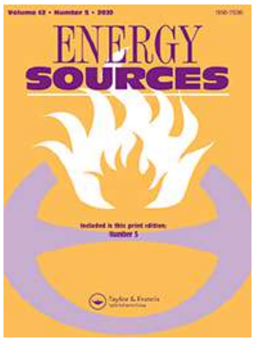

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Developing a mathematical model of location decision optimization for solar cells using genetic algorithm

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ABSTRACT

With growing proliferation of environmental pollution and reduction of energy sources, human being has been always looking for a solution to reduce pollution. One of these solutions is to use solar energy. In this research, a mathematical model is developed for optimization location decision of solar cells to minimize the operational and investment costs. The location of placement and the type of solar technology is planned and optimized by Genetic Algorithm (GA). To show the validity of the model, an accurate solving method is applied for small dimensions. Then, the GA efficiency is shown by comparing GAMS and GA results in large dimensions using the optimum values of the GA parameters. Finally, the applicability of the proposed model is presented for Jarghoyeh power plant in Iran. The results indicate that GA with spending less time could find better answers in comparison with GAMS. The results show the effectiveness of the proposed model.

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Optimization; genetic algorithm; solar energy; Jarghoyeh power plant; solar technology type

Introduction

In recent years, the growth of energy consumption in Iran is more than five times the average growth of energy consumption in the world. Considering the total expenses, about 5 billion dollars of energy is wasted, which is more than the average annual not-oil exports during the past 10 years (Ekrami and Sadeghi 2008). Therefore, optimum energy consumption is of high importance, which is made possible with energy management in energy-consuming sectors. Electricity energy is the main source of greenhouses gas emission in the world. Based on the calculations, 5.37% of carbon release in the world arises from power production activities (Balat and Balat 2009; Omer 2008). Since more than 90% of energies are supplied by underground and fossil resources, which are limited and ending, this issue is of high importance. Therefore, proper design of energy production power plants should be turned into a national determination to serve ourselves and next generations (Asumadu-Sarkodie and Owusu 2016; Georgiou, Polatidis, and Haralambopoulos 2012).

This paper develops a mathematical model considering technology variety to reduce various costs of investing and operating solar cells in designing power plants, particularly Jarghoyeh power plant as a case study. For location decision optimization of solar cells, the Genetic Algorithm (GA) is applied. In the basic model, the concept of various technologies of solar systems has not been articulated well and only investment costs of solar systems have been considered, while these systems impose various costs every year, which should be taken into account. Moreover, in the basic model, solar cells have been placed in all areas that require more accurate location of placing by determining the place and dimension of solar cells with the aim of reducing various costs of investing and operating by various technologies.

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Literature review

Considering the importance of using solar energy as a clean energy, research and study on producing and commercializing solar cells are increasing. One of the problems of solar cells mass production is low efficiency and high cost. Based on this problem, researchers have attempted to present proper methods and approaches to implement renewable energies.

Ghoneim (2006) presented the optimized design of photovoltaic systems for water pumping for the first time. This research has first simulated the intended system by using electrical science rules, and then the results were analyzed and compared with DC motors (Ghoneim 2006).

Cai et al. (2009) planned a comprehensive system to manage renewable energies. In this study, they used a two-stage planning model with periodic parameters in order to present a model for supporting renewable energies' macro-management (Cai et al. 2009).

Using integers planning technique in their study, Muis et al. (2010) presented an optimized pattern for electricity production with the purpose of reducing CO2. The results of this study showed that an optimized pattern of gas mixed cycle, natural gas mixed cycle, nuclear energy, and biomass energy arising from landfill is selected in order to reduce CO2 release (Muis et al. 2010).

Arnette and Zobel (2012) presented an optimized pattern for regional development of renewable energies in the east of USA In this research, a mathematical model is presented with the purpose of reducing the cost of renewable energies, based on which the most appropriate urban area will be determined for development of renewable energies (Arnette and Zobel 2012).

Shafiullah et al. (2012) examined the renewable energies potential and identified some regions of Australia that have the potential of generating renewable energy particularly solar energy and wind energy. Presenting a mixed optimized model, they developed a prospect of wind energy in an area of Australia considering production, energy, and reduced emission costs (Shafiullah et al. 2012).

In their study, Xydis and Koroneos (2012) studied the energy system of Greece due to inconsistency between energy supply and final consumption. The final purpose of this study was to present an optimized pattern in order to meet the requirement of energy from municipal solid waste in each area (Xydis and Koroneos 2012).

Employing optimization approach in their study, Koo, Han, and Yoon (2011) examined CCS technology integration, the trade of release, and fuel price inconsistency for energy sustainable planning. Having presented a mathematical model, they adopted the approach of sustainable optimization in the circumstances of uncertainty and fuel price fluctuations (Koo, Han, and Yoon 2011).

Dominguez, Baringo, and Conejo (2012) proposed a method to illustrate the curve of energy supply in central solar power plants. They used the model of linear planning and maximized profit target function in the study (Dominguez, Baringo, and Conejo 2012).

Ferrer-Martí et al. (2013) presented a linear integer mathematical model in order to optimize power supply system using renewable energies. They investigated hybrid and wind photovoltaic systems due to their continual growth and development (Ferrer-Martí et al. 2013).

