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OPTIMAL OPERATION OF MICROGRIDS USING RENEWABLE ENERGY RESOURCES

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Abstract- With the development of distributed generation resources and the increase of energy generation technologies, the operation of power systems faced with new complexities. Due to the development of smart grids and the use of renewable energy resources, a suitable method for the optimal use of these resources is of great importance. International organizations and institutions are trying to develop appropriate encouraging methods based on the agreements, but these methods have been developed in traditional environments and are not precise and codified procedures in electrical smart grids. Established microgrids of the distribution companies that are managed locally should also be able to take advantage of these laws. A classification of different issues of a microgrid provides an appropriate method for optimal control of energy resources in this paper. A day-ahead market is intended as an appropriate market and the operation planning for a power distribution network is performed.

Keywords: Multi Feature Functions, Microgrids, Renewable Energy Resources, Local Control of the Distribution Network.

I. INTRODUCTION

With the development of distributed generation resources and the increase of energy generation technologies, the operation of power systems faced with new complexities [1]. Using renewable energy resources with small installable capacities at the demand (consumption) side, emplacement is a way to reduce environmental pollution, the use of fossil energy resources and save transport costs. Using advanced techniques and technologies appropriate to the type of energy generation and utilization in power system control and operation is a part of the current requirements. Electric smart grids [2, 3] provide a future of managing energy distribution networks. Having a suitable electrical network requires technology, telecommunication platform, intelligent local and regional algorithms, protective equipments and a remote control system [4].

Regional management of the power system gives the power system operators more choice for their own network management, with the installation of distributed generation resources in the network and setting a connection with the global network [5]. As it is mentioned in various references according to Figure 1, electric smart grids have three main dimensions, the economic, technical and environmental dimensions. This paper aims to examine the various issues surrounding the management and operation of microgrids in attendance of renewable energy resources [6]. The economic and environmental issue of energy generation will be formulated as a multi feature problem and the impact of environmental constraints on the generation rate of different resources will be investigated.

Figure 1. A view of the different sectors of industry in an electric smart grid [7]

II. REGIONAL MANAGEMENT OF DISTRIBUTION NETWORKS (MICROGRIDS)

Microgrids are separate regional parts in low voltage network level which are made up from the combination of small loads, distributed energy resources, storage resources, control and intelligent equipments and loads accountable to the system administrator [7-10]. Microgrid management reduces the cost of providing the required energy; Minimizes costs to customers, improves the power quality and increases social welfare. Several microgrids could connect the distribution network and have power exchange with each other.

The utilized Microgrid control method in this paper is a hierarchical method. This control method is determined at different levels [11]:

- *Distribution Management System level* (*DMS*): The *DMS* level is responsible for the Management of several microgrids. These microgrids are connected together by feeders.
- *Microgrid System Central Controller level* (*MGCC*): The *MSCC* level is responsible for controlling and operating and the protection of a microgrid. The market and fuel prices are at this unit's disposal.
- *Microsource Controllers level* (*MC*): The *MC* level includes collection of power electronic equipment and controls the voltage, power and frequency through managing the resource owners.
- *Load Controllers level* (*LC*): The *LC* level manages controllable loads. The load control level and small resources control level are parallel at these levels. These levels are shown in Figure 2.

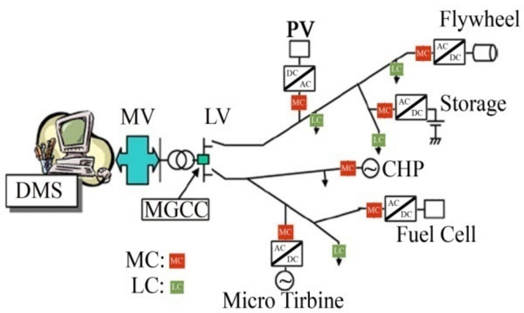

Figure 2. Different control levels of a microgrid [11]

III. PRICING POLICY

According to the energy market and the various methods of market such as the overall market and retail market, it can be concluded with a very simple check that the presence of distributed energy resources with low capacity have practically no effect on the overall market prices. These resources will only have a low impact on the retail markets. Realistically these resources will lose in competition with large power plants. Their only duty is following the announced prices by the market for selling energy.

