Day-Ahead Demand Response in Microgrid Operation Considering Renewable Uncertainty and Network Reconfiguration

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Optimal energy management in microgrids will increase their economic and technical efficiency, and it is usually carried out as an optimization problem for day-ahead operation strategies. Although many perspectives have been proposed for optimal operation, with increasing energy demand and imbalance between production and consumption, the lack of coherent planning to reduce costs and environmental consequences is still felt. Therefore, creating a new framework to consider uncertainties and operation issues simultaneously is necessary to increase reliability. For this purpose, in this paper, a two-level energy management system is presented at the first level determines the role of the load response program, the unit Synchronization, the generator unit production rate, and the storage charge and discharge rate, then the network reconfiguration in the presence of renewable energy sources is considered with the aim of maximizing the network operating profit and minimizing environmental pollutants at the second level. Also, the output power of renewable energy sources, including solar and wind, with uncertainty and scenario generation, has been considered. The presented model has been tested as a combination of two software, MATLAB and DigiSilent, on a 33-bus IEEE network to make it more realistic and increase the accuracy of the simulation. The results show that the load response program, along with the network feeder rearrangement and the problem of bringing the units into orbit simultaneously, in addition to reducing losses by 20% and increasing reliability by 10%, results in profitability for the microgrid operator.

Keywords: *Demand response program, Wind energy, Uncertainty, Renewable energy sources, Reconfiguration.*

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Nomenclature

Indices	
t,t_{ch},t_d,h	Time, charging and discharging time, hour
S,N_s	Scenario
D,w,pv	Indices diesel, wind, photovoltaic
I,j,N_b	Index of the number of units and bus
DG	Index of DGs
br,N_b	Index of branch
d,ch	Index of discharge and charge
r_a	A positive constant which defines the neighborhood of a data point.
Variables	
$E_{old}^{s}(t)$, $E_{New}^{s}(t)$	Amount of unsupplied energy before and after optimization in megawatts in the sth scenario
Em,B_D	Minimum environmental pollutant, Maximum profit Disco
$E_{h,k,h,s},E_k$	The amount of energy stored in the battery unit
I_{br}, $I_{br}^{\max}$	Current of each branch, maximum current of each branch
$I_i(t)$	On or off being unit i at time t
I_h	Binary variable to drive the generator
$Idr_{h,s}$	The amount of load transferred in the load response program at level h
$T_{i,off}$, $T_{i,Down}$, $T_{i,cold}$	Shutdown time of unit i, minimum shutdown time and cold start time at time t
T_{ij}, T_{ji}	transmission power
$F_i(P_{D,t}(t))$	Unit fuel cost i at time t
$P_{L,old}^{s}(t)$, $P_{L,New}^{s}(t)$	Amount of wasted active power before and after optimization in megawatts in the same scenario

$P_{Pv}^{s}(t)$ $P_{W}^{s}(t)$ $P_{D}^{s}(t)$	The production power of wind, sun and diesel in the scenario
$P_{ch}^{s}(t_{ch})$ $P_{d}^{s}(t_{d})$	Charging and discharging capacity of the storage device
P_{DG} $P_{DG}^{\min}$ $P_{DG}^{\max}$	Minimum and maximum output power of distributed generation sources
$P_{EXT}^{s}(t)$ $P_{L}(t)$ $P_{D,i}(t)$	Power received from the network, load per hour, diesel power
$P_{k,h,s}^{ch}$ $P_{k,h}^{ch,\max}$	Charging power and maximum charging power of the storage device
$P_{k,h,s}^{d}$ $P_{k,h}^{d,\max}$	Discharge power and maximum discharge power of the storage device
$P_{i,h}^{DR}$ $P_{i,h}^{D}$	Consumption load after running DR at time h, Initial charge at time h
P_j , P_i	Active demand load
RS_D RS_{pv} RS_W	Sales rate of wind, solar and diesel energy
V_{min} V_{max} $V_{j,s}$	Minimum and maximum bus voltage
π_s^{pv} , π_s^{w} , π_s^{T}	Wind, photovoltaic, and total scenario
$L_p(t)$, $L_p(t_d)$, $L_p(t_{ch})$, $L(t)$	Electricity price in dollars per MWh, electricity price at discharge and charge, consumer load in MWh
α_{ENS} , α_L , α_d , $\alpha_{E,s}$	Price coefficients in order of increasing reliability, reducing losses, battery discharge, and selling electricity to customers
$DR_{h,s}$, $DR_h^{\min}$, $DR_h^{\max}$	The coefficient of customer participation in the load response program
a_i , b_i , c_i	Unit cost coefficients i
$S_{i,h}$, $S_{i,c}$, S_i	The cost of setting up i at time t, Hot and cold setup cost
$b_{k,h}^{d}$, $b_{k,h,s}^{d}$, $b_{k,h}^{ch}$, $b_{k,h,s}^{ch}$	Storage binary variable
λ_i , η_i , q_{ij}	Binary variable
H_D , H_G	Diesel pollution and the upstream network
M	large amount

1. Introduction

Due to the increase in sensitive loads and the need to increase the reliability of distribution networks, as well as environmental pollution, much attention has been paid to microgrids as a reliable and clean source. Current distribution networks must undergo many changes in various technical, economic, and environmental aspects to meet society's needs and keep up with the growth of other industries. Therefore, microgrids have received special attention as an appropriate response to these requirements. On the other hand, using renewable resources in microgrids and applying various load response programs increases the uncertainty in the operating parameters of these networks. Therefore, the probabilistic nature of its elements should be considered in the operation of microgrids to show a more realistic view. Optimal management of energy resources in microgrids reduces the total cost of operation and reduces exhaust gases from power plants and the impact of environmental pollution. Therefore, in studies and planning of unit production, the amount of ecological pollution emissions should also be considered in addition to the operator's profitability. Also, uncertainty in the output of distributed generation resources is another planning challenge and has affected energy management in microgrids. [1,2,3].

On the other hand, implementing optimal energy management in microgrids has become significantly important due to the increase in daily power demand, the increase in the cost of operating microgrids, and environmental issues [2]. Load response programs also have a great impact on the power system, including reducing peak loads, improving reliability, and providing a useful way to balance it [4]. Usually, the best solution to balance electricity supply and demand is to use a load response program, as it is cheap, environmentally friendly, and does not require new grid investments [5]. The key performance indicators of energy management systems in microgrids that can be improved include active power losses, voltage stability, and environmental pollutants emissions. Optimal energy management of microgrids involves economic dispatch (ED), unit commitment (UC), demand-side management (DSM), and distribution feeder reconfiguration (DFR) [6]. Reconfiguring feeders in the network also adjusts the status of line switches to influence the power flow in the distribution network and further improve operational criteria [7,9]. During network incidents and islanding, loads are supplied from the available resources in each section. However, due to the shortage of power supply, there is no other suitable way to continue power supply and operators are forced to use load shedding. Line arrangement can improve power system performance by reducing load shedding while maintaining the network's radial structure [8].