Ismail, Moghavvemi, and Mahlia (2014) analyzed optimizing solar panel costs. To do this, they presented a scenario-based mathematical model with the purpose of reducing solar panels' operational cost on the grounds that all demands will be met (Ismail, Moghavvemi, and Mahlia 2014).

Ma et al. (2015) analyzed independent photovoltaic systems as an effective tool in power supply of remote areas. In this type of renewable energy system, there is no relationship between different systems of electricity production in different areas, and only sub-systems of each area are connected. A mathematical model with economic criteria and reliability has been presented for optimization (Ma et al. 2015).

Jung and Villaran (2017) designed an optimized system based on renewable energies. To do this, a mathematical model of energy distribution consistent with customer needs has been presented that has determined the final amount and the type of distributed energy in each system of energy production (Jung and Villaran 2017).

Sundaramoorthy (2017) optimized the hybrid electrical energy production systems. To optimize these solar energy-based systems, determining the dimension of each panel is of highest importance. Moreover, a mathematical model is presented with the purpose of determining the size of solar panels in order to minimize the whole costs of system (Sundaramoorthy 2017).

The summary of aforementioned studies are synthesized into Main Limitations, Decision Variable, and Objective Function as seen in Table 1.

From the literature, it may be pointed out no research with objective function of system expense minimization has yet been published including launch costs, transfer costs, and costs of wiring network that show the costs of investment in solar energy system and annual operational costs. It means all these expenses have not been observed together. Moreover, these expenses are consistent with the type of technology employed, which has not been witnessed in other researches.

The proposed mathematical model

Consider an urban network, which requires installation of solar panels at a different point. The function of these solar panels is electricity production for electrical appliances consumption at that point. These locations have predetermined demands in which the number and the surface of solar panels should be set up consistent with these demands. There are different types for installation of these solar panels in which each one has different technologies. Solar panels with high technology have high purchase cost and high launch cost; low technology solar panels have low purchase cost and low launch costs. On the other hand, solar panels with high technology will absorb more solar energy with potential of storage and transfer to other high-demand locations. While solar panels with low technology absorb less solar energy and might fail to meet the requirement of that point, it might be necessary to provide electricity from other points.

As stated above, since the whole urban need should be met, it is necessary to provide electrical charge displacement between different points. It is also essential to have wiring between different points of this urban network. The costs of wiring and creating infrastructures should also be considered. On the other hand, the length of wiring between different points is more than the predetermined level. Therefore, there is an attempt to have the least electrical charge displacement at each point by choosing proper technology.

Therefore, the main purpose of this section is to determine the place of installation for solar panels, the type of technology employed at each point and the amount of electrical charge displaced to minimize the launching and operating costs of this project. On the other hand, the installation of solar panels is simple; it does not require wire, cable, or other energy sources. In spite of geothermal energy and wind stations that require excavation machineries, solar panels do not require these machines and could be installed on the roofs. Therefore, a new location is not needed and every

Table 1. Summary of investigated researches.

	Objective function	Decision variables		Main limitation	
Researchers	optimization	Equipment dimension	Location of placement	Capital	Space
(Ghoneim 2006)	*	*		*	
(Cai et al. 2009)		*		*	*
(Muis et al. 2010)			*		*
(Arnette and Zobel 2012)	*		*	*	*
(Shafiullah et al. 2012)	*		*		*
(Xydis and Koroneos 2012)			*	*	
(Koo, Han, and Yoon 2011)			*	*	
(Dominguez, Baringo, and Conejo 2012)	*		*	*	*
(Ferrer-Martí et al. 2013)	*	*			*
(Ismail, Moghavvemi, and Mahlia 2014)	*	*			*
(Ma et al. 2015)	*	*		*	*
(Jung and Villaran 2017)	*		*		*
(Sundaramoorthy 2017)	*		*		*

residential or commercial location could guarantee its power supply. In addition, they could be installed by new distributive methods; hence, no macro-installation is needed.

The assumptions of this research are as follows:

- Each solar panel has one or more batteries with specific capacity in which decision should be made regarding the number of batteries.
- Each point of network has predetermined demand which should be met.
- Electrical charge transfer system has a specific function and a percent of energy might be wasted within transfer.
- The minimum and the maximum acceptable voltage should be observed.
- The amount of ampere available should be less than its maximum for each point of demand.
- Various technologies in solar panels are different in terms of efficiency, launching costs, and operational costs.

Indices

d, p	Consumption points indices
a	Solar system technology indicator
c	Type of wiring network indicator
b	Type of solar battery

The parameters and decision variables are presented in Appendices A and B.