IV. THE EFFECT OF ENVIRONMENTAL ISSUES ON ENERGY GENERATION

Distributed generation with low power is mainly emplaced at the demand location for lower delivery costs. The best place for locating an energy resource is at the consumer's place. While environmental concerns are considered by national and international institutions and organizations in order to preserve natural resources and increase social welfare, the pollution production by energy resources must be least. To encourage investors, the United Nations Framework Convention on Climate Change (UNFCCC) dedicated a stock as promotion for any organization or investor for reducing pollution over the Kyoto Protocol which is pointed with regard to energy generation by renewable energy resources in this paper and causes a reduction in the energy cost [12].

V. PROBLEM FORMULATION

The day-ahead market is chosen for the planned generation rate per unit. The combination of all large power plants and the global network made ups the primary network which connection to the microgrid is modeled (simulated) in this formulation.

A. Day-Ahead Market

Regarding the microgrid's conditions and its connection to the global network in the presence of distributed generation resources, the one day-ahead market will be selected for modeling. Increasing profits will be the market's main goal. The resulted profit includes the generation, consumption and network management profit. The main objective function of the problem will be shown as Equation (1):

$$Max\ Profit = Revenue - Expenses \quad (1)$$

This relation will be studied at a 24 hour period. The income includes the amount paid to the large power generation units, the money paid to the distributed generation units and the promotion paid to distributed generation units with renewable energy resources. The microgrid management will try to increase its profits through applying intelligent systems. However, the constraints of the problem must also be considered.

B. Modeling Constraints

B.1. Customers Load Supply

The amount of energy generated by distributed generation resources in the microgrid in addition to the total delivered energy from the global network must provide the customer's demand.

$$P_{MG} + \sum_{j=1:N} P_{DG} \geq \sum_{i=1:L} P_{loadi} \quad (2)$$

In order to increase the reliability of the power network, the operator of the microgrid needs minimal power storage due to the network load, history of network events and available resources. This storage will be provided through the overall market or internal resources. A schematic diagram of a connected microgrid to the global network is shown In Figure 3. The variable parameters are specified to display the constraints.

$$P_{DER} = P_{PVs} + P_{WTs} + P_{SEs} \quad (3)$$

$$P_{PVs}(t) = \sum_{r=1:R} f_r(T(t), Q(t)) \quad (4)$$

$$P_{WTs}(t) = \sum_{k=1:K} f_k(V(t)) \quad (5)$$

$$P_{SEs}(t) = \sum_{s=1:S} P_{SE}(t-1) + (P_{Gen} - P_{De})(\frac{\Delta t \alpha(t)}{V(t)}) \quad (6)$$

$$P_{SE}(t=0) = A \quad (7)$$

$$P_{SE}(t=Nt) = B \quad (8)$$

P_{DER} is the amount of generated power by renewable distributed generation resources in this relation. This power includes the output power of small wind turbines and solar cells. $P_{SE}(t)$ and $P_{SE}(t\text{-}1)$ are the stored power in batteries. $\alpha(t)$ is the battery's efficiency at the time period t.

It can be concluded from the relation relevant to the solar cell power which is shown with P_{PV} that the amount of this power depends on the temperature and penetration level of the cells. The maximum and minimum stored powers in the batteries are shown with the words *A* and *B*.

