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Exploitation of Photovoltaic Resources Using BeeColony Optimization Algorithm to Improve Reliability of Distribution Network

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Abstract

In this article, attempts are made to make daily exploitation of photovoltaic units in order to increase profit of exploitation considering impacts of distribution network. In addition to increased exploitation profit, the issue of reliability, i.e., index of undistributed energy, is intended to be examined so as to make possible an optimized exploitation under an optimized condition. The proposed framework enables power network operators to take into account all security considerations alongside with other noteworthy issues, applying an optimized solution for optimization exploitation problem in photovoltaic resources and electrical storage existing in distribution systems.

1. INTRODUCTION

Recloser is a device which is able to reveal overcurrent phase-to-phase and phase-to-ground conditions to cut circuit when overcurrent remains in circuit after a pre-determined duration of time. It, then, reconnect the line automatically. If a fault is still in the circuit, recloser would try to open the line after some predetermined operations. In an air distribution system, 80% to 95% of faults are innately temporary and are eliminated after some cycles or seconds. Hence, recloser keeps distribution circuit from temporary faults. Typically, reclosers are designed for three opening/closing operations after occurrence of faults, after which a final opening operation is performed to lock this sequence [1].

Given the complexity of the issue of optimized placement of reclosers, few scholars have conducted studies in this respect. In 2008, optimized placement of protective equipment and distributed generation (DG) in radial feeders was carried out using the ant colony optimization algorithm (ACO) to improve reliability. To do so, a hybrid reliability index is introduced [2]. Popovic et al. examined optimized placement of reclosers and distributed generation units for improved security (voltage profile and power loss) as well as network's reliability. Determination of optimized location of DGs has been performed using sensitivity analysis of load distribution equations [3]. [4] performed a similar study.

In 2011, reclose-fuse operation and coordination issue in distribution systems with superconductor-based fault current limiter (SFCL) was investigated. To do so, recloser, fuse, resistance SFCL, loads, and lines are combined. They, finally, conducted required experimental investigations for application of SFCLs in a distribution network, resolving and improving reclose-fuse operation and coordination issues [5].

Another reference suggested a method to achieve threshold value of DG capacity outside the state in which the reclose-fuse coordination is lost. Mathematical relations are applied to enable protective configurations and calculate threshold values. Three reliability indices, i.e., SAIFI, SAIDI, and ENS, are calculated and compared in RBTS 2 Shane. Results indicate that the suggested method is sensitive to

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reliability of the system. In addition, a simple modification of protective system was presented as a primary solution [6].

Li et al. in [7] defined a new reliability index and applied the region-network method for evaluation of this hybrid index in presence of DG units. Simple genetic algorithm (GA) is improved using a multi-population method. Abdi et al. in [8] placed recloser and separator key to improve reliability using a cost/profit analysis-based methodology. Improved PSO-based hybrid method and Monte Carlo simulation were applied. Simulations were conducted on a real Iranian network. Dehghani et al. in [9] determined number and position of reclosers to improve feeder reliability using GA. The proposed method tried to streamline structure of the problem, increase precision, and reduce time. Outcomes are expressive of the fact that the proposed technique is advantageous.

To reduce the total power loss and to improve the voltage profile of the radial distribution systems in the presence of Distributed Generation unit, a new method based on a Bacterial Foraging Optimization algorithm is proposed in [10].

For optimal planning of multiple distributed generation (DG) [11], an improved non-dominated sorting genetic algorithm-II (INSGA-II) has been proposed.

For optimal location and sizing of distributed energy resources, a hybrid configuration of ant colony optimization (ACO) with artificial bee colony (ABC) algorithm called hybrid ACO–ABC algorithm is presented [12] in a recent advancement. To achieve advantages of the global and local search ability of ABC and ACO algorithms, the proposed algorithm is a combined strategy based on the discrete (location optimization) and continuous (size optimization) structures, respectively.

