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A Technical and economic evaluation of how to supply energy to consumers through the system of Combined Heat and Power with solar cells

Abstract

Today, hybrid energy supply systems are used due to the reduction of electrical and thermal losses, better control of DG sources to feed the system loads better, reduce the emission of environmental pollutants and increase in the reliability of load supply. In this research, an optimal and economical method to design a hybrid energy supply system based on CHP sources and photovoltaic sources to combine heat and power required by consumers, taking into account various costs such as initial investment cost, operating cost, Fuel costs, maintenance costs and various technical constraints such as production limitations of each source, power exchange. A Genetic algorithm has been used to solve the resulting optimization problem due to its ability to solve complex problems with many variables. The results show that in designing the system to supply electricity and heat, the system connected to the grid requires lower operating costs than the other two modes and the possibility of exchanging power. That reduces system costs in the event of a shortage of photovoltaic panels and the sale of power to the grid during off-peak hours and during peak hours of the upstream grid, where electricity prices are higher.

Keywords: Combined Heat and Power (CHP), Photovoltaic Solar Cell (PV), Technical and Economic Evaluation

1. Introduction

The ever-increasing need for energy and increasing environmental concerns at the level of the global and sustainable society in energy technologies creates situations and contexts for the general use of energy resources as a source of energy supply. Technological advances have made a favourable environment for generating electricity from renewable sources. Production can be done in two ways: connected to the network and separate from the network[1]. Technical **and economic connections in many parts of the world and our country, Iran, have caused them not to be connected to the national electricity grid and deprived** the people of that region's blessing of electricity[2]. **Among the technical issues, it is difficult to pass and lacks proper access. Economic relations are also due to the small population and being far from the production centres. In these areas residents of these areas can also benefit from the blessing of electricity by using unauthorized sources based on restrictions. Among the unique power plants the reduction of environmental consumption, operating costs, diversity in energy supply sources and improvement of the non-operating defence. Of course, some disadvantages are the most important—the highest investment cost. Therefore, the designers of power systems must reach the necessary economic justification for their use. Another disadvantage of variable energies is their inherent uncertainty. Similar cases of different infrastructures, adding loads and passive experiences around the world in the last years all over the globe made power system operators to solutions such as the development of hybrid energy supply systems, the expansion of microgrids, the development of smart grids, the use of distributed (renewable) energy sources. and non-rateable) and small identification and position management to increase the efficiency and reliability of** the power system[3].

Today, we are witnessing a significant increase in the activities and budgets of governments and companies in the research, development and supply of renewable energy systems, and these efforts and spending in the budgets mentioned above have ultimately reduced the energy cost. Renewable energy and competitiveness with traditional energy systems are available. One of the most important goals of using renewable energy sources is to reduce costs. Using renewable energy sources to provide electricity for scattered and off-grid loads in remote areas is a suitable solution for reducing economic costs from developing grid transmission lines, reducing environmental pollution and increasing energy efficiency. The introduction of renewable resources in the electricity industry has created tremendous changes, which have shown themselves in all network parts. The fact that renewable resources are considered new technology. Therefore, high costs should be spent in the investment sector, and the designer of power systems should reach the necessary economic justification for their use. Of course, the operating cost of renewable power plants is much lower than that of fossil fuel power plants, and it can largely offset the high initial investment cost[4]. **Naturally, renewable power plants cause changes in the power grid; the entry of renewable power plants into the power grid causes a challenge in the coordination between the protection equipment, and therefore the network protection system needs to be changed, and the existing equipment should be reset. In the usual methods for meeting electrical and thermal needs, electricity is supplied from the national distribution**

