Journal of Operation and Automation in Power Engineering

vol. 11, no. Special Issue, Dec. 2023, Pages: 8-14

http://joape.uma.ac.ir

Optimization of a Hybrid Photovoltaic System with Gas Engine to Supply Electricity and Heat

D. Abdullah[1], *W.K. Al-Azzawi*[2,*], *J.K. Abbas*[3], *S.H. Talib*[4], *B.M. Ali*[5], *S.H. Hlail*[6], *A.A. Ali*[7],

M.Q. Mohammed[8], *C.I. Erliana*[9]

[1] *Department of Informatics, Universitas Malikussaleh, Aceh, Indonesia*
[2] *Department of Medical Instruments Engineering Techniques, Al-farahidi University, Baghdad, Iraq*
[3] *Department of engineering, AL-Nisour University College, Baghdad, Iraq*
[4] *Medical Instrumentation Techniques Engineering Department, Al-Mustaqbal University College, Babylon, Iraq*
[5] *Department of Construction Engineering & Project Management, Al-Noor University College, Nineveh, Iraq*
[6] *National University of Science and Technology, Dhi Qar, Iraq*
[7] *College of Petroleum Engineering, Al-Ayen University, Thi-Qar, Iraq*
[8] *Al-Esraa University, College, Baghdad, Iraq*
[9] *Department of Industrial Engineering, Universitas Malikussaleh, Aceh, Indonesia*

Abstract— *Numerous factors, such as the expansion of the growing demand for energy, depletion of fossil resources, environmental disasters caused by fossil fuels, global warming of the atmosphere, the greenhouse effect, and the need to balance the emission of polluting gases, have prompted a new scientific approach to natural renewable energies. However, large-scale electricity production and transfer to consumers are accompanied by significant losses. The purpose of this study was to design and optimize the use of a hybrid photovoltaic system and a gasoline-powered engine to generate electricity and heat. In this study, the design and operation of a hybrid photovoltaic system and a gas engine as a combined heat and power source were explored using the following three thermal loads, following electric load methods, and the GAMS-optimized simultaneous optimization model. With a description of the revenues, costs, and limitations of the problem, these optimizations were performed to reduce the net pure cost and determine the rate of return on investment, and the following results were obtained. This investigation was conducted to find ways to reduce operational costs. The amount of electricity produced by the following thermal load and optimal methods is greater than the amount of electricity consumed during the majority of hours in a day. This indicates that the system has made the decision to sell electrical energy to the network to reduce the costs associated with operating the system. When compared to the following thermal load method, the simultaneous optimal method for operation results in an approximately 15% reduction in the costs associated with operation.*

Keywords— Gas Engine, Electricity and Thermal Load, Photovoltaic, Optimized Hybrid System.

NOMENCLATURE

Acronyms

CHP	Combined heat and power
FEL	Following electric load
FTL	Following thermal load
MILP	Mixed integer linear programming
NPC	Net pure cost
PV	Photovoltaic
UMA	University of mohaghegh ardabili

1. INTRODUCTION

The use of energy has led to the progress and development of industrial societies on a large scale. Energy is a political and economic instrument upon which a country's security depends [1, 2]. Environmental pollution caused by the combustion of fossil fuels and the accelerating depletion of energy resources are two of the greatest crises facing humanity today [3, 4]. Global advancements in the preservation of the environment and the depletion of fossil resources have accelerated the trend toward the use of renewable energy, which is gaining increasing attention [5]. With the advancement of science and technology related to the use of renewable energy sources worldwide, there is a need for numerous studies and investigations in this area, as well as an increase in the proportion of renewable energy sources in the Iraq energy portfolio [6].

In addition, distributed production systems are utilized to optimize energy consumption and reduce the waste caused by the transmission and distribution of electrical energy in the network [7, 8]. In addition, the reduction in pollution caused by the combustion of fossil fuels in large power plants, large-scale electrical energy production, and large-scale electrical energy transmission and distribution, transferring it to consumers incurs significant losses [9]. On the other hand, large power plants have low electrical efficiency owing to their large production capacity and volume, as well as high installation, operation, and

Received: 10 Jun. 2022
Revised: 11 Jan. 2023
Accepted: 26 Mar. 2023
*Corresponding author:
E-mail: a.abdollahi@azaruniv.ac.ir (A. Abdolahi)
DOI: 10.22098/JOAPE.2023.10963.1812
Research Paper

maintenance costs [10]. They also increase the fuel consumption, pollutant levels, and ecology [11].

The combination of these factors and others, such as increased dependability and restructuring in the electricity industry, has led the world to adopt distributed production [12]. Using distributed production systems with an overall efficiency between 70 and 90 percent is one of the most effective methods to reduce energy consumption [13].

