# OPTIMAL DEPLOYMENT OF COMBINED HEAT AND POWER IN RESIDENTIAL DWELLINGS IN IRAN

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*ABSTRACT*

*The Iranian government encourage the implementation of Distributed Generations (DGs) especially high-efficiency combined heat and power (CHP) systems. CHP could be a sustainable provider of a significant proportion of energy needs for domestic properties.*

*In this paper the use of CHP for a large building complex to provide electric power and the necessary heat for residential dwellings in Iran is investigated. Different factors such as investment cost, maintenance and operation costs of CHP, demand, and the numbers of hours that CHP can provide energy in a year are taken into account. On the other hand the cost of procurement, operation and maintenance of the heating and water heating devices are also considered.*

*Two different scenarios have been considered and investigated for investors. In the first one the output and heat power is used for the building and in the second one the electric output power is sold to the distribution system and the required electric power is bought from the network. These two scenarios are implemented and results along with discussion in detail are provided.*

## INTRODUCTION

Restructuring of power systems have created an augmented interest in Distributed Energy Resources (DERs), including Distributed Generation (DG) and energy storage devices, which is expected to play an increasingly important role in electric power systems operation and planning. DERs are emerging in the industry and being dispersed throughout distribution and sub-transmission systems to provide load services [1].

Combined heat and power (CHP) systems have been widely used by business customers including hotels, office buildings, and manufacturing plants since they are an effective means of energy conservation and cost reduction. As of 2006, CHP systems with a total capacity of 8.6 GW, which is equivalent to 3% of the national generation capacity, are being operated in Japan. CHP systems provide customers with the option to generate electricity from natural gas or oil instead of the purchase of grid electricity. However, residential dwellings have been beyond the scope of these systems because of the scale of the available CHP systems [2].

The Iranian government has initiated deployment programs to encourage the penetration of especially CHP systems that have a very high efficiency. The government provides sixty to eighty percent of the capital investment cost of the DG through long term loans. Buying the output electric power of DG is also warranted by government for up to five years. The gas needed for electric and heat power production of the CHP is also guaranteed through a subsidy scheme.

CHP systems incorporating different prime movers like gas engines and fuel cells have been commercialized for use in residential dwellings. CHPs are expected to stabilize the distribution grid and improve the reliability of the electricity supply. In this paper the use of CHP for a large building complex to provide electric power and the necessary heat for residential dwellings in Iran is investigated.

Different factors such as investment cost, maintenance and operation costs of CHP, demand, and the numbers of hours that CHP can provide energy in a year are taken into account. On the other hand the cost of procurement, operation and maintenance of the heating and water heating devices are also considered.

Two different scenarios have been considered in this study. In the first one the power and heat output of the CHP is initially used for the houses in the building and then the surplus of the electric power is sold to the distribution network. In the second scenario the owner sell the output electric power of the CHP to the network and provide the required electric power through the distribution network. Financial issues of both scenarios are analyzed and compared.

A real test system including about 450 houses in a large building complex has been used for studying the impact of CHP on residential dwellings in Kerman, Iran.

## PROBLEM FORMULATION

In this section we formulate the problem of evaluating costs and benefits of CHPs used for building complex. Economic considerations are the most important aspect of any type of DER. Here, an approach is explained for economic appraisal of using CHPs in distribution system. Two different scenarios are considered and financial appraisal of both scenarios is investigated and based on the results of this analysis the best scenario is determined for investors.

Here, a cost/worth approach is explained for placement and sizing of a CHP. The objective function is the benefit to cost ratio of CHP application. CHP cost is composed of the Investment Cost (IC), Operation Cost (OC) and Maintenance Cost (MC). CHP benefit is composed of Connection Fee Reduction (CFR), Elimination of Heating Devices Purchase Costs (HDC), Power Purchase Saving (PPS) and Heat Purchase Saving (HPS), Surplus Power Selling (SPS). The objective function is defined as follows:

$$Max\ BCR = \frac{Benefit_{CHP}}{Cost_{CHP}} \quad (1)$$

Where, *BCR* refers to Benefit to Cost Ratio, $Benefit_{CHP}$ and $Cost_{CHP}$ refer to the total benefits and total costs of CHP application, respectively.

$$Benefit_{CHP} = \sum_{t=1}^{T} \sum_{k=1}^{N_{CHP}} [PPS_{t,k}^{CHP} + HPS_{t,k}^{CHP} + CFR^{CHP} + HDC_{t,k}^{CHP}] \quad (2)$$

$$Cost_{CHP} = \sum_{k=1}^{N_{CHP}} IC_{k}^{CHP} + \sum_{t=1}^{T} (OC_{k,t}^{CHP} + MC_{k,t}^{CHP}) \quad (3)$$

Where, $N_{CHP}$ and $T$ are the number of CHPs and number of years in study period, respectively.