Mathematical model

In Equation (1), objective function states system costs minimization, which include launching, transfer, and wiring network costs. Section 1 to section 3 of objective function states the costs related to investment in solar energy system, but the last section of objective function states the annual operational costs. These costs are related to the type of technology employed, which has not been seen in similar researches. Equation (2) guarantees that energy transfer takes place only through a network that had been launched before (Ferrer-Martí et al. 2013).

$$\min Z = \sum_p \sum_a CA_a xa_{pa} + \sum_p \sum_d \sum_c L_{pd} CC_c xc_{pdc} + \sum_c CM_c xm_c + \sum_a C_a^{Oper} \tag{1}$$

$$\sum_d \sum_p xc_{pdc} \leq (P-1) Xm_c \qquad \forall c = 1, 2, \ldots, C \tag{2}$$

Equation (3) guarantees that demand will be met at different points (Ismail, Moghavvemi, and Mahlia 2014). Equation (4) states that one type of wiring network should be used in all areas. This equation is one of the research innovations in the model.

$$\sum_p fp_{pd} + \sum_a xa_{da} EA_{pa} \geq ED_d \qquad \forall d = 1, 2, \ldots, D \tag{3}$$

$$\sum_c xm_c = 1 \tag{4}$$

Equation (5) states the maximum length of wire network at each point. This limitation is also considered as research innovations in the model. The left hand of Equation (6) states the useful capacity of battery and the battery consumption. In other words, the consumption of each battery should be less than its useful voltage (Ferrer-Martí et al. 2013).

$$\sum_d L_{pd} xc_{pdc} \leq L_{\max} \tag{5}$$

$$\sum_{b} EB_b xb_{pb} + (\frac{VB}{DB}\sum_{d}\frac{ED_p}{\eta b\ \eta c})(1 - xa_{pa}) \geq (\frac{VB}{DB}\sum_{d} fp_{pd} + ED_p) \quad \forall p = 1, 2, \ldots P \tag{6}$$

Equation (7) states that electrical charge transfer between two points depends on the wiring between these two, and if this electrical charge transfers according to wiring efficiency, customers demand will be met (Ferrer-Martí et al. 2013). Equation (8) determines a minimized amount between voltage of solar center placement point and demanded point. This amount is stated according to minimum and maximum voltage and it attempts to produce average voltage for all demanded points (Ismail, Moghavvemi, and Mahlia 2014).

$$fe_{pd} \leq (\sum_{d}\frac{ED_p}{\eta b\ \eta c})\sum_{c} xc_{pdc} \quad \forall p = 1, 2, \ldots, P\ d = 1, 2, \ldots D \tag{7}$$

$$\begin{gathered} v_p - v_d \geq \frac{L_{pd}\ Rc_c\ fp_{pd}}{V_n} - (V_{\max} - V_{\min})(1 - xc_{pdc}) \\ \forall p = 1, 2, \ldots, P\ c = 1, 2, \ldots, C\ d = 1, 2, \ldots, D \end{gathered} \tag{8}$$

Equation (9) calculates the amount of ampere at each point based on transfer system efficiency and minimum voltage and it guarantees that this amount of ampere will be less than its maximum (Ferrer-Martí et al. 2013). Equation (10) calculates all operating costs. This equation has not been seen in similar researches; it is considered as the innovation of this research. In the first section, the costs of transfer from solar panels; in the second section, the costs of receiving electrical charge from other points in order to meet the needs of that point; in the third section, the costs of electrical charge storage in embedded batteries; and finally in the fourth section, the costs of maintenance and repair have been calculated.

$$\frac{fd_{pd}}{V_n} - (\sum_{d}\frac{ED_p}{V_{\min}\eta c})(1 - xc_{pdc}) \leq IC_c \quad \forall p = 1, 2, \ldots, P\ d = 1, 2, \ldots D\ c = 1, 2, \ldots, C \tag{9}$$

$$\begin{aligned} C_a^{Oper} = {} & C_a^{Send}(\sum_{d}\frac{ED_p}{\eta c})xa_{pa} \\ & + C_a^{recive}(\sum_{p}\frac{fp_{pd}}{\eta b})xa_{da} \\ & + \sum_{p} C^{hold} VB\ xb_{pb} xa_{pa} \\ & + \sum_{p} \mathrm{C}_a^{\mathrm{Re}} \mathrm{Re}_a \quad \forall a = 1, 2, \ldots, A \end{aligned} \tag{10}$$

Equation (11) calculates the reliability of each installed solar system. The maximum electrical resistance has been calculated and shall be deducted from initial reliability. Electrical resistance is calculated by dividing voltage into electricity intensity. The resistance is different at each point; therefore, the reliability of a system with specific technology is different according to place of installation. Equations (12) and (13) determine the type of decision variables.

$$\mathrm{Re}_{pa} = \mathrm{Re}_a^0 - \sum_{d}\frac{v_p}{IC_c L_{pd}} xc_{pdc} xa_{pa} \quad \forall p = 1, 2, \ldots, Pa = 1, 2, \ldots, A \tag{11}$$

$$xa_{pa}, xc_{pdc}, xm_c \in \{0, 1\} \tag{12}$$

$$fp_{pd}, Re_{pa}, C_a^{Oper} \geq 0 \tag{13}$$

Genetic algorithm

The range of GA is so vast. With increasing growth of science and technology, using this method in optimizing and problem-solving has been expanded. GA is a subset of evolved calculations which is related directly to artificial intelligence. In fact, GA is a subset of artificial intelligence. GA could be called a method of general search which imitates the regulations of natural biologic evolution. GA implements the best survival law on problem answers in the hope of reaching better answers. In every generation, with the help of selected process corresponding with answers values and reproduction of selected answers through operators that have been imitated from natural genetics, better approximates of final answer were reached. This process causes new generations will be more consistent with problem conditions.