The dropouts have strong self-healing capabilities and can maintain their stable performance by exchanging excess energy with other connected microgrids. They also provide their own generation capability to ensure system reliability and prevent load shedding [10,11]. One of the main objectives of the distribution system operator (DSO) is to maximize system reliability and minimize operating costs. The cost of electricity is directly related to the reliability of the distribution system. Various strategies can be employed to improve the reliability of distribution networks, such as energy resource planning [12,13], network reconfiguration, optimal planning of storage systems, and demand response. The main strategy for the network operator is to reduce active losses and increase reliability using available options [14].

In [7], a multi-objective optimization problem is formulated for optimal energy management and network reconfiguration to minimize active power losses, annual operating costs, and greenhouse gas emissions, considering the forecasted wind speed, solar irradiance, and electrical load demand. In [15], by using a neural network and genetic algorithm, it predicts the power of the photovoltaic system, and then based on it, it uses the storage to exploit the distribution network. In [16], an optimization method based on the Artificial Ecosystem (AEO) algorithm is considered to find the answer to the network reconfiguration (NR) problem to reduce energy losses. In [17], with short-term operational planning in a model based on demand response, microgrid operation based on renewable energy has been established by considering technical, economic, and practical issues. In [18], by defining and comparing, it examines the application of dynamic and dynamic reconfiguration and divides them into five groups: classical, heuristic, meta-heuristic, hybrid, and based on machine learning. In [19], optimize energy management and structural configuration of microgrids to reduce operational and capital costs, energy waste, and pollution. Various tools have been considered to achieve these goals.

In [20], according to the objectives of reliability, operation, and economy of the distribution system, the simultaneous planning of distributed generation and distribution is presented. The objective of the objective function is to minimize the overall costs of construction, maintenance, and operation of resources and distribution automation devices, as well as the cost of voltage deviation. And unsupplied energy is expected. In [21], the services that can be provided by hydrogen refueling and electric vehicle charging stations are investigated in the optimal performance of microgrids, which includes a two-stage stochastic model for resource scheduling in microgrids, especially hydrogen refueling stations and electric vehicle charging, and the main goal is to minimize Cost reduction and greenhouse gas emissions are considered. In [22] it focuses on flexible energy management of grid-connected microgrids to analyze the effects of flexibility options such as demand response electric vehicles, battery storage systems, and hydrogen storage systems. The grid-connected optimal performance is modeled as a mixed integer linear programming problem considering the uncertainties of wind turbines and photovoltaic resources. In [23], develops a two-level model that integrates renewable energy sources, energy storage systems, electric vehicles, and demand-side management with dynamic reconfiguration to increase utilization efficiency. In [24], it discusses the simultaneous management of active and reactive power of the virtual power plant based on renewable energy, which is placed in the distribution system, based on the security, economic, operational, and voltage objectives of the distribution system operator. In [25], at the first level, it is evaluated for information configuration based on minimizing losses, and at the next level, an optimization model is created to increase the economy and stability of the distribution network. In [26], uncertainty is managed using energy storage systems to reduce microgrid costs. Meanwhile, the optimal capacity of the energy storage system is determined based on the energy balance limit and the scenario of renewable resources. In [27], a day-ahead planning model for acceptable scaling up and operation of a microgrid is designed. This model deals with a combination of issues, consumption patterns, and resources to reduce costs and losses. In [28], reconfiguration in the distribution network is emphasized by considering technical objectives such as losses, voltage stability, and load demand and improving planning and operation. In [29], two meta-heuristic algorithms of Plant Growth Simulation (PGS) and Particle Swarming (PSO) have been used to reconfigure the distribution network and use the generator to reduce losses in different load conditions. In [30], the optimal management of microgrid performance is focused on reducing costs and environmental pollution while also considering the uncertainty in energy production and consumption. It also improves the performance of microgrids by optimizing energy distribution, reducing pollutant emissions, and reducing costs, and offers a promising approach to sustainable energy management. In [31], economic dispatch optimization is mentioned, which involves prioritizing available power generation units to reduce operating costs while considering environmental constraints. In [32], a framework for energy management in the retail market is presented. It focuses on energy zones, i.e., local locations where energy producers and consumers interact. In [33], a fault-tolerant energy management system for microgrids is presented. In [34], a reinforcement learning-based energy management system for storage is proposed using a Markov decision-making method to optimize battery charging and discharging decisions in a grid-connected DC microgrid with solar panels, wind turbines, and microturbines. In [35], an optimal peak-suppression strategy for dynamic demand response using PV and energy storage is presented. In [36], the study deals with the techno-economic, environmental, and risk analysis of electricity and district heating distribution networks equipped with flexible energy sources. It emphasizes establishing an integrated energy management structure to optimize electricity and heat loads. In [37], a method for assessing the network riskiness of promoting microgrid resilience is presented. In [38], an advanced retail electricity market for distribution systems and coordination of household microgrids is presented that uses game theory to optimize market operations.

Table 1. A comparative summary of this study and previous publications

Ref		Micro grid	Bi level	Day ahead	Der	Renewable		UC	Rec	En	storage	Uncer-tainty
						PV	WT					
[7]	2018					✓	✓		✓	✓		✓
[15]	2024					✓					✓	✓
[16]	2021								✓			
[17]	2023	✓			✓	✓	✓		✓		✓	
[19]	2024	✓		✓		✓	✓		✓	✓	✓	
[20]	2024	✓						✓				
[21]	2024	✓	✓			✓	✓				✓	✓
[22]	2024	✓			✓	✓	✓			✓		✓
[23]	2024		✓		✓	✓	✓		✓	✓	✓	✓
[24]	2024					✓	✓	✓				✓
[25]	2024		✓			✓	✓		✓			✓
[26]	2024	✓				✓	✓	✓			✓	✓
[27]	2024	✓	✓	✓		✓	✓				✓	✓
[28]	2024					✓			✓			✓
[29]	2024	✓	✓						✓			
[30]	2025	✓				✓	✓			✓	✓	✓
[31]	2023	✓	✓					✓		✓		
[32]	2016	✓				✓	✓				✓	✓
[33]	2024	✓	✓			✓	✓				✓	✓
[34]	2024	✓	✓			✓	✓				✓	✓
[35]	2024	✓	✓	✓	✓	✓					✓	✓
This paper	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓