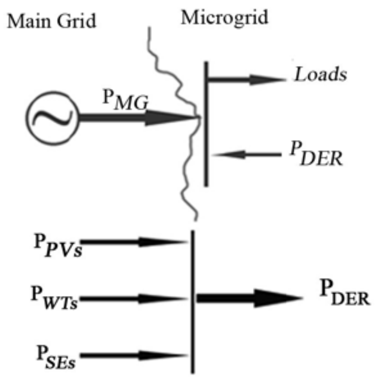

Figure 3. Schematic diagram of a microgrid and energy resources

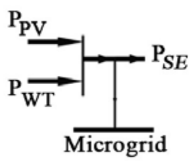

Figure 4. Schematic diagram of the battery charging and discharging and power transmission to the network

B.2. Reducing Environmental Pollution Costs Promotion

The *EC* in the following relation indicates the amount of the earned money from the generated energy by renewable energy resources. *C* is the amount of money that is paid for each kW power per hour.

$$EC = (P_{DER}) \times C \quad (9)$$

The reduction in fossil energy consumption per ton will be calculated. The considered proportional number in this paper is 250.

VI. SIMULATION

The studied network is made up a microgrid with distributed energy resources which is connected to the global network. The microgrid feeders that are fed radial are shown schematically in Figure 5. The low voltage Levels are 380 V and the medium voltage level is 20 kV. The low voltage network is 5 km long. The performed simulations are modeled in the GAMS software and have been studied by applying the Non-Linear-Programming (NLP) method [13].

Figure 6 shows the demand curve of the subscribers (customers). Due to the overall market run, the maximum power that can be injected from the global network to the microgrid will be determined. The overall market price for several hours will be specified which are shown in Table 1.

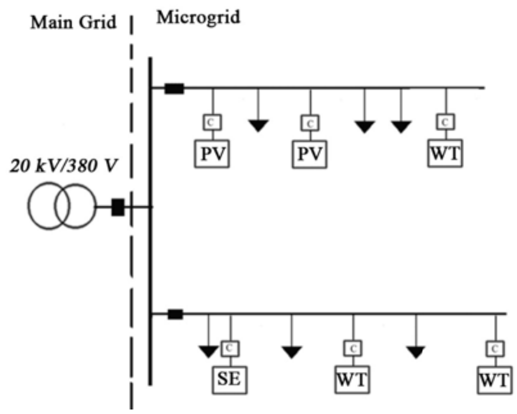

Figure 5. Sample studied network

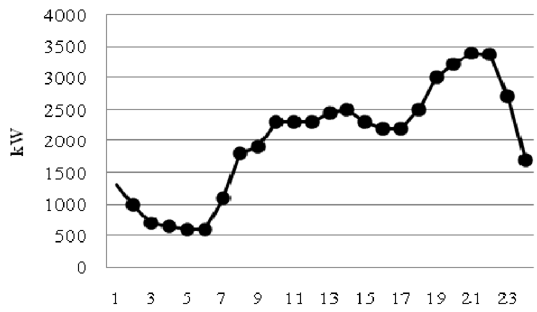

Figure 6. Customer's load curve in the studied microgrid

The maximum delivered power of each distributed generation unit and their offered prices at different hours are shown in Table 2. The amount of the promotion paid to each of the energy-generating units is determined according to a survey done about the reduced pollution level that is shown in Table 3.

VII. RESULTS SURVEY

The simulation is performed on a sample system in a 24 hour time period in a typical day. Only distributed generation resources are assumed controllable in the simulation conditions. (Modeling of the changeable loads by the operator is not considered according to the simulation type). As seen, units 1 and 4 are photovoltaic. The units 2 and 6 are wind turbines and 3 and 5 are storage energy units.

In determining the amount of the Clean Development Mechanism Price (CDMP) the position of the resources plays a very impressive role. The simulation is done in two cases 1 and 2. In the first case, only the energy market has been considered and no incentive payments are given to the energy generating units. In the second case, in addition to the payment of the delivered energy cost to each unit, there will be also an extra payment based on the CDMP parameters of the units using renewable energy resources as a reward.

It is observed from Table 4 that no power is provided from renewable energy resources in the first 7 hours and the total load is supplied by the global network. At the hours 8 and 9, given that the energy prices in the global network are more than the energy prices of the microgrid's internal resources, so there is no power injection from the global network. Also, at hour 23 given that the energy prices of the global network are very expensive and therefore the main load is provided through the internal network and only 600 kW is supplied by the global network.

