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Evaluation economic and reliability issues for an autonomous independent network of distributed energy resources

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ABSTRACT

Electrical energy can be supplied in different ways, but consumers want to do it with the highest quality, lowest cost and highest reliability. The purpose of this paper is evaluating the effect of creating a micro grid and using of distributed generation resources to reduce costs and increase the reliability of supplying energy. Economic issues and reliability are two dimensions of proposed objective function. Economical dimension consists of the initial costs and operational costs. Reliability dimension includes non-delivered energy (NDE) for the consumers. The two dimensional objective function is optimized by using weighting method. For this, four scenarios are compared to each other in case of economic and reliability issues. The four scenarios are providing energy by main grid, main grid and distributed generation resources, isolated micro grid and a micro grid connected to an upstream network. Each scenario is considered in two cases for evaluating reliability. First, the loads on one feeder and second is the loads on separated feeders.

The proposed method is compared with a similar method and the comparison results show that it is more efficient and applicable.

1. Introduction

Micro grids are the small grids which supply consumers load. These grids have the generators near the consumers, therefore it decreases distribution line cost and the power losses, also increase reliability. Micro grid power suppliers are distributed generators (DGs) and the upstream grid. Those DGs generate more power and if DGs could not supply all loads, then the upstream grid will supply them. Economical and technical issues must be considered when micro grid is installed. In micro grid installation, the first thing is to examine costs reduction and the benefit. In [1], the authors used a linear programming to optimize the MG (micro grid) initial cost and the operation cost. In [2] authors found best solution for supplying the power to the loads by combining linear programming with genetic algorithm. Nonlinear programming was used to optimize the costs of micro grid and pollutions reduction in [3].

Reliability is another issue which has an impact on micro grid installation. In [4,5], the authors evaluated the effects of micro grid installation on reliability improvement and they explained that failure rate and failure time reductions will increase the reliability. In [6] authors evaluated the impact of micro grid on reliability and power quality.

Other issues that impact the micro grid installation and operation are the upstream network connection [7], the micro grid protection [8,9], the micro grid control system of power generation and load [10–12] and the load forecasting [13].

Considering economical and reliability issues together in objective function is more realistic. In previous work, the reliability was considered as a non-delivered energy and then by multiplying it to the penalize coefficient is taken as cost in objective function. In [14], authors included reliability, initial cost, and operation cost in the objective function. Besides the micro grid capacity and the operational cost were optimized for a year. The authors considered a simple formula for calculating the reliability by taking it as 100% for the isolated micro grid. While in reality the failure probability is not zero for an isolated operation of micro grid. In [15], authors assumed the existence of micro grid and known capacity for the generator, then, they optimized the objective function for the cost of power supply in 24 h, the reliability and pollution reduction.

In this paper, long-term energy management on consumer's demands done by considering energy generation cost and reliability as two dimensions of objective function. Energy generation cost is the sum of initial cost and operational cost. The Initial cost conversion to annual cost needs a depreciation rate adjustment which is a function of micro grid lifetime. But to solve this two-dimensional objective function, the reliability of Non-Delivered Energy (annual) expressed and then dimensions of the objective function multiplied by the weighting coefficients and optimized by using linear programming. Proposed methodology was

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Nomenclature

$C(x)$	energy costs
$C_1(x)$	initial costs
$C_2(x)$	operational costs
d_s	number of days in season
F_B	fuel cost of boiler
F_{FC}	fuel cost of fuel cell
HR	heat recovering rate
IC_B	initial cost of boiler
IC_{FC}	initial cost of fuel cell
IC_{MG}	initial cost of micro grid installation
IC_{SS}	initial cost of energy storage system
IB	installed capacity of boiler
IFC	installed capacity of fuel cell
ISS	installed capacity of energy storage system
l	load index
L_C	load of consumer C
L_e	electric load
L_h	heat load
M_B	maintenance cost of boiler
M_{FC}	maintenance cost of fuel cell
M_{SS}	maintenance cost of energy storage system
NDE_c	non-delivered energy for consumer C
P_B	output power of boiler
PC_{SS}	charged electric power
PD_{SS}	discharged electric power
P_{FC}	output power of fuel cell
P_{SS}	output power of energy storage system
P_{buy}	bought electric power from upstream network
P_{sell}	sold electric power to upstream network
PR_{buy}	buying energy cost
PR_{sell}	selling energy cost
PR_{base}	base charge of power contract
P_M	failure probability of protection device
P_L	failure probability of micro grid
r_i	time for removing fault
$R(x)$	reliability function
S	season index
t	time index
t_{repair}	time of repair
$t_{isolate}$	time of isolate
$t_{reconfig}$	time of reconfiguration
T_a	time for repairing micro grid
U	interest rate
U_C	lack of access for consumer C
U_{up}	lack of access for upstream network
U_{MV}	lack of access for MV network
X	objective function variables
α, β, λ	depreciation rate
λ_i	failure probability of section i
λ_C	failure probability of consumer C
λ_{up}	failure probability of upstream network
λ_{MV}	failure probability of MV network

evaluated in low voltage network with 4 loads for 4 different scenarios. In these scenarios the load demands are supplied by main grid, main grid and distributed generation resources, isolated micro grid and a micro grid connected to an upstream network.