Before implementing a GA, a proper coding (displaying) should be considered for that problem. The typical method of displaying chromosomes in GA is binary string. Each decision-making variable is binary and then chromosome is created by putting these variables together. Although this method is the most widespread coding method, other methods such as displaying real numbers are expanding. A fitness function should also be invented to assign a value to each coded solution within implementation. Parents are chosen for reproduction and are mixed by crossover and mutation operators to reproduce new children. This process is repeated several times to create the next generation of population. Then, this population is examined and provided that convergence principles are met, the above process will be ended as shown in Figure 1. It is essential to determine parameters of this algorithm optimally in order to use GA for solving the investigated case. Therefore, GA parameter will be determined in section Adjusting Parameters of GA.

Case study

The case study of this research is related to the biggest solar photovoltaic power plant in Iran with the production capacity of 10 megawatts in the area of Jarghoyeh (located at 65 km from eastern-south of

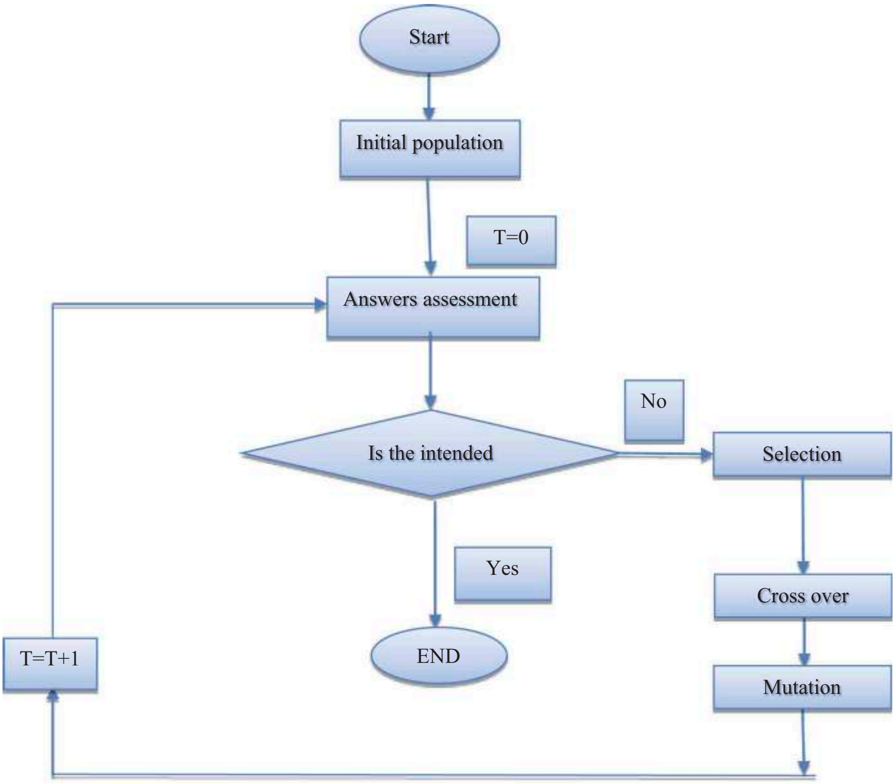


Figure 1. virtual program code of simple genetic algorithm and its flowchart.

Esfahan) launching on April 25, 2017. This power plant is composed of 39,000 solar panels with dimensions of 1, 65, and 98 cm which have been installed in a 20-hectare area. With a dedicated 3.5 km line, the electricity produced in this power plants is connected to 63 kilo-watt power post. The GIS of the candidate places for Jarghoyeh solar power plant has been shown in Figure 2. Jarghoyeh solar power plant has been built with solar tracing systems in a single step, which means solar panels of this power plant trace sun rays automatically and turn it towards sun. With regard to this solar power plant, while focusing on social responsibilities of this company, environmental protection, and using renewable energies, it can be claimed that 330 sunny days in a year in Esfahan with average of 6-h sunlight inspired professionals to maximize exploitation from this natural energy.

Having gathered necessary data on case study, 20 potential points were considered for installation of solar panels. Also, four different types of technology, one type of wiring system, and one type of solar battery were taken into account.

Result and discussion

In this section, to show the validity of the model, an accurate solving method is applied for small dimensions. Then, the GA efficiency is shown by comparing GAMS and GA results in large dimensions using the optimum values of the GA parameters. Finally, the applicability of the proposed model is presented for Jarghoyeh power plant in Iran.

Validation of the proposed model

To validate and measure the accuracy of the proposed mathematical model, it is coded in GAMS software. The results are investigated at micro level for the proposed model. For validation, five potential consumption points are considered for locating three types of technology, two types of wiring, and two kinds of solar batteries. The assumptions of the designed example for solar systems are shown in Table 2.

Other parameters have been used randomly by continuous uniform distribution. The amount of these parameters and the range of random number production are presented in Table 3. These data, as inputs for mathematical model of solar panels placing, have been given to GAMS software to implement. The results are shown in Figure 3.