Table 1. Maximum power and the delivered power price to the microgrid

Hour	Market Clearing Price ($/kW)	Max Power Transfer from Main Grid (kW)
1	40	3000
2	40	3000
3	40	3000
4	40	3000
5	40	3000
6	40	3000
7	40	1500
8	170	1500
9	170	1500
10	170	1500
11	170	1500
12	170	1500
13	170	1500
14	170	1500
15	180	1500
16	180	1500
17	180	1500
18	180	600
19	210	600
20	210	500
21	210	500
22	210	600
23	210	600
24	200	600

Table 3. CDMP for each distributed energy unit

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
CDMP ($/kW)	10	4	5	1	11	4

Table 2. The maximum delivered power of each distributed generation unit and their offered prices at different hours

Hour	Unit 1		Unit 2		Unit 3		Unit 4		Unit 5		Unit 6	
	Max Pg (kW)	Price ($/kW)	Max Pg (kW)	Price ($/kW)	Max Pg (kW)	Price ($/kW)	Max Pg (kW)	Price ($/kW)	Max Pg (kW)	Price ($/kW)	Max Pg (kW)	Price ($/kW)
1	570	130	665	400	765	250	368	100	740	113	915	140
2	570	130	665	400	765	250	368	100	740	113	915	140
3	570	130	665	400	765	250	368	100	716	113	915	140
4	570	130	665	400	765	250	368	100	736	113	915	140
5	570	130	665	400	765	250	368	100	724	113	915	140
6	570	130	665	400	765	250	368	100	720.4	150	915	140
7	570	130	665	400	740	250	368	100	716.8	150	915	140
8	940	130	665	300	740	250	368	60	713.2	150	915	230
9	940	130	665	75	740	250	368	60	79.6	150	914	230
10	940	130	655	75	740	250	368	60	86	150	914	230
11	940	130	665	75	740	250	368	60	86	150	914	230
12	940	220	665	75	540	250	861	60	86	150	914	230
13	940	220	665	75	540	250	861	60	86	150	914	230
14	940	220	665	75	540	250	861	60	86	150	914	230
15	940	220	665	75	540	250	861	60	86	150	768	230
16	940	220	665	75	540	250	861	60	86	150	768	230
17	755	210	665	75	540	250	861	60	86	150	768	230
18	755	210	665	300	540	250	861	100	86	113	768	230
19	755	210	665	300	540	250	861	100	86	113	768	140
20	755	210	665	300	765	250	861	100	86	113	768	140
21	755	210	665	300	765	250	861	100	86	113	768	140
22	755	210	665	300	765	250	861	100	86	113	768	140
23	755	210	665	300	765	250	861	100	86	113	768	140
24	755	210	665	300	765	250	870	100	86	113	768	140

Table 4. Case 1 of the simulation, generated power of each generating-unit

Hour	Generated Power of Unit (kW)					
	1	2	3	4	5	6
7-1	0	0	0	0	0	0
8	940	0	0	368	493	0
9	867	665	0	368	0	0
10	940	655	0	368	86	0
11	940	665	0	368	86	0
12	0	665	0	861	86	0
13	0	665	0	861	86	0
14	0	665	0	861	86	0
15	0	665	0	861	86	0
16	0	665	0	861	86	0
17	0	665	0	861	86	0
18	755	0	0	861	86	198
19	685	0	0	861	86	768
20	755	0	240	861	86	768
21	755	0	430	861	86	768
22	755	0	300	861	86	768
23	385	0	0	861	86	768
24	0	0	0	870	86	744

Table 5. Case 2 of the simulation, allocated power to the global network for providing the network load

Hour	kW	Hour	kW	Hour	kW	Hour	kW
1	1300	7	1090	13	838	19	600
2	1000	8	0	14	888	20	500
3	700	9	0	15	688	21	500
4	650	10	251	16	588	22	600
5	620	11	241	17	588	23	600
6	600	12	688	18	600	24	0

Table 6 displays the allocated power of generation units using renewable energy resources, in the second simulation case. This Table shows that most of the microgrid's load will be provided by renewable energy resources at all hours of the day. For example, comparing hours 1 to 7 from the Tables 4 and 6, it can be seen that 5438 kilowatts of the loads are provided through internal energy resources of the microgrid.