This paper is organized as follows: micro grid definition, economical and reliability issues and weighting-method optimization will be explained in Section 2. In Section 3, problem formulation and in Section 4 case studies described. Simulation results and discussion in Section 5 and the conclusion in Section 6 are described.

2. Background

2.1. Micro grid

Fig. 1 shows a micro grid. The micro grid includes control system, generators, power storage system and loads. Connecting micro grid to upstream network or an isolated micro grid, the loads type and amount of load have effects on micro grid operation.

Control system: each micro grid has a control system that controls the load and the generation. Control system installation implies capital cost which will be considered in proposed objective function costs.

Load: types and amounts of loads are the most important factors for the micro grid operation. In this paper, 4 consumers are selected to find an optimized way of supplying electrical and thermal demands for supporting the loads.

Power generators: power generators in micro grid can consider as different DGs, such as the wind turbine, the solar cell, the fuel cell and the micro turbine. Each of those DGs has various characteristics in power generating in regards with the economy and the climate condition. In this paper, fuel cell is used as power supplier. Fuel cell is chosen because of the need to both electrical and thermal energies and also for the independency of climate conditions.

Storage system: the storage system is another factor affecting on micro grid operation. The storage system supply power in peak times by saving it in the midnight, so this plays an important role in unifying the demands. Storage system type is dependent on power generator type. Battery and electrolyzer could be used as storage system if a fuel cell generates energy. In this paper battery is chosen as storage.

Micro grid operations modes: There are two different operational modes for micro grids as connected micro grid to upstream network and isolated micro grid. In peak times, the micro grid buys energy from upstream grid and in off-peak times it sells extra energy when a connected micro grid to upstream is operating. Off

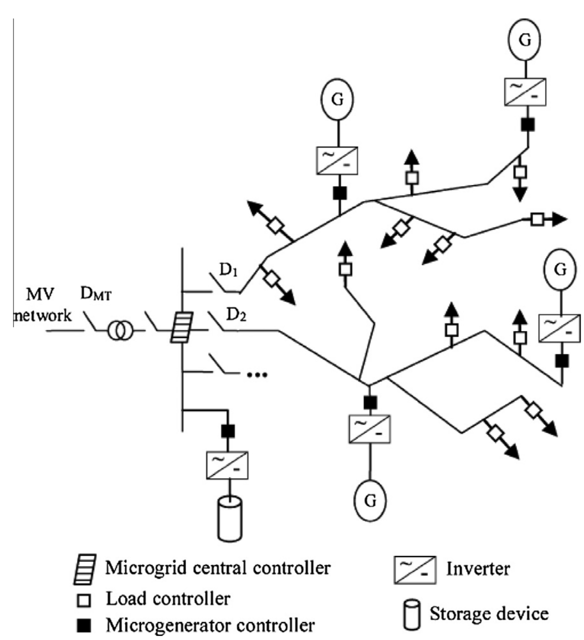

Fig. 1. Micro grid [4].

course this kind of operation will always be affected by the selling and buying prices.

2.2. Economical issues

The cost of micro grid in objective function is considered as the initial cost and the operational cost. The Initial cost is the cost that consumers must pay for building micro grid, including of buying and installing costs of DGs and other equipment such as distribution line, and local controller. Maintenance and fuel costs are the operational costs. Both initial and operational costs in objective function convert to annual cost.

2.3. Reliability

Non-delivered energy (NDE) in a year will lead to fines for the system. This fine is due to the energy supply system commitment to consumers and the amount of it depends on load type and the time period that loads are not provided. NDE is associated with system reliability so that increasing the reliability cause to lowers NDE and consequently the fine will be reduced. Also different loads interruption lead to different fines payment. The reliability will be discussed for different cases [4]. In case 1, the reliability for a low voltage network in the absence of micro grid is checked. In the second case, the reliability of a low voltage micro grid will be reviewed and for the third, the upstream medium voltage network reliability will be discussed with and without the micro grid.