In reviewing the references, managing the production and supply of consumer loads is considered an important issue. However, given that each reference looks at the issues from different, limited, and individual aspects, although the examination of each is evident, the analysis of the impact of methods and issues on each other is lost. This prevents a more realistic state of planning. In most previous works, advanced planning has not been considered. Also, load response tools and their impact can be examined more comprehensively. On the one hand, with the development of networks and the increasing needs of consumers, environmental restrictions to prevent increased pollution are considered a limiting and vital issue that requires further analysis and examination of its effect on operating conditions. On the other hand, the set of these issues creates a challenge for the issue of bringing units into orbit and economic planning to reduce costs. In this regard, the following issues have been considered in this article:

1) Optimal planning for the exploitation of the distribution network on a day-ahead scale, the use of renewable resources, and the uncertainty of their production through scenario creation are considered.

2) Adding a load response program, using a storage generator, examining charging and discharging issues, bringing the generator into the circuit, and using the network rearrangement capacity to feed the loads faster, which is added to the previous case, optimizes their planning.

3) Examining environmental constraints in different scenarios dependent on UC issues and the previous cases will also affect it.

4) Considering voltage stability and reliability compared to before and after the optimization mode

Finally, the results obtained from the model based on the scenarios created on the parameters, considering the operating conditions, are compared and analyzed. For this purpose, the proposed model is implemented on the IEEE 33-bus test system. The structure of this study is organized as follows. After the introduction, in Section 2, the formulation and description of the model are presented. In Section 3, a case study is introduced to illustrate the application of the proposed model. Finally, the conclusion is given in Section 4.

In the Table 1, Der is load response, UC is unit commitment, Rec is reconfiguration, and En is environmental pollution.

2. Problem formulation

In the modeling of this paper, two important issues in power systems are considered: the profit from operation and the reduction of environmental pollutants, which have recently received much attention. To improve these two issues, demand response, reconfiguration, and dispatching of diesel generator units have been used. Therefore, it is necessary to consider optimal operation. This operation is related to the shiftable load resulting from the demand response program, reconfiguration in the 33-bus distribution network, and the profit resulting from the reduction of active power losses and unsupplied energy in a 24-hour study period.

The formulas presented in the modeling are such that the distribution system operator (DSO) incurs costs and generates revenue. These include:

1) DSO costs: purchasing power from distributed generation sources (photovoltaic, wind turbine, battery charging), purchasing power from the upstream network.

2) DSO revenue: profit from increasing reliability (reducing unsupplied energy (ENS) and also profit from reducing active power losses in the network, selling electrical energy to end-users or consumers, and selling electrical energy from battery discharge during peak load periods.

Table 2. Considered coefficients for energy price

Energy coefficients	Amount	Symbol
Increased reliability	5	α_{ENS}
Reduce casualties	2.5	α_L
Battery discharge	2.5	α_d
Selling electricity to subscribers	1.5	$\alpha_{E.s}$

2.1 The objective function

The optimal planning of the network operator is based on two objectives, which include the maximization of Disco's profit and the reduction of environmental pollution.

2.1.1 Profit from the network operator

The goal of the network operator's performance in the framework of short-term planning is to maximize the benefits of the network for one day, which provides the benefit of one night of Disco according to the following equation.

The operator of the distribution network will increase the reliability and reduce the active power losses with the work done in the network. Reducing losses and reducing lost energy in the network will lead to the sale of power to the consumer and will also stabilize the voltage in the network. This work is profitable for the operator of the distribution network, which is modeled with a factor in the energy price as a parameter α. This coefficient is shown in Table 2.

$$\begin{aligned}B_D = &\sum_{s=1}^{9}\sum_{t=1}^{24}(((E_{old}^{s}(t) - E_{New}^{s}(t)).\alpha_{ENS} \\ &+ (P_{L,old}^{s}(t) - P_{L,New}^{s}(t)).\alpha_L.1000 - P_{EXT}^{s}(t)) \times L_p(t)) \\ &+ \sum_{t=1}^{24}(L(t) \times (\alpha_{E,s}.L_p(t)) + \sum_{s=1}^{9}\sum_{t_d=1}^{n}(P_d^s(t_d) \times (\alpha_d.L_p(t_d)) \\ &- \sum_{s=1}^{9}\sum_{t=1}^{24}(P_{Pv}^{s}(t).RS_{pv} + P_W^s(t).RS_W + I_h.P_D^s(t).RS_D) \\ &- \sum_{s=1}^{9}\sum_{t_{ch}=1}^{24}(P_{ch}^{s}(t_{ch}).L_p(t_{ch}))\end{aligned} \tag{1}$$

In other cases, including the cost of purchasing electricity from distributed generation sources, the cost of purchasing electricity from the storage system during charging, and purchasing electricity from the upstream network are considered equal to one.

2.1.2 Minimizing environmental pollutants

Environmental restrictions refer to the reduction of pollution in the studied network. This means that the power values of the diesel generator and the upstream network are directly related to environmental pollution and should be reduced. Therefore, if the pollution is modelled in the objective function, the power produced by the diesel generator and the power taken from the upstream network is determined by the algorithm in such a way that the pollution in the network is minimized and at the same time, due to the low fuel cost of the fuels Fossil also generates profitability for the grid operator, and a balance is achieved between minimal environmental pollution and maximum grid profitability.

The parameters related to diesel generator emissions and the upstream network are listed in references [42] and [43], respectively.

$$Em = \sum_{s=1}^{9}\sum_{t=1}^{24}((P_D^s(t)) \times (H_D + (P_{EXT}^S(t)) \times (H_G)) \tag{2}$$

By merging two objective functions in one expression according to equation (2), the final objective function has been obtained, which is obtained by minimizing OF, the minimum environmental pollutant, and the maximum benefit of Disco (minimum operating cost).

$$OF = -B_D + Em \tag{3}$$

2.2 Constraints of the optimization problem

Modelling the problem is subject to a set of restrictions, which are:

2.2.1 Power balance

DG sources include wind and solar renewable sources, batteries that have two charge and discharge modes, and diesel generators [44].

$$P_L(t) = P_{DG}(t) + P_{EXT}(t) \tag{4}$$

2.2.2 The range of bus voltage changes

The voltage range is introduced in (5) [41].

$$V_{\min} \le V_{j,s} \le V_{\max} \quad j = 1,\dots N_b \\ s = 1,\dots, N_S \tag{5}$$

2.2.3 Active power range of each distributed generation source

The DG power range is introduced in (6) [41].