Based on the various reasons for the need to use renewable energy sources of scattered and simultaneous production, as well as economic concerns, it is crucial to conduct a comprehensive analysis of these methods to determine the optimal approach [14]. From an economic standpoint, cost reduction is one of the most important objectives for using renewable energy sources [15]

More emphasis has recently been placed on CHP systems, which integrate renewable energy sources with classic combined heating and power systems fueled by natural gas [16]. Controlling the use of fossil fuels, lowering the emission of pollutants into the environment, and fostering sustainable development may all be accomplished via the complementary use of renewable energy and natural gas [17]. Various technologies, such as photovoltaic panels, solar thermal collectors, and photovoltaic thermal solar collectors, may convert solar energy into thermal or electric energy [18].

For an economic analysis, Sun [19] compared a gas engine-based cogeneration system with conventional power supply modes and investigated the annual storage income and investment payback period. The results of the calculations indicate that a simultaneous production system is economically advantageous. The objective of the optimization by Li et al. [20] was to reduce the cost of the CHP system. The problem was solved nonlinearly and mixed with an integer, and the obtained results were subjected to a sensitivity analysis. Li et al. [21] investigated the 15-year performance of small CHP systems with a gasoline engine as the primary generator is modeled. The authors proposed a method based on a comparison of various systems from an engineering economics perspective. Because a portion of the input energy is converted into heat in photovoltaic panels, extensive research has been conducted on the simultaneous production of electricity and heat from photovoltaic panels. The thermal energy produced increases the cell temperature and reduces cell efficiency. In addition to improving the cell performance, recycling heat, electricity, and heat can be produced simultaneously, which is a problem from various modeling viewpoints [22], design and simulation [23], performance review [24], and energy and energy analysis [25]. Hybrid CHP systems were proposed by Ren et al. [26]. According to the findings, the operation of System A according to the FEL approach yields the most advantages for all three buildings. In addition, the type of structure has a significant impact on the layout of the system, as well as the size of its components. An optimum design model that considers energy consumption throughout the manufacturing and operation phases was presented by Bahlawan et al. [27] to reduce the primary energy demand of the hybrid energy plant as much as possible. Mehregan et al. [28] examined a new configuration of a CHP system with two primary movers. They concluded that using the suggested CHP system with a hybrid prime mover boosts the efficiency by 10%. The optimization findings also indicate that the proposed system decreases operational expenses by more than 60% and fuel energy savings by approximately 50%. Incili et al. [29] investigated a unique CHP that was built and constructed in Mula, Turkey for the heating of multifamily dwellings. They demonstrated that the average daily power generation is 3.126 kWh. The average daily heat output is 985.97 kWh. The average thermal efficiency of the CHP system was approximately 30%.

Iraq has shown a willingness to make the most of its abundant renewable energy resources; thus, these sources should be given priority in the country's energy policy planning [30]. This means that, as science and industry advance, we must also be dynamic in the direction of expanding possibilities, identifying economic approaches, introducing novel patterns of consumption, and developing suitable models for the long-term sustainability of new fossil resources. Consequently, the process of developing such approaches is currently of utmost importance, as they are practical and, on the same principle, save time, which is the most crucial determining factor. Therefore, the objective of this study is to design and optimize the use of a hybrid photovoltaic system and a gas-powered engine to generate electricity and heat. An optimal configuration of the system is proposed for this purpose. It is assumed that the hybrid CHP system is connected to the global electricity grid and that trading electricity to the grid is possible. In addition, the system was equipped with a secondary boiler to satisfy the heat demand under all conditions. The optimization is based on minimizing costs and the rate of capital return.

2. MATERIALS AND MEHODS

The demand for electric and thermal load from a system is not a constant value, and their quantity and even price vary from day to day and hour to hour. The effectiveness of these units is highly dependent on the determination of their parameters. If the design's required parameters are not accurately determined, it may lose effectiveness in the future as conditions change. To provide a complete design, it is necessary to identify numerous parameters. Among these parameters are the number (total capacity) of units, the programming of each unit, and the number (total capacity) of auxiliary equipment, such as auxiliary boilers, among others. The objective of this study is to identify the system's components in a way that minimizes the investment and exploitation costs over the long term. In this context, a 15-year planning horizon has been considered.

This study makes the following assumptions:

1) The primary engine in this study is a gas-burning engine powered by natural gas.
2) In this research, only the amount of heat absorbed by the heat recovery system is considered; its use as steam, hot water, or in an absorption chiller, etc., is not taken into account.
3) It is possible to receive heat from one or more auxiliary boilers or to purchase or sell electricity to the grid.
4) It is not possible to simultaneously purchase and sell electricity.
5) The average prices for purchasing and selling electricity, as well as fuel, are known for each month of the year.
6) The monthly averages of the electric and thermal load demand curves for each month of the year are considered.
7) The nominal capacity of the equipment that can be installed, such as the gas engine, boiler, and solar panels, has been specified, and their numbers are included in the decision variables.