network, and heat is supplied by burning fuel in boilers and heat-generating equipment in a different production method. In these methods, significant energy is wasted through the hot exhaust gases of chimneys, cooling towers, condensers, and coolers in internal combustion engines, as well as the losses of transmission and distribution of electricity in the national network. most of this heat can be recycled and used to provide thermal energy. Against these centralized systems, there are decentralized and independent production methods using CHP technology with a combination of simultaneous electricity and heat production [5]. In terms of thermodynamics, this method means the simultaneous production of two common forms of energy, namely electrical and thermal, using a primary energy source. Thermal energy is obtained from the recovery of thermal losses of these independent generators, and this heat is used in various industrial, commercial and residential sectors. Many studies have been conducted in the field of optimal exploitation from the economic point of view of hybrid energy supply systems based on renewable resources. In the optimal design of combined systems, in other words, determining the optimal capacity of system equipment with different energy sources and strategies is studied. The design of these systems has been done more from an economic point of view to reduce energy production costs and increase system reliability and load supply. Intelligent optimization algorithms are also the goal of many studies, and newer algorithms with high computing power are used daily to optimize the combined system. In reference, a hybrid energy system consisting of solar panels, a wind turbine and a diesel generator is proposed to produce electricity in a remotely controlled off-grid site in one of the cities of Pakistan. To improve solar energy production, information from the nearest weather station and NASA solar satellite information have been used, and then an optimal model for the energy production of this site has been proposed. In reference, a method for determining the optimal combination of distributed production resources in a defence site separated from the grid is presented; the main goal of presenting the proposed method is to increase the reliability of the hybrid system of supplying the required energy by considering the technical constraints of the grid along with uncertainty. Energy resources and the priority of cutting off sensitive loads have been considered. Energy supply adequacy to consumers has been evaluated by solving a set of optimal load distribution problems. The proposed method for solving the problem is based on the colonial competition algorithm, scenario reduction and optimal load distribution. The exploitation of a sample microgrid based on the use of CHP units is explained[6]. The difference between this research and other studies is considering the technical characteristics of CHP units, including the increasing and decreasing slope rate of production and the effect of knee point 2 in the production characteristics of these units. Also, this article presents a comparative method to determine the required reserve for the battalion. Similarly, reference has proposed using a microgrid based on CHP, in which various sources of distributed electric and heat production and electric storage sources participate in providing electric and thermal energy to the microgrid and solving the optimization problem. -PSO algorithm is used for the resulting construction. The investment planning model in the new power plant has been studied from the perspective of the private sector investor to participate in the electricity market. The objective function presented in this model is intended to maximize the net present value of the investor during the planning period. Decision variables for investment are determining the optimal investment capacity and the right time to install this capacity[7].

2. Material and Method

In planning to design a hybrid photovoltaic system and sources of simultaneous electricity and heat production, the objective function is considered based on the minimization of net present cost (NPC). The current net price can be divided into three parts: installation cost, operation and maintenance cost, and scrap value. The method of calculating the current net cost using the sum of the above three costs that have been returned to the first year is according to the following relationship:

$$NPC = Cost_{inst} + Cost_{O\&M} + Salvage \tag{1}$$

In calculating each of the three mentioned costs, the real interest rate (RI) value has been used to analyze the capital return factor (CRF), which has different values. RI is the real interest rate. The real interest rate is obtained from the difference between the nominal interest rate and the inflation rate, which is mentioned in relation (1). This research assumes that nominal interest rates and inflation are constant.

$$RI = I - IR \tag{2}$$

In equation (3), which shows the amount of the initial installation cost of the unit, these two costs are separated. The binary variables of installation and the year of a building are specified, and the price is calculated using the coefficient of return of the installation capital. , is transferred to the first year. The first part of this relationship is related to the primary driver, the second to the auxiliary boiler, and the third to the solar panels.

$$\sum_{y=1}^{Ny}\sum_{n=1}^{N}\left[\left(Inv_{CHP}^{dep} + Inv_{CHP}^{nondep}\right) \times \left(ui_{y,n}^{CHP} + ui_{y-1,n}^{CHP}\right) \times CRF_y^{inst}\right] + \left[\left(Inv_{Boi}^{dep} + Inv_{Boi}^{nondep}\right) \times \left(ui_{y,n}^{Boi} + ui_{y-1,n}^{Boi}\right) \times CRF_y^{inst}\right] + \left[\left(Inv_{PV}^{dep} + Inv_{PV}^{nondep}\right) \times \left(ui_{y,n}^{PV} + ui_{y-1,n}^{PV}\right) \times CRF_y^{inst}\right] \tag{3}$$

This cost includes the cost of buying electricity from the grid, fuel cost, variable cost of repairs and maintenance, and fixed cost of maintaining the units,

which is reduced from the amount of this cost depending on the amount of electricity sold to the grid. The amount of fuel consumed in cubic meters is obtained using equation (4).

$$G_{y,p} = \sum_{n=1}^{N} \left[P_{y,p,n}^{CHP} + ui_{y,p,n}^{Boi}\right] \times P2G, \forall y, \forall p \quad (4)$$

After the design period of CHP units is completed, the auxiliary boiler and installed PV have a scrap value. This value is a coefficient of the depreciable installation cost, which also depends on the unit's number of years of use. The scrap value is created in the last year of the design period, and the scrap value recovery factor is used to return it to the first year. The scrap value is calculated according to equation (5).

$$Salvage = \sum_{n=1}^{N} CRF_y^{Sal} \times Inv_{CHP}^{dep} \times \left[\left(\frac{LifeTime_{CHP} - Age_n^{CHP}}{LifeTime_{CHP}}\right) + ui_{y=Ny,n}^{CHP} - 1\right] + \sum_{n=1}^{N} CRF_y^{Sal} \times Inv_{Boi}^{dep} \times \left[\left(\frac{LifeTime_{Boi} - Age_n^{Boi}}{LifeTime_{Boi}}\right) + ui_{y=Ny,n}^{Boi} - 1\right] + \sum_{n=1}^{N} CRF_y^{Sal} \times Inv_{PV}^{dep} \times \left[\left(\frac{LifeTime_{PV} - Age_n^{PV}}{LifeTime_{PV}}\right) + ui_{y=Ny,n}^{PV} - 1\right] \quad (5)$$

