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Demand response planning in capacity market using microgrid

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ABSTRACT

Planning of the demand response has received special attention due to the cost of transmission lines development and shortage of energy resources beside the growth of demand. This research work is focused on the role of microgrid (MG) as an alternative solution for transmission system development and proposed a method for modeling of MGs in the capacity market. The results show that using of MGs leads to reduce the development costs of transmission system. Moreover, MGs cause a slight increase in the profitability of selling capacity to the consumers. These outcomes prove that continuing to grow the number and capacity of MGs in each area ultimately eliminate the inquiry of transmission network development and minimize the cost of capacity market.

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1. INTRODUCTION

Environmental considerations such as pollutions, greenhouse gases and landfills are the major issues in recent years [1]–[3] which has attracted a lot of attention for efficiency improvement of power systems and electrical machines [4], [5]. Development of the transmission system is a significant factor in power network design that determine the optimal configuration for a system based on load demand and increases network reliability. In fact, the expansion of transmission lines is not always cost-effective and other solutions need to be considered. The load response programs have been considered for several reasons such as reducing the peak, preventing the rapid price changing in the electricity market, and increasing the efficiency of the power system and the energy market. Planning for system development was started in 1970 with the aim of minimizing development costs and considering power generation constraints and line capacity using the linear planning method. Different techniques have been used in network development planning such as sensitivity analysis algorithm, ant colony algorithm, genetic algorithm, and Tabu search [6]–[12]. Electric industry has undergone fundamental changes around the world in the last two decades which are referred to various headings such as restructuring [13], [14]. Demand response can be applied for source of power supply and improve the system reliability. To solve the planning problem for transmission system development, the microgrids (MGs) will be the best solution to reduce the capacity of load demand instead of implementing the new costly transmission line. MGs consist of a set of the energy sources which are able to supply their local load by two modes as separate and grid-connected. MGs can interact with each other as well as with distribution companies. The interaction of MGs with the distribution company can take place in a local electricity market in which MGs can act as consumers or producers at any time according to their resources and consumption. MGs can also provide the amount of reservation requested by the distribution company in order to accompany with the upstream reservation market. Certainly, the simultaneous interaction of MGs and distribution companies in the energy markets and local reserves will change their behavior and decision-making. On the other hand, MGs can interact with each other so that they use each other's resources to reduce the cost of the entire system. The interaction of MGs lead to the use of resources and reduce the dependency to the upstream system [15]. Planning of transmission lines development by MGs is not reported well as a solution for capacity market. One of the problems in development of power system is to determine the time, place, size, and optimal number of new elements to supply the demand [16]. The transmission expansion planning (TEP) problem can be expressed in terms of methods, constraints, and objective functions. It can also be studied from various aspects such as modeling and solution method [17]. The TEP problem is modeled on a pond-based electricity market [18]. In this model, a number of scenarios have been presented for future consumption demand, which will help to examine the issue of operation in planning. A three-level model is formulated for TEP, which is performed at the lowest level of market settlement, at the middle level of production capacity development, and at the highest level of transmission capacity development [19]. A dynamic capacity investment model is proposed in [20] to investigate the effect of various options in capacity market design within three frameworks. The outcomes are compared in electricity pricing policy, reliability, and sustainability. The effect of integrating distributed generation resources and MGs in the development and production of transmission systems is investigated [21]. An optimal method for integrating these resources transmission development planning is presented with the main purpose of cost minimization.

Independent operators of different systems around the world based on the consuming of load in the capacity market are divided into three categories. Some of them are the operators in California and United Kingdom which studied and designed an appropriate structure for capacity market to implement the programs of load response and energy efficiency. The mentioned operators believed that it is necessary to study further and use the experiences of the other markets in resource management. The second group of operators such as New York independent system operator (NYISO) and Midwest independent system operator (MISO) in the United States use consumption management programs to provide adequate resources but introduce a competitive structure to compete between subscribers [22]. The New York operator is forcing the resource providers to participate in times of shortage. These suppliers receive a monthly stipend in exchange for a commitment to participate when needed. The operator of Mideast region also uses these resources in two ways of providing capacity. The first method is to use emergency response programs to ensure resource adequacy. This operator pays a price equal to the highest bid from providers to all participants. The second method is to allow the distribution company to reduce the load of subscribers in order to commit to their monthly capacity [23]. The third category of operators such as New England and Pennsylvania-Jersey-Maryland (PJM) operators has three types of demand response (DR) products including the limited DR, extended summer DR and annual AD with the capacity to involve in the market [24]. This participation in the PJM capacity market has been introduced and modeled in [25].