In this study, attempts are made to make daily exploitation of photovoltaic units in order to increase profit of exploitation considering impacts of distribution network. Our variables are charging and discharging batteries during different hours of the day. Sections for generation of electrical energy perform in several modes, ranging from distribution posts and/or transmission network to photovoltaic systems that generate electrical power in some hours of the day. While, batteries serve as a consumer in charged mode. We intend to configure daily charges and discharges in such a way to obtain the least energy expense and highest profit. In addition to increased exploitation profit of reliability indices, i.e., index of undistributed energy, would be examined in this study so that an optimized operation would be obtained in an optimized condition. All simulations were conducted and examined in MATLAB programming space on the IEEE standard network.

2. BEE COLONY OPTIMIZATION ALGORITHM

Bee Colony Optimization Algorithm was proposed by A. Afshar to solve optimization problems like optimized performance of water tank [13]. Afterwards, it was applied in such other problems as clustering [14], estimation of state of distribution network [14], and rearrangement of distribution network [15].

Bee Colony Optimization Algorithm undertakes to simulate mating process of honey bee queens that starts with flight of the queen intending to attract male bees which then go to outbreed the queen in the air. Searching for this algorithm should be based on population in which group performance of bees are utilized including queens, worker bees, and drones.

Nuptial flight might be taken as a series of passages among state spaces where queen flies with different speeds and mates with drones which are probably there. At the beginning of the flight, queen has a primary energy. She returns the hive when her energy is less than a threshold limit or her spermatheca is full.

2.1. Stages of HBMO Algorithm

Honey-Bees Mating Optimization (HBMO) algorithm is summarized in five chief stages, as follows:

1. The algorithm starts with the mating-flight, where a queen (best solution) selects drones probabilistically to form the spermatheca (list of drones). A drone is then selected from the list at random for the creation of broods.

2. Creation of new broods (trial solutions) by crossoverring the drones' genotypes with the queen's.

3. Use of workers (heuristics) to conduct local search on broods (trial solutions).

4. Adaptation of workers' fitness based on the amount of improvement achieved on broods.

5. Replacement of weaker queens by fitter broods.

2.2. Basic Stages in HBMO Algorithm

Nuptial flight by queen is performed together with a number of drones that pursue queen. In this procedure, queen mate with several drones for several times. In each mating, sperm enters spermatheca of the queen, which applies a mixture of the sperms to sprawl eggs. In this process, queen mates with drones with whom she randomly confront according to the following probability law that serves as a metal-plating function [13].

$$prob\left(D\right)=e^{\frac{-\Delta(f)}{s(t)}} \tag{1}$$

Where,

Prob (Q,D) is probability of addition of drones (D) in spermatheca of the queen (Q) as a successful mating. $\Delta(f)$ is absolute value of the difference between D objective function (f(D)) and Q objective function (f(Q)). S(t) is velocity of queen at *t* moment.

Nuptial flight might represent a movement in time and space where queen confronts with different drones in different times and locations. Given the nature of the function, possibility of mating is certainly high at the beginning of the flight when queen has high speed and/or at the time when capabilities of drones are close to those of queen.

After each replacement in space and elapsing of time, queen's primary energy and velocity is changed based on following equations:

$$R\left(t+1\right)=\beta\times R(t) \tag{2}$$

$$Z\left(t+1\right)=Z\left(t\right)-\gamma \tag{3}$$

Where,

β is a coefficient belonging to the interval [0,1], and γ is the amount of reduction in queen's energy upon each movement. Queen's velocity at the beginning of the flight is selected in a random way.

At the beginning of each nuptial flight, drones are randomly selected by queen based on above probability function. If mating is successful, drones' sperms are saved in spermatheca of the queen until either it is filled up or her energy runs out. When queen terminates mating, hatchlings start to be generated until a pre-determined number is covered. Each queen randomly selects one sperm from her spermatheca. New hatchlings (trial solutions) are generated using genotypes of queen and drones. Workers, then, are selected to improve and care from newborns based on their capabilities.

One advantage of HBMO algorithm as to other classic ones is the manner new hatchlings (trial solutions) are generated. Since queen makes use of drones' sperm, she is able to utilize different genotypes of drones. This increases possibility of better replies (more suitable newborns). Worker bees are responsible for safekeeping hatchlings and feeding queen. Therefore, workers are able to work as a revealer (mutation operator) to improve newborns' conditions. Newborns are arranged based on their fitness function. The best newborn replaces queen if it is found to be better that her. Other hatchlings are taken as drones in next mating processes. This is continued until convergence criteria are met and/or nuptial flights are complete.