2.1. Objective function

In the programming for the simultaneous production of electricity and heat in this study, the objective function is based on the minimization of the current net cost. The current NPC can be divided into three parts. These three parts are the cost of installation ($Cost_I$), the cost of operation ($Cost_O$), the cost of maintenance of scrap value ($Cost_M$) and Salvage is the value of $Salvage$ where, After completing the design period of the CHP units, the auxiliary boiler and the installed PV have a scrap value (Eq. 1) [31].

$$NPC = Cost_I + Cost_O + Cost_M - Salvage \tag{1}$$

2.2. Operational limitations of different system components in the daily operation model

The operational restrictions related to the utilization review include things such as the limitation of the production capacity of

CHPs and auxiliary boilers, the limitation of buying and selling electricity, etc., which are explained below.

In the case of using the system, it is possible to buy and sell electricity with the grid at the same time every hour or none of them will be done (Eq. 2) [31].

$$I_t^{buy} + I_t^{sel} \leq 1, \quad \forall t \tag{2}$$

Where, I_t^{buy} and I_t^{sel} indicate the binary variable of buying and selling electricity from the grid at time t, respectively.

In order to comply with the mentioned above and to ensure that the amount of electric power purchased and sold to the network is within a certain range, the ratio 3 is used. $\bar{P}$ indicates the maximum electrical power that can be exchanged with the network [31].

$$\begin{cases} 0 \leq P_t^{buy} \leq \bar{P} \times I_t^{buy}, & \forall t \\ 0 \leq P_t^{sel} \leq \bar{P} \times I_t^{sel}, & \forall t \end{cases} \tag{3}$$

2.3. Basic information of the studied system

For the planning and operation of the simultaneous production system, two methods are considered. The first strategy is to utilize the cogeneration system as a heat demand provider. In this method, CHP continues to produce electricity until the heat demand is satisfied and no additional heat is produced. Thus, it is possible to produce more heat and electricity than is required to meet demand, and the excess is sold to the upstream network.

The objective of the second method is to use the co-generation system as an electrical source. In this method, only the required amount of electrical energy is produced by CHP, so there is no sale of electrical energy to the grid, although it is possible. A portion of the electricity requirements are met by the upstream network.

Initially, using the three methods of FEL, FTL, and simultaneous optimization, a suitable simultaneous production system for the ten-year design period of the study case was designed. After implementing the aforementioned procedures, the optimal configuration for the primary engine and auxiliary boiler will be established. After determining the number of primary engine and auxiliary boiler units suitable for the design period, this configuration will be utilized daily. This section includes the electric load, heat, the market price of electricity for purchasing or selling, and the hourly price of gas.

Each month's maximum hourly electrical and thermal power consumption is depicted in Table 1, respectively. The maximum amount of thermal energy used during the winter months differs significantly from other months. This is the reason why it can be challenging to provide heating in the winter and cooling in the summer for residential communities. It is stated that the amount of energy required for cooling during the summer is considered alongside the equivalent amount of thermal energy; consequently, cooling energy is not evaluated separately. Assistance and CHP are made available.

The real interest rate, the inflation rate, the length of the design period, the annual load growth rate, the price of gas, and the price of purchasing and selling electricity from the grid are also required for programming the production system with the described methods. Table 2 displays the values of this data.

Table 1. The maximum amount of hourly electrical and heating power needed per month

Month	Electric Load (kWh)	Thermal Load (kWh)
Jan	145.0	342.6
Feb	145.6	360.7
Mar	150.5	194.2
Apr	143.4	172.5
May	144.7	205.1
Jun	145.9	272.7
Jul	150.9	334.2
Aug	154.8	359.5
Sep	155.8	273.9
Oct	152.7	172.5
Nov	148.3	190.6
Dec	144.8	235.3

Table 2. Initial system design data

Data	Value
Inflation	0.2
Rate of interest	0.18
Gas price (\$/m^3)	0.1
Electric buy and sell price (\$/kWh)	0.05
Life span (year)	15