As seen in Figure 3, GAMS software could find the possible answer for this problem. The best cost calculated was 1559.054. To find this answer, the software spent the time model of 1 min and 7

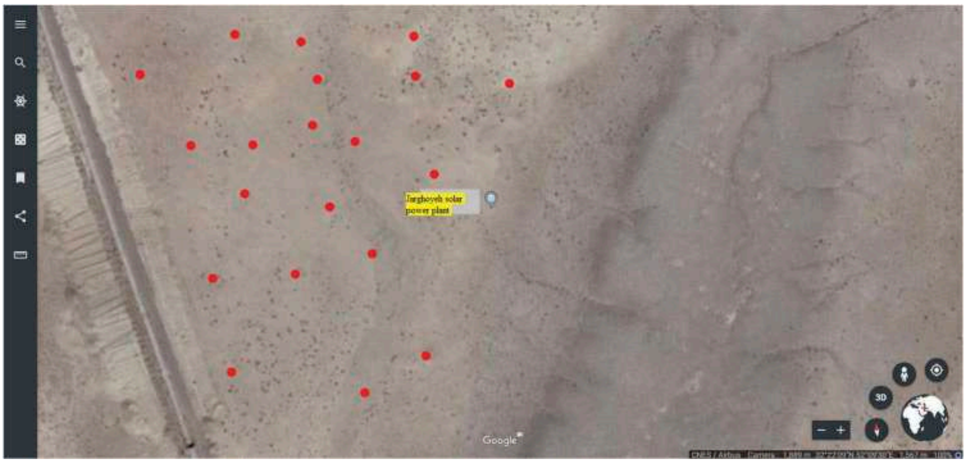


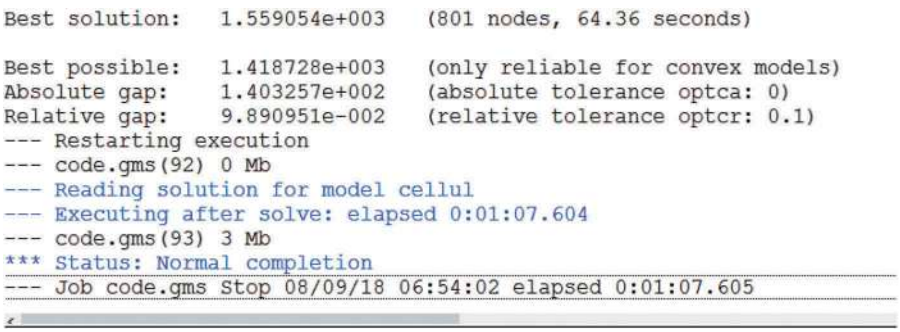
Figure 2. The GIS of the candidate places.

Table 2. Model parameters.

Parameter	Symbols	Amount
Maximum length of wiring	$L\max$	10,000
Cost of designing a wiring system	CM	100
Minimum required voltage	$V_{\min}$	1
Average required voltage	V_N	5
Maximum required voltage	$V_{\max}$	10
Required time period for each battery	VB	10
Maximum percentage of batteries charge drain	DB	0.99
Efficiency of each battery	ηb	.8
Efficiency of each solar panel	ηc	.9
Initial reliability	Re_a^0	.95

Table 3. Other model parameters.

Parameter	Symbols	Minimum	Maximum
The distance between points (km)	L_{pd}	5	10
Demands of each point (KW)	ED_p	7	9
The energy produced by each technology (Kilo Watt)	EA_{pa}	200	210
Launching cost (Million US Dollar)	CA_a	18	19
The cost producing wiring infrastructure((Million US Dollar)	CC_c	8	9
Resistance of each wire (Ohm)	RC_c	2	4
Each wire maximum ampere(Ampere)	IC_c	5	7
Battery voltage(volt)	EB_b	7	9
Point voltage (volt)	υ_p	5	6
Electricity transfer cost (US Dollar)	C_a^{Send}	2.0	3.0.
Electricity receipt cost (US Dollar)	C_a^{recive}	0.2	0.3
Battery charge cost (US Dollar)	C_a^{hold}	0.1	0.2
Repair and maintenance cost (US Dollar)	C_a^{Re}	200	300



```
Best solution:   1.559054e+003   (801 nodes, 64.36 seconds)

Best possible:   1.418728e+003   (only reliable for convex models)
Absolute gap:    1.403257e+002   (absolute tolerance optca: 0)
Relative gap:    9.890951e-002   (relative tolerance optcr: 0.1)
--- Restarting execution
--- code.gms(92) 0 Mb
--- Reading solution for model cellul
--- Executing after solve: elapsed 0:01:07.604
--- code.gms(93) 3 Mb
*** Status: Normal completion
--- Job code.gms Stop 08/09/18 06:54:02 elapsed 0:01:07.605
```

Figure 3. GAMS output for mathematical model validation.

s. The amounts of gap in the outputs reveal that GAMS software has worked out its output with some errors due to over-complexity of mathematical model as seen in Figure 3. The best possible placement offered by this software is shown in Table 4.

As seen in Table 4, in optimal solution, two types of different technologies have been employed. This distinction in various technologies is due to fixed and variable costs and their reliability.