3. OPTIMIZATION OF THE PROBLEM USING HBMO ALGORITHM

To apply the HBMO algorithm on a problem, following steps are to be taken:

Step 1) Definition of problem's input data: In this stage, input data including length of lines, rate of damages, average repair time of lines and locations nominated for recloser installation, queen's velocity at the beginning of nuptial flight (S_{max}), queen's velocity at the end of nuptial flight (S_{min}), speed reduction coefficient (α), frequency, number of workers (N_{worker}), number of drones (N_{drone}), dimensions of queen's spermatheca (N_{sperm}), and number of hatchlings (N_{brood}) are defined.

Step 2) Formation of a random primary population: In this stage, a random primary population is generated based on state variables and are coded as follows:

$$\begin{aligned} Drones &= \left[D_1, D_2, \ldots, D_{N_{Drone}}\right]^T \\ D_1 &= \left[Can_1, Can_2, \ldots, Can_n\right], \qquad i = 1, 2, \ldots, N_{Drone} \end{aligned} \tag{4}$$

Where,

D_i is the *i*-th drone, N_{drone} is the number of drones, *n* is the number of locations nominated for installation of recloser, and the number zero is for the state of non-installation of recloser.

Step 3) Calculation of objective function: For each possible reply in population X_i, the value of objective function is calculated.

Step 4) Examination of problem's limitations: Examine the purview of limitations cited in problem codification section. Accept that member of the population in case all limitations are covered; otherwise, reject it.

Step 5) Selection of queen: After arrangement based on value of objective function for population, the best response (Fbest) should be selected as queen.

Step 6) Creation of queen's random speed:

$$H_{queen} = rand\,(.) \times \left(H_{max} - H_{min}\right) + H_{min} \tag{5}$$

Step 7) Selection of the matrix for queen's sperm storage (nuptial flight): Queen randomly selects a drone during her flight to form the matrix for queen's sperm storage. According to probability functions, possibility of mating is calculated, which is a number between 0 and 10. If mating is successful, drone's sperm is saved in queen's spermatheca until either it is filled up or queen's velocity is leveled.

$$Sp_i = \left[Can_1, Can_2, \ldots, Can_n\right], \qquad i = 1, 2, \ldots, N_{Sperm} \tag{6}$$

Where, Sp_i is the *i*-th newborn sperm in queen's spermatheca.

Step 8) Newborn generation stage: A population of newborns is generated based on queen-drone mating (crossing operator). Sperms are retrieved from within the spermatheca in a random manner. The *i*-th person is generated as follows: firstly, the *i*-th member is randomly selected from queen's spermatheca, and an integer number (m) is then randomly generated between 1 and n. The *i*-th hatchling is generated as per the following process.

$$Y_{be} = \left[Y_{be}^1 Y_{be}^2 \ldots Y_{be}^n\right]$$

$$Spe_i = \left[Sp_i^1 Sp_i^{21} \ldots Sp_i^n\right]$$

$$Brood_j = round\left(\bar{Y}_{be} + \mu\left(Y_{be} - Spe_i\right)\right),\ j = 1, 2, 3, \ldots, N_{Brood}$$

(7)

Where,

$Brood_j$ is the *j*-th newborn.

Step 9) Workers feeding newborns and queen with royal jelly: In this stage, after workers improve a series of generated replies, they apply intelligent functions and operators. In the beginning, *i*-th hatchling is randomly selected, and an integer (B_1,B_2) is then randomly selected between 1 and n. It is supposed that $B_2 \rangle B_1$. In this case, newborns are changed and improved as follows:

$$\begin{aligned}
&Brood_1(j) = Brood_1(j) \quad if \quad j \le B_1 \\
&Brood_i(j) = rand(.) \times \left(X_{max}^j - X_{min}^j\right) + X_{min}^j, \quad if \quad B_1 \le j \le B_2 \\
&Brood_1(j) = Brood_1(j) \quad if \quad j \le B_2 \quad if \quad j \ge B_2, i = 1, 2, 3, \ldots, N_{worker}
\end{aligned} \tag{8}$$

Where, X_{max}^j and X_{min}^j are maximum and minimum values of *i*-th state variables, respectively.