From equation (6), the unknown interest rate or **the rate of return on investment is calculated.**

$$eq(i) = \sum_{y=1}^{Ny} \begin{pmatrix} CRF_y^{inst} \times Inst\,Cost_y - CRF_y^{Sal} \times SalVal_y \\ +CRF_y^{O\&M} \times \begin{pmatrix} OM\,Cost_y + Feul\,Cost_y + ElecPurch\,Cost_y \\ -ElecSell\,Rev_y - Surplus_y \end{pmatrix} \end{pmatrix}$$

$$\underset{i}{Solveeq}(i) = 0 \quad (6)$$

Equation (7) shows how to calculate the operating **cost that should be minimized.**

$$Cost_{O\&Mt} = \sum_{t=1}^{T} \begin{pmatrix} P_t^{buy} + \pi_t^{buy} - P_t^{sel} \times \pi_t^{sel} \\ +G_t' \times \pi_t^G \end{pmatrix} + \sum_{t=1}^{T} \sum_{n=1}^{N} \begin{pmatrix} Var\,Cost_{O\&M}^{CHP} \times P_{t,n}^{CHP} \times \eta_{CHP}^{el} \\ +Var\,Cost_{O\&M}^{Boi} \times P_{t,n}^{Boi} \times \eta_{Boi}^{th} \end{pmatrix} \quad (7)$$

3. Simulation and numerical results

The proposed method for designing a combined solar system and a source of simultaneous electricity and heat generation in two operating modes connected to the national grid and independent from it to provide the electrical power and heat required for a residential load is presented according to Figure (1). In the proposed system, as shown in Figure (1), the required thermal load of the **system is provided through the simultaneous production of electricity and heat. The required electrical gear is supplied by combining photovoltaic panels and a CHP source. To be Considering the nature of photovoltaic panels and the inherent uncertainty of these sources due to fluctuations in the amount of solar radiation and ambient temperature, the battery has also been used to support the electric load of the system so that in case of a shortage of production power by photovoltaic sources, the battery of this shortage to compensate.**

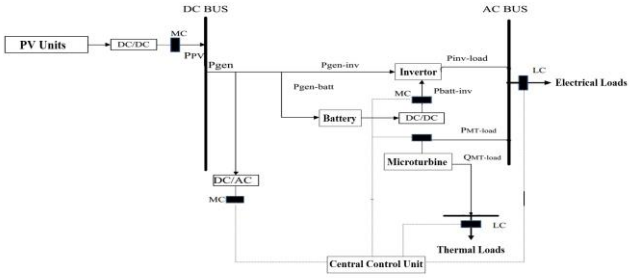

Figure 1. Structure of the Proposed Hybrid System

The graph of the price of power exchange with the upstream network is shown in Figure (2); as can be seen **in this Figure, the cost of buying power from the upstream network in the intermediate period or the price of selling power from the microgrid to the upstream network in the middle period. The load is more than the low load intervals.**

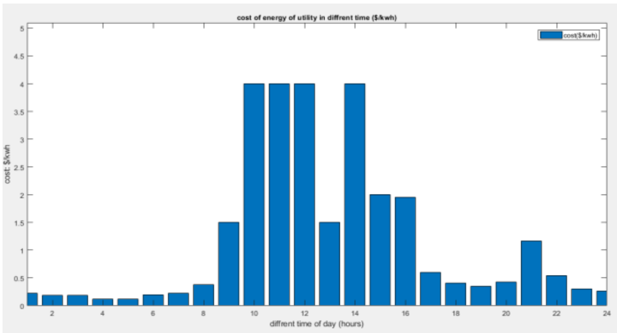

Figure 2. Price Diagram of Energy Exchange with the Upstream Network

To evaluate the technical and economical design of the hybrid energy supply system, the desired system has been operated in two modes, separated from the national network and connected to the upstream network. To solve this optimization problem, the genetic algorithm, which has an excellent ability to solve nonlinear and complex issues with a large number of constraints, was used with the help of MATLAB software. The studied scenarios are:

First scenario: In this scenario, the introduced hybrid system is completely isolated from the upstream network. In this case, the source of simultaneous electricity and heat production alone is responsible for providing the thermal energy required by the system loads at different hours. The necessary electrical energy is combined using the CHP source and photovoltaic panels. Considering the lack of Certainty in the production power of photovoltaic sources, the battery is used as a backup system. It fulfils the condition of electric power balance.