This article examined the effectiveness of MGs as an alternative solution for development of transmission line in capacity market. An effective method is proposed for modeling of capacity market and demand response. The application of MG as a power supply source of capacity market is analyzed. The results show that the addition of MGs causes a significant reduction in the cost of transmission system development.

2. RESEARCH METHOD

Sellers and buyers have been existed in a capacity market to trade of the sources [26]. Normally, the purchaser are LSEs that supply the needs of their zone. Owners of production stations are the vendors. The objective function of the problem of MGs participation in the capacity market is obtained as (1).

$$\begin{aligned} Minimize \sum_{r=1}^{R}\sum_{b=1}^{B}(\pi_{r.b}^{GR}.P_{r.b}^{GR}) - \sum_{l=1}^{L}\sum_{b=1}^{B}(\pi_{l.b}^{VRR}.[P_{l.b}^{VRR} - P_{l.b}^{VRR-MG}]) \\ + \sum_{l=1}^{L}\sum_{b=1}^{B}(\pi_{l.b}^{TU}.P_{l.b}^{TU}) + \sum_{c=1}^{C}\left[\frac{\sum_{i=1}^{N_s} C_i^I.P_i^{MG}}{Ny \times 365} + \sum_{i=1}^{N_s} C_i^{OM}.P_i^{MG} + \pi_c^{DR}.DR_c^{MG}\right] \end{aligned} \quad (1)$$

Where R, L and B are the number of sources, number of variable resource requirements (VRR) and blocks, repectively. $\pi_{r,b}^{GR}$ and $P_{r,b}^{GR}$ are the suggested price and capacity of producer r while $\pi_{l,b}^{VRR}$ and $P_{l,b}^{VRR}$ are the proposed price and capacity of load l in the cpacity block b, respectively. π_l^{TU} and P_l^{TU} are the parameters of new transmission line installation. $P_{l,b}^{VRR-MG}$ is an auxiliary variable that indicate the effect of MG on VRR. DR_c^{MG} is the value of demand response in MG. C_i^I, C_i^{OM} and $\pi_c^{DR}$are the cost of new sources, operation cost (excluding fuel) and π_c^{DR} is maintenance of distributed generation resources while the cost of responding to loads in dollars per kilowatt-day, respectively. Ns is the sources of MG and Ny is also the number of planning periods of investment in the MG based on the year [27]. The introduced strategy is implemented on BRA of 2020/2021 PJM capacity market data. One-block offering curves, and for VRR three-block bidding curves are used for production source and demand response. All case studies have been run using CPLEX within general algebraic modeling system (GAMS). To investigate the efficiency of the proposed model, its performance must be evaluated considering various core parameters. In the following, the effects of DR, generation capacity, and CETO on the proposed model are discussed in detail.

3. RESULTS AND DISCUSSION

3.1. Analysis based on the certain number of microgrids in each area (case 1)

The capacity market is solved in the following four modes for the system in question; i) capacity market regardless of MG, ii) capacity market with the maximum of one MG in each area, iii) capacity market by considering the maximum of two MGs in each area, and iv) capacity market with the maximum of three MGs in each area.

Based on the simulation results, in modes 2 to 4, the maximum allowable number of MGs in areas 1, 2 and 10 is considered. The cost of power generation, the cost of transmission network development, the profit of selling capacity to consumers, the cost of MG and finally the cost of capacity market is presented in Table 1. It is clear that the addition of MGs causes a significant reduction in the cost of transmission system development. With the addition of the first MG to each area, the development cost of transmission system will be reduced about $6 million, while the MG will cost only about $2 million. Moreover, the addition of MGs causes a slight increase in the profitability of selling capacity to consumers.

