. By increasing the power generation of micro turbine, on one hand the electricity generating cost will increase and on the other hand due to increase of recovered thermal energy, the boilers' load and consequently the gas consumption is reduced. As seen in figure (3), by comparison with the state of no participation of CHP, the major grid is purchasing at the hour of 17 to 23. One can say in the hour of high cost grid's electricity, the Micro-Grid would inject its own extra power in to the major grid.

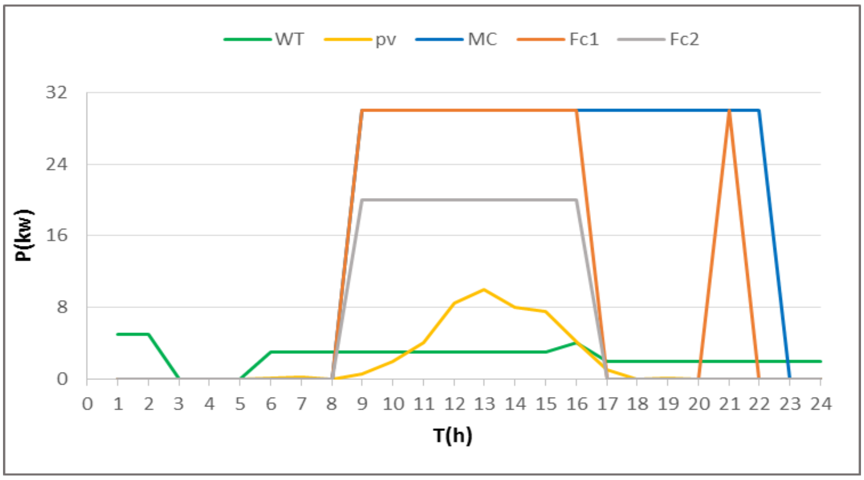

Fig. 3. The scheduled power of small scale generators with CHP

Figure (4), (5) demonstrates the gas consumption versus time by applying CHP and without CHP for isolated Micro-Grid and connected Micro-Grid, respectively. It is observed that the gas consumption with CHP is lower than gas consumption without CHP, so by using CHP, the costs decrease.

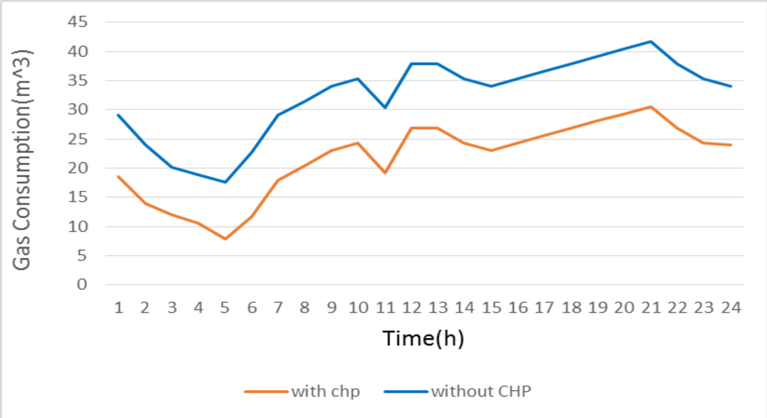

Fig. 4. Comparison gas consumption with CHP and without CHP isolated mode

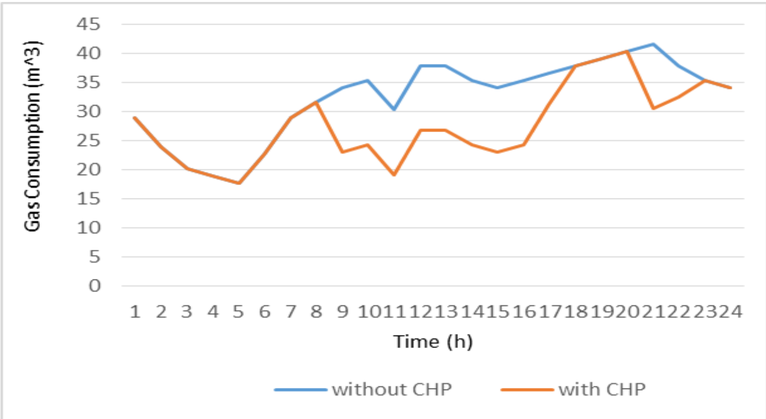

Fig. 5. Comparison gas consumption with CHP and without CHP connected mode

Time of charging battery with the major grid's energy cost have a close relation. Figure (6) indicates that the storage energy in batteries is provided from major grid at the hours of 3, 4, 5, 13, 18, 19 and 20. But at the hours of 1, 12, 14, 21 and 22 the energy costs are more and the Micro-Grid would discharge the batteries' energy and sale the extra energy to the major grid.

Comparison between the costs of isolated and connected Micro-Grid by considering and neglecting CHP is demonstrated in Table 4. As it can be seen the lower cost of operation is related to connected Micro-Grid by using CHP while the highest cost of operation is related to isolated Micro-Grid without CHP.