The second scenario: In this scenario, it is assumed that the optimal hybrid system obtained in the first scenario is connected to the upstream network, and the system has a power exchange with the upstream network. In this plan, similar to the first scenario, the source of simultaneous production of electricity and heat alone will be responsible for supplying the thermal energy required by the system loads at different hours, and the necessary electrical energy will be combined using the CHP source and photovoltaic panels and the upstream supply network. Due to the uncertainty in the production power of photovoltaic sources, the battery has also been used as a backup system and fulfils the condition of electric power balance. In this design, the battery allows the operator to sell electrical energy to the upstream network if there is excess power in the desired hybrid system and during the peak hours of the upstream network, which is willing to buy electricity at a higher price.

The third scenario: In this scenario, the entire design of the hybrid system and the solution of the resulting optimization problem have been made with the assumption of connection to the national network and power exchange with the upstream network, which naturally results will be different from the previous scenarios.

Considering that the system's only suppliers of heat loads are CHP sources, a sufficient number of these sources must be available to supply the peak (peak) heat load (Qload. max). Therefore, it must be considered that the production power of a sufficient number of CHP sources is greater than the maximum thermal load according to the full production power and thermal efficiency. This problem is shown in relation (8).

$$n_{chp} \times \eta_{heat.chp} \times p_{chp.rated} \geq Qchp \frac{Q_{load.max}}{\eta_{heat.chp} \times p_{chp.rated}}_{load.max} \quad (8)$$

Table (1) shows the results related to the cost reduction and the user's profit due to connecting the system to the upstream network. As the results show, in the second scenario, where the microgrid from the first scenario is connected to the upstream network, due to the purchase of power from the upstream network during off-peak hours and the sale of power to the upstream network during peak hours, the amount of operating costs has decreased dramatically.

Table 1. Comparison of the total costs of the optimal hybrid system in two modes - disconnected from the network and connected to the upstream network

The amount of cost reduction	Second	First	Scenario
179,704	237,575	417,279	Operation cost (currency)

As can be seen in Table (2), considering the possibility of exchanging power with the upstream network (buying and selling management to the network), compared to the design mode separated from the network, considering the improvement of system reliability and the possibility of supplying power from In the upstream network, we need less storage system (battery). The number of photovoltaic panels required is also reduced due to the possibility of purchasing power from the upstream network.

Table 2. The number of equipment installed in the optimization performed in the third scenario

Qty	Type of equipment
23	Photovoltaic panels
9	Battery
5	CHP

Table 3. Comparison of the total costs of the hybrid system in different modes

Third	Second	First	Scenario
196,713	237,575	417,279	Operation cost ($)

As shown in Table (3), designing an optimal hybrid energy supply system in a separate state from the national grid due to the need to supply optimal and reliable thermal and electrical loads is more expensive than when this system is connected to the upstream grid. It also requires the possibility of power exchange (buying and selling) with the upstream network due to the possibility of buying power at the time of need and then selling power at the hour when faced with excess production, significantly reducing operating costs. The design of an optimal system connected to the network has a lower total cost than the optimal system isolated from the network and the optimal system designed separately from the network connected to the upstream network. The obtained results show that in the design of the desired method for electricity and heat supply, the optimal system connected to the grid requires a lower total operating cost compared to the other two modes and the possibility of exchanging power with the upstream grid due to the purchase of the necessary electrical power. From the grid, in case of a shortage of production of photovoltaic panels and selling power to the grid during low system load hours and excess output, as well as peak hours of the upstream network, which has a higher purchase and sale price, significantly reduces the system costs. Due to the higher cost of the sources of simultaneous production of electricity and heat compared to other sources, due to the optimization, the number of these sources has been reduced, and also due to the fluctuation in the production power and the lower rated capacity of the photovoltaic sources. The number of photovoltaic sources required to supply the electrical load of the system is also more optimal than other sources.

4. Conclusions

In this research, an optimal and economical solution to design a hybrid energy supply system based on CHP and photovoltaic sources to supply electricity and heat needed by consumers, taking into account environmental pollution and limitations. The appropriate technique was presented. As mentioned, the genetic algorithm was used to solve the proposed optimization problem, which has an excellent ability to solve nonlinear and complex problems with many constraints. The design of the intended system was studied in different modes, such as the optimal design of the system separately from the network and then connecting the system with the optimal combination obtained to the upstream network, as well as the optimal design of the system connected to the network. The obtained results show that in the design of the desired system for the supply of electricity and heat, the optimal system connected to the grid requires a lower total operating cost compared to the other two modes and the possibility of power exchange with the upstream grid is also possible due to the purchase of electric power. The need from the grid in case of shortage of production of photovoltaic panels and sale of power to the grid during low system load hours and excess production as well as peak load hours of the upstream network, which has a higher purchase and sale price, will significantly reduce system costs.

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