Adjusting parameters of GA

To choose the optimum value for the GA parameters, the Taguchi method is used. Taguchi is a Japanese engineer who inserted revolutionary ideas and measures into comprehensive quality

Table 4. Optimal output of solar cells (GAMS software).

location	Technology 1	Technology 2	Technology 3
Point 1	*		
Point 2			*
Point 3	*		
Point 4	*		
Point 5	*		

domain. Based on the Taguchi method, design of the main component of final product cost or product development are included as follows (Chen, Wu, and Lin 2018).

- System design: system design takes place with innovation and it requires engineering knowledge.
- Parameter design: it is a key stage which determines the quantities of product parameter and the level of process factors in order to have the least sensitivity to turmoil factors.
- Tolerance design: it means spending money for higher quality materials, components, and machineries only provided that reduced deviations due to parameter design do not have necessary qualifications.

According to Taguchi method, three quantities of GA are proposed for every parameter as shown in Table 5.

For the Taguchi L9 plan, GA is implemented and the outputs are presented in Table 6. After inserting these data in Minitab software and implementing Taguchi method, S/N quantities are presented in Figure 4.

According to Figure 4, the proper quantity is the least S/N quantity for each parameter. Therefore, optimal quantities are obtained as shown in Table 7 and the other examples will be implemented with these quantities for GA.

Table 5. Parameters and their quantity levels for GA.

		The quantities of each level		
Examined algorithm	Parameter	Level 1	Level 2	Level 3
Genetic	Percentage of crossover (*Pc*)	0.7	0.8	0.9
	Percentage of mutation (*Pm*)	0.05	0.1	0.15
	Number of solutions in the population (N-pop)	50	100	150
	Maximum iteration (Max-iteration)	100	200	300

Table 6. Quantity of answer variable within Taguchi technique for GA.

	Algorithm parameters				Response
Run order	P_{cr}	P_{mut}	N- Pop	Max-iteration	Genetic
1	1	1	1	1	21.98
2	1	2	2	2	33.79
3	1	3	3	3	28.91
4	2	1	2	3	27.83
5	2	2	3	1	26.47
6	2	3	1	2	15.55
7	3	1	3	2	48.05
8	3	2	1	3	19.34
9	3	3	2	1	20.02

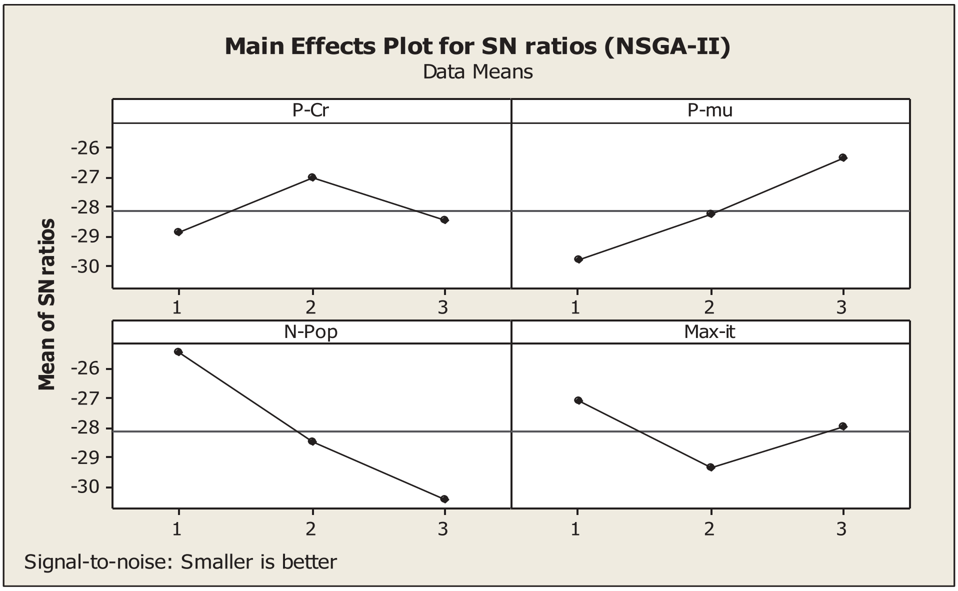


Figure 4. Taguchi method output in GA.

Table 7. Optimal value of GA parameters.

The algorithm examined	Parameter	The optimal quantity
Genetic algorithm	Percentage of Crossover (*Pc*)	0.7
	Percentage of Mutation (*Pm*)	0.05
	Number of Solutions in the Population (N-pop)	150
	Maximum iteration	200

Table 8. Numerical examples data.

Number of problems	Number of points	Number of Technologies	Number of wirings	Number of batteries
N1	4	2	1	1
N2	6	3	1	2
N3	8	3	2	2
N4	10	4	2	3
N5	12	4	3	3
N6	14	5	3	4
N7	16	5	3	4
N8	18	6	4	5
N9	20	7	4	5
N10	25	8	4	6

Effectiveness of the GA performance

In this section, the results from GAMS software and GA are compared with the produced 10 random cases in various aspects for large dimension. The data on designed example is presented in Table 8. To solve the macro problems, time required by GAMS software is 3,600 s. It is worthy noted that in this condition, GAMS software presents a reasonable answer not necessarily optimal answer. The comparing results of GAMS software and GA for the large dimension are presented in Table 9.