Step 10) Calculation of value of objective function for newly generated responses.

Step 11) Examination of final criterion: If the final criterion is met, finish the algorithm; otherwise, put aside all previous responses from trial ones and move back to stage 2 until convergence criterion is met.

4. RESULTS OF SIMULATIONS

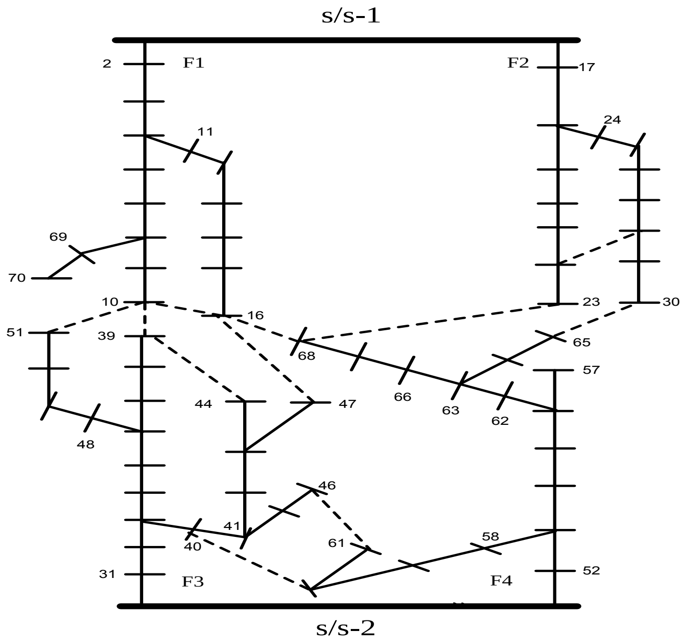

Figure 1. *Single-line scheme of the 70-bus IEEE test network*

Scenario 1: Exploitation cost considerations

In the first scenario, the charge and discharge states of Battery Energy Storage Station (BESS) are planned so that capital recovery occurs in the least number of years through the profit gained from exploitation cost optimization. The charge and discharge states of the batteries are graphically shown in Figure 2. According to the figure, from the beginning of the day until midday, the battery is charged up by the network, and then it returns the stored energy to the network for the rest of the day. In other words, during off-peak times, the battery is recharged, and during peak times, the battery is discharged at a higher rate. Since the photovoltaic system generates power during daylight hours, the charge and discharge rates are relatively low because the batteries are quite charged before the sunlight. Moreover, since power is injected into the network by the photovoltaic system, there is no need to discharge the batteries during daylight hours.

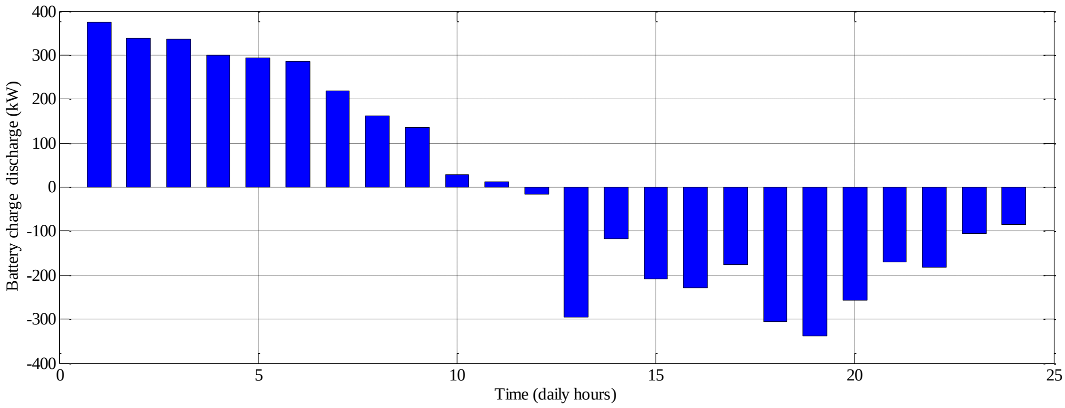

Figure 2. *Battery charging and discharging schematics of scenario 1 (positive parts are related to charging and negative parts are related to discharging)*

Figure 3 shows the amount of power received from the distribution network station in optimized mode. Figure 3 also displays the power profile received from the station before the presence of photovoltaic resources and BESSs.