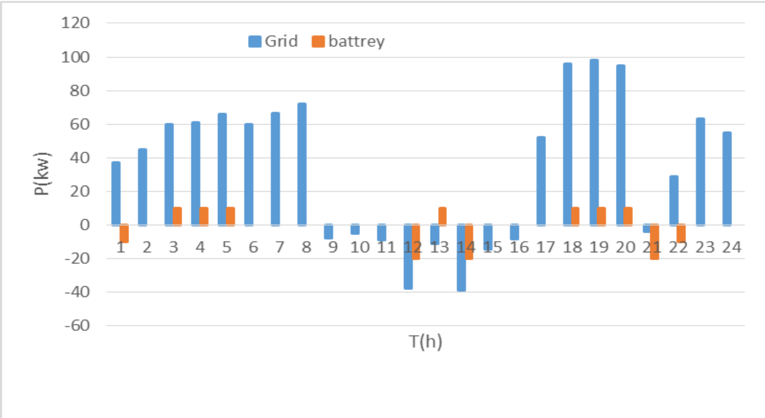

Fig. 6. The amount of purchased and sold power to the major grid

Table 4. Comparison of costs

Model	Total Cost	Gas Cost	DGs Cost
MG Without CHP(Isolated)	440.953	225.189	215.764
MG with CHP(Isolated)	369.53	152.69	216.84
MG Without CHP(Connected)	290.621	225.189	65.432
MG With CHP(Connected)	260.5319	193.15	67.381

5 Conclusion

So far, the comprehensive model for isolated and connected Micro-Grid that considers CHP systems and also presents the collaboration in the electricity supply marketing has not been introduced. In suggested model, isolated and connected Micro-Grid by considering and neglecting CHP are used. Some portion of thermal load of Micro-Grid is provided by the recycled heat from micro turbine and fuel cell so, CHP systems increase the efficiency of small scale generators, fuel cell and micro turbine. In addition, the cost of purchasing natural gas for boiler is reduced. When the price of electricity of major grid is down, the electricity of the major grid is bought by Micro-Grid; some portion of it is used and the remaining is stored in the batteries. But when the price of electricity of major grid is high, the Micro-Grid uses its own internal resources for feeding the loads. Furthermore, the extra power of generators and the stored energy in batteries are sold at the power supplying market. The cost of energy is reduced by exchanging energy between Micro-Grid and major grid for consumers of Micro-Grid but it should be mentioned that the exchanging energy between Micro-Grid and major grid is only for connected Micro-Grid ,so the connected Micro-grid are more profitable than isolated Micro-Grid. As it has been seen, when the price of electricity is low, the Micro-Grid uses most of its electrical energy.

References:

1. S. Siddiqui, C. Marnay, O. Bailey, K. H. LaCommare, “Optimal selection of on-site power generation with combined heat and power applications”, Int. J. Distrib. Energy Res., 1(1), 33–62 (2005).
2. F. Katiraei, R. Iravani, N. Hatziargyriou, A. Dimeas, “Micro-Grids management”, IEEE Power Energy Mag., 6(3), 54–65 (2008).
3. C. Chen, S. Duan, T. Cai, B. Liu, G. Hu, “Smart energy management system for optimal Micro-Grid economic operation”, IET Renew. Power Gener., 5(3), 258–267 (2011).
4. A. G. Tsikalakis, N. D. Hatziargyriou, “Centralized control for optimizing Micro-Grids operation”, IEEE Trans. Energy Convers., 23 (1), 241–248 (2008).
5. J. M. Guerrero, J. C. Vasquez, J. Matas, M. Castilla, L. G. deVicuna, “Control strategy for flexible Micro-Grid based on parallel line-interactive UPS systems”, IEEE Trans. Ind. Electron., 56, (3), 726–736 (2009).
6. C. Marnay, G. Venkataramanan, M. Stadler, A. S. Siddiqui, R. Firestone, B. Chandran, “Optimal technology selection and operation of commercial-building Micro-Grids”, IEEE Trans. Power Syst., 23 (3), 975–982 (2008).
7. K. A. Papadogiannis, N. D. Hatziargyriou, “Optimal allocation of primary reserve services in energy markets”, IEEE Trans. PowerSyst., 19(1), 652–659 (2004).
8. GAMS: A User’s Guide, A. Brooke, D. Kendrick, A. Meeraus, and R. Raman. (2003). http://www.gams.com.
9. E. Alikhani, M. Ahmadian, A. Salemnia, "Optimal Short-term Planning of a Stand-Alone Micro-Grid with Wind/PV/Fuel Cell/Diesel/Microturbine", Canadian Journal on Electrical and Electronics Engineering, 3(3), 135-141 (2012).
10. A. Mohamed Faisal, H. Koivo, “System modelling and online optimal management of Micro-Grid using Mesh Adaptive Direct Search”, Int. J. Elec. Power Energy Syst., 32(5), 398–407 (2010)