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Multi-Objective Optimization of Demand Side Management and Multi DG in the Distribution System with Demand Response

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Abstract- *The optimal management of distributed generation (DG) enhances the efficiency of distribution system; On the other hand, increasing the interest of customers in optimizing their consumption improves the performance of DG. This act is called demand side management. In this study, a new method based on intelligent algorithm is proposed to optimal operate the demand side management in the presence of DG units and demand response. Firstly, the best location and capacity of different technologies of DG are selected by optimizing the technical index including the active and reactive loss and the voltage profile. Secondly, the daily performance of multi-DG and grid is optimized with and without consideration the demand response. The economic and environmental indices are optimized in this step. In the both steps, the non-dominated sorting firefly algorithm is utilized to multi-objective optimize the objective functions and then the fuzzy decision-making method is used to select the best result from the Pareto optimal solutions. Finally, the proposed method is implemented on IEEE 33-bus distribution system and actual 101-bus distribution systems in Khoy-Iran. The obtained numerical results indicate the impact of the proposed method on improving the technical, economic and environmental indices of distribution system.*

Keyword: Distributed generation, Demand response program, Demand side management, Fuzzy decision-making, Non-dominated sorting firefly algorithm.

NOMENCLATURE

The main notation needed in this paper is provided in this section for quick reference. Other symbols are defined as required throughout the text.

A_{pv}	The area of solar panel (m^2)
μ	Solar irradiance (w/m^2)
A_{wt}	Swept area of wind turbine (m^2)
C_p	Power coefficient (Albert Betz limit)
$P_0(i), P(i)$	Initial and DR price of power at i^{th} hour
$E(i,j)$	The cross-elasticity of DR
P_l , Q_l	The active and reactive loss indices
N_{br}	Branch number
I_i	Current of branch i after placement
V_{i_ins} , V_i	Initila and ultimate Voltage of bus i
n_{DG}	Number of DG units
$P_{grid}(h)$	The power of grid at h^{th} hour
$MP(h)$	Market price at h^{th} hour
$M_{unit\_i}(h)$	The situation of i^{th} unit at h^{th} hour
n_{PG}	Number of pollution gases
PG_{ij}	The rate of j^{th} pollution gas of i^{th} unit
η_{charge}	ESS efficiency during charging
β	The efficiency of solar panel (%)
ρ	Air density (kg/m^3)
V_w	Wind speed (m/s)
$d_0(i), d(i)$	Initial and DR demand of system at i^{th} hour
$E(i,i)$	The self-elasticity of DR
C_p , Q_l	Penalty coefficients
R_i , X_i	Resistance and reactance of branch i
$I_{i_{ins}}$	Initial current of branch i
V_b	Nominal voltage
n	number of buses
$P_{DG\_i}(h)$	The power of i^{th} DG at h^{th} hour
C_{DG_i}	The cost of power generation at i^{th} DG
C_{ss_i}	The cost of start-up/shut-down at i^{th} unit
n_{unit}	Number of units
$P_{unit_i}(h)$	The power of i^{th} unit at h^{th} hour
$W_{ESS}(t)$	energy stored within the ESS at h^{th} hour
$\eta_{discharge}$	ESS efficiency during discharging

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1. INTRODUCTION

Demand side management (DSM) is a useful method to improve the efficiency of distribution system. DSM is the planning, implementation and monitoring of utility activities that are designed to influence the consumption of customers. DSM causes to change the daily pattern and magnitude of various loads. Distributed generations are one of the important devices that are utilized to apply the DSM to distribution system (smart grid). DG units improve the technical, economic and environmental indices of power network. Renewable and non-renewable DG units are used in the distribution systems; these units assist the grid to supply the demanded power of network. Another useful technology of DSM is demand response (DR). Demand response can be defined as a method for improving the energy consumption pattern of an electric utility customer. DR causes to better match the demand with the supply of energy [1-3].

DSM is the modification of demand for energy through various methods such as financial incentives and behavioral change through education. In other words, the goal of DSM is encouragement of consumers to decrease their energy consumption during peak hours or to move the time of energy use to off-peak times. Totally, operators and customers of distribution system can manage consumption of smart grid based on six offered programs including peak clipping, conservation, load building, valley filling, flexible load shape and load shifting. These DSM strategies have been shown in Fig. 1. Distributed generation and demand response are the practical ways for doing DSM and load management [4].

In the last years, DSM has been studied by many researchers from around the world that some of them are reviewed in the following. The authors in the Ref. [5] proposed a concept of DSM through the spatial and tem-

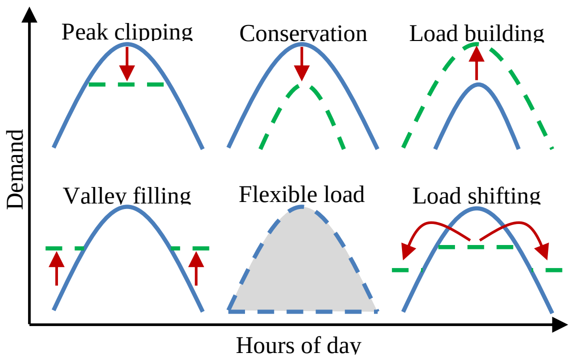

Fig. 1. The DSM strategies

-poral DSM. The minimum daily energy losses and minimum daily operating costs are the objective functions of problem. In the Ref. [6], a DSM model was developed to investigate the response capacity and rapid response capability of different resources. The considered resources are DG and electrical vehicle. In this study, a unified state model of different demand resources is developed after selecting the state model of energy resources. A direct load control based on DSM algorithm was proposed to perform peak shaving in the Ref. [7]. In this study, time-varying renewable DG and thermal comfort of the building have been considered during DSM. The aims of the problem are peak shaving and reduction of energy costs. After applying the considered DSM method, peak-shaving is done without breaching thermal comfort margins of the customer. The authors in the Ref [8] studied DSM in the context of building energy systems combined with thermal storage systems. Different penetrations of renewable energy sources and different building types have been considered for better evaluating the results. Providing the heat demand and satisfying the comfort criteria of the residents are done during applying the considered DSM method. Shakouri and Kazemi proposed an intelligent energy management framework for DSM [9]. The minimization of electrical peak load and reduction of electricity cost are considered as objective functions in this study. The used model for DSM is a multi-objective mixed integer linear programming. In the Ref. [10], DSM was done to accommodate curtailed wind power with a typical wind power output profile and energy storage systems. An hour-ahead heating strategy scheduling mode is proposed to accommodate curtailed wind power in this study. The results show that thermal power is reduced substantially due to the contribution of DSM and energy storage. The researchers proposed the optimal energy management for a grid-connected photovoltaic-battery hybrid system in the Ref. [11]. The main purpose of study is to sufficiently explore solar energy and benefit customers at distribution system. In this study, an open loop control method was used to schedule the power flow of hybrid system over 24-hour and a closed loop control method was utilized to dispatch the power flow in real time when uncertain disturbances occur. In the Ref [12], DSM was done in the residential area with high penetration of rooftop photovoltaic units. An autonomous energy consumption scheduling algorithm has been proposed to decrease the peak load and reverse power flow. The objective functions of DSM are the cost of energy consumption, the revenue from energy export and the cost of voltage rise. The applied DSM method reduces the peak to average ratio of the load and mitigates the voltage rise problem. The pricing strategy for DSM in the electricity market was done in the Ref. [13]. The utility company was considered to play the role between the generation and consumption sides. In this study, the retail and wholesale prices are evaluated so that the proposed method is applied to distribution system for selecting the optimal equilibrium price. The authors in the Ref. [14] studied DSM to adjust the real time residential load to follow a preplanned day-ahead energy generation by the smart grid. Electrical vehicle, energy storage system and renewable DG units are considered for DSM. The proposed method helps the operator better deal with uncertainties in the system through better planning day-ahead electricity generation and purchase.