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \tag{6}$$

2.2.4 The maximum range of current passing through network lines

The final flow range is introduced in (7) [41].

$$\left|I_{br}\right| \le I_{br}^{\max}, br = 1,\dots, N_{br} \tag{7}$$

Where $|I|_{br}$ ‘$|I|_{br}^{max}$ and N_{br} respectively show the amount of current of each branch, the maximum passing current of each branch, and the number of all lines of the studied network.

2.2.5 Profitability for the network operator

One of the limitations in simulating the problem is the profit obtained during the day and night for the network, which is considered greater than or equal to zero [36].

$$B_D \ge 0 \tag{8}$$

2.2.6 Radial condition of network

The constraint of the radially of the network to perform the rearrangement is modelled as follows [44]:

$$\sum_{(i,j)\in\Omega_b} q_{ij} = N_b - \sum_{j\in\Omega_b} \lambda_i \tag{9}$$

$$\forall (i,j)\in\Omega_b, l\in\Omega_L, \{q_{ij}, \lambda_i, \eta_i\}\in\{0,1\}$$

$$\sum_{j\in\Omega_L} T_{ij} = -P_j \tag{10}$$

$$T_{ij} = -T_{ji} \tag{11}$$

$$-M.q_{ij} \le T_{ij} \le M.q_{ij} \tag{12}$$

$$-M(\lambda_i.\eta_i)+1 \le P_i \le M(\lambda_i.\eta_i)+1 \tag{13}$$

2.2.7 Storage system limitations

Eqns (14)-(18) express the limitations of the storage system [39].

$$0 \le P_{k,h,s}^{ch} \le b_{k,h}^{ch} P_{k,h}^{ch,\max} \tag{14}$$

$$0 \le P_{k,h,s}^{d} \le b_{k,h}^{d} P_{k,h}^{d,\max} \tag{15}$$

$$E_k^{\min} \le E_{k,h,s} \le E_k^{\max} \tag{16}$$

$$b_{k,h,s}^{ch} + b_{k,h,s}^{d} = 1 \tag{17}$$

$$\{b_{k,h,s}^{ch}, b_{k,h,s}^{d}\}\in\{0,1\}$$

$$E_{k,h+1,s} = E_{k,h,s} \tag{18}$$

2.2.8 Demand response constraints

Distribution companies (Disco) implement demand responsiveness (DR) to shift the load of their consumers from high-cost periods to low-cost periods to reduce their costs. It is assumed that customers participate in TOU programs and have limited ability to change their demand [42,43].

$$P_{i,h}^{DR} = P_{i,h}^{D} + Idr_{h,s} \tag{19}$$

$$Idr_{h,s} = P_{i,h}^{D} \times DR_{h,s} \tag{20}$$

$$P_{i,h}^{D} \times DR_h^{\min} \le Idr_{h,s} \le P_{i,h}^{D} \times DR_h^{\max} \tag{21}$$

$$\sum_{h=1}^{24} Idr_{h,s} = 0 \tag{22}$$

$$DR_h^{\min} \le DR_{h,s} \le DR_h^{\max} \tag{23}$$

2.2.9 Restrictions on bringing the diesel generator unit into operation

The modeling of the diesel generator unit is done as follows [44]:

$$\sum_{i=1}^{N}\sum_{t=1}^{24}[I_i(t)F_i(P_{D,i}(t)) + S_i(t)(1-I_i(t-1)I_i(t))] \tag{24}$$

$$F_i(P_{D,i}(t)) = a_i + b_i P_{D,i}(t) + c_i P_{D,i}(t)^2 \tag{25}$$

a_i ‘ b_i and C_i are the cost coefficients of unit i. $S_i(t)$ is the cost of setting up i at time t [42]:

$$S_i(t) = \begin{cases} S_{i,h} \text{ if } T_{i,off}(t) \le T_{i,Down} + T_{i,cold} \\ S_{i,c} \text{ if } T_{i,off}(t) \ge T_{i,Down} + T_{i,cold} \end{cases} \tag{26}$$

$T_{i.off}(t)$shutdown time of unit i, $T_{i.Down}$ and $T_{i.cold}$ respectively, the minimum shutdown time and cold start-up time at time t, and S_{hi} and S_{Ci} respectively, startup cost It is hot and cold.

Table 3. Probability of each scenario

Wind	possibility	Sun	Possibility
Scenario1	0.2	Scenario1	0.15
Scenario2	0.6	Scenario2	0.7
Scenario3	0.2	Scenario3	0.15