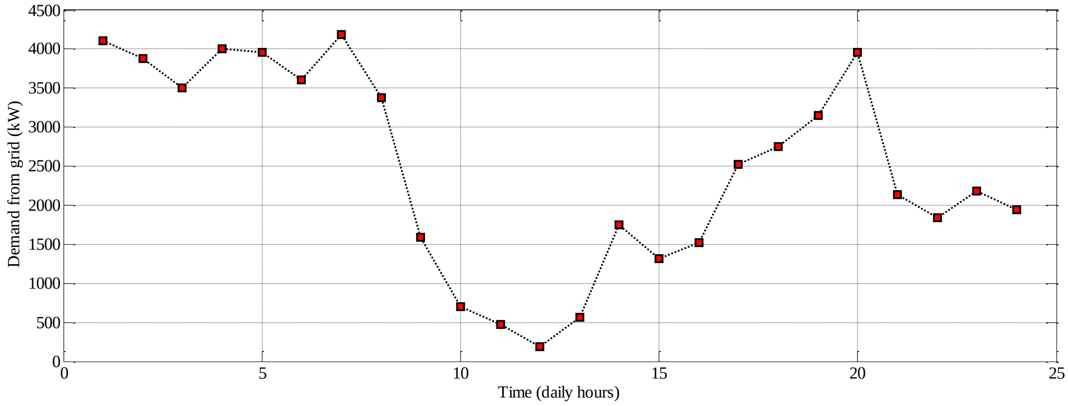

Figure 3. *Optimal demand sent to the power network in scenario 1*

By comparing these two profiles, it is known that the power output from the network is higher in the optimized mode during the early hours of the day (non-peak hours). The energy price is lower at these hours because BESSs are charged then. Therefore, it is the best time to charge the BESSs. During the midday, there is sunlight, and therefore, power can be injected into the network by the photovoltaic resources, thus receiving less power from the station. Therefore, in Figure 3, the graph area associated with the midday hours is much less than that in Figure 4. In the late hours of the day, energy consumption as well as energy price is higher compared with the rest of the day. Meanwhile, the stored power is injected into the network by the BESSs, which will reduce the peak demand on the network and the power output from the station. Hence, it will reduce the energy exploitation cost of the network.