Even though various studies have been done about the DSM, optimizing the location and capacity of DG units before applying the DSM is done in this study. Moreover, technical, economic and environmental indices are optimized to select the best schedule for DSM. Therefore, multi-objective optimization of demand side management is implemented in the distribution system in the presence of multi-DG and demand response program. The DSM is done in two steps: firstly, the best location and total capacity of DG units are optimized by non-dominated sorting firefly algorithm (NSFA). Technical indices of distribution system including the active and reactive loss and the voltage profile are optimized to select the location and size of multi-DG. Secondly, NSFA is utilized to optimize the daily performance of DGs and grid with/without the involvement of demand response. The objective functions of this step are economic and environmental indices. In the both steps, the fuzzy decision-making method is used to choose the best result from the Pareto optimal solutions. The proposed method is tested on IEEE 33-bus and actual 101-bus distribution systems in Khoy-Iran. The results indicate the high efficiency of proposed method to improve the considered indices and the performance of distribution system after applying the DSM.

2. PROBLEM DEFINITION

In this study, optimization of location and size of DG units is done before studying the DSM. Renewable and nonrenewable DGs are considered so that each type of them has a unique performance on the distribution system. Totally, the performance of DG units depends on their technology and output power. After finding the best location and total capacity of DGs, DSM is done in the distribution system in the presence of DG and demand response program. The details of DG technologies and DR are explained as follow:

2.1. Distributed generation

The technologies of DG units can be divided into renewable and nonrenewable ones. The output power of nonrenewable DGs is stable and it depends on the primary fuel and demand of system; while the output power of renewable sources is unstable and it depends on the weather condition. In this study, diesel generator (DIG), micro turbine (MT) and fuel cell (FC) are considered as nonrenewable DG while renewable DG units are photovoltaic (PV) and wind turbine (WT). The following sections are dedicated to the description and modeling of the considered DGs [15, 16].

2.1.1. Diesel generator

A diesel generator (DIG) uses a diesel engine and electric generator to generate electrical energy. Liquid fuels or natural gas are usually used as a primary fuel of DIG. The output power of DIG can be changed based on demand of network. A DIG produces active and reactive power, simultaneously. So in the load flow equations, DIG is considered as a PQ bus which provides active and reactive power. In this study, the operating power factor of DIG is set at 0.85.

2.1.2. Micro turbine

Micro turbine (MT) is the technology which has the unique ability to produce electricity and heat, simultaneously. MT can run on a variety of fuels, including natural gas, propane and fuel oil. A MT has capable of injection both active and reactive powers to the network. Therefore, this kind of DG is modeled as a constant voltage bus model in load flow equations.

2.1.3. Fuel cell

A fuel cell (FC) is a nonrenewable DG that converts the chemical energy from a fuel into electricity. Of course, a FC is difference from a battery because the FC can produces electricity continuously for as long as fuel is supplied while in the battery, the electrical energy comes from chemicals already present in the battery. A FC produces just active power; therefore, it is modeled as a P bus model in load flow studies.

2.1.4. Photovoltaic

Photovoltaic (PV) is one of the popular and useful technologies of renewable DGs. Totally, PV is a solar power technology that uses solar cells or solar photovoltaic arrays to convert the light of the sun directly into the electricity. The output power of each PV panel relates to the amount of solar irradiance, the area and efficiency of the solar panel. Mathematically, the active power of PV can be calculated by Eq. (1).

This DG type produces only active power; so PV is modeled as a P bus model in load flow analysis.

$$P_{PV} = A_{pv}\beta\mu \quad (1)$$

2.1.5. Wind turbine

In most countries which are pioneer in the clean energy, wind turbine (WT) is one of the common and useful renewable DG technologies. The output power of WT has direct relation to wind speed and swept area of the turbine; of course, the other parameters such as air density and power coefficient affect the power of WT, too. Therefore, the active power of WT can be calculated by Eq. (2).

$$P_{WT} = \frac{1}{2}\rho A_{wt} V_w^3 C_p \quad (2)$$

A WT usually consumes reactive power to produce active power. Therefore, this technology of DG is modeled as a PQ bus model with variable reactive power in load flow equations. The consumed reactive power of WT in a simple form has been given in Eq. (3).

$$Q_{WT} = -(0.5 + 0.04{P_{WT}}^2) \quad (3)$$

2.2. Demand response

The daily changes of power of distribution system are considerable so that the difference between the minimum and maximum consumed energy sometimes is a large amount. Demand response is one of the methods for modifying the consumption curve of customers. Totally, DR is a change in the power consumption of an electric utility customer to better match the demand of system with the supply. On the other words, demand response programs seek to adjust the demand for power instead of adjusting the supply. DR programs are divided into two basic categories including time-based rate programs and incentive-based programs [17].

In this study, time of use (TOU) program is utilized as demand response program because it is the common and useful DR program and also TOU is easier than other programs to apply to a real distribution system. Therefore, it can be said that results of this study are so close to the result of the operation of a real distribution system. Totally, the considered model of DR program can be calculated by Eq. (4) [17].

$$d(i) = d_0(i) \times [1 + E(i,i)\frac{P(i)-P_0(i)}{P_0(i)} + \sum_{\substack{j=1 \\ j\neq i}}^{24} E(i,j)\frac{P(j)-P_0(j)}{P_0(j)}] \quad (4)$$

3. OBJECTIVE FUNCTIONS

In this study, simultaneous finding the location and total capacity of multi DG and also selecting the best schedule for DSM are done as multi-objective optimization. As mentioned above, optimization is done during the two steps. Technical indices including loss index and voltage index are considered as the first objective functions while the second objective functions are economic and environmental indices. Mathematically, the considered objective functions are formulated as:

$$first\ objective\ function : \min\ \{I_{ARL},\ I_{VP}\} \quad (5)$$

$$second\ objective\ function : \min\ \{I_{OC},\ I_{PE}\} \quad (6)$$

Where I_{ARL} and I_{VP} are power loss index and voltage profile index, respectively. In the second objective function, I_{OC} and I_{PE} are operational cost index (economic index) and pollution emission index (environmental index), respectively. The following sections are dedicated to the formulation of the objective functions.

3.1. Technical indices

Technical indices of distribution system are important to increase the efficiency and performance of network; therefore these indices should be evaluated during the development and planning of distribution network. In this study, loss and voltage indices are considered as technical indices for optimizing the location and capacity of multi DG units.