The main part of the power is supplied by unit 5 because of its higher CDMP than other units. Table 7 displays the amount of the allocated power to the global network for providing the microgrid's load. The total supplied power by the global network contains 14130 kW in the first case, while in case 2, this amount is equal to 1942 kW. The difference will be 12188 kW, which is a considerable number.

Figure 7 shows the graphs of the delivered powers by the global network in the two different simulation cases. It is observable from the cost comparison between the two cases of simulation that the total costs paid to the microgrid's internal renewable energy resources will be much more than the first case of the simulation. In general, the costs in the second case are higher than the first case.

The encourage cost paid to the distributed generation units for increasing their generation will be equal to $273392. In addition to reducing the money transfer from the microgrid to the global network, the amount of the generated power by the renewable energy resources will increase and environmental pollutants will be reduced proportionally.

Table 6. Case 2 of the simulation, generated power of each generating unit

Hour	Generated Power of Unit (kW)					
	1	2	3	4	5	6
1	560	0	0	0	740	0
2	260	0	0	0	740	0
3	0	0	0	0	700	0
4	0	0	0	0	650	0
5	0	0	0	0	620	0
6	570	0	0	0	0	0
7	570	0	0	0	0	0
8	940	0	0	368	492	0
9	940	592	0	368	0	0
10	940	655	0	368	86	0
11	940	665	0	368	86	0
12	688	665	0	861	86	0
13	838	665	0	861	86	0
14	888	665	0	861	86	0
15	688	665	0	861	86	0
16	588	665	0	861	86	0
17	588	665	0	861	86	0
18	755	0	0	861	86	198
19	755	0	530	861	86	768
20	755	0	740	861	86	768
21	755	0	765	861	86	768
22	755	0	765	861	86	768
23	755	0	230	861	86	768
24	0	0	0	870	86	744

Table 7. Case 2 of the simulation, generated power by the global network

Hour	kW
6	30
7	520
10	251
11	241
18	600
21	165
22	135

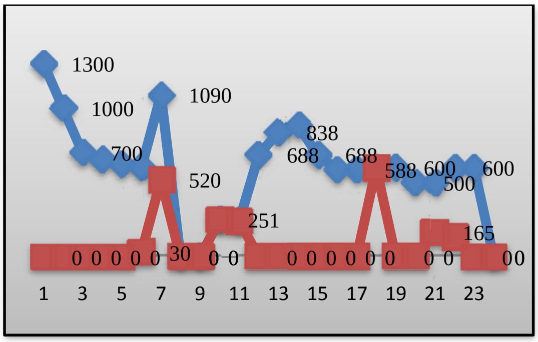

Figure 7. The delivered power by the global network in case 1 and 2 of the simulation

VIII. CONCLUSIONS

This paper offers a method for the more usage of renewable energy resources by simulating a sample network considering various environmental constraints and the maximum and minimum limits of the energy resources. The results show that paying a cost to encourage distributed generation units can prevent out funds from the microgrid. Also centralized management of microgrids depends on having obedient control systems and smart algorithms. Note that the response speed of the microgrids is very important, therefore, the smart algorithms must have the most optimal answers in the shortest time.

Table 8. Total cost of the cases 1 and 2

	Case 1	Case 2
Payment for Main Grid ($)	1763940	276640
Payment for Distributed Energy Resource (DER) ($)	3963041	6154386
Total Cost ($)	5726981	6431026

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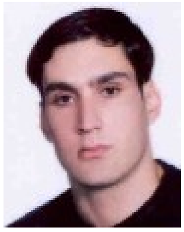

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