2.3.1. LV network reliability

Low voltage network reliability is expressed in terms of upstream network reliability and network supplier of low voltage energy. The probability of failure (λ_C), lack of access (U_C) and Non-delivered energy (NDE) for the consumer C in low voltage network showed in Fig. 2 and is expressed as the following equations:

$$\lambda_C = \sum_{i \in f} \lambda_i + \lambda_{up} \tag{1}$$

$$U_C = \sum_{i \in f} \lambda_i r_i + U_{up} \tag{2}$$

$$\mathrm{NDE}_c = \left(\sum_{i \in f} \lambda_i r_i + U_{up} \right) L_c \tag{3}$$

where λ is the probability of failure per kilometers and it depends on environmental and climate conditions [16].

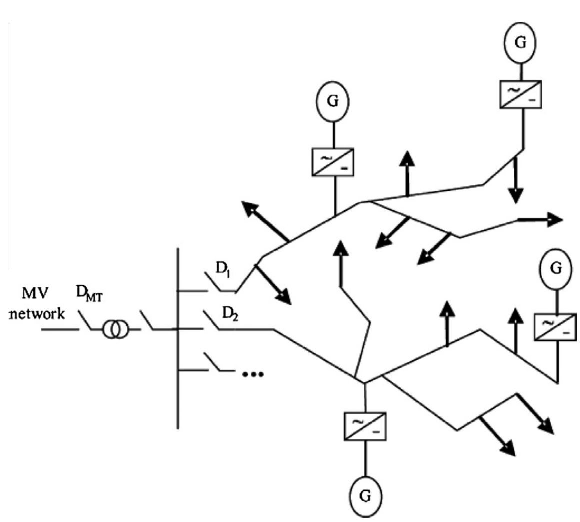

Fig. 2. LV Network [4].

2.3.2. Micro grid reliability

If instead of the low voltage network (Fig. 2); the micro grid (Fig. 1) is replaced, the above equations will be changed. In the event of a failure in an upstream network, the micro grid will be isolated repeatedly, it works and provides loads. If generator resources capacity is sufficient, the load will be fully supplied, otherwise, the micro grid control system disconnects several loads to meet the power quality requirements. To isolate the micro grid from the upstream network, the security systems will be engaged. These systems perform with high success probability in the events of failure in grid, but there is a possibility (P_M) of failure in security system. But when the failures occur within the low voltage network, the conditions will be completely different. This micro grid will be completely disable and requires restart. This is modeled by the second term in the following equation. Also, Non-delivered energy is expressed in the following equation.

$$\mathrm{NDE}_c = \left(\sum_{i \in f} \lambda_i r_i + \sum_{i \in \Phi} \lambda_i P_L T_a + \lambda_{up} P_M T_a \right) L_c \tag{4}$$

In above equation, the second term is related to the occurrences of failures in the feeders, except for the feeder f which leads to blackout the micro grid. In this equation, T_a is the micro grid repairing time. Restarting a micro grid depends on multiple factors such as a central control system of micro grid and the inverter controller. At the same time, restarting time does not depend on the location of load and the generators. It is assumed that after a failure in a micro grid, micro grid will be switched off, means $P_L = 1$.

Eq. (4) shows NDE for micro grid, supposing that in isolated mode micro grid is able to supply the full loads. Otherwise, if micro grid cannot supply the full load, micro grid control system will disconnect some loads off to prevent the frequency and voltage drops. Eq. (5) shows NDE this situation.

$$\mathrm{NDE}_c = \left(\sum_{i \in f} \lambda_i r_i + \sum_{i \in \Phi} \lambda_i P_L T_a + U_{up} \right) L_c \tag{5}$$

As it is clear from the above equation that the upstream network reliability effects on micro grid reliability. It needs to be mentioned that the upstream network reliability will also be affected by the micro grid and other low voltage networks positions.

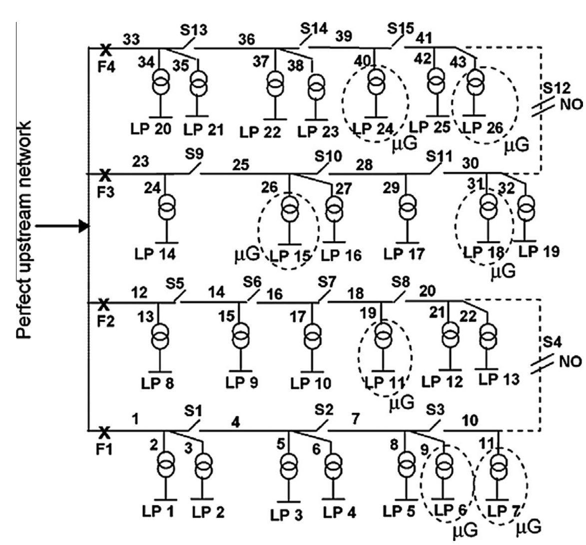

Fig. 3. MV network [4].