2.4. Determining the optimal configuration of components

The configuration results and costs for three FEL, FTL and optimal energy supply methods are displayed in the Table 3. According to this table, the configuration and cost outcomes of the FTL and optimal methods are identical. The only difference between these two methods is the cost of their operation and maintenance, which differs minimally due to the nature of these two designs. Since the objective of the FTL method is to use the system as a thermal load supplier, the production of thermal power will be precisely the amount required and there will be no thermal energy waste. This restriction in the absence of heat loss restricts the CHP system to producing only enough electrical energy for the consumer to fully consume the produced heat. Consequently, although the CHP system is still capable of producing electricity, it has not reached its maximum capacity. Due to the limitation of heat consumption, he was unable to produce more electricity to sell to the upstream network for a greater profit. Since energy waste is permitted in the simultaneous optimal method, the CHP system generates more power and earns more profit by selling more electricity to the upstream grid. In the first year, according to the configuration of these two methods, seven solar modules, each with an area of 100 square meters, have been installed. Given that the electricity generated by these modules is more expensive than that generated by other modules, one may question why the model chose to install the solar module. This is due to the absence of fuel costs and the ability to sell these methods to the upstream network. Since these two methods involve the sale of electricity to the upstream network, the long-term profit from this sale will return the initial investment and generate a profit overall. Obviously, had the planning period been shorter (for instance, two years), the installation of solar-powered electrical energy production equipment would not have been economically viable and would have been rejected. In the simulation, this issue was observed in every detail. However, the discussion in the FEL method is unique. In this method, the CHP system will produce electricity as long as the consumer is able to consume it. This is due to the lack of permission to sell to the network and the one-way nature of the communication. As a result, the model loses a substantial amount of profit that would reduce operating expenses, and its total cost is significantly higher than those of the other two models. As seen in this method's configuration, no solar module is installed. This is because in this method there is no energy sale to the upstream network, and the cost of producing electric energy using modules is quite high; as a result, the model relies solely on CHP and the upstream network to provide consumed electricity. It has no solar modules installed. In addition, because the electricity produced by CHP systems is limited and, as a result, the heat produced will be insufficient, it can be seen that more auxiliary boilers are installed with this method.

Table 3. Configuration and NPCs of different methods

	Gas engine	Auxiliary boiler	PV module	NPC ($)
FEL	2	3	0	385995
FTL	3	2	9	298925
Optimal	3	2	9	292605

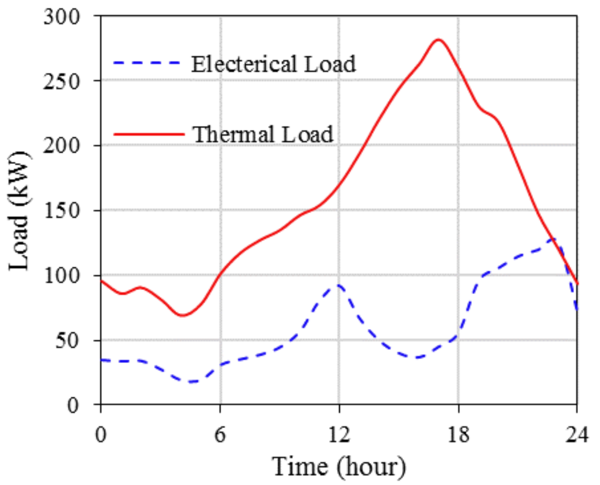

Fig. 1. Daily electrical and thermal load on the peak day of July

3. RESULTS AND DISCUSSION

This section investigates the utilization of the simultaneous production system for the optimal configuration determined during the design phase. This study's objective function is to minimize daily operating expenses. This section examines a model regarding the optimal daily utilization of solar module production capacity.

3.1. Basic information for daily operating model

The daily electricity and thermal load curve of the consumer during one sample day, which corresponds to the peak of the month of July in the utilization section, is shown in Fig. 1. As can be seen, the peak heating load consumption occurs between 12:00 and 18:00, and after 18:00, the heating load consumption decreases. In contrast, the electric charge rises from 16:00 until 23:00, when it reaches its maximum value.

The price of electricity in the upstream network for use in the daily operation of distributed generation systems can also be seen in the Fig. 2. The price of gas is considered equal to 0.1 $/m^3 for all hours of the day and night. The most expensive times of day, in terms of heating and electric load (Fig. 1), are between 6:00 and 12:00, and 17:00 p.m. and 18:00.

3.2. The results of the daily optimal utilization model

This section presents the results of daily optimal utilization based on the configuration presented in the previous section. The assumption is that exploitation will occur within the first year. Therefore, the configuration considered for this section consists of three gas engines, two auxiliary boilers, and nine solar modules, the specifications of which were described in the preceding section. Since the configuration evaluated in this section consists of nine solar modules, the sale of electrical energy to the grid must be considered. Since the production rate exceeds the consumption rate, the FEL energy supply method will be inapplicable to this configuration. Therefore, only FTL and simultaneous optimization methods are examined in this section. In this section, the linear model is combined with MILP in the GAMS model, which is then solved by the Cplex.12 solver.