3.1.1. Loss index

Power loss index as the most important technical index is defined with combination of active and reactive power losses as:

$$I_{ARL} = C_p P_l + C_q Q_l \quad (7)$$

Where:

$$P_l = \sum_{i=1}^{N_{br}} R_i |I_i|^2 / \sum_{i=1}^{N_{br}} R_i |I_{i_{ins}}|^2 \quad (8)$$

$$Q_l = \sum_{i=1}^{N_{br}} X_i |I_i|^2 / \sum_{i=1}^{N_{br}} X_i |I_{i\_ins}|^2 \quad (9)$$

3.1.2. Voltage index

In this study, voltage profile is considered as voltage index. This index indicates bus voltage deviation from nominal voltage. Hence, the network performance will be better when the amount of this index is closer to zero. The considered voltage index is calculated by Eq. (10).

$$I_{VP} = \sum_{i=1}^{n}(V_i - V_b)^2 / \sum_{i=1}^{n}(V_{i\_ins} - V_b)^2 \quad (10)$$

3.2. Economic index

The economy is the integral part of decision-making in all daily activities; the distributions system is not exempt from this principle. Here, the operational cost index is considered as economic index of optimizing the DSM. The daily operational cost index can be calculated by Eq. (11).

$$I_{OC} = OC_{DG} + OC_{grid} + MC \quad (11)$$

Where OC_{DG} and OC_{grid} are the operational cost of multi DG and grid, respectively, while MC relates to the situation of units; on the other words, MC shows running and shutting down costs for the i^{th} unit during the h^{th} hour.

$$OC_{DG} = \sum_{h=1}^{24}\left[\sum_{i=1}^{n_{DG}}\left(P_{DG\_i}(h) \times C_{DG_i}\right)\right] \quad (12)$$

$$OC_{grid} = \sum_{h=1}^{24}\left[P_{grid}(h) \times MP(h)\right] \quad (13)$$

$$MC = \sum_{h=1}^{24}[\sum_{i=1}^{n_{unit}}(C_{ss_i} \times |M_{unit_i}(h) - M_{unit\_i}(h-1)|)] \quad (14)$$

3.3. Environmental index

Nowadays, most countries have special attention to environmental aspects of their decisions because the environmental condition gets worse every year. In this study, the considered environmental index is equal to the amount of pollution emission of all units. The main pollutant gases are Carbon Monoxide (CO), Carbon Dioxide (CO_2), Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_x) and Particulate Matter (PM_{10}) [15]. Therefore, the considered pollution emission index can be calculated by Eq. (15).

$$I_{PE} = \sum_{h=1}^{24}\sum_{i=1}^{n_{unit}}\sum_{j=1}^{n_{PG}} P_{unit\_i}(h) \times PG_{ij} \quad (15)$$

4. PROBLEM CONSTRAINT

There are following constraints during the implementation of the proposed algorithm.

1. The range of voltage of buses: The following range of voltage of the buses is allowable:

$$V_{min} \leq V_i \leq V_{max} \quad (16)$$

2. The range of power generation of DG units: The utilized DG units must have the allowable size as the following range:

$$P_{DG}{}^{min} \leq P_{DG\_i} \leq P_{DG}{}^{max} \quad (17)$$

3. Power balance constraint: The total generated power of multi DG and grid must be equal to the sum of the total demand and active loss of distribution system.

$$\sum_{i=1}^{n_{DG}} P_{DG\_i} + P_{grid} = \sum_{j=1}^{n} P_{demand_j} + \sum_{i=1}^{N_{br}} P_{loss_i} \quad (18)$$

4. Energy storage system constraint: There are limitations of charging and discharging in energy storage system (ESS) during each hour. The following equations can be expressed for limitations of ESS.

$$W_{ESS}(t) = W_{ESS}(t-1) + \eta_{charge}P_{charge}(t) - \frac{1}{\eta_{discharge}}P_{discharge} \quad (19)$$

$$W_{ESS\_min} \leq W_{ESS}(t) \leq W_{ESS\_max}$$

$$P_{charge}(t) \leq P_{charge\_max} \quad (20)$$

$$P_{discharge}(t) \leq P_{discharge\_max}$$

5. OPTIMIZATION ALGORITHM

The combination of NSFA and fuzzy decision-making method is utilized to multi-objective optimization of technical, economic and environmental indices. In the following sections, firstly, the NSFA and fuzzy decision-making are explained briefly and then proposed method is completely described in section 5.3.

5.1. Non-dominated sorting firefly algorithm

Intelligent algorithms typically are inspired their performance from nature. In FA, which is inspired from the social behavior of firefly, an absorption power is considered for each artificial firefly and worms move toward the firefly with greater absorbency power. Finally, an insect is selected as the most attractive one, which is the optimal solution for the problem. Changes in light intensity and formulating attractiveness of the insects are the two considerable topics in this algorithm. In general, attractiveness is a relative parameter and it is measured from the perspective of the other insects; it also depends on the distance from other insects. In this algorithm, location of each particle (firefly) is updated when the brightness of the j^{th} firefly is more than the i^{th} as follow [19]:

$$\acute{x}_i = x_i + \beta_0 e^{-\gamma r^2}\left(x_j - x_i\right) + \alpha\varepsilon_i \quad (21)$$

In Equation 21, γ is the absorption coefficient ($\gamma = 1$), β_0 is the attractiveness at $r = 0$ and r is the distance between any two fireflies i and j. The third term is randomization with α being the randomization parameter.

Even though single-objective optimization methods have acceptable performance, multi-objective optimization algorithms are more accurate and reliable than single ones in complex problems [20]. As regards that optimizing of DG units and DSM is the nonlinear and complex problem, the multi-objective optimization algorithm is proposed in this study. Therefore, the multi-objective form of firefly algorithm is utilized to optimize the objective functions. The used method in Ref [20] is utilized to improve the FA for solving the multi-objective problem. In other words, non-dominated sorting firefly algorithm (NSFA) is used for optimizing the DSM. In this method, particles are optimized based on non-dominated sorting and also crowding distance sorting so that after each repetition, particles that have the high-value (based on non-dominated sorting and crowding distance sorting) remain and others are rejected. The simple model of NSFA procedure is shown in Fig. 2.

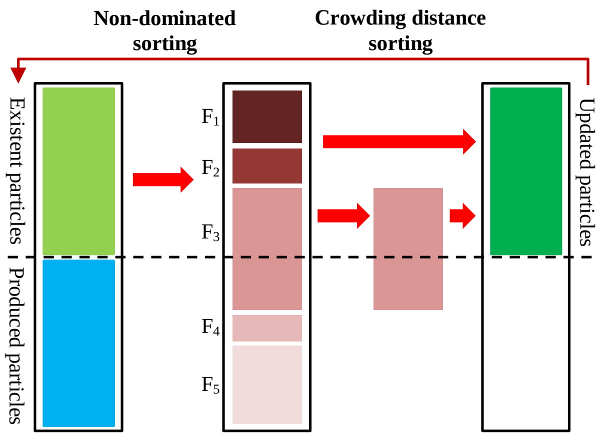

Fig. 2. NSFA procedure

Totally in the NSFA, particles are compared with all particles in the population in terms of all objective functions. Therefore, non-dominated fronts (Pareto optimal front) are used to sort the population in the proposed NSFA.