2.3.3. MV network reliability

Fig. 3 shows a medium voltage network which is composed of several micro grids and low voltage networks. If a fault happens in branch 14, protection device, F2 works and the following steps occur:

(i) Open S5 and S6 to isolate the fault from the rest of the network.
(ii) Close S4 to supply the loads LP10–LP13 by the alternative MV feeder.
(iii) Close F2 to reestablish the normal supply to load LP8.

S4 closing and network restructuring are not always possible and technical limitations such as voltage profile and network capacity must be respected. Micro grids in feeder which the fault occurs will help the process of restructuring the network by providing loads. Especially, if the ratio of internal generation and load (GLR) of micro grid is more than 1, so the micro grid will supply all internal demands and also it can supply a part of the external power demands.

Micro-grid location is effective in the upstream network restructuring. For example, in Fig. 3 with the operation of MV controller and the separation of error, there exist three conceivable positions for micro grid:

(1) MG is a part of the feeder which stays connected to initial structure (LP-8).
(2) MG is in error part of the feeder and will be isolated (LP-9).
(3) MG is part of the feeder which will be disconnected and it reconnects to a new restructuring through S4 (LP-10_LP-13).

Micro grid in third position can provide a part of demands and helps restructuring process. Meanwhile in cases 1 and 2, the micro grid has little effect on the grid restructuring. The restructuring of MV network causes interruption time reduction for the loads in third position; this will be equal to fault isolation time plus the time for creating the new structure. At the same time, interruption time for loads in the first position is the time required for fault isolation and in the second position (LP-9), it is equal to the time of removal fault. As the results, although the fault probability does not change thus the non-provided loads will decrease. Fault probability and non-delivered energy in upstream network can be expressed as the following equations.

$$\lambda_{MV} = \sum_{i \in \Phi} \lambda_i \tag{6}$$

$$U_{MV} = \sum_{i \in \Theta} \lambda_i t_{repair} + \sum_{i \in \Omega} \lambda_i t_{isolate} + \sum_{i \in \Lambda} \lambda_i t_{reconfig} \tag{7}$$

- Λ, Θ, Ω are the buses in positions 1, 2 and 3, respectively.
- Ω: part of network which its loads is supplied by upstream grid after the fault.
- Θ: part of the network which must be repaired after the fault
- Λ: part of network which provides through the upstream network restructuring

It is important to mention that by restructuring; the loads are supplied by alternative feeders, separated from the Θ set and added to the Λ set.

2.4. Weighting-Method optimization

Weighting method is known as a parametric method that is most used in multi-dimensional problems. This multi-dimensional problems becomes a number problem as bellows:

$$\begin{aligned} \min \quad & \sum_{i=1}^{G} w_i * f_i(x) \\ \text{s.t.} \quad & x \in X \\ & \sum_{i=1}^{G} w_i = 1, \quad w_i \geqslant 0 \quad (i = 1, 2, \ldots G) \end{aligned} \tag{8}$$

In the above equation $f_i(x)$ is dimension and w_i is weighting coefficient, Then, by changing the amount of weight, the importance of each dimension can be changed and the different results will be obtained.

3. Problem formulation

This optimization aimed at reducing the energy costs for consumers and increasing reliability. Proposed objective function and the constraints are expressed in Eq. (9) which reduces initial and operational costs and also decreases NDE (increase reliability).

$$\begin{aligned} \min \quad & F(x) = \{C(x), R(x)\} \\ \text{s.t.} \quad & G_i(x) = G_{ie}(x) \\ & G_{il}(x) \leqslant G_i(x) \leqslant G_{iu}(x) \end{aligned} \tag{9}$$

Two dimensions for this objective function are the energy cost and the reliability. The energy cost kind is money and reliability kind is power. In Eq. (8), NDE for consumers in the period of a year is considered as reliability. The relationship between NDE and reliability is demonstrated in Eqs. (22) and (23). In this paper, both economic and reliability dimensions of objective function with weighting coefficients ($w1$, $w2$) will convert to the number dimensions and solved by linear programming

$$F(x) = w_1 * C(x) + w_2^* R(x) \tag{10}$$

In Eq. (10), vector X includes variables that will change the final cost.

Solving the objective function will calculate the optimal value for X, including power generation of fuel cell, boiler, battery and energy exchange with the upstream network at any time, day or night, four seasons and for each consumer.