Initial cost (IC) includes procurement, installation costs and costs of required equipment for connection of DER to transmission system. Operating cost (OC) is the fuel cost that will be calculated for each year. Maintenance cost (MC) consists of maintenance and repair costs.

As mentioned, sixty to eighty percent of investment cost can be provided by loans based on encouragement plans provided by Iranian government. In order to calculate the annual payback of this loan (4) has been used:

$$AP = \frac{Lr}{(1-(1+r)^{-t})} \quad (4)$$

Where *AP* is annual payback; L is the amount of loan; r is interest rate per year (converted to a decimal) and t is number of years.

## PROPOSED METHOD

In order to determine the best solution for this problem financial issues of both scenarios are investigated. The detailed explanation of proposed scenarios is provided below separately. In the first scenario the power and heat produced by CHP is used for the building demand and the surplus is sold to the network. In the second one the whole power produced by the CHP is sold to the network and the required demand of the houses in the building complex is purchased from the distribution network.

### 1. First Scenario

In this scenario the benefits of CHP when its heat and power are used for residential dwelling are considered. The owner has the option to sell the surplus of the power output of CHP to the distribution network both the produced heat is considered to only be used for the building.

*CHP BENEFITS CALCULATION*

All of the benefits of CHP systems cannot be modeled on economic values such as environment benefits and voltage improvement which are quantified in non-economic values in [3].

- *Connection Fee Reduction (CFR)*

In order to benefit from the electrical energy in Iran new domestic customers should pay the demand capacity costs to distribution companies. However this price does not have a high value yet it is considered to improve the accuracy of the calculations. Connection fee for domestic customers is about 2000,000 Rial in Iran.

- *Elimination of Heating Devices Purchase Costs (HDC)*

To have access to heat water and environment the householders are needed to provide heating devices. Using the heat output of the CHP systems these needs could be satisfied and the necessity of procurement of heating devices is eliminated.

- *Power Purchase Saving (PPS)*

PPS represents the saving due to reduction in electric power that must be purchased from electricity market to supply the customers.

$$PPS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{CHP}} D_t \times EP_t \quad (5)$$

Where, $D_t$ is the cumulative demand of the building and $EP_t$ is the energy price at the *t*-th year. Considering interest rate (IR), the value of EP for the *t*-th year can be calculated using

$$EP_t = EP_1 \times (1+IR)^{t-1} \quad (6)$$

- *Heat Purchase Saving (HPS)*

HPS represents the saving due to purchased heat to supply the customers.

$$HPS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{CHP}} H_{k,t}^{CHP} \times HP_t \quad (7)$$

Where, $H_{k,t}^{CHP}$ is the heat output of the *k*-th CHP unit at the *t*-th year and $HP_t$ is the heat price at the *t*-th year. Considering interest rate (IR), the value of HP for the *t*-th year can be calculated using

$$HP_t = HP_1 \times (1+IR)^{t-1} \quad (8)$$

- *Surplus Power Selling (SPS)*

The surplus output power of the CHP regarding to the demand of the building complex is sold to the distribution company at a pre-defined price. The SPS is represented as (9).

$$SPS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{CHP}} (P_{k,t}^{CHP} - D_t) \times PDP_t \quad (9)$$

Where, $P_{k,t}^{CHP}$ is the output power of the *k*-th CHP unit at the *t*-th year, $D_t$ is the cumulative demand of the building and $PDP_t$ is the pre-defined energy price at the *t*-th year. Considering interest rate (IR), the value of EP for the *t*-th year can be calculated using

$$PDP_t = PDP_1 \times (1+IR)^{t-1} \quad (10)$$

***2. Second Scenario***

In this scenario the electric power and heat production of CHP is purchased by distribution company and a heat customer, respectively. Therefore in this situation the income of the owner is composed of only two components.

The difference of this scenario and the first one is that the whole output power of the CHP is sold to the distribution company while in the first scenario the surplus of the electric power output is sold to the network. Benefits of deploying CHP in this situation are as follows:

- *Power Selling (PS)*

The whole output power of the CHP is sold to the distribution company at a pre-defined price. The PS is expressed as (11).

$$PS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{CHP}} P_{k,t}^{CHP} \times PDP_t \quad (11)$$

Where, $P_{k,t}^{CHP}$ is the output power of the *k*-th CHP unit at the *t*-th year and $PDP_t$ is the pre-defined energy price at the *t*-th year. Considering interest rate (*IR*), the value of PDP varies during the study period and is calculated using (10).

- *Heat Selling (HS)*

HS represents the income due to selling heat to supply the customers.

$$HS = \sum_{t=1}^{N_{year}} \sum_{k=1}^{N_{CHP}} H_{k,t}^{CHP} \times HP_t \quad (12)$$

Where, $H_{k,t}^{CHP}$ is the heat output of the *k*-th CHP unit at the *t*-th year and $HP_t$ is the heat price at the *t*-th year. The HP varies during study years based on Eq. (8).