Table 1. Capacity market costs with different numbers of MGs in each area (case 1)

Costs	0 MG	1 MG	2 MGs	3 MGs
Generation Cost	44,092,610	44,092,610	44,092,610	44,092,610
VRR Revenue	99,528,450	100,564,200	101,052,000	101,175,400
Upgrade cost	89,839,000	83,839,000	77,839,000	71,839,000
MG Cost	0	2,029,315	4,058,630	6,087,945
Capacity Market Cost	34,403,160	29,396,670	2,493,820	2,084,414

According to Table 1, with the addition of the first MG to each area, the capacity market cost is reduced more than $5 million, which is significant and equivalent to a reduction of 15% in the capacity market cost for the first case**.** With the increase in the number of MGs in each area, the process of reducing the cost of transmission development and also the process of reducing the cost of capacity market continues. Finally, the addition of the third MG the cost of line development reduced about 18 million in comparison with the first case, while the cost of capacity market has also condensed by 14 million. The outcomes proved that increasing the number and capacity of MGs in each area result in the eliminating the need for transmission system development and reduce the market cost of capacity**.** Figure 1 shows the amount of resource power generation for the four modes for each region. Figure 2 also shows the amount of consumer purchased capacity (P^{VRR}).

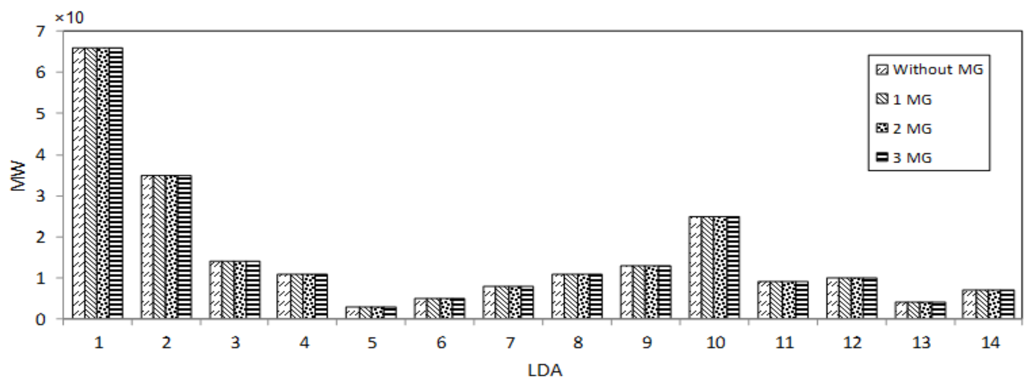

Figure 1. The amount of sold capacity resources in the capacity market (case 1)

As shown in Figure 2, with increasing the number of MGs, P^{VRR} has also enhanced. Figure 3 shows the extent of transmission network development without MG and with different numbers of MGs. It is indicated that the addition of MGs will gradually decrease the amount of transmission system development.

Based on the simulation results, the values of transmission network development in the four desired modes are 89,839, 8,389, 77,839, and 71,839 MW respectively. Comparing the capacity of the first and second modes shows that addition of one MG to the areas, the amount of capacity which is required to develop the transmission system reduced by 6,000 MW, almost equal to 6.6% reduction in capacity. This amount is significant, then MG can be considered as a suitable alternative for transmission system development. The second mode compared to the third mode and also the third mode compared to the fourth mode had a reduction in transmission capacity of 600 MW. Figure 4 shows the sold capacity of all MGs for all four modes. So, increasing the number of MGs result in the growing of the amount of sold capacity.

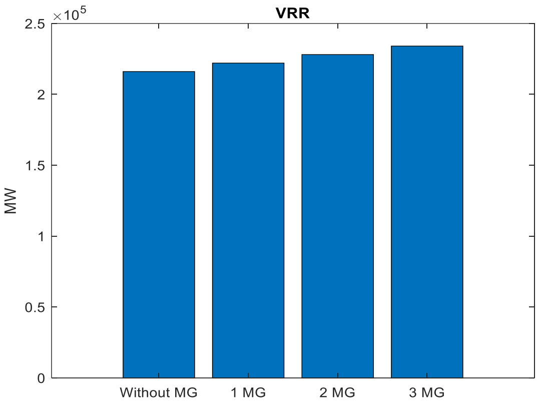

Figure 2. The amount of capacity purchased by consumers (case 1)