3.1. Energy cost

Energy costs for consumers included both initial costs and operational costs (Eq. (11)). Later, $C1(x)$ the initial costs and $C2(x)$ the operational costs will be explained.

$$C(x) = C_1(x) + C_2(x) \tag{11}$$

3.1.1. Initial cost

Initial costs are including, the initial investment to purchase, to install distributed generation resources, and investment to create a micro grid. Investment to create a micro grid includes funds for purchasing and installation of a micro grid control systems, purchasing the protective systems, networks communication and distribution lines which is expressed by IC_{MG} in the following equation.

$$\begin{aligned} & C_1(x) = \alpha \cdot IC_{FC} \cdot IFC + \beta \cdot IC_B \cdot IB + \gamma \cdot IC_{SS} \cdot ISS + IC_{MG} \\ & \alpha, \beta, \gamma = \frac{u(1+u)^{n_{\alpha,\beta,\gamma}}}{(1+u)^{n_{\alpha,\beta,\gamma}} - 1} \end{aligned} \tag{12}$$

Initial costs converted to annual cost with depreciation rate. In the above equation, IC_{MG} is initial cost to create a micro grid which is converted to annual cost.

3.1.2. Operational cost

Operational costs include the cost of generators fuel, cost of buying and selling energy and the equipment maintenance cost. These costs are shown in the following equation.

$$C_2(x)=\sum_{l=1}^{4}\sum_{s=1}^{4}d_s\sum_{t=1}^{24}\{(F_{FC}+M_{FC})P_{FC}(t,s,l)+(F_B+M_B)P_B(t,s,l)+M_{SS}P_{SS}(t,s,l)$$
$$+PR_{buy}(t,s,l)P_{buy}(t,s,l)-PR_{sell}(t,s,l)P_{sell}(t,s,l)\}+12PR_{base}P_{buy}^{\max}$$
$$P_{buy}^{\max}=\max\left\{\sum_{l=1}^{4}P_{buy}(t,s,l)\middle|t=1,\ldots,24,s=1,\ldots,4\right\} \tag{13}$$

In Eq. (13), the first term shows operation cost of fuel cell, the second term shows operational cost of boiler and the third part shows operational cost of storage system. The forth part declare cost of buying energy from upstream network and the fifth part declare benefit of selling energy to upstream network. The last one is base charge of power contract.

3.1.3. Constraints

Constraints are: the balance between electrical energy produced by generators and purchased electrical energy from an upstream network with electric energy requirements and the energy sold to upstream network. The above statement is expressed by Eq. (14). Eq. (15) explains the balance between thermal energy produce by generators with required thermal energy. The battery discharge limits is expressed in Eq. (16).

$$\sum_{l=1}^{4}L_e(t,s,l)=\sum_{l=1}^{4}\{P_{FC}(t,s,l)+PD_{SS}(t,s,l)-PC_{SS}(t,s,l)$$
$$+P_{buy}(t,s,l)-P_{sell}(t,s,l)\} \tag{14}$$

$$\sum_{l=1}^{4}L_h(t,s,l)\le\sum_{l=1}^{4}\{HR\cdot P_{FC}(t,s,l)+P_B(t,s,l)\} \tag{15}$$

$$\sum_{t=1}^{24}\{PD_{SS}(t,s,l)\}\le\sum_{t=1}^{24}\{PC_{SS}(t,s,l)\} \tag{16}$$

Minimum and maximum limits of power produced by the fuel cell, boiler and battery respectively, is expressed in 17–20. Eq. (21) will satisfy the requirement to be positive.

$$0\le P_{FC}(t,s,l)\le IFC(l) \tag{17}$$

$$0\le P_B(t,s,l)\le IB(l) \tag{18}$$

$$0\le PD_{SS}(t,s,l)\le Iss(l) \tag{19}$$

$$0\le PC_{SS}(t,s,l)\le Iss(l) \tag{20}$$

$$0\le P_{buy}(t,s,l),P_{sell}(t,s,l),IFC(l),IB(l),Iss(l) \tag{21}$$

3.2. Reliability

Eq. (4) expressed NDE for a micro grid in which the λ is fixed for all seasons and every hours of the day. But really, λ is a function of loads, seasons and times. For example, by increasing energy consumption in summer, NDE will be at maximum. Also, the possibility of interruption in peak time is more than off peak time. Some researchers have used daily reliability. In this paper, reliability is considered as seasonal. Therefore, Eq. (4) can be rewritten to Eq. (22). In this equation λ is a function of load type, season and time. Also there is an assumption that the isolated micro grid can provide all internal loads. Eq. (6) shows the probability of failures in the upstream network.

$$\mathrm{NDE}(t,s,l)=\left(\sum_{i\in f}\lambda(t,s,l)r+\sum_{i\in\gamma}\lambda(t,s,l)P_LT_a+\lambda_{up}(t,s)P_MT_a\right)L(t,s,l) \tag{22}$$

Above equation shows NDE for each consumer. Following equation express $R(x)$ as function of NDE.

$$R(x)=\sum_l\sum_s\sum_t\mathrm{NDE}(t,s,l) \tag{23}$$

4. Case study

In this section, Fig. 1 is considered as case study. For supplying the consumers' loads, 4 scenarios are studied. In scenario 1, the consumers load will be supplied by main grid and in 2, the consumers can buy their energy needs from the grid or from the installing DG's. In both above scenarios micro grid does not exist. In scenarios 3 and 4, micro grid form. In 3, DGs are the only load suppler and in 4, besides the DGs, upstream grid can also be used as load suppliers if needed. Table 1 summarizes the scenarios.