As seen in Table 9, GAMS software is unable to find optimal answer for the last three problems within 1 h. However, GA shows better answers with less time as compared with GAMS. Time diagram for two methods is shown in Figure 5. As seen in Figure 5, solving time by GAMS increases exponentially, while solving time by GA is linear and at minimum value. Objective value for accurate

Table 9. The comparing results of GAMS software and GA for the large dimension.

	GAMS software results		GA results		
Number of problem	Target function	Solving time	Target function	Solving time	Algorithm error
N1	8593	56.3	8561.12	18.19	0.003710
N2	12678	82.9	11659.90	21.60	0.08030
N3	22540	179.3	21624.46	34.90	0.04062
N4	39765	295.1	39040.24	49.70	0.01823
N5	66038	688.2	59674.57	58.90	0.09636
N6	103957	933.5	85634.37	79.60	0.17625
N7	259760	1247.2	237113.04	102.90	0.08718
N8	546375	2144.6	540826.92	129.70	0.01015
N9	896485	3600.0	858857.50	154.60	0.04197
N10	1065720	3600.0	1005238.01	188.10	0.05675
Average	302191.10	1282.71	286823.01	83.82	0.06115

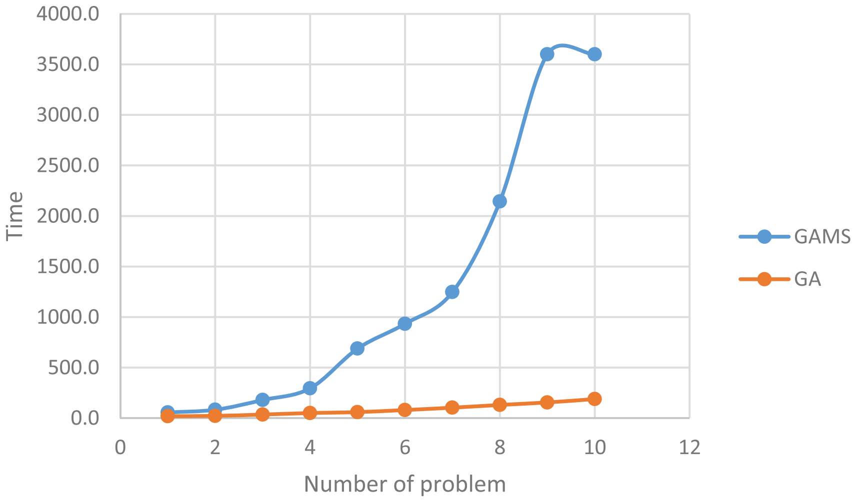


Figure 5. Comparing of time diagram for GA and GAMS.

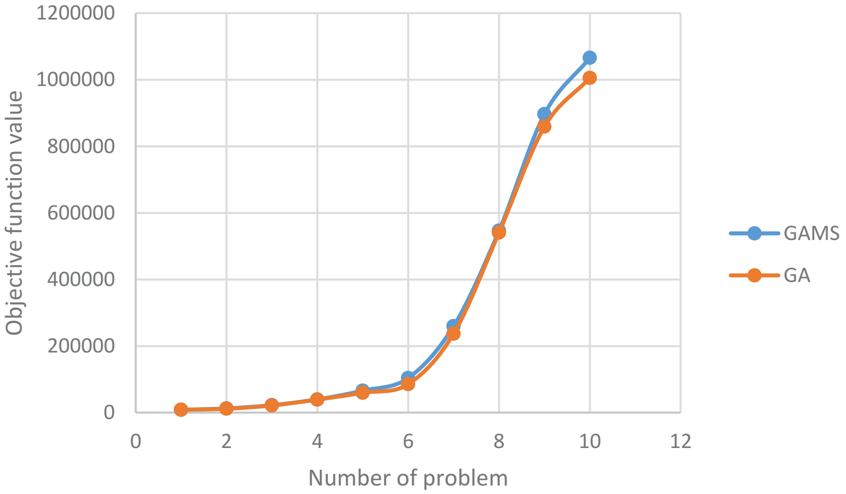


Figure 6. Objective value for GA and GAMS.