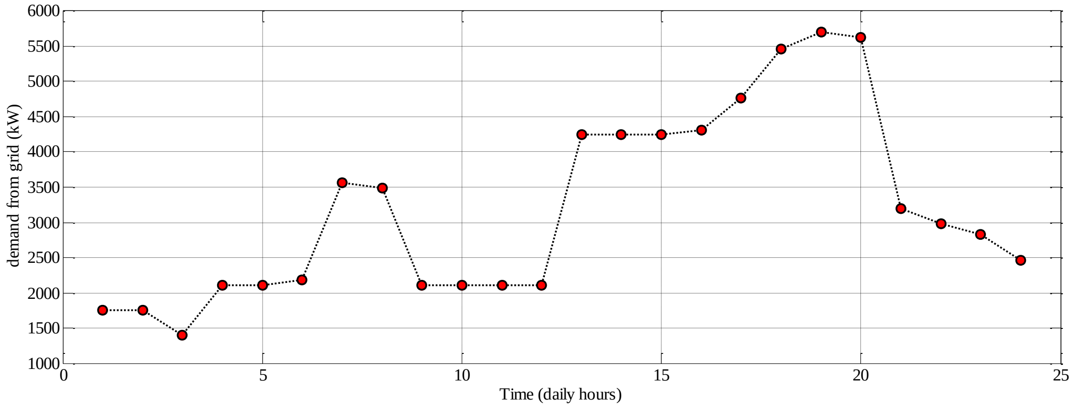

Figure 4. *Normal demand on the electricity network*

The total cost of network exploitation from photovoltaic resources and BESSs in optimized mode is 202281,777 dollars per year, while in the normal mode; it costs 288247.463 dollars per year. In other words, in the optimized mode, the exploitation cost decreased by about 30%, which can be used for capital recovery. The investment cost for five photovoltaic and storage units is 1320000 $. By calculating the cumulative exploitation profit (difference between exploitation costs in both the normal and optimized modes), and taking into account the net present value, the number of years required for capital recovery can be obtained. Figure 5 shows the required number of years by presenting the cumulative exploitation profit obtained in optimized mode along with the investment cost. According to the figure, one year is required for the capital recovery. In other words, in a 20-year period, the installed units can be used 9 years free of charge. The net profit for this 10 year period is 2204205.62 $.

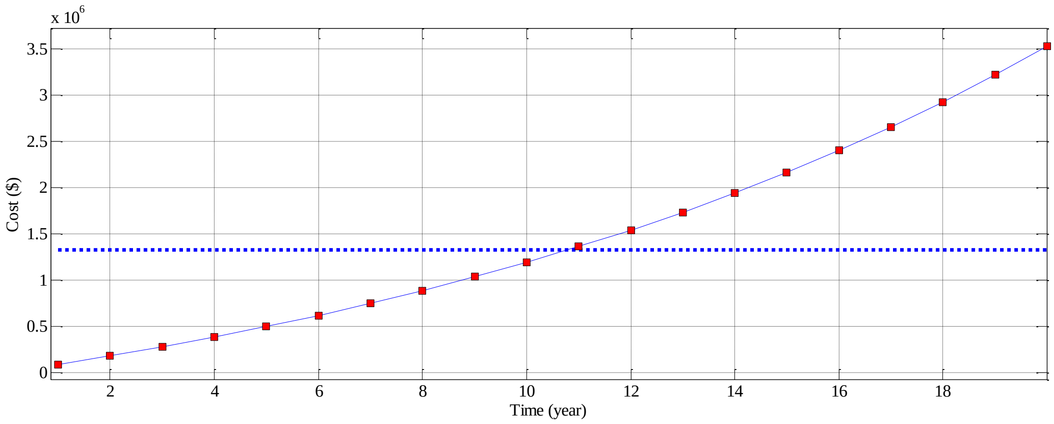

Figure 5. *The manner investment expense is returned in scenario 1*

Scenario 2: Consideration of exploitation and reliability expenses

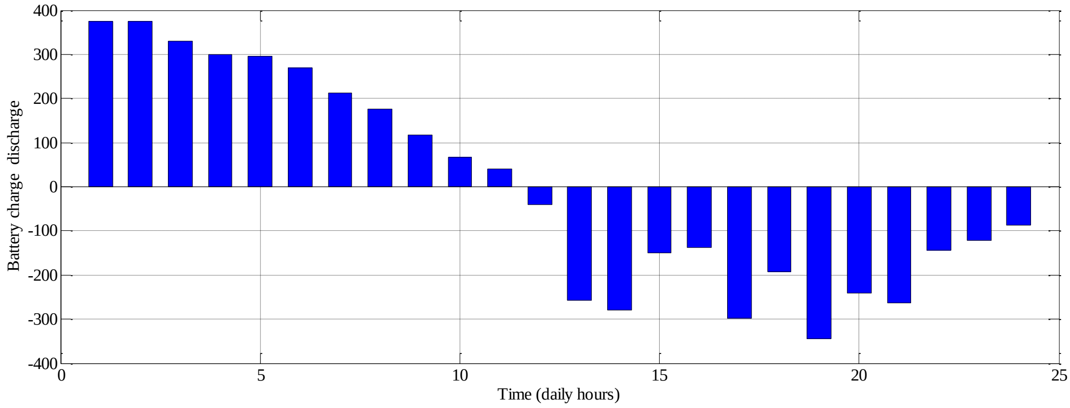

Figure 6. *Charging and discharging scheme of batteries (positive sections represent charging and negative ones discharging)*

As shown in the Figure 7, price and consumption of energy is low in primary hours of the day, because of which electrical storages are charged in these hours. In middle hours, electrical storages are charged and sunlight starts to glow. Thus, charging and discharging are still unnecessary. In final hours of the day, electrical storages are discharged and power profile received from the network is decreased.