The energy costs and reliability (NDE) in various scenarios are compared and the best scenario is chosen.

In addition of considering 4 scenarios and to obtain the micro grid reliability two models for the network structure can be expected:

- Model 1: Four loads are connected to a feeder.
- Model 2: Each loads is connected to a feeder.

Model 1, if a fault occurs in micro grid, the time needed for supplying the loads is equal to the time required to remove the fault (which is assumed for 4 h in this paper). But in model 2, time needed to power up other feeders is the same as the time for starting the micro grid (0.25 h). Faults occurrences in this model causes the micro grid disability and forcing to switch off, then the faulted feeder will be isolated from the micro grid and the micro grid restarts to supply demands. Eq. (22) shows the reliability for these two models which are different.

Table 2 gives the costs of creating a micro grid in separated components, such as local controller, compensator device, energy manager, transmission line and communication lines along its length. These costs are going to be converted to annual costs and substituted in Eq. (12). Table 3 shows initial and operation costs and the lifetime of the fuel cell, energy storage system and boiler. Tables 4 and 5 show the existing contracts to purchase energy from the network. Figs. 4 and 5 also show electrical and thermal energy demands considered for four consumers in the spring.

By solving the objective function, required electrical and thermal energies for every load will be scheduled for daily consumptions in each season. Fig. 6 shows the supplied electrical energy to hotel for daily consumption in the spring. Finally, Tables 6 and 7 are showing the production capacity for each resource, the cost reliability and the total energy costs.

Table 1
Summarized scenarios.

	LV Network		Micro grid	
	Upstream network	DGs	Upstream network	DGs
Scenario 1	✓			
Scenario 2	✓	✓		
Scenario 3				✓
Scenario 4			✓	✓

Table 2
Micro grid installation cost.

Equipment's	Energy manager	Separation device	Local controller	Distribution line	Communication line
Cost ($)	45,500	195,000	3900	39,000	39,000
Lifetime (year)	6	20	6	30	20

Table 3
DGs costs.

	Fuel cell	Storage system	Boiler
Operational cost ($/kw)	0.13	0.013	0.08
Initial cost ($/kw)	2600	2600	260
Lifetime (year)	6	15	30

Table 4
Contract tariff (constant rate).

Type	Base charge ($/kw h)	Electricity rate ($/kw h)	
		Summer	Others
Commercial power	20.475	0.1582	0.14378
High-voltage power	14.69	0.14586	0.1326

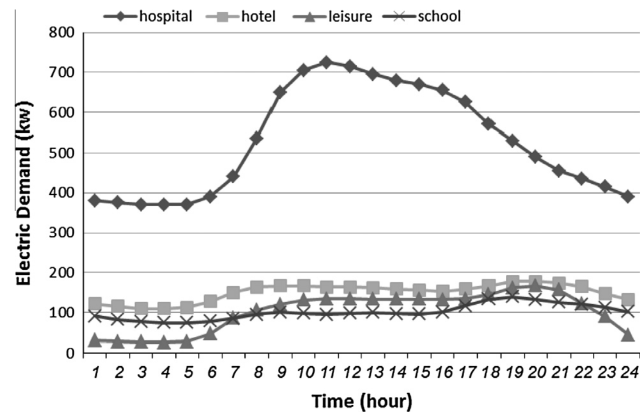

Fig. 4. Consumers electrical demands in spring.

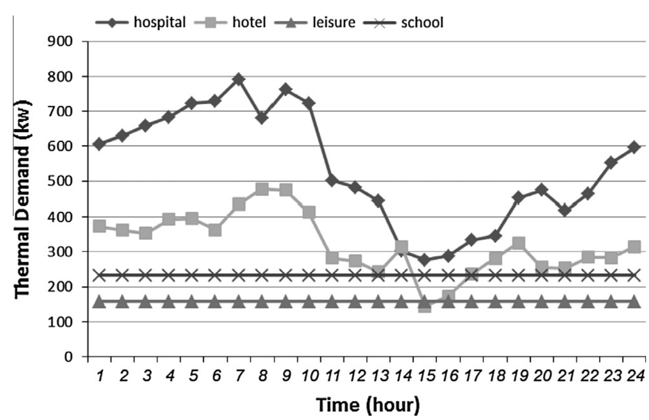

Fig. 5. Consumers thermal demands in spring.