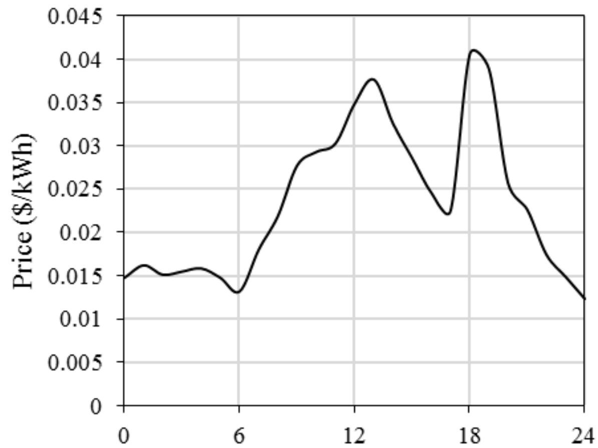

Fig. 2. The price of electricity in the upstream network for the daily operation

Fig. 3(a) depicts the comparison between the system's electric power output and its electric demand (simultaneous optimum). In the majority of hours, as shown in the graph, the amount of electricity produced exceeds the amount of electricity consumed. In order to reduce operating costs, the model has decided to sell electricity to the upstream grid for the majority of hours. Only after 20 to 24 hours does the model decide to produce less than the required amount and provide a tiny fraction of the required electrical energy via the upstream network. Observable are the amount of produced heat power and the required amount. As shown in the Fig. 3(b), the production thermal capacity exceeds the consumption amount in some hours, indicating that the excess production is lost. This issue occurs between 13 and 18 and 22. There are two causes for this problem; First, that the midday peak and the peak at the beginning of the night occur during the specified hours. In order to generate more electricity, a certain amount of heat energy is left unused and wasted. The second reason is the comparatively high price of electricity in the upstream network during these hours. As a result, the model for greater benefit, in order to sell more electricity to the upstream network, has taken action to produce more thermal energy than is required.

As depicted in Fig. 3 is the amount of usable electric power produced by the FTL method. By comparing this figure to the corresponding figure in the simultaneous optimal method. The difference is only related to the hours in which thermal energy loss occurs in the simultaneous optimal method, i.e., the electric power produced in the optimal method, simultaneously in hours 8 to 13, 17 and 19 to 23 hours is greater than the corresponding value in FTL method. The reason for this is that in the FTL method, the amount of electrical power can be limited to the number of hours and the corresponding heat can be consumed, preventing thermal energy loss. As a result of the FTL method's peak consumption of electric energy during the day and at the beginning of the night, the amount of electricity produced is restricted, resulting in less profit. It is self-evident that the amount of thermal energy produced and consumed in this process is identical, so there is no need to depict its shape.

The daily operating cost for the FTL method is 927$, while the daily operating cost for the simultaneous optimal method is 788$. Comparing the simultaneous optimal method to the FTL method, the results indicate that the simultaneous optimal method reduces operation costs by approximately 15%.

In the Table 4, the amount of daily optimal operation cost or benefit changes relative to gas price changes in the two modes of simultaneous optimal operation and FTL are depicted. This Table illustrates that when natural gas prices are low, exploitation is profitable. The cause of this problem is the widening gap between the final cost of electricity production and the income from selling