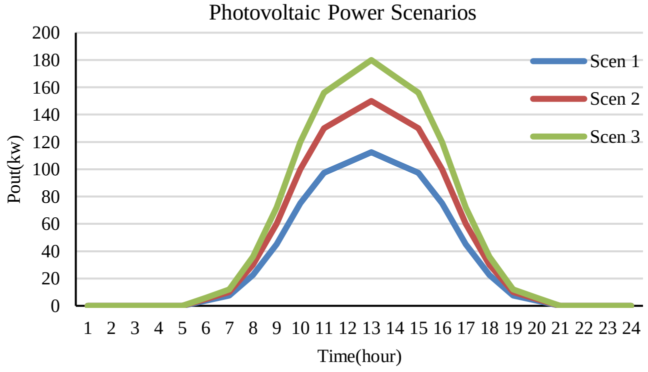

Fig.1. Scenarios related to photovoltaic production power

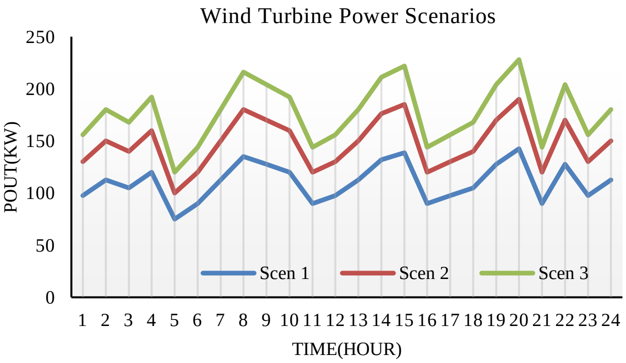

Fig.2. Scenarios related to wind production power

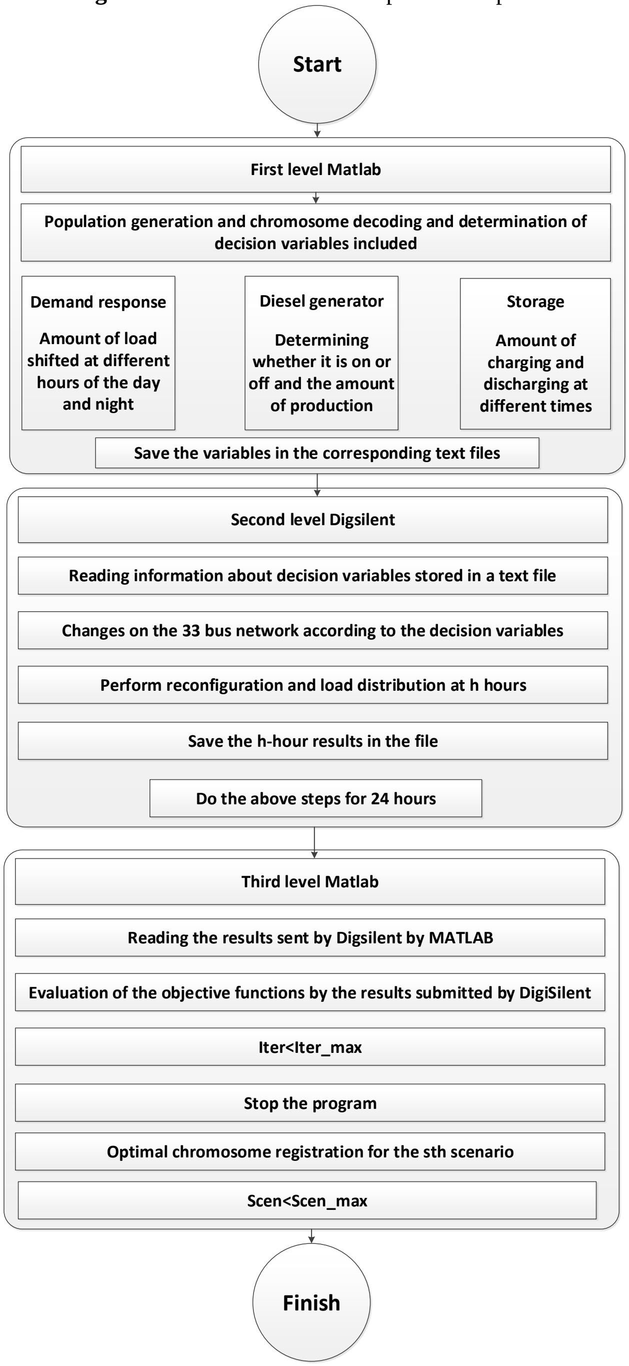

Fig.3. Flowchart of the optimization process

2.3. Uncertainty of renewable resources

Wind and sun have a random nature, and there is inherent uncertainty in them. To model this uncertainty, three separate scenarios are considered for wind and solar, and the probability of each of these scenarios is considered. Figs 1 and 2 show the scenarios related to wind and solar production, respectively. The points of each scenario are part of the points of the normal and Weibull probability distribution functions, respectively.

It should be noted that each of these scenarios represents the uncertainty of renewable resources in the distribution network. Table 3 shows the probability of each scenario. According to the scenario tree method [39], we will have 9 scenarios for the uncertainty of renewable resources.

$$\pi_s^T = \pi_s^{pv} \times \pi_s^w \tag{27}$$

The final modeling of the network optimization process using MATLAB and DigSilent software is shown in the flowchart of Fig 3. The initial information, along with the decision variables, including the load response method, diesel generator parameters, and storage, are implemented in the MATLAB software environment. Then, at the next level, the information processed by the DIGSILENT software is applied to the network, load distribution and rearrangement are applied to it, and finally, the results are transferred back to the MATLAB environment.

3. Simulation results

In Fig 4, a single-line diagram of the 33-basis network and the installation location of distributed generation sources is drawn. Scattered production sources are wind turbines, photovoltaics, diesel generators, and storage systems (batteries), among which only solar cell and wind turbine sources have uncertainty. Each of the sources with uncertainty has three separate outputs, which are converted into 9 scenarios in total by the scenario tree method. The load factor of the 33-base network and the price of electric energy in the network in terms of dollars per megawatt are shown in Figs 5 and 6, respectively. The amount of active load in the standard network of 33 buses is equal to 3270 kilowatts, which is multiplied by the load coefficients every hour of the day and night.

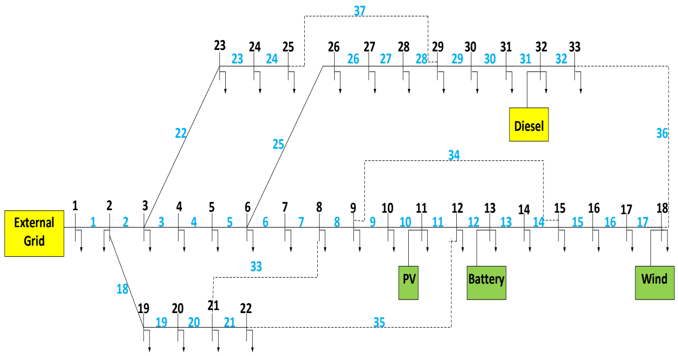

Fig.4. The single-line diagram of the 33-base network

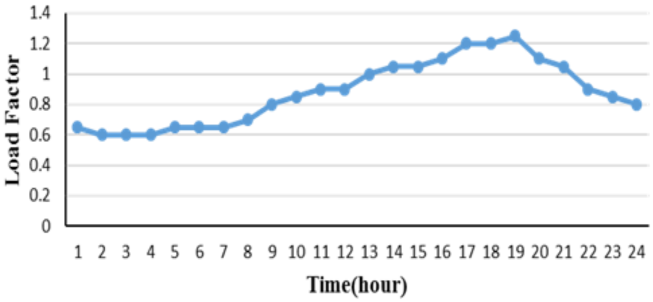

Fig.5. Network load coefficients [42]

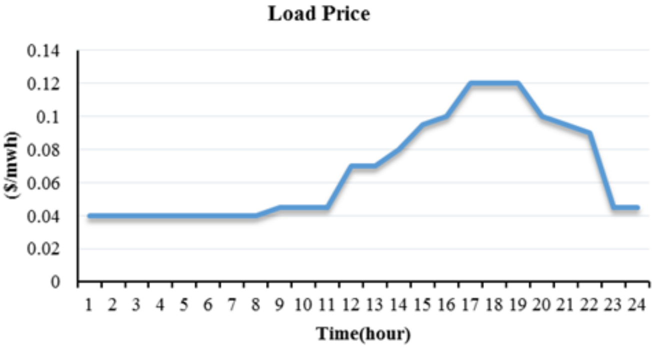

Fig.6. Price of electric energy [45]