5.2. Fuzzy decision-making

The fuzzy satisfying method, which represents the best particle based on all objective functions, is applied to find the best compromise solution from the Pareto optimal front. The membership function is defined as follow:

$$\mu_i{}^k = \begin{cases} 1 & F_i{}^k \le F_i{}^{min} \\ \dfrac{F_i{}^{max} - F_i{}^k}{F_i{}^{max} - F_i{}^{min}} & F_i{}^{min} < F_i{}^k < F_i{}^{max} \\ 0 & F_i{}^{max} \le F_i{}^k \end{cases} \quad (22)$$

For each member of the non-dominated set, the normalized membership value is calculated by Eq. (23).

$$\mu^k = \frac{\sum_{i=1}^{NO} \mu_i{}^k}{\sum_{k=1}^{NK} \sum_{i=1}^{NO} \mu_i{}^k} \quad (23)$$

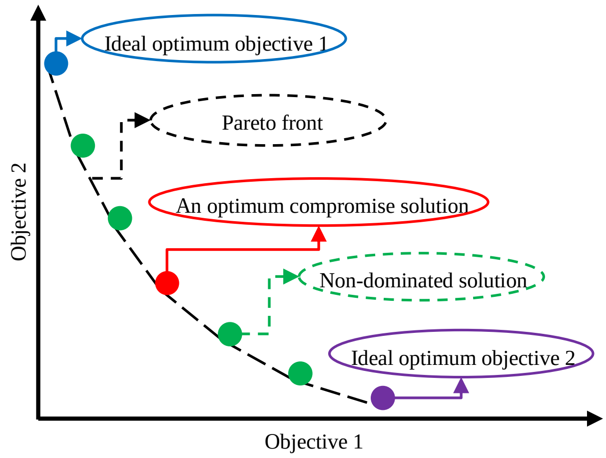

Fig. 3. The optimum compromise solution

The maximum value of the membership (μ^k) is chosen as the best compromise solution. Fig. 3 shows the simple idea for the compromise solution among the Pareto front.

5.3. Proposed method

In previous sections, the details of different technologies of DGs, objective functions, constraints and intelligent algorithm have been completely explained. In this section, the proposed method for finding the best schedule for DSM is described.

Firstly, simultaneous optimization of location and size of multi DG is done by applying the combination of NSFA and fuzzy decision-making method. The technical indices including active and reactive losses and voltage profile are improved during the multi objective optimization. Fig. 4 shows a clear picture of first step of simulation.

Secondly, after placement of multi-DG in the best locations, DSM is done in the distribution system in the presence of DR. Of course, the distribution system is also considered without DR for better evaluating the results. The economic and environmental indices are optimized by combination of NSFA and fuzzy decision-making method in this step. The power balance and ESS constraints are evaluated in all reiterations of intelligent algorithm. Moreover, the technical indices are also calculated after finding the best schedule for DSM. The complete algorithm for finding the optimal schedule for DSM is shown in Fig. 5.

6. NUMERICAL RESULTS

In this section, the proposed algorithm is test on IEEE 33-bus radial distribution system and actual 101-bus distribution system in Khoy-Iran. The daily load curve of distribution system is shown in Fig. 6.

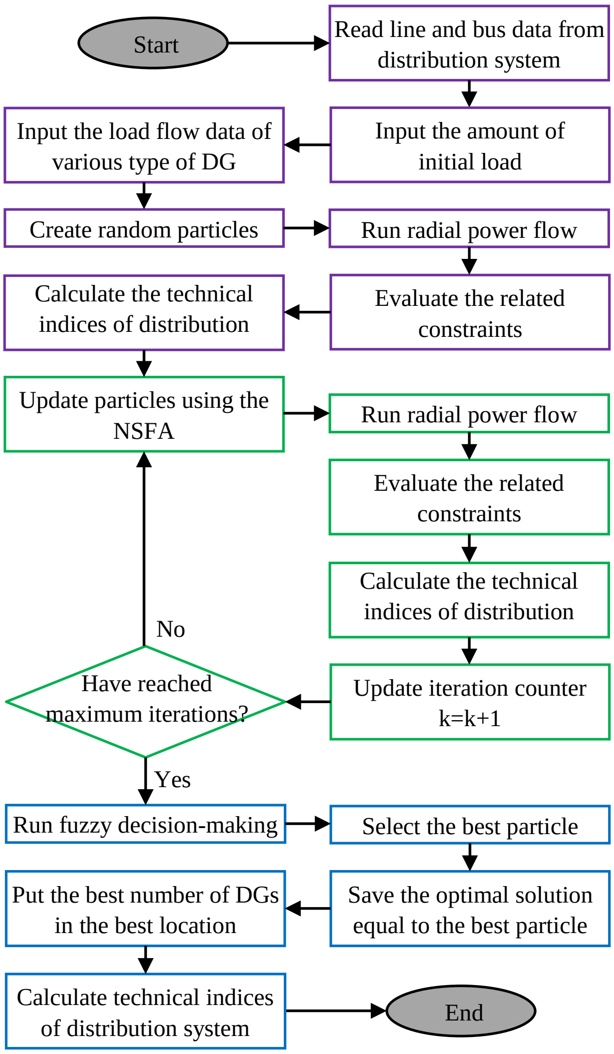

Fig. 4. Flowchart of the first step of optimization – finding the best location and size of multi-DG

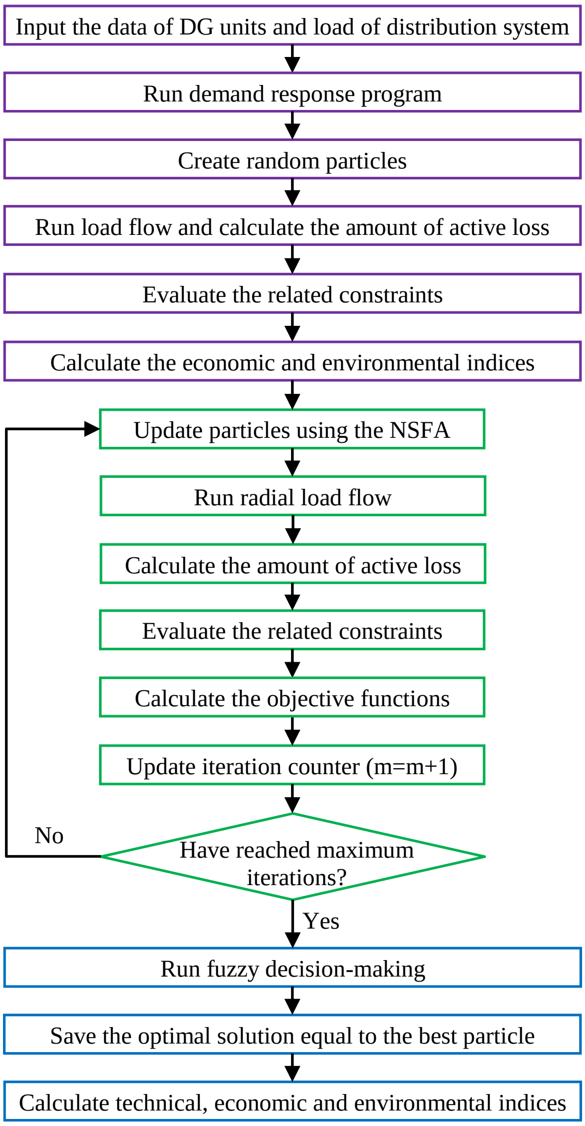

Fig. 5. Flowchart of the second step of optimization – finding the best schedule for DSM

It is assumed that 40 percent of consumers participate in demand response programs. It is assumed that DG units are available in the steps of 100 KW. Moreover, the minimum and maximum capacities of each type of DG units are 100 and 4000 KW, respectively. The hourly power of WT and PV (In Per-units) is shown in Fig. 7. The minimum and maximum charges of ESS are considered to be 10 and 100 percent of the ESS capacity, respectively, with a charge and discharge efficiency of 94%. The economic and environmental information of various units are presented in Table 1. Figure 8 shows the real-time market price of network.