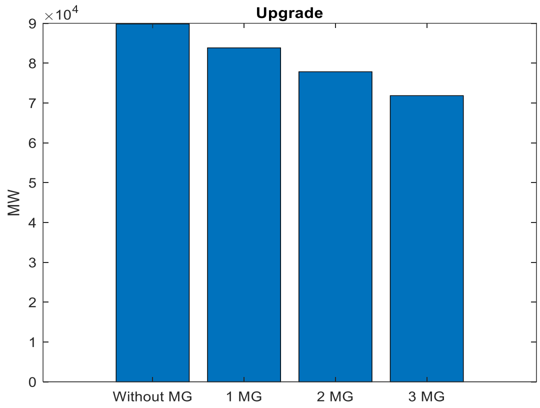

Figure 3. The amount of transmission network development (case 1)

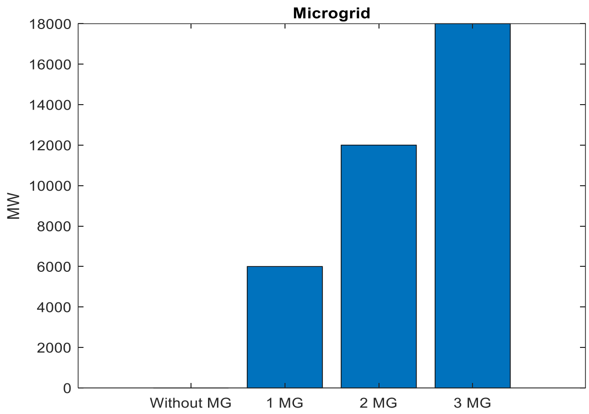

Figure 4. The amount of sold capacity of MGs in each mode (case 1)

3.2. Analysis for maximum number of microgrids in all areas (case 2)

In the previous simulation, it was assumed that each region would be able to construct a certain number of MGs. A general constraint exists for the second scenario such a way that a maximum number of Nmg MGs can be constructed in one or more areas. Four different modes are introduced is being as; i) mode 1: none of the areas have MGs, ii) mode 2: maximum 5 MGs in all areas, iii) mode 3: maximum 10 MGs in all areas, and iv) mode 4: maximum 15 MGs in all areas

The related results of production cost, line investment cost, capacity sales profit, and MG cost are presented in Table 2. Figure 5 shows that the application of MGs did not affect the amount of sold capacity in any areas. Figure 6 displays that increasing the number of MGs will enlarge the amount of profit from capacity. Because, using of MGs reduced the price of capacity. According to Figure 7, by using of MGs the transmission development capacity is reduced. It can be found from Figure 8 that enhancement of the number of MGs lead to growth of sold capacity.

Table 2. Capacity market costs with different numbers of MGs in all areas (case 2)

Costs	0 MG	5 MGs	10 MGs	15 MGs
Generation cost	44,092,610	44,092,610	44,092,610	44,092,610
VRR revenue	99,528,450	101,119,280	101,580,010	101,938,700
Upgrade cost	89,839,000	79,839,000	69,839,000	59,839,000
MG cost	0	3,382,191	6,764,383	10,146,580
Capacity market cost	34,403,160	26,121,020	19,115,720	12,139,510

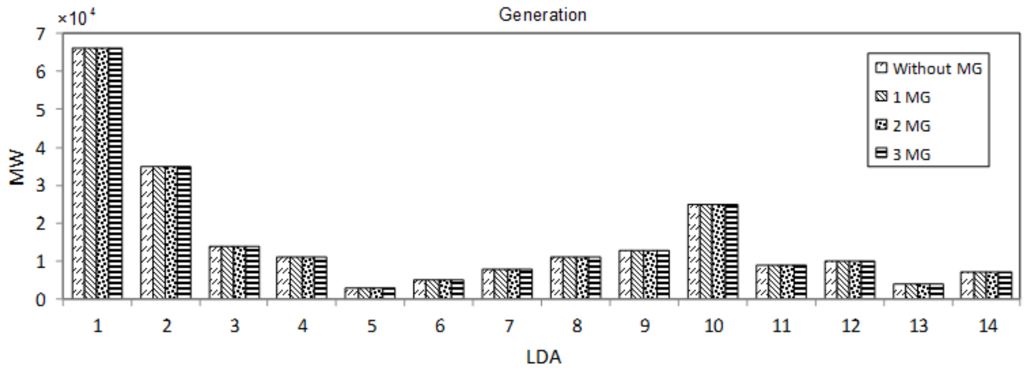

Figure 5. The amount of sold capacity resources in the capacity market (case 2)