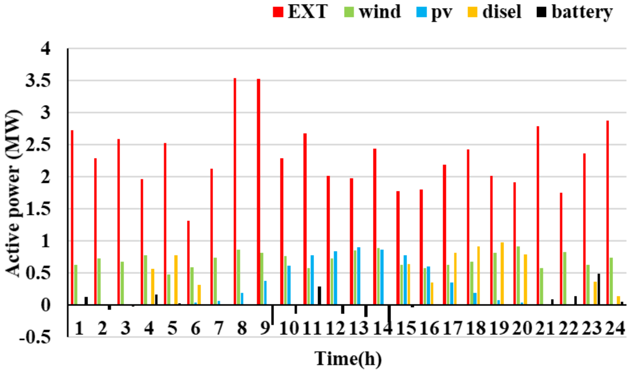

Fig.7. Diagram of production capacity of the upstream network and scattered production sources in 9 scenarios

From the point of view of the network operator, the problem is solved by taking into account the uncertainty of the amount of photovoltaic and wind turbine production power and performing its optimal planning according to the load response and network rearrangement, as well as the issue of bringing the diesel generator into operation. In the following, the results obtained for the ninth scenario, which has a higher probability of occurrence than other scenarios, will be discussed, and then, for review, the results of the nine scenarios will be compared with the state before optimization. It should be noted that in the pre-optimization mode (Before Opt), there is only a wind turbine, photovoltaic, and upstream network, and a diesel generator and battery are not used in the network, and no optimization has been done. In the post-opt mode (after-opt), wind and photovoltaic turbines according to the output power in 9 scenarios, upstream network, diesel generator, and storage system according to modeling and optimization with the help of load response, rearrangement, and putting the diesel generator into operation.

The planning of the network operator for a scenario with the production power of photovoltaic and wind turbines is such that the following variables are determined for the next day and night. These variables are:

1) On and off of the diesel generator and the amount of power produced by the diesel generator every hour of the day and night

2) The cost of bringing the diesel generator into operation

3) Charge and discharge rate of the storage system every hour of the day and night

4) Shift ability of loads

5) Sectionals that are opened every hour for rearrangement.

Fig 7 shows the results of the optimal planning of the upstream network and distributed production resources for 9 scenarios. As can be seen, a major part of the network load is provided by the upstream network, and the other part is provided by the optimal planning of distributed production resources. According to the limitations considered for its performance, i.e., the environmental pollutant limit and the UC problem, the diesel generator is on when it is switched off and on, as shown in Fig 7, in the early hours of the day and peak consumption time, and when the photovoltaic and wind turbines are at their maximum efficiency, that is, they are off in the middle of the day.

According to the expected performance of the storage system in the early and late hours of the day, they are discharged (positive power) and charged in the middle of the day despite the maximum output power of photovoltaic and wind turbines. Therefore, the optimal planning of the network is in such a way that the maximum production power of renewable resources that cannot be dispatched is used, and for the storage system, during the peak production power of photovoltaic and wind turbines, it is in charge mode, and at the time of peak consumption, it is in discharge mode. Due to the controllability of the output power of the diesel generator, the UC problem, and also considering the minimum emission of environmental pollutants as one of the objective functions, the diesel generator has been used only in the hours of power shortage of renewable resources, and the peak consumption areas of the load support.

According to the assumptions of optimization, the loads in the network can respond to the load, so that due to the high price of electric energy during the peak load, the subscribers can shift part of the loads during the day and night hours so that the total shift loads are given to be zero during the day and night.

According to Fig 8, the optimal planning of load response can be seen. According to the figure, the consumption load has decreased during its peak time and has been shifted to the early hours of the day, which will have a significant impact on reducing active power losses. It also improves and increases the reliability of the network due to the reduction of unsupplied energy. As seen in Fig 7, during peak consumption, the planning of scattered productions is associated with the maximum output power of the diesel generator, which by responding to the load and shifting the peak load to different areas, reduces the performance of the diesel generator at the time of peak load and reduces the resulting environmental pollution. It will be considered a significant impact on the optimal planning of the network.

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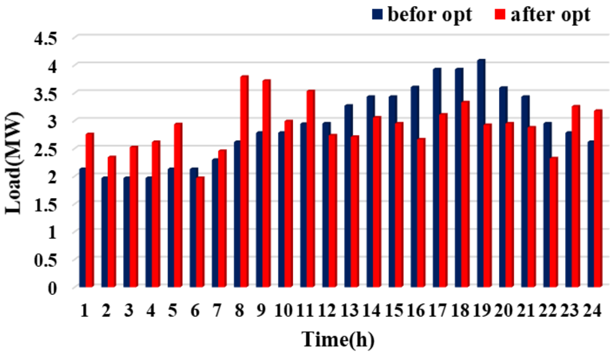

Fig.8. Demand response (load shift) in 9 scenarios

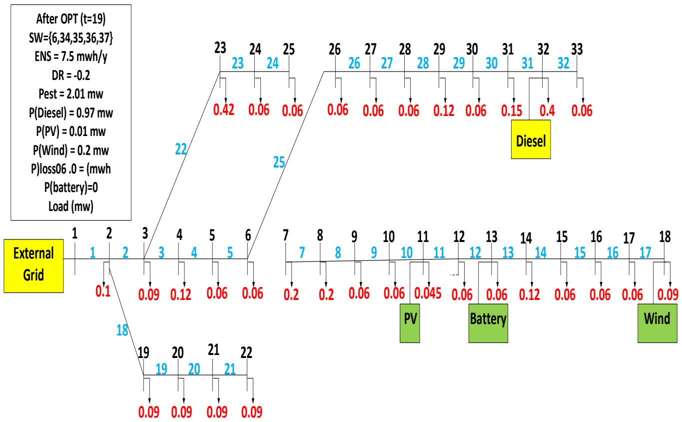

Fig.9. The single-line diagram of the 33-base network after optimization in 9 scenarios at 7:00 pm

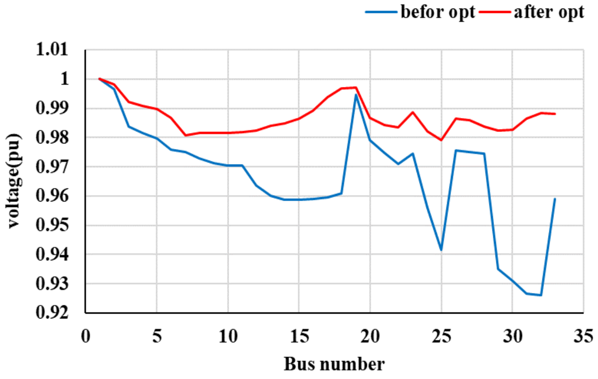

Fig.10. Bus voltage before and after optimization of 9 scenarios at 19:00

Another task that is considered for network utilization is to rearrange the network every hour of the day and night. In this method, it is important to pay attention to the fact that the additional lines that take the network out of the radial state are not included in the network by default, but they are added for network rearrangement operations. This program, which is carried out by DigiSilent software, actually determines which lines should be removed from the network so that the network remains radial and the total loss and lost energy (ENS) is minimized. As can be seen in Tables 4 and 5, the amount of unsupplied energy has been significantly reduced by reorganizing, which increases the reliability of electricity consumed by subscribers.