Table 1. The economic and environmental information of sources

	Economic data		Pollution gases rate (Kg/Kwh)				
	Power cost ($/Kwh)	Start-up and shut-down cost ($)	CO_2	SO_2	NO_x	CO	PM_{10}
DIG	1.172	0.35	0.65	0.093	4.483	1.275	0.16
MT	0.914	1.92	0.72	0.002	0.091	0.247	0.018
FC	0.588	3.32	0.46	0.012	0.006	0.002	0
PV	5.168	0	0	0	0	0	0
WT	2.146	0	0	0	0	0	0
ESS	0.760	0	0.02	0	0.00001	0.0003	0.001
grid	-	0	0.85	2.14	9.723	6.043	0.87

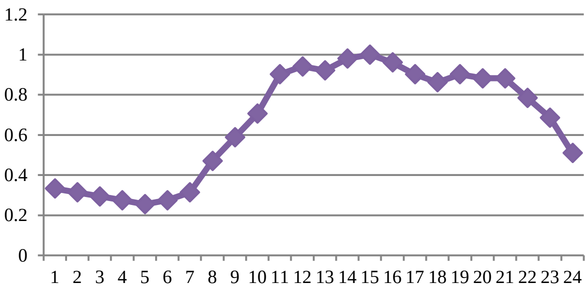

Fig. 6. Daily load curve of distribution network

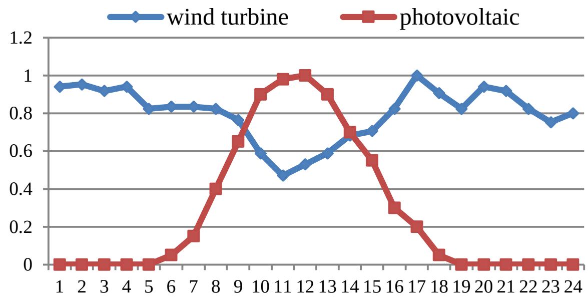

Fig. 7. The hourly power of WT and PV (Pu)

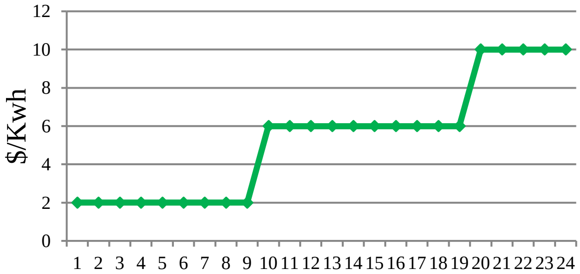

Fig. 8. The real-time market price

6.1. 33-bus standard distribution system

In this section, the proposed method is applied to IEEE 33-bus distribution system (Fig. 9). Firstly, the best location and total capacity of DG units are optimized by combination of NSFA and fuzzy decision-making method. Table 2 represents the optimal place and size of various types of DGs in the 33-bus distribution system. The amounts of technical indices before and after placement of devices are also given in Table 3.

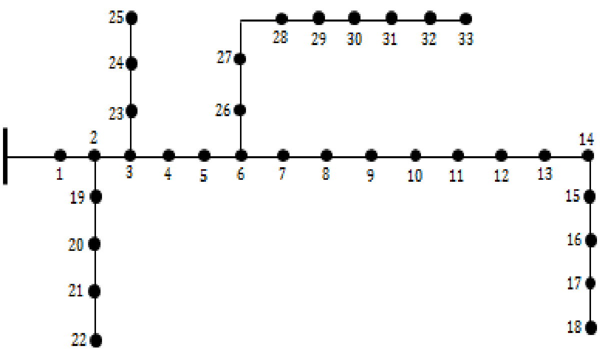

Fig. 9. The single diagram of 33-bus network

Table 2. The optimal location and size of DGs in the 33 bus-system

	Location (No. Bus)	Capacity (MW)
DIG	30	1.3
MT	25	0.6
FC	6	0.5
PV	15	0.6
WT	19	0.8

Table 3. The amounts of technical indices of 33-bus system

	Before placement	After placement
Active loss (MW)	0.2025	0.0248
Reactive loss (Mvar)	0.1351	0.0191
Voltage profile (Pu)	0.1169	0.0021

The initial results of simulation show that DG units improve the technical indices of standard network. The Active and reactive losses are reduced about 87.75 and 85.86 percent, respectively, after locating the various technologies of DG in the best location. Moreover, the amount of voltage profile is also improved about 98 percent. Therefore, the efficiency of 33-bus distribution system improves after using the DG units.

After finding the best location and size of considered resources, the combination of NSFA and fuzzing method is utilized to find the best schedule for DSM. For better evaluating the results, DSM is done with and without consideration of demand response program (TOU). The daily optimal powers of resources without consideration of TOU are presented in Table 4. The hourly amount of technical, economic and environmental indices of distribution system are given in Table 5.

According to Table 4, the nonrenewable DG units have an important role in power generation; the produced power of these technologies is about 66.79 percent of total provided energy. The 24.36 percent of load is produced by renewable DG units. Of course, WT has more influence than PV so that the produced power of WT is approximately twice higher than the produced power of PV in the DSM. Even though the grid provided the total demand of network before DSM, the provided power by the grid is about 2 percent of total demand after doing DSM in the distribution system. On the other words, located DG units can provide the load of system in the most times; therefore it can be said that the grid is the backup source after doing DSM. The considered indices are considerably improved after doing DSM in the distribution system. The loss and voltage indices are reduced about 69 and 78 percent, respectively. Moreover, the amounts of reduction of economic and environmental indices are also considerable. The operational cost of system is reduced about 499.59 million $ after applying DSM. The rate of pollution emission is also decreased about 86.15 percent than initial amount.

Now the demand response program is also considered in the DSM. The obtained produce power of different types of DG, ESS and grid in the DSM with consideration of TOU program are presented in Table 6. The variation of load of 33-bus system after applying the DR program is also shown in Fig. 10. According to this figure, it can be said that the difference between the minimum and maximum demand of system is considerably reduced by participating the customers in DR program. This reduction causes to improve the performance and efficiency of distribution system.