5. Discussion

In this work, 4 energy scenarios are compared in terms of the economy and the reliability. For comparing the scenarios in proposed objective function, the initial/ operational costs and the reliability are considered as the two dimensions. Then by using weighting method the objective function has been optimized. In this section, firstly the results from our proposed method are compared to a similar method [14] and then they are discussed in different scenarios.

5.1. Comparing with same method

They are similarities between our proposed method and Ref. [14]. Both used the 4 scenario option and the two dimensional objective function, energy costs and the reliability.

5.1.1. Differences of two methods

Reliability calculation: In Ref. [14] the reliability for isolated micro grid is considered 100%, but in reality it is not, the fault probability and the interruption in micro grid does exist. In this paper, the micro grid reliability is calculated as a function of interruption probability therefore, the cost of NDE is included in objective function. Improved method used in paper [4], was implied for calculating the reliability. In this method, failure rate is a function of load amount and weather conditions. Then, higher loads, cause higher failure rates. In this paper, for simplification it is assumed that the isolated micro grid can supply all internal demands when there is an upstream grid interruption.

Energy exchange with the upstream network: In Ref. [14], possibility of selling the produced electricity by distributed generation resources to the upstream network is not considered, but in this research, the possibility of selling energy to the upstream network was accepted.

Optimization method: in Ref. [14] objective function will be optimal as one-dimension (cost) while in this paper the weighting method is used, because the amount of fines paid by system to customer for each kilowatt hour will be affected the optimization problem. This cost is a function of the loads type and their sensitivity. Therefore, different fine should be paid to different costumers. Also comparing the scenarios shows that cannot be identified system to pay fines to consumers. In scenarios 1 and 2 if the original network would be required to pay these costs in scenarios 3 and 4, which system supply these costs?

Table 5
Contract tariff (time of use rate).

Type	Base charge ($/kw h)	Electricity rate ($/kw h)			
		Peak	Daytime		Midnight
			Summer	Others	
Commercial power	20.475	0.22815	0.1866	0.1804	0.08151
High-voltage power	14.69	0.21879	0.1788	0.1686	0.08151

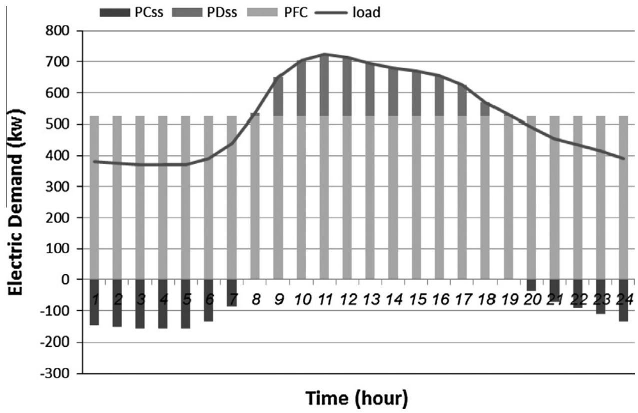

Fig. 6. Hospital electrical demand supply in spring.

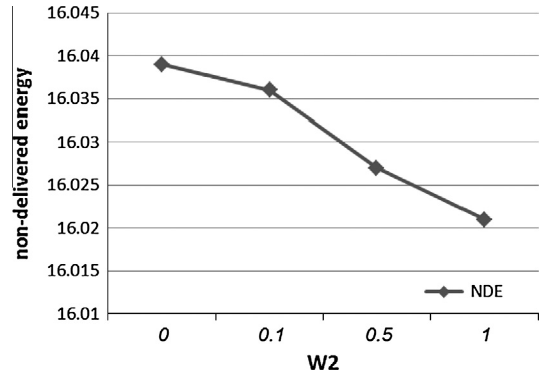

Fig. 8. reliability change of weighting coefficient change in scenario 4.

Table 6
Simulation results of 4 scenarios in model 1.

Model 1	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IFC (kw)	0	1134.034	886.218	1113
ISS (kw)	0	0	321.764	0
IB (kw)	2415.564	1848.547	1981.313	1859.064
NDE	20.027	20.027	16.021	16.036
Cost (10^7)	2524.1	2134.5	2234.975	2168.075

Table 7
Simulation results of 4 scenarios in model 2.