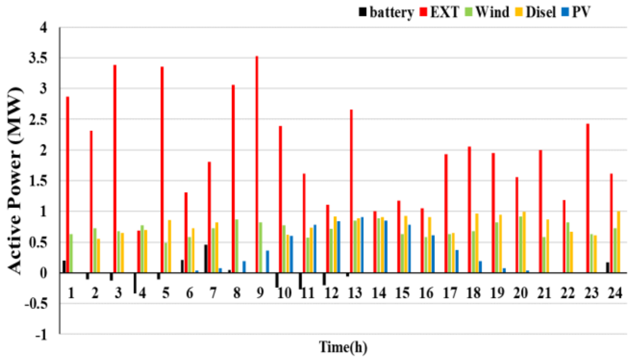

Fig.11. Diagram of scattered production sources and upstream network in 9 scenarios in the state without environmental pollution restrictions

By simultaneously performing demand response, UC, and rearranging the single-line diagram of the network at 19:00 according to Fig 9. Because 19:00 is one of the peak load hours, in this case, 20% of each network load has been reduced while carrying out demand response. Considering the resources of the diesel generator and the storage system, a part of the network load is provided. The lost energy is 7.5 megawatt hours per year, which is one-tenth of the ENS value of the pre-optimization state. Also, by comparing the loss results, the loss optimization dimension has been reduced by 20%, which shows favorable results for network operation.

For optimal network operation planning, in addition to reconfiguration and load response, the issue of connecting a diesel generator (UC) has been considered. While a diesel generator is a cost-effective unit and can be used around the clock, it also increases environmental pollutants. Since one of the optimization objectives is to reduce environmental pollutants, the operation of the diesel generator throughout the day should be minimized. Therefore, one of the advantages of UC is that it reduces the operation of the diesel generator. Another result of optimal network operation planning is the voltage stability of the network buses. Figure 10 shows the bus voltages of the network before and after optimization in 9 scenarios at 19:00 per unit, indicating that the voltage in the post-optimization state is within the ideal and stable region. Before optimization, the voltage range fluctuated between 0.92 and 0.93 to 1 per unit, but after optimization, this range has narrowed to 0.98 to 1 per unit, which is 4 times less fluctuation.

Table 4. The results related to the calculation of ENS in every hour of day and night in rearrangement mode after optimization for 9 scenarios

Senario	Time																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Senario1	6	6	6	34	7	6	6	7	7	34	6	34	34	34	34	34	34	34	6	6	6	34	6	6
Senario2	34	34	34	33	34	34	34	11	11	33	8	33	33	11	33	33	33	33	34	34	34	33	34	34
Senario3	35	35	35	35	10	35	35	14	13	35	13	35	35	33	35	35	35	35	35	35	35	35	35	35
Senario4	28	28	28	28	28	28	28	17	17	28	35	28	28	28	28	28	28	28	37	37	28	28	28	28
Senario5	36	36	36	31	30	31	36	28	28	36	28	36	36	32	31	31	31	31	36	36	36	36	31	36
EMS reconfig	35.9	26.7	34	2.3	27.3	3.8	22.1	50.8	51.5	18.9	21.1	14.7	10.3	23.7	4.7	6.5	1.1	3.2	7.5	6.1	39.6	7.2	17.9	36.4

Table 5. The results related to the calculation of ENS every hour of the day and night in the state before optimization

Senario	Time																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Senario1	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Senario2	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Senario3	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Senario4	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
Senario5	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
EMS reconfig	37.8	29.4	31.2	27.6	43.2	39.3	38	39.6	42.1	38.6	46.5	43.4	48.1	49.6	49.4	70	83.4	85.7	87.8	70.2	78.4	54.7	57.1	48.6

Table 6. comparing the results of 9 scenarios in the states with and without considering environmental pollution limits

9 scenarios	profit disco ($/day)	Diesel generator power (MW/day)	Upstream network power (MW/day)
Considering the emission limit	4629	6.8	55.3
Regardless of the emission limit	5058	16.1	47

3.1 Investigating the impact of pollutants on the profitability of the 33-bus network

To determine the role of environmental pollutant constraints on Disco's profitability, simulation results are shown in two cases: with and without considering pollutant constraints, as illustrated in Fig 11. As expected, in the case without pollutant constraints, the total diesel generator power increased and the upstream network power decreased, leading to an increase in Disco's profit. The reason for this result is the low price of diesel generator electricity and the objective function of maximizing Disco's profit. As shown in Fig 11, the diesel generator operated at a high level, and it was only shut down for three hours a day to meet the electricity demand (for comparison, in the case of considering pollutant constraints, the diesel generator was shut down for 13 hours). According to Fig 11, at times when the battery is discharging (negative power) (at 4 AM), the upstream network has less power compared to other hours. Also, when photovoltaic power enters the network, the upstream network generation decreases. At times when distributed generation sources have less power (at 9 AM), the upstream network power has a higher value. Comparing the upstream network power, in the case without pollutant constraints, the amount of pollution is lower. The reason is that while the network's power consumption remains constant, the increase in diesel generator power generation has caused this. According to the results in Table 6, the profit of Disco in the state without pollution restrictions increases with the increase in the performance of the diesel generator and the power taken from the upstream network decreases.

3.2 Overall results and comparison of the results obtained before and after optimization

The results of the objective functions, which include the maximum profitability of the network operator and the reduction of environmental pollutants for 9 scenarios during one day and night, are shown in Table 7. It shows the profit obtained from losses, reliability, electricity sales for end users, and battery charging for the operator, as well as the costs related to the purchase of electricity from distributed generation sources and the upstream network. In the last section, the production power of each power supply source is mentioned.