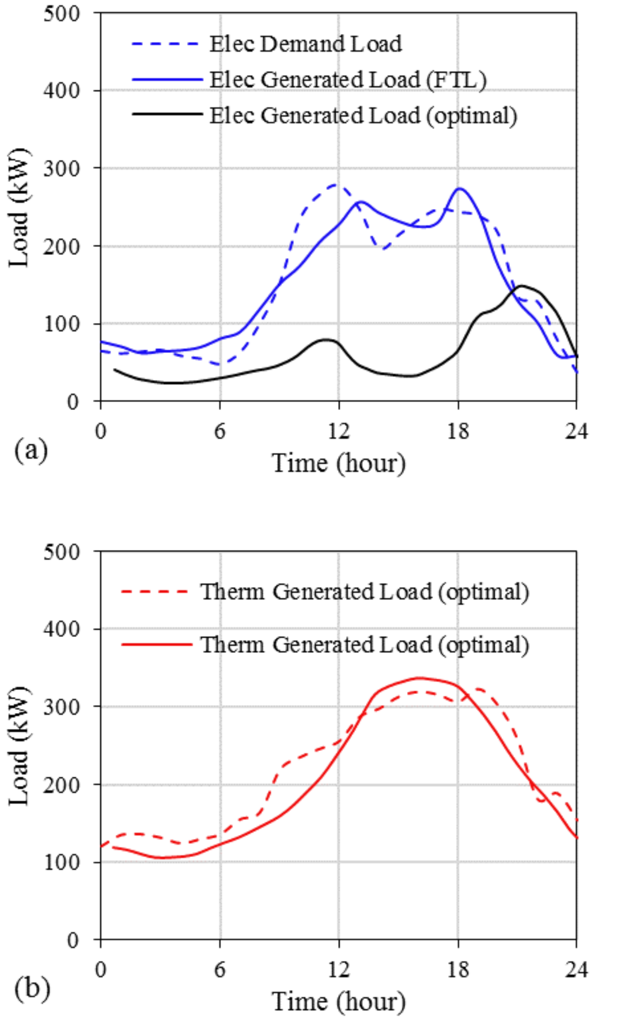

Fig. 3. A Comparing between the a) electrical power produced by the system and the amount of electrical demand b) thermal power produced by the system and the amount of thermal demand

electricity to the grid. As a result, the income obtained from the sale of a portion of the generated electricity, in addition to covering the cost of electricity consumption, leaves the user with a surplus and a profit. This subject is observed in both simultaneous optimal utilization and FTL methods. The difference between these two strategies is their profit margin. The optimal method yields a greater profit than the FTL method, as demonstrated by this graph. This issue is a result of the simultaneous optimal method allowing the system to waste unused additional heat. In the FTL method, however, the solar system, which can absorb the generated heat, begins to generate electricity. Consequently, electricity production is constrained. Since the price of gas is low, the optimal method produces and sells significantly more electricity to the upstream grid than the FTL method, resulting in a greater profit from selling electricity to the grid.

With an increase in gas prices, the profit from selling electricity to the grid decreases, and in the subsequent period, the cost exceeds the income; however, efficiency comes at a price. As shown in the graph, both methods of exploitation incur costs when the price of gas increases by 0.05 cents or more. Also applicable to these prices, the last topic holds. Thus, the presence of heat losses in the optimal method simultaneously results in the production of more electricity, its sale to the grid, and a higher income, which ultimately reduces the total cost of this method relative to the FTL method. Notable in this section is the equivalence of the operating

Table 4. The effect of gas price fluctuations on profit and cost in optimal condition

Gas price ($)	Operation cost/benefit ($)	situation
0.01	77.79661017	benefit
0.02	59.3220339	
0.03	40.84745763	
0.04	24.57627119	
0.05	9.491525424	cost
0.06	1.355932203	
0.07	13.72881356	
0.08	27.62711864	
0.09	34.06779661	
0.1	45.59322034	
0.11	58.30508475	
0.12	69.3220339	
0.13	79.83050847	

costs between the two methods when gas prices exceed 0.10 per gallon. At these prices, the cost of gas supply for electricity generation skyrockets to the point where it exceeds the profit from selling electricity to the grid. Consequently, the system only generates electricity to the extent that its heat can be consumed. In reality, the only limitation in this instance is the amount of heat consumed, and the cost of heat production exceeds the revenue from selling electricity to the grid. Therefore, the working point of the optimal operation method is also inclined toward the FTL operation method and is equal to it. The general conclusion that can be drawn from this is that the optimal simultaneous operation for all gas prices is superior to the FTL method, and in the worst-case scenario, it is equivalent to the FTL method.

4. Conclusion

In this study, the design and operation of a hybrid photovoltaic system and gas engine as a CHP were investigated using three FTL FEL methods and the GAMS-optimized simultaneous optimization method. With a description of the revenues, costs, and constraints in the problem, these optimizations were performed to minimize the NPC and determine the rate of return on investment. The following results were obtained:

In the FEL method, because the system follows the electric load and cannot generate and sell additional electricity, the model loses a substantial amount of profit, which would have reduced operating costs, and the total cost was significantly higher than in the alternative method. The other two models were also a result of the lack of electricity sales and the high cost of producing electrical energy using solar modules. Consequently, the model only utilized CHP and the upstream network as sources of consumed electricity, and no solar modules were installed. Because of decreased heat production, additional auxiliary boilers have been installed.

In terms of the configuration, the results of the two simultaneous FTL and optimal methods were identical. The only difference between these two methods is the difference in their operation and repair costs, which is negligible, and the optimal method has lower operation and repair costs.

After selecting the proper configuration in the previous section, the system operation issue was investigated as follows. The objective of this study was to reduce operating expenses. In the majority of hours, the amount of electricity produced by both the FTL and optimal methods exceeded the amount consumed. This indicates that the system decided to sell electrical energy to the network to reduce operating costs. Compared with the FTL method, the simultaneous optimal method for operation reduces operation costs by approximately 15%.

It is suggested that the viability of using these systems in remote and inaccessible regions can be evaluated by employing them in off-grid mode. In addition, it is possible to investigate the impact of incorporating a battery and heat storage into these systems. Checking the uncertainty of electric and thermal loads is possible.