***3. CHP Benefits Calculation***

Since the gas microturbines can't deliver energy to the system during the maintenance outage of $d_{main}$ days, benefits of application of gas microturbines are obtained as in (12):

$$Benefit_{GMT} = \left(\frac{365 - d_{Main}}{365}\right)(CIC_{Old} - CIC_{New}) + \left(\frac{d_{Main}}{365}\right)(CIC_{Old}) \quad (13)$$

Where

$CIC_{Old}$ Annual Customer interruption cost, without gas microturbines application (Rial[1]).

$CIC_{New}$ Annual Customer interruption cost, gas microturbines applied (Rial).

$$CIC = H \times InCost \quad (14)$$

Where H is the number of hours that electric power from distribution system is not provided; InCost is interruption cost (Rial/h).

## CASE STUDY

Case system of this study is a real system in Kerman, Iran. A large building complex composed of 450 apartments is considered as the test system.

The interest rate is 0.1 p.u. and the economic life cycle is considered to be five years. The price of utility electricity for domestic customers is 450 Rial/kWh. The use of water heating device is considered to be 320 $m^3$ of gas per year. The gas price is 1200 Rial/$m^3$. The distribution company purchases the output power of CHP with the price of 340 Rial/kWh while provide the natural gas for them with the price of 158 Rial/$m^3$.

The data for microturbine as prime mover of CHP (U.S.$/kW/year): the investment cost is U.S. $1000/kW. The maintenance cost plus operation cost plus fuel cost are 779.64/kW/Yr. Data of heat exchanger (in per unit) are: The turnkey cost is U.S.$190/kW. The (O&M) fixed and variable costs are assumed zero. The efficiency is 0.8 [4].

The following assumptions are made based on [5] to model the reliability and the impact of CHP on it. In 98.39999% of the cases, the CHP system generates hot water, and in 94.2074% of the cases, the CHP generates electricity.

Four 500kw CHP are considered to be installed to produce heat and power. The calculation of costs of implementation of these units is provided in Table 1.

1 Rial is Iran currency and each 12,260 Rial is equal to one US $.

Table 1. Costs of deploying CHP

| Costs | IC (Bank Loan) (*USD/year*) | IC (Investor) (*USD/year*) | O&M C (*Rial x $10^6$/year*) |
|---|---|---|---|
| Value | 303,322.362 | 214,787.197 | 3,365. 811 |
| Total Cost (*Rial x $10^6$/year*) | 6,352.026 | | |

Table 2. Benefits of using CHP- First Scenario

| Benefit | CFR | HDC | PPS | HPS | SPS |
|---|---|---|---|---|---|
| Value (*Rial x $10^6$/year*) | 900.0 | 2,250.0 | 2,956.5 | 172.8 | 2,233.8 |
| Total Benefit (*Rial x $10^6$/year*) | 7,703.10 | | | | |

Table 3. Benefits of using CHP- Second Scenario

| Benefit | PS | HPS |
|---|---|---|
| Value (*Rial x $10^6$/year*) | 5,599.39 | 172.8 |
| Total Benefit (*Rial x $10^6$/year*) | 5,772.19 | |

It is assumed that 60% of the investment cost is provided through bank loan with the *IR* of 12.5% and the investment cost of the investors are considered with the *IR* of 15% and the costs are calculated annually via Eq. 4. Each scenario in considered separately and the result are compared to determine the best solution.

***1. First Scenario***

The results of this scenario are provided in Table 2. The benefit of each factor is presented separately along with the total benefits value. As the results show in this situation the total benefit regarding employing CHP will be about 7.7 billion *Rial/year*. It is notable that CFR is only calculated once in the study horizon since the customer should pay the connection fee once and not annually. The highest value of benefits is related to PPS where about 2.9 billion Rial incomes are earned annually.

***2. Second Scenario***

The results of this scenario are provided in Table 3. AS provided in this table in this situation only two different benefits including power and heat selling are considered. Total benefits in this scenario are about 5.7 billion *Rial/year*.

***3. Discussion***

In order to provide the comparison of the two presented scenarios benefits, costs and BCRs of them are provided in Table 4. As the result show the first scenario offers a better solution than the second scenario. In the first scenario the investment cost will return in less than five years that indicate this investment is financially reasonable. It is notable that the lifetime of the CHP systems is about 15 years and after returning the investment cost the investors can benefit from a high rate income from their units.

Table 4. Costs of deploying CHP

| | *Scenario 1* | *Scenario 2* |
|---|---|---|
| Benefit (*Rial x $10^6$/year*) | 7,703.100 | 5,772.190 |
| Cost (*Rial x $10^6$/year*) | 6,352.026 | 6,352.026 |
| BCR | 1.2127 | 0.9087 |

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