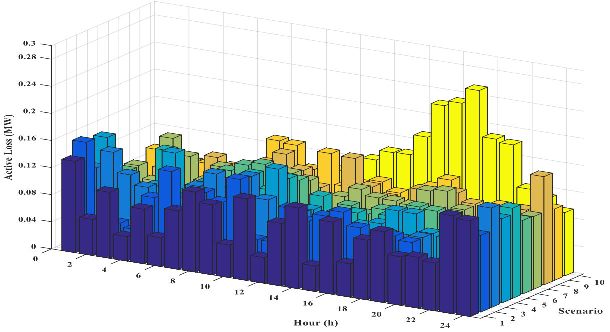

Fig.12. Comparison of active power losses in 9 scenarios before and after optimization

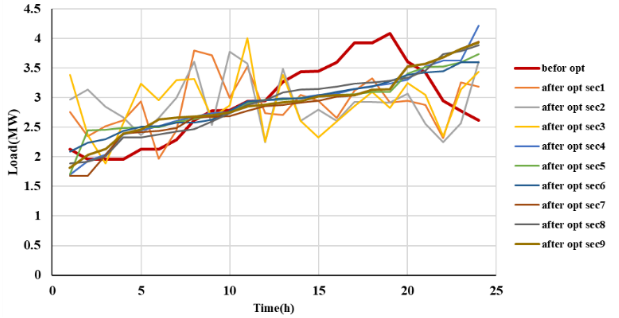

Fig.13. Demand response results in 9 scenarios before and after optimization

Table 7. The results of objective functions, revenues and costs in different scenarios of scattered production resources during one day

	Scenarios								
	1	2	3	4	5	6	7	8	9
The possibility of uncertainty	0.03	0.14	0.03	0.09	0.03	0.09	0.03	0.14	0.42
Profit of the network operator (10^3$/day)	4.45	4.6	4.7	4.7	4.46	4.6	4.57	4.62	4.63
The amount of pollution (10^3kg/day)	2	2	2.15	2.15	1.9	1.95	1.76	2.1	1.92
Losses ($/day)	241.9	230	245	194	178	206	167	156	222
ENS ($/day)	607	626	542	595	542	577	507	573	546
Income from the sale of electrical energy to subscribers (10^3$/day)	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
Battery discharge income ($/day)	105	57	57	76.4	75.5	74	87.1	95	89
Cold and hot setup cost (10^3$/day)	1.5	1	1	2	2.5	1.5	1	1.5	2.5
The cost of purchasing electrical energy from the upstream network (10^3$/day)	4.1	4	3.8	3.8	3.6	3.7	3.8	3.6	3.8
Buying of electrical energy from diesel generator ($/day)	162	170	189	225	164	164	148	189	172
Buying electricity from photovoltaics ($/day)	227	301	362	227	356	362	227	301	301
Purchase of electricity from wind power plant ($/day)	425	425	425	567	679	567	679	679	567
The cost of charging the battery ($/day)	101	72.3	61.4	39	60.3	59	55.3	69	33
Total photovoltaic power (MW/day)	0.82	1.1	1.3	0.82	1.3	1.3	0.82	1.1	1.1
The total power of the wind power plant ($/day)	2.65	2.65	2.65	3.5	4.25	3.5	4.25	4.25	3.5
The total power of the diesel generator ($/day)	6.5	6.77	7.6	7.65	6.5	6.6	7	7.6	6
Total upstream power ($/day)	63	62	61	61	60	58	55.3	55.6	59

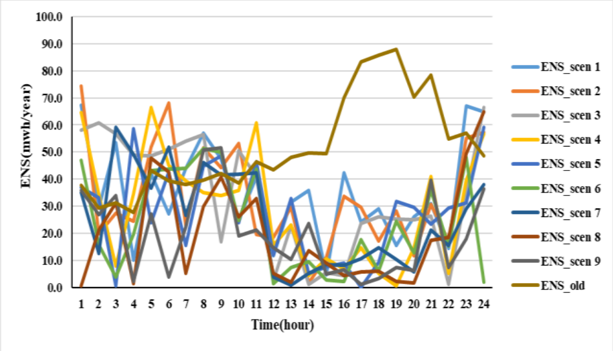

Fig.14. Comparison of reliability results (ENS) in megawatt hours per year in 9 scenarios before and after optimization

Another result is carrying out load accountability to reduce losses. In Fig 12, the yellow color shows the results before optimization and, while comparing it with 9 scenarios, the reduction of active power losses. The number of casualties has decreased from 12:00 to 22:00. Based on the load response modeling, due to the high price of electricity during the peak load time, the subscribers transfer a part of their consumed load to the non-peak time, i.e., the beginning and end hours of the day and night, as shown in Fig 13 in the load response. With the shift of peak load to non-peak times during the day and night, the reduction of losses occurs during the day and night, especially in the areas of peak load consumption.

As expected, performing the rearrangement in the simulation will reduce the unsupplied energy and increase the reliability. Fig 14 shows that after optimization during the day and night, the unsupplied energy has decreased, and this benefit is more visible during the peak consumption period.

4. Conclusions

This paper carried out a set of simultaneous planning methods for distribution to maximize profitability for the operator and reduce environmental pollutants in 9 scenarios. These methods were carried out in two stages, considering the day-ahead schedule. Initially, scheduling was carried out only with the help of renewable resources and the upstream network. The load response plan, network reorganization, use of storage, and bringing the generator unit into orbit were put on the agenda. On the other hand, considering different scenarios, all of the methods above were examined under the influence of the uncertainty of renewable resources in such a way that the response plan with a load shift of 20% from peak to off-peak time was able to reduce losses by 20% and improve voltage stability by 5%. Therefore, the role of load response in optimal scheduling, load shift ability, and peaking has caused the reduction of losses and performance of the generator unit and, consequently, the reduction of environmental pollutants. The main advantage of the rearrangement is the reduction of outage time and losses by shortening the power transmission path in the network, which caused the ENS to decrease by 10%. Also, using UC reduces the diesel generator's performance, and a storage device is used instead. This led to the reduction of environmental pollutants and the minimization of the emission objective function by 9%. As a result, the reduction of losses and the increase in the reliability of the objective function (operator's profit) have been maximized. In future work, intelligent methods such as reinforcement learning (RL) can be used for planning. RL can make optimal decisions for exploiting renewable resources with dynamic algorithms that learn from the environment and constraints. It can also automatically determine the optimal strategies for transferring the load from peak to off-peak times and determine the optimal energy storage and discharge patterns to increase the operator's profit while reducing operating costs.

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