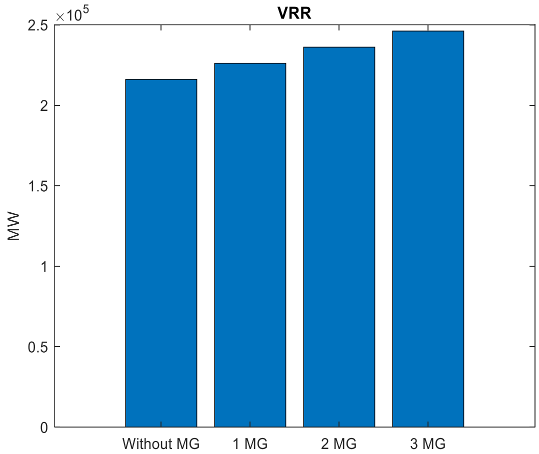

Figure 6. The amount of capacity purchased by consumers (case 2)

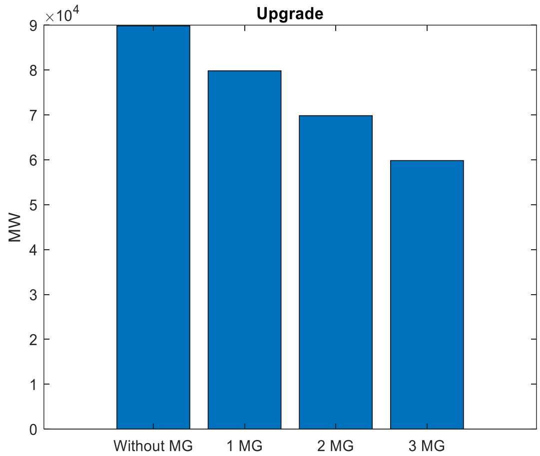

Figure 7. The amount of transmission system development (case 2)

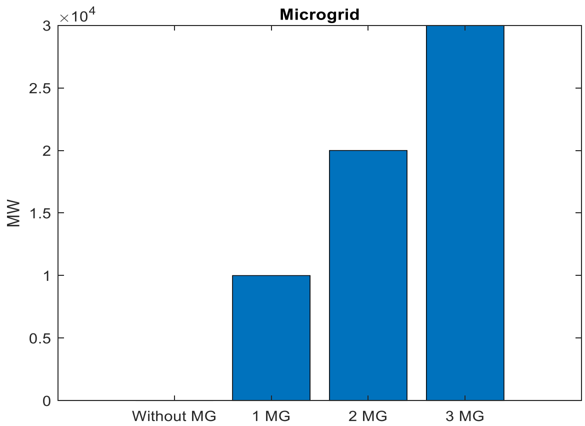

Figure 8. The amount of sold capacity of MGs in each mode (case 2)

4. CONCLUSION

Role of MGs as an alternative solution for transmission system development was investigated to inspect if MGs can be introduced as a suitable alternative for transmission line development. A method has been proposed for simulation of MGs in the capacity market as a solution for the problem of transmission system development planning. The capacity market is analyzed in four modes such as no MG, with only one MG in each area, with two MGs in each area, and three MGs involved in each area. The results show that the addition of MGs causes a significant reduction in the cost of transmission system development. By adding of one MG to each area, the cost of system development will be reduced by 6 million dollars, and while the cost of MG will be only 2 million dollars. Increasing the number of MGs caused a slight increase in the profitability of selling capacity to consumers. These results proved that the requirement of power system development will be eliminated using enough numbers of microgrids with a suitable capacity.

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