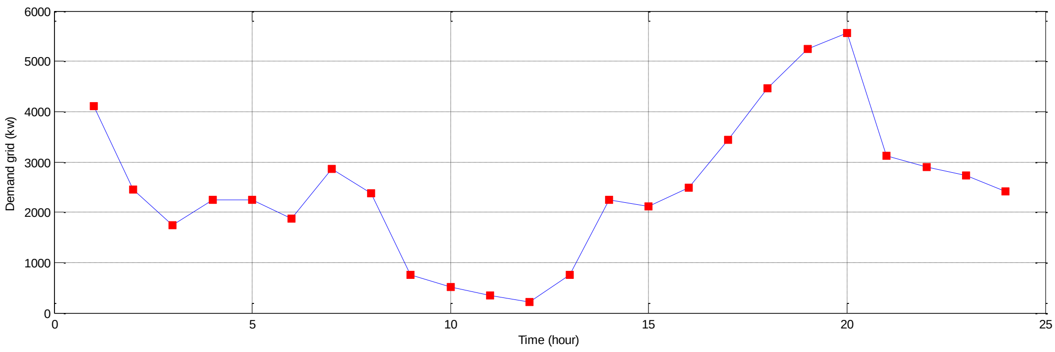

Figure 7. *Optimized demand from power network*

Considering reliability expense and exploitation expense, total expense for annual optimization of the network is equal to 220851.7385 USD. The same expense would be annually 313883.811 USD for the network being in normal states. Although exploitation expenses would be reduced up to 29% in optimized state, investment expenses are returned in relatively fewer years in this state. The number of years required for return of investment is between 10 to 11 years in this state, as shown in the Figure 8. It is safe to say that equipment is used for free for 10 years in a 20-year period under these conditions. Pure profit of this 10-year period is 2493895.6138 USD.

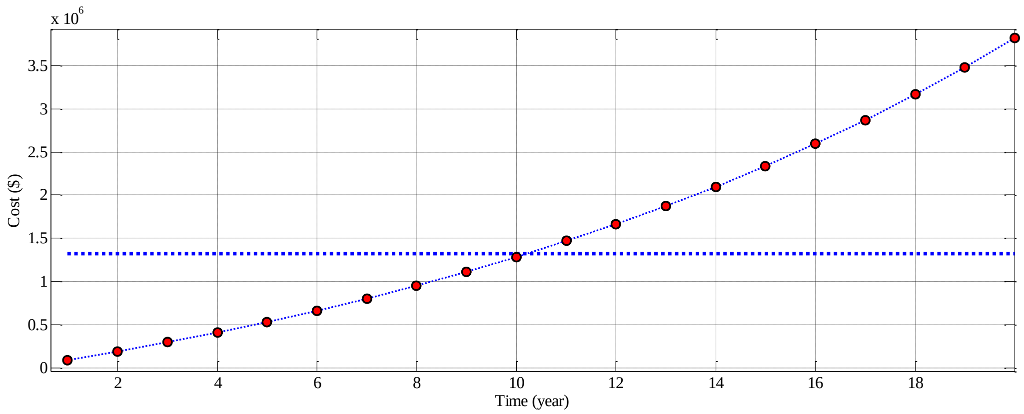

Figure 8. *The manner investment expense is returned in scenario 2*

5. CONCLUSION

In this article, a framework for safe optimized exploitation of photovoltaic resources and electrical storage in distribution systems was proposed. Reduced exploitation expenses were taken into account aimed at quicker return of investment expense of optimization objective function. To do so, several photovoltaic resources and electrical storage were adopted as distributed generation. Bee Colony Optimization Algorithm was applied in order to solve optimization problem. Additionally, all simulations were conducted in MATLAB with numerical modeling.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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