Table 4. The schedule of energy resources for DSM in the 33-bus distribution system without demand response

Hour	Power of resources (MW)						
	DIG	MT	FC	PV	WT	ESS	Grid
1	0.0000	0.5493	0.5000	0.0000	0.0000	0.1889	0.0000
2	0.0000	0.4045	0.4978	0.0000	0.0181	0.2450	0.0000
3	0.0000	0.4889	0.5000	0.0000	0.0000	0.1037	0.0000
4	0.0000	0.6000	0.5000	0.0000	0.0000	-0.0802	0.0000
5	0.0000	0.0198	0.5000	0.0000	0.0000	0.4271	0.0000
6	0.0020	0.6000	0.5000	0.0000	0.0000	-0.0822	0.0000
7	0.0000	0.1654	0.5000	0.0000	0.0000	0.5000	0.0000
8	0.0814	0.6000	0.5000	0.0000	0.6588	-0.0919	0.0000
9	0.0000	0.6000	0.5000	0.0000	0.5852	0.5000	0.0000
10	0.5633	0.6000	0.5000	0.5400	0.4706	-0.0515	0.0000
11	0.7956	0.6000	0.5000	0.5789	0.3765	0.5000	0.0000
12	1.3000	0.6000	0.5000	0.5900	0.4670	-0.0824	0.1220
13	0.9307	0.6000	0.5000	0.2100	0.7910	0.3620	0.0300
14	1.3000	0.6000	0.5000	0.3940	0.7570	0.0172	0.0740
15	1.2917	0.6000	0.5000	0.3300	0.5647	0.4285	0.0000
16	1.3000	0.6000	0.5000	0.1800	0.6588	-0.0216	0.3000
17	0.8646	0.6000	0.5000	0.1200	0.7959	0.4704	0.0000
18	1.3000	0.6000	0.5000	0.0300	0.7390	-0.0391	0.0750
19	0.7529	0.6000	0.5000	0.4550	0.7100	0.3230	0.0020
20	1.3000	0.6000	0.5000	0.0000	0.7530	0.1252	0.0000
21	1.1282	0.6000	0.5000	0.0000	0.7341	0.3159	0.0000
22	1.0215	0.6000	0.5000	0.0000	0.6544	0.1282	0.0095
23	0.5614	0.6000	0.5000	0.0000	0.6023	0.2859	0.0000
24	0.0000	0.6000	0.5000	0.0000	0.6386	0.1553	0.0000

Table 5. Hourly amount of technical, economic and environmental indices of 33-bus network without demand response

Hour	Without DSM					With DSM				
	AL (MW)	RL $(MVar)$	VP (Pu)	I_{OC} $(M\$)$	I_{PE} (Mg)	AL (MW)	RL $(MVar)$	VP (Pu)	I_{OC} $(M\$)$	I_{PE} (Mg)
1	0.0670	0.0446	0.0379	21.852	27.590	0.0384	0.0277	0.0211	2.9334	0.8895
2	0.0617	0.0411	0.0348	20.979	26.488	0.0238	0.0176	0.0125	2.7670	2.2350
3	0.0500	0.0333	0.0282	18.939	23.912	0.0277	0.0202	0.0142	2.4663	0.8896
4	0.0540	0.0360	0.0304	19.667	24.832	0.0300	0.0219	0.0158	2.5461	0.8956
5	0.0462	0.0308	0.0260	18.211	22.993	0.0185	0.0139	0.0088	2.3109	2.2647
6	0.0447	0.0298	0.0251	17.921	22.627	0.0244	0.0179	0.0124	2.0250	0.8975
7	0.0447	0.0298	0.0251	17.921	22.627	0.0212	0.0157	0.0103	2.2921	1.4532
8	0.0425	0.0283	0.0239	17.483	22.074	0.0231	0.0169	0.0116	1.9486	0.8820
9	0.0670	0.0446	0.0379	21.852	27.590	0.0182	0.0133	0.0048	4.2293	2.1574
10	0.1035	0.0689	0.0587	26.952	34.030	0.0372	0.0264	0.0122	5.5123	1.4616
11	0.0868	0.0578	0.0492	24.768	31.272	0.0130	0.0098	0.0030	4.4316	4.8156
12	0.1094	0.0729	0.0621	27.680	34.947	0.0360	0.0256	0.0106	5.7951	1.8868
13	0.1488	0.0992	0.0847	32.049	40.465	0.0189	0.0143	0.0016	6.2940	7.8406
14	0.1155	0.0769	0.0656	28.409	35.869	0.0319	0.0226	0.0127	5.2826	2.7716
15	0.1349	0.0899	0.0767	30.593	38.627	0.0183	0.0145	0.0031	4.7938	8.6584
16	0.1282	0.0855	0.0729	29.685	37.707	0.0293	0.0213	0.0152	4.5983	4.5457
17	0.1035	0.0689	0.0587	26.952	34.030	0.0173	0.0135	0.0066	3.9324	6.1463
18	0.1282	0.0855	0.0729	29.865	37.707	0.0328	0.0244	0.0185	4.0631	5.1059
19	0.1417	0.0945	0.0806	31.321	39.546	0.0213	0.0156	0.0046	6.3981	8.0198
20	0.0868	0.0578	0.0492	24.768	31.272	0.0423	0.0304	0.0242	3.3734	1.7221
21	0.0868	0.0578	0.0492	24.768	31.272	0.0196	0.0158	0.0041	3.0255	8.3831
22	0.0922	0.0614	0.0522	25.496	32.191	0.0347	0.0252	0.0201	3.3670	2.8345
23	0.0922	0.0614	0.0522	25.496	32.191	0.0179	0.0144	0.0063	3.1098	6.8818
24	0.1035	0.0689	0.0587	26.952	31.030	0.0285	0.0212	0.0161	3.4917	4.4275

Table 6. The schedule of energy resources for DSM in the 33-bus system with demand response

Hour	Power of sources (MW)						
	DIG	MT	FC	PV	WT	ESS	Grid
1	0.0000	0.5944	0.5000	0.0000	0.6785	0.4122	0.0000
2	0.2023	0.6000	0.5000	0.0000	0.7623	0.0333	0.0000
3	0.0000	0.6000	0.5000	0.0000	0.6616	0.1323	0.0000
4	0.0005	0.6000	0.5000	0.0000	0.6086	0.2576	0.0000
5	0.1498	0.6000	0.5000	0.0000	0.6588	-0.1178	0.0303
6	0.0000	0.6000	0.5000	0.0000	0.1921	0.5000	0.0000
7	0.0689	0.6000	0.5000	0.0000	0.6682	-0.0536	0.0086
8	0.0000	0.5857	0.5000	0.0000	0.1626	0.5000	0.0000
9	0.1911	0.6000	0.5000	0.3900	0.6118	-0.1077	0.0000
10	0.0847	0.6000	0.5000	0.5400	0.4706	0.5000	0.0000
11	0.5650	0.5578	0.5000	0.3400	0.6750	-0.178	0.0170
12	0.1400	0.6000	0.5000	0.6000	0.4235	0.5000	0.0045
13	0.9540	0.5599	0.5000	0.5890	0.6200	-0.0690	0.0510
14	0.2679	0.6000	0.5000	0.4200	0.5459	0.5000	0.0071
15	1.1669	0.6000	0.5000	0.2815	0.5647	-0.0538	0.0000
16	0.5477	0.6000	0.5000	0.1800	0.6588	0.5000	0.0000
17	0.7837	0.6000	0.5000	0.1200	0.8000	-0.1117	0.0033
18	0.6318	0.6000	0.5000	0.0300	0.7247	0.5000	0.0000
19	0.7180	0.5690	0.4170	0.5640	0.7550	-0.0830	0.1921
20	0.1238	0.6000	0.5000	0.0000	0.7530	0.5000	0.0000
21	1.1230	0.5288	0.5000	0.0000	0.7060	-0.3890	0.0080
22	0.2908	0.6000	0.5000	0.0000	0.6588	0.5000	0.0000
23	0.8981	0.6000	0.5000	0.0000	0.6023	-0.0519	0.0011
24	0.5302	0.6000	0.5000	0.0000	0.6400	0.4250	0.0000