Model 2	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IFC (kw)	0	1044.5	886.218	1014.5
ISS (kw)	0	0	321.764	0
IB (kw)	2415.564	1893.314	1981.313	1908.314
NDE	20.027	20.027	4.7564	4.7574
Cost (10^7)	2524.1	2134.5	2234.975	2168.075

5.1.2. Comparing the results of the two methods

Energy cost: Comparing the results from our proposed method (Fig. 7), with the method from Ref. [14] (Fig. 8 in [14]) show that scenario 1 has the highest energy cost for both methods. But the differences are in scenarios 2, 3, 4. In paper [14], the energy cost in scenario 2 is bigger, because the energy selling to the upstream grid is not taken to be account. But in this work the possibility of selling energy to the upstream network was made possible. So the energy cost in scenario 2 became less than scenario 3 and 4. In scenarios 3 and 4 the cost of creating a micro grid, which is increasing the cost of Scenarios 3 and 4 has been considered. The two alternatives in scenario 2 for supplying energy (upstream grid and DGs) in comparison to scenario 3 which have one alternative (only DGs) confirm result of this paper, in that energy cost in scenario 2 is less.

Reliability: Paper [14] considered 100% reliability for the isolated micro grid, so the NDE fine will be zero. While in our method, the interruption to micro grid is possible then the NDE fine was considered in the objective function and is not zero (Fig. 7).

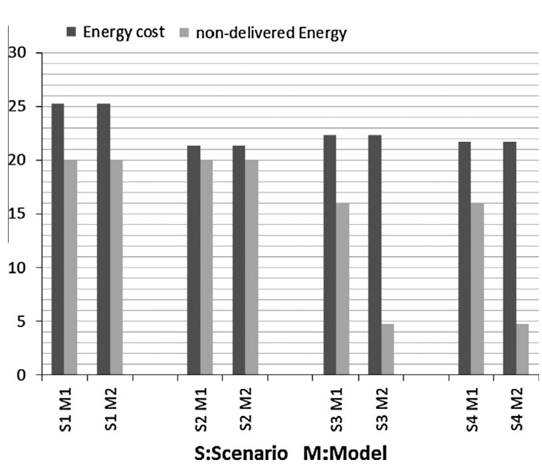

Fig. 7. Energy cost and reliability cost for 4 scenarios in 2 models.

5.2. Comparing results for different scenarios in the proposed method

Energy cost: Fig. 7 shows energy cost for 4 scenarios. According to the chart, the energy cost for scenarios 2, 4, 3 and 1 is incremental respectively, showing that the installation of DGs will help to reduce the energy cost. The results of simulations showed that the energy sales to the upstream grid and the energy price have important influences on the energy cost for the scenarios with DG.

Reliability: As seen in Fig. 7, the NDE fines paid for scenarios 3, 4, 2, and 1 are incremental respectively. In other words, scenario 3 has the highest reliability and scenario 1 the lowest. Having micro grid will increase reliability, with the highest in model 2.

Effect of weighting coefficients: The effect of the weighting coefficients on the energy cost and Non-Delivered energy has been shown in Table 8. By Increasing W2, the reliability effect in objective function will be increased, which it occurs in Scenario 4. But in scenarios 1 and 2 and 3 the reliability of the system does not change. Because in scenarios 1 and 3, there is only one way to provide energy and therefore, the reliability in not change with W2 changing. Also, in the second scenario, it is assumed that with energy supply from the grid interruption, the consumer access to distributed generation will also be interrupted. Hence in this scenario the reliability is independent from the weighting coefficients and it is expected to be unchanged.

Highest reliability is related to the isolate micro grid. Therefore, the reliability of scenario 4 is less than the reliability of scenario 3

Table 8
Energy cost and NDE by changing weight.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	NDE	*Cost*	*NDE*	*Cost*	*NDE*	*Cost*	*NDE*	*Cost*
$W1 = 0.9$, $W2 = 0.1$	16.036	2168	16.021	2237	20.027	2134.5	20.027	2524.1
$W1 = 0.5$, $W2 = 0.5$	16.027	2171.17	16.021	2235	20.027	2134.5	20.027	2524.1

in all cases Table 8. Fig. 8 shows the effect of changing weighting coefficients in increasing the reliability for scenario 4 in Model 1.

Also with increasing the weighting coefficient, W2, reliability increase and NDEs decrease which these cause additional cost.

6. Conclusion

The purpose of this paper is to evaluate the effects of micro grids on the consumers' energy costs and system reliability. There are four scenarios in supplying energy. The proposed objective function for each of these scenarios consists of the initial and operational energy costs and the reliability. Energy supply scenarios include: the power supply only by grid, by grid and distributed generation resources; by micro grid alone and by micro grid / upstream grid. Results show that the energy supply using micro grid connected to upstream grid imposes the least energy cost with higher reliability for the consumers. Furthermore, these results indicate that the installation of distributed generation sources by forming a micro grid or with no micro grid will reduce the energy costs.

Results also show that if the loads or the similar loads are connected to a separated feeder of a micro grid, then the reliability will be improved.

Comparing proposed method with the similar revealed more efficiency and higher applicability for the proposed method.

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