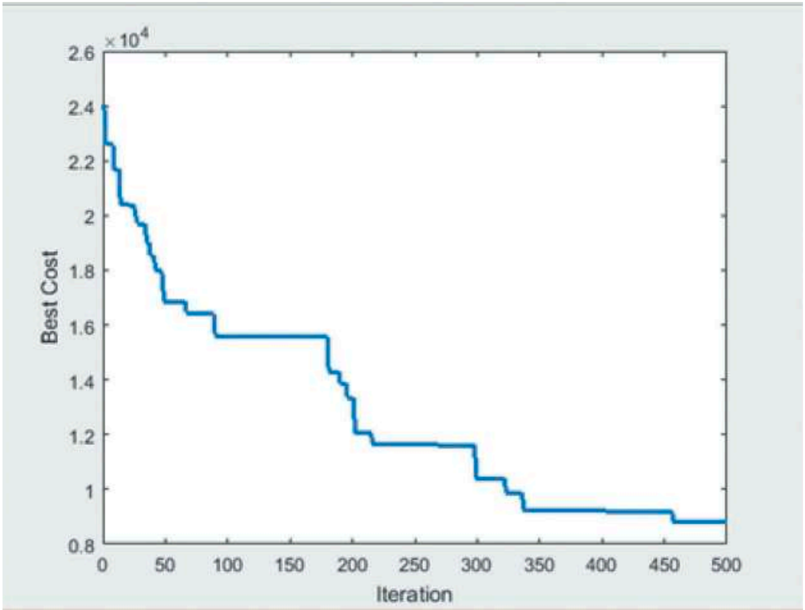


Figure 7. Genetic algorithm output for the case study.

and super-innovative solving is shown in Figure 6. Figure 6 shows that GA does not have much discrepancy with accurate solving. The problems solved by GAMS software has 6% error in this case, which indicates the proper performance of GA to find optimal answers.

Problem-solving in case study

There are 20 location candidates for solar panels and 4 technologies in this case. GA is applied to find the optimum location and the best technologies. The results are shown in Figure 7 and Table 10.

Table 10. Optimum location and the best selection of technologies for case study.

Number of potential locations	Technology 1	Technology 2	Technology 3	Technology 4
1	*			
2	*			
3	*			
4		*		
5	*			
6			*	
7				
8	*			
9	*			
10		*		
11			*	
12			*	
13				
14				*
15		*		
16		*		
17		*		
18	*			
19	*			
20				

As seen in Figure 7, GA has downward trend in expenses. It reveals the efficiency of GA in solving real problems. In order to understand better the output of this case study, the chosen locations and technologies have been presented in Table 10.

It is worthy to note that according to defined mathematical model, each of these 20 potential locations is a demand point for electricity. Therefore, according to Table 10, it has been determined that which solar panel with which technology should be placed at every point. No technology has been chosen in 7, 13, and 20 points. However, it does not mean that demands at these points should not be met. Instead, the needs of these points are stored in solar batteries by electricity produced at other points and it is transferred to these points. This plan to provide electricity is the best possible plan with the most proper technologies. This output has the least operational cost and launching cost. It is worth mentioning that no comparison with real conditions is possible due to lack of historical data on the costs of this system of producing solar energy.

Conclusion

In this paper, a mathematical model has been developed for placement of solar panels to meet the demands of solar energy in one region. In the mathematical model, different technologies with fixed and variable expenses and their reliability have been defined and implemented. Also, the mathematical model has been solved with Genetic Super-Innovative Algorithm and compared with the accurate solving method in small dimensions. The results indicate that GA with spending less time could find better answers in comparison with GAMS. GAMS software output with 0.06% errors as compared to GA does not have much discrepancy with accurate solving. It reveals the proper performance of GA in finding the optimal answer for the problem. Finally, the best location of solar panels and the necessary technologies in Jarghoyeh solar power plant have been chosen. Moreover, the following guidelines could be suggested in order to develop this research and carry out more researches:

- to consider the mathematical model of energy supply network in this research in more than one power plant and in different cities;
- to consider uncertainty in the capacity and expenses of supply in phases;
- to use sustainable optimization approach while the parameters of time and the expenses of energy transfer are uncertain.

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Appendix A: Parameters

L_{pd}	Distance between two consumption points of d and p
$L_{\max}$	Maximum length that is possible for wiring network
ED_P	Energy demand of p point
CM	Cost of designing a wiring system at each point
EA_{pa}	Amount of solar energy production with type-A system at M point
CA_a	*Cost of launching solar system with type-A technology*
CC_c	Cost of building infrastructure for type-c wiring system per meter
RC_c	Resistance of type-c wire per meter
IC_c	Maximum ampere of type-c wire per meter
$[V_{\min}, V_N, V_{\max}]$	Minimum voltage, Average voltage, Maximum voltage
EB_b	Voltage capacity of type-B solar battery
VB	Required time for type-p battery in terms of day
DB	Maximum percentage of charge drain for each battery
ηb	Efficiency of each battery
ηc	Efficiency of each solar panel
υ_p	Voltage at p point
C_a^{Send}	Cost of sending one unit of power if type-a technology is used
C_a^{recive}	Cost of receiving one unit of power if type-a technology is used
C_a^{hold}	Cost of holding electrical batteries charge if type-a technology is used
C_a^{Re}	Cost of annual repairing and maintain solar panels if type-a technology is used
Re_a^0	Reliability of solar panels with type-a technology which is determined by producer at the time of purchase

Appendix B: Decision variables

xa_{pa}	Binary variable equal to 1 if type-a technology is used at p point of solar system
xc_{pdc}	Binary variable equals to 1 if type-c wiring network is used between d and p point
fp_{pd}	Amount of electrical charge transferred between d and p point
xm_c	Binary variable equals to 1 if type-c wiring network is used
xb_{pb}	The number of type-b batteries located at p point
C_a^{Oper}	Operational costs of launched solar system
$\mathrm{Re}_{p\,a}$	Reliability of type-a Solar system located at p point