Table 7. Hourly amount of technical, economic and environmental indices of 33-bus network with demand response

Hour	Without DSM					With DSM				
	AL (MW)	RL $(MVar)$	VP (Pu)	I_{OC} $(M\$)$	I_{PE} (Mg)	AL (MW)	RL $(MVar)$	VP (Pu)	I_{OC} $(M\$)$	I_{PE} (Mg)
1	0.0213	0.0142	0.0118	12.382	15.634	0.0116	0.0087	0.0041	1.0922	0.8360
2	0.0189	0.0126	0.0104	11.654	14.714	0.0094	0.0070	0.0038	1.0786	0.6800
3	0.0167	0.0111	0.0092	10.926	13.795	0.0089	0.0067	0.0028	0.9006	0.7690
4	0.0145	0.0097	0.0080	10.198	12.876	0.0096	0.0073	0.0020	0.7189	0.8850
5	0.0126	0.0084	0.0069	9.4700	11.956	0.0071	0.0051	0.0026	0.9698	0.2700
6	0.0145	0.0097	0.0080	10.198	12.876	0.0095	0.0073	0.0020	0.7185	0.8980
7	0.0189	0.0126	0.0104	11.654	14.714	0.0097	0.0070	0.0045	1.2155	0.4290
8	0.0425	0.0283	0.0239	17.483	22.074	0.0195	0.0145	0.0092	2.2104	1.4270
9	0.0670	0.0446	0.0379	21.852	27.590	0.0384	0.0276	0.0212	2.8686	0.8970
10	0.0977	0.0651	0.0554	26.224	33.111	0.0155	0.0116	0.0017	5.2243	4.6380
11	0.1635	0.1090	0.0931	33.509	42.309	0.0232	0.0170	0.0050	6.3446	6.1970
12	0.1789	0.1193	0.1020	34.966	44.148	0.0228	0.0176	0.0012	6.5344	11.085
13	0.1711	0.1141	0.0975	34.237	43.228	0.0288	0.0216	0.0130	5.3334	7.4730
14	0.1952	0.1302	0.1114	36.422	45.986	0.0248	0.0192	0.0049	6.2012	10.781
15	0.2036	0.1358	0.1162	37.150	46.906	0.0272	0.0210	0.0074	5.9334	9.5000
16	0.1870	0.1247	0.1066	35.694	45.067	0.0289	0.0226	0.0094	5.2768	13.333
17	0.1635	0.1090	0.0931	33.509	42.309	0.0324	0.0242	0.0165	4.9083	6.6560
18	0.1488	0.0992	0.0847	32.049	40.465	0.0284	0.0227	0.0087	4.1967	10.492
19	0.1635	0.1090	0.0931	33.509	42.309	0.0253	0.0185	0.0084	6.1185	5.9340
20	0.1561	0.1040	0.0889	32.781	41.389	0.0310	0.0247	0.0106	4.1747	9.5490
21	0.1561	0.1040	0.0889	32.781	41.389	0.0312	0.0244	0.0134	4.2265	8.4080
22	0.1218	0.0811	0.0692	29.137	36.788	0.0238	0.0188	0.0094	3.6604	7.8140
23	0.0922	0.0614	0.0522	25.496	32.191	0.0230	0.0174	0.0123	3.2332	4.6320
24	0.0500	0.0333	0.0282	18.939	23.912	0.0276	0.0202	0.0142	2.4523	0.8900

Table 7 represents the amount of technical, economic and environmental indices of 33-bus distribution system before and after applying the DSM and demand response program.

After simultaneously applying the DSM and demand response program, the influence of nonrenewable DGs on total load is 60.18 percent while the effect of renewable DG units increases about 7 percent than the DSM without considering of DR so that they provide 31.57 % of total demand of network.

According to Table 7, after applying the DSM by proposed method, the considered indices are considerably improved than initial situation. Moreover, the amounts of indices are lower than the DSM without considering of TOU program. The effect of demand response program on the performance of distribution system is clearly shown in Fig 11. According to this figure, it can be said that the technical, economic and environmental indices of 33-bus distribution system are approximately improved about 80 percent after applying the DSM, DG and DR program by proposed method.

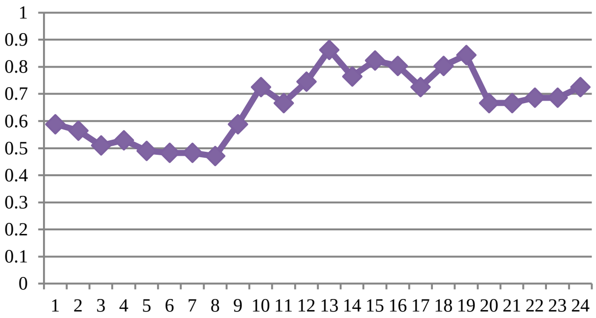

Fig. 10. Load demand after demand repsponse implementation

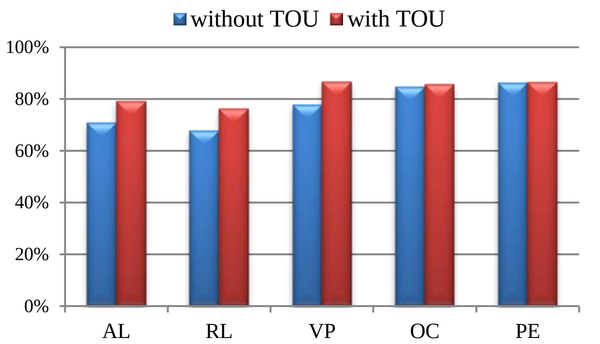

Fig. 11. The reduction amount of indices of 33-bus system after DSM

6.2. 101-bus actual distribution system

After testing the proposed algorithm on the standard system, it is applied to the 101-bus actual distribution system in Khoy-Iran for evaluating the ability of proposed method in the more reality conditions of operation. The single diagram of 101-bus actual system is shown in Fig 12. This network is the 20-KV distribution system that 205 customers consume about 21037-KW active and 12806-Kvar reactive power.