REFERENCES

[1] A. Molajou, P. Pouladi, and A. Afshar, "Incorporating Social System into Water-Food-Energy Nexus," *Water Resources Management*, vol. 35, no. 13, pp. 4561–4580, 2021, doi: 10.1007/s11269-021-02967-4.

[2] R. Madurai Elavarasan et al., "The untold subtlety of energy consumption and its influence on policy drive towards Sustainable Development Goal 7," *Applied Energy*, vol. 334, p. 120698, Mar. 2023, doi: 10.1016/j.apenergy.2023.120698.

[3] Q. Wang et al., "Biogas generation from biomass as a cleaner alternative towards a circular bioeconomy: Artificial intelligence, challenges, and future insights," *Fuel*, vol. 333, p. 126456, Feb. 2023, doi: 10.1016/j.fuel.2022.126456.

[4] A. Motevali, N. Hooshmandzadeh, E. Fayyazi, M. Valipour, and J. Yue, "Environmental Impacts of Biodiesel Production Cycle from Farm to Manufactory: An Application of Sustainable Systems Engineering," *Atmosphere*, vol. 14, no. 2, p. 399, Feb. 2023, doi: 10.3390/atmos14020399.

[5] A. Molajou, A. Afshar, M. Khosravi, E. Soleimanian, M. Vahabzadeh, and H. A. Variani, "A new paradigm of water, food, and energy nexus," *Environmental Science and Pollution Research*, Feb. 2021, doi: 10.1007/s11356-021-13034-1.

[6] H. N. Bekheet and S. S. Najm, "The Future of Renewable Energy in the Iraqi Economy under Fossil Energy: Forward-Looking Study," *Webology*, vol. 19, no. 1, pp. 2979–2999, Jan. 2022, doi: 10.14704/WEB/V19I1/WEB19198.

[7] M. A. M. Sadeeq and S. Zeebaree, "Energy Management for Internet of Things via Distributed Systems," *Journal of Applied Science and Technology Trends*, vol. 2, no. 02, pp. 59–71, Apr. 2021, doi: 10.38094/jastt20285.

[8] T. Xia et al., "Efficient Energy Use in Manufacturing Systems—Modeling, Assessment, and Management Strategy," *Energies*, vol. 16, no. 3, p. 1095, Jan. 2023, doi: 10.3390/en16031095.

[9] Y. Ou, N. Kittner, S. Babaee, S. J. Smith, C. G. Nolte, and D. H. Loughlin, "Evaluating long-term emission impacts of large-scale electric vehicle deployment in the US using a human-Earth systems model," *Applied Energy*, vol. 300, p. 117364, Oct. 2021, doi: 10.1016/j.apenergy.2021.117364.

[10] D. Maradin, "Advantages and disadvantages of renewable energy sources utilization," *International Journal of Energy Economics and Policy*, vol. 11, no. 3, pp. 176–183, 2021, doi: 10.32479/ijeep.11027.

[11] A. Afshar, E. Soleimanian, H. Akbari Variani, M. Vahabzadeh, and A. Molajou, "The conceptual framework to determine interrelations and interactions for holistic Water, Energy, and Food Nexus," *Environment, Development and Sustainability*, vol. 24, no. 8, pp. 10119–10140, Aug. 2022, doi: 10.1007/s10668-021-01858-3.

[12] M. Mohsin, I. Hanif, F. Taghizadeh-Hesary, Q. Abbas, and W. Iqbal, "Nexus between energy efficiency and electricity reforms: A DEA-Based way forward for clean power development," *Energy Policy*, vol. 149, p. 112052, Feb. 2021, doi: 10.1016/j.enpol.2020.112052.

[13] A. J. Welch, I. A. Digdaya, R. Kent, P. Ghougassian, H. A. Atwater, and C. Xiang, "Comparative Technoeconomic Analysis of Renewable Generation of Methane Using Sunlight, Water, and Carbon Dioxide," *ACS Energy Letters*, pp. 1540–1549, Mar. 2021, doi: 10.1021/acsenergylett.1c00174.

[14] Y. A. Solangi, C. Longsheng, and S. A. A. Shah, "Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach," *Renewable Energy*, vol. 173, pp. 209–222, Aug. 2021, doi: 10.1016/j.renene.2021.03.141.

[15] T. Adefarati and R. C. Bansal, "Reliability, economic and environmental analysis of a microgrid system in the presence of renewable energy resources," *Applied Energy*, vol. 236, pp. 1089–1114, Feb. 2019, doi: 10.1016/j.apenergy.2018.12.050.

[16] S. Safari, T. Hajilounezhad, and M. A. Ehyaei, "<scp>Multi-objective</scp> optimization of solid oxide fuel cell/gas turbine combined heat and power system: A comparison between particle swarm and genetic algorithms," *International Journal of Energy Research*, vol. 44, no. 11, pp. 9001–9020, Sep. 2020, doi: 10.1002/er.5610.

[17] F. Wang et al., "Technologies and perspectives for achieving carbon neutrality," *The Innovation*, vol. 2, no. 4, p. 100180, Nov. 2021, doi: 10.1016/j.xinn.2021.100180.

[18] F. Hossain, M. R. Karim, and A. A. Bhuiyan, "A review on recent advancements of the usage of nano fluid in hybrid photovoltaic/thermal (PV/T) solar systems," *Renewable Energy*, vol. 188, pp. 114–131, Apr. 2022, doi: 10.1016/j.renene.2022.01.116.

[19] Z.-G. Sun, "Energy efficiency and economic feasibility analysis of cogeneration system driven by gas engine," *Energy and Buildings*, vol. 40, no. 2, pp. 126–130, Jan. 2008, doi: 10.1016/j.enbuild.2007.01.013.

[20] C. Z. Li, Y. M. Shi, and X. H. Huang, "Sensitivity analysis of energy demands on performance of CCHP system," *Energy Conversion and Management*, vol. 49, no. 12, pp. 3491–3497, Dec. 2008, doi: 10.1016/j.enconman.2008.08.006.

[21] L.-L. Li, S.-J. Zheng, M.-L. Tseng, and Y.-W. Liu, "Performance assessment of combined cooling, heating and power system operation strategy based on multi-objective seagull optimization algorithm," *Energy Conversion and Management*, vol. 244, p. 114443, Sep. 2021, doi: 10.1016/j.enconman.2021.114443.

[22] C. S. Malvi, D. W. Dixon-Hardy, and R. Crook, "Energy balance model of combined photovoltaic solar-thermal system incorporating phase change material," *Solar Energy*, vol. 85, no. 7, pp. 1440–1446, Jul. 2011, doi: 10.1016/j.solener.2011.03.027.

[23] J. I. Rosell, X. Vallverdú, M. A. Lechón, and M. Ibáñez, "Design and simulation of a low concentrating photovoltaic/thermal system," *Energy Conversion and Management*, vol. 46, no. 18–19, pp. 3034–3046, Nov. 2005, doi: 10.1016/j.enconman.2005.01.012.

[24] M. Y. Hj. Othman, B. Yatim, K. Sopian, and M. N. Abu Bakar, "Performance analysis of a double-pass photovoltaic/thermal (PV/T) solar collector with CPC and fins," *Renewable Energy*, vol. 30, no. 13, pp. 2005–2017, Oct. 2005, doi: 10.1016/j.renene.2004.10.007.

[25] S. Agrawal and G. N. Tiwari, "Energy and exergy analysis of hybrid micro-channel photovoltaic thermal module," *Solar Energy*, vol. 85, no. 2, pp. 356–370, Feb. 2011, doi: 10.1016/j.solener.2010.11.013.

[26] F. Ren, Z. Wei, and X. Zhai, "Multi-objective optimization and evaluation of hybrid CCHP systems for different building types," *Energy*, vol. 215, p. 119096, Jan. 2021, doi: 10.1016/j.energy.2020.119096.

[27] H. Bahlawan, M. Morini, M. Pinelli, W.-R. Poganietz, P. R. Spina, and M. Venturini, "Optimization of a hybrid energy plant by integrating the cumulative energy demand," *Applied Energy*, vol. 253, p. 113484, Nov. 2019, doi: 10.1016/j.apenergy.2019.113484.

[28] M. Mehregan, M. Abbasi, and S. Majid Hashemian, "Technical, economic and environmental analyses of combined heat and power (CHP) system with hybrid prime mover and optimization using genetic algorithm," *Sustainable Energy Technologies and Assessments*, vol. 49, p. 101697, Feb. 2022, doi: 10.1016/j.seta.2021.101697.

[29] V. İncili, G. Karaca Dolgun, A. Georgiev, A. Keçebaş, and N. S. Çetin, "Performance evaluation of novel photovoltaic and Stirling assisted hybrid micro combined heat and power

system," *Renewable Energy*, vol. 189, pp. 129–138, Apr. 2022, doi: 10.1016/j.renene.2022.03.030.

[30] H. M. S. Al-Maamary, H. A. Kazem, and M. T. Chaichan, "The impact of oil price fluctuations on common renewable energies in GCC countries," *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 989–1007, Aug. 2017, doi: 10.1016/j.rser.2016.11.079.

[31] A. J. Conejo, M. Carrión, and J. M. Morales, *Decision making under uncertainty in electricity markets*. Springer, 2010.