International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

Septembr 2016 | Issue 28 | Volume 8 | Number 3 | Pages 9-16

# OPTIMAL ENERGY MANAGEMENT OF A SMART RESIDENTIAL COMBINED HEAT, COOLING AND POWER

**H. Moradi** [1] **A. Abtahi** [2] **M. Esfahanian** [1]

*1. Department of Computer and Electrical Engineering and Computer Science, Florida Atlantic University,*
*Boca Raton, USA, hmoradi@fau.edu, mahdi.esfahanian@gmail.com*
*2. Department of Ocean and Mechanical Engineering, Florida Atlantic University, Boca Raton, USA, abtahi@fau.edu*

**Abstract-** Smart homes are one part of smart grid and smart distributed generation is one of the important components of smart homes. To minimize the generation costs to investors, a novel approach for smart production of energy in residential buildings is introduced in this paper. CHCP technologies offer a more beneficial way to provide home with heat, cooling and power in addition to advantages of high energy efficiency, emission reduction, and independency from centralized power networks. In this research, an energy dispatch algorithm is presented to minimize the total cost of energy (e.g., cost of natural gas into the engine and boiler and also cost of electricity from the grid) considering energy efficiency constrains for individual components. Additionally, the possibility of buying from or selling electrical power to the electrical local utility is investigated. The system consists of various kinds of loads (electrical, thermal and cooling) and energy resources (combined heat, power and cooling system, external main grid, boiler, absorption chiller and site chiller). A load profile of a residential building is considered and the optimizer selects the best state with the least cost in each time interval in order to run the system. Also, the on and off status of CHCP, boiler and site chiller as well as their levels of power, heating and cooling production is determined. By using different strategies, the utilization of these systems is feasible. Electrical, thermal and hybrid dispatches are three kinds of such strategies, which have been presented in this paper.

**Keywords:** Optimization, Combined Heat and Power, Energy Dispatch, Smart home, Demand Response.

## I. INTRODUCTION

The demand for electrical power along with energy for heating and cooling of residential uses is increasing which makes a rising global concern [1, 12]. DER has different forms, where the major development one is CHCP system. The system studied in this paper is focusing on the natural gas CHCP system. An excellent cycle CHP system producing electrical energy and thermal energy is recovered as a byproduct from the wasted flow.

Then applicable heating and/or cooling energy are generated as byproduct [13]. Power generation units produce the electric energy used to supply electrical facilities and building lights and running heating and cooling devices. If the power generated by the unit does not produce sufficient electric energy and cannot cover the power demand, the remaining power needs can be imported from the main grid [2]. On the other hand, combined heat and power system of power and heat generation in a single process has emerged as another matured form of DER which not only yields more than 80% efficiency [3] but also helps to reduce emission level, primary energy usage and production cost.

The distribution of CHP and CHCP systems is slowly become one of the most launched subdivisions of the self-generation energy for commercial centers, industries, hospital and residential structures [4]. The cooling part of CHCP systems usually includes absorption chillers fed by generated thermal energy (steam or hot water). For the CHP side of a trigeneration system, it is substantial to consider the regulatory strategies as below:

- To supply electrical or heating base load: CHP system is designed to cover just a fixed section of the electrical or heating load.
- To supply electrical or heating load following: CHP system designed to follow the progression of the electrical (heating) load.
- To use for peak shaving purposes: CHP system planned to supply the electrical peak load for a restricted amount of time [5].

Moreover, compared with burning coal, burning natural gas is a more environmentally friendly, which makes the micro energy grids advantageous for both society and environment [6]. There are several techniques to manage the energy produced by different cogeneration systems. For instance, linear programming method can be used to optimize the energy flow in a small power-generating component, which is only a cogeneration system, or when produced heat and electricity of the CHP system are consumed to cover thermal and electrical loads respectively. An optimization of a cogeneration system can be modeled economically and numerically [7, 8].

When energy prices are changing, the power management of this generation unit is a challenging task, for example, electricity and fuel costs for the energy production units and electrical, heating and cooling load demands from a building on a daily or weekly time frames. Therefore a suitable optimization is required for production scheduling [9]. The electricity cost can change seasonally as TOU pries, considering the time in a day. Sharp peak prices can be seen for very limited lengths of time. A convenient optimization algorithm is needed to operate the CHP units at the maximum efficiency and the minimum cost.

A typical trigeneration system, shown in Figure 1, includes a power source unit interacting with thermally activated components. An implemented program in this paper identifies the produced amount of electric, heating and cooling energy in a CHCP system for a given load forecast in a period of 24-hour. Flow of energy is obtained in the system by using the proposed model.

## II. TRIGENERATION DEFINITION

The conventional production of energy aspects such as electricity, heat and cooling power occurs in separate manner. Particularly, heat and electricity are traditionally produced in boilers or CHGs and large power plants, respectively.

Concerning the cooling generation (typically in the form of chilled water), a CEC may be accepted as the most common solution. In addition, cooling can be produced in GAC or in an EDC in which the energy input to the equipment is directly fuel, such as natural gas. Also an IFAC, typically fired by locally waste heat, could be adopted [9].

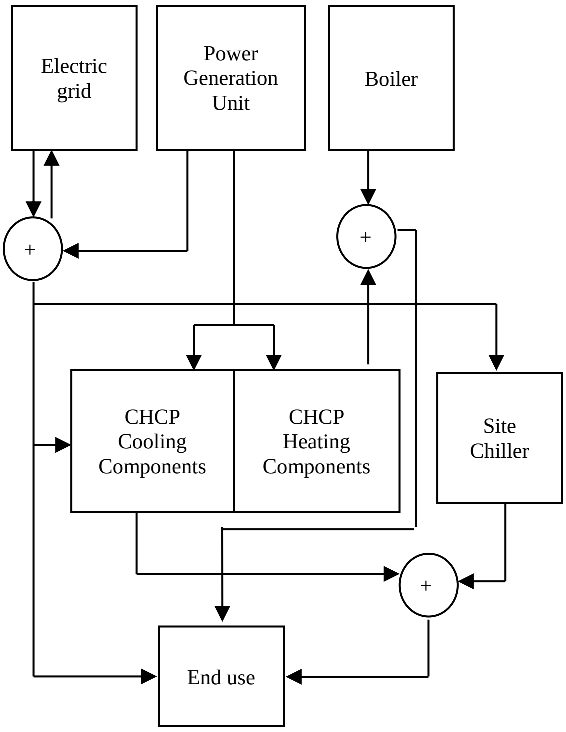


Figure 1. Diagram of a typical CHCP system [12]

An example is used to better describe the system. A local boiler with efficiency of 0.9 and a local chiller with COP of 3.33 are considered. It is desired to supply electric, thermal, and cooling load once by grid power, local boiler and site chiller and once by trigeneration source [10]. Then results of these two ways are compared. The goal is to supply electric load of 14 GWh and thermal load of 7 GWh and cooling load of 8 GWh. In a classic system by using separate equipment, system needs 7.8 GWh natural gas and 16.4 GWh power to fulfill this load, as shown in Figure 2.

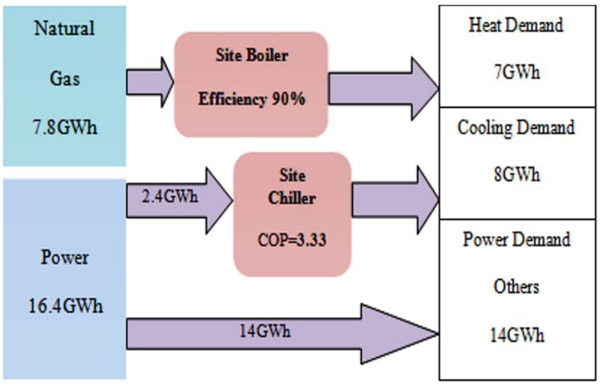


Figure 2. Classical solution for load supply [12]

If a part of load is supplied by a CHCP source, efficiency would significantly increase. Considering $\eta_p$ of 38.8%, if the amount of natural gas to the unit becomes 20.6 GWh, its output power will be 8 GWh as shown in Figure 3. As illustrated in this figure, these two values are calculated as:

CHP output power $= 20.6 \times 0.388 = 8$ [GWh]

Maximum CHP output heat $= 20.6 \times 0.427 = 8.7962$ [GWh]

where 3.8 GWh of maximum CHP output heat is consumed for heat demand and the remaining is used to meet cooling demand. Therefore:

CHP output cooling $= 4.9962 \times 0.7 = 3.5$ [GWh]

Finally it is possible to find the absorption chiller efficiency as below:

$\eta_{ab} = 0.427 \times 0.7 = 0.298$

Therefore, absorption chiller efficiency is nearly 30% in this system.

## III. THESTERATEGIES OF CHP OPRATION

Different kinds of strategies are available to operate a trigeneration system and each method has its own benefits and drawbacks.

### A. Electrical Dispatch

In this strategy, CHCP system operates when the first priority is taken to fulfill electrical load demand and the second priority is taken for supplying thermal demand. In this dispatch, the power output of CHCP is set on generating required electricity load but if electrical load exceeds the trigeneration rated power, the remaining needed electricity is imported from the grid.