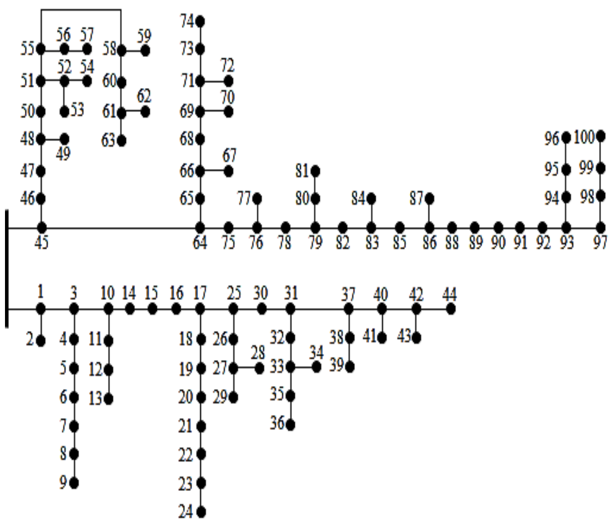

Fig. 12. The actual 101-bus distribution system in Khoy-Iran

Table 8. The location and size of DGs in the 101 bus-system

	Location (No. Bus)	Capacity (MW)
DIG	89	4
MT	44	4
FC	28	2.6
PV	61	4
WT	79	3

Table 9. The amounts of technical indices of 101-bus system

	Before placement	After placement
Active loss (MW)	0.4496	0.0941
Reactive loss (Mvar)	0.2635	0.0552
Voltage profile (Pu)	0.0470	0.0020

The optimal location and size of DG units are presented in Table 8. Table 9 shows the amount of loss and voltage indices before and after locating of DG units.

According to table 9, technical indices of actual system are improved considerably after operating of DG units so that the loss and voltage indices are decreased about 79 and 95 percent, respectively.

After finding the best location and capacity of DG units, the combination of NSFA and fuzzing method is used to find the best schedule for DSM in the actual distribution system. The daily optimal powers of different sources with and without demand response program are shown in Fig. 13.

Although the grid supplied total demand of actual network before DSM, after that, the injected power of grid into system is 7.46 and 18.13 percent of total demand with and without consideration of TOU program. Therefore the dependence of the system on the grid is reduced after applying the proposed method. The produced powers of non-renewable and renewable DGs are 62.35 and 18.12% of total demand after DSM, respectively, while these amounts are 69.69 and 22.34% of total demand after applying DSM with DR. on the other hands, the effect of ESS on the actual system is reduced about 50% after participating of customers in the TOU program; this means that the patterns of supply and demand are more similar after DR.

Table 10 represents the average amount of technical, economic and environmental indices of actual 101-bus distribution system in the different situation of operation.

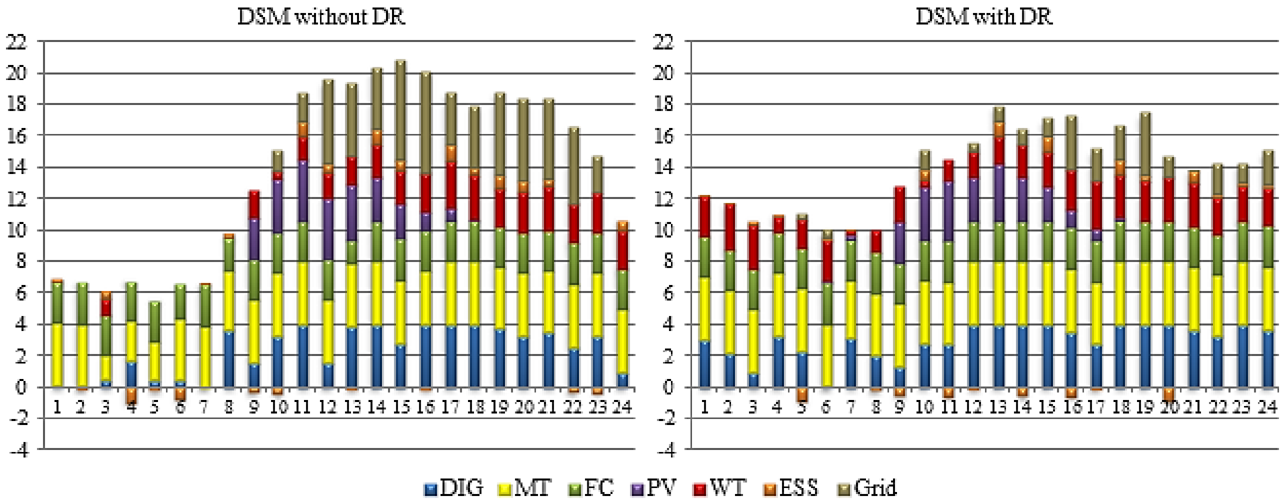

Fig. 13. The schedule of energy resources for DSM in the actual system with/without TOU program

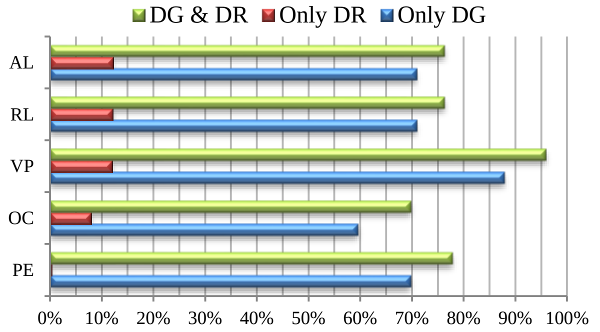

Fig. 14. The improvement of indices of actual system after DSM

Table 10. The average amount of indices of the actual system

		AL (MW)	RL $(MVar)$	VP (Pu)	I_{OC} $(M\$)$	I_{PE} (Mg)
	Initial	0.2397	0.1405	0.0250	84.967	174.29
DSM	Only DG	0.0695	0.0407	0.0030	34.338	52.653
	Only DR	0.2106	0.1234	0.0219	78.204	173.85
	DG & DR	0.0567	0.0332	0.0010	25.607	38.618

The considered indices are significantly improved after applying of DSM. The improvement of indices is clearly shown in Fig. 14. As shown in this figure, the DR program increases the efficiency of DG units; for example, the improvement of loss index is raised about 7 percent after applying TOU program to DSM.

Therefore, it can be said that the proposed method has the proper performance in the actual distribution system so that the efficiency of the network is increased considerably after applying DSM in the presence of multi DG and DR program.

7. CONCLUSIONS

Applying the DSM to the distribution system is the effective method to balance the dynamics of power supply and demand at the side of consumption. In this study, DSM was done in the distribution system with multi DG and DR program. The combination of NSFA and fuzzy decision-making method was utilized to optimize the technical, economic and environmental indices of distribution systems. Finally, the proposed method was tested on IEEE 33-bus and actual 101-bus networks.

The results show that the proposed method can properly optimize a schedule for DSM so that considered indices of distribution system are improved significantly after applying the DSM. The nonrenewable DG units provide the most part of the demand because the produced energy of them is stable and it depends on demand of system. Although the produced power of renewable DGs is about one-third of the total demand, the effect of them on environmental indices is considerably because the produced energy of them is clean and eco-friendly. Technical, economic and environmental indices are improved after utilizing the DSM; of course, this improvement is considerably with participation of customers in the demand response program. Totally, it can be said that the proposed method has the proper performance in improving the efficiency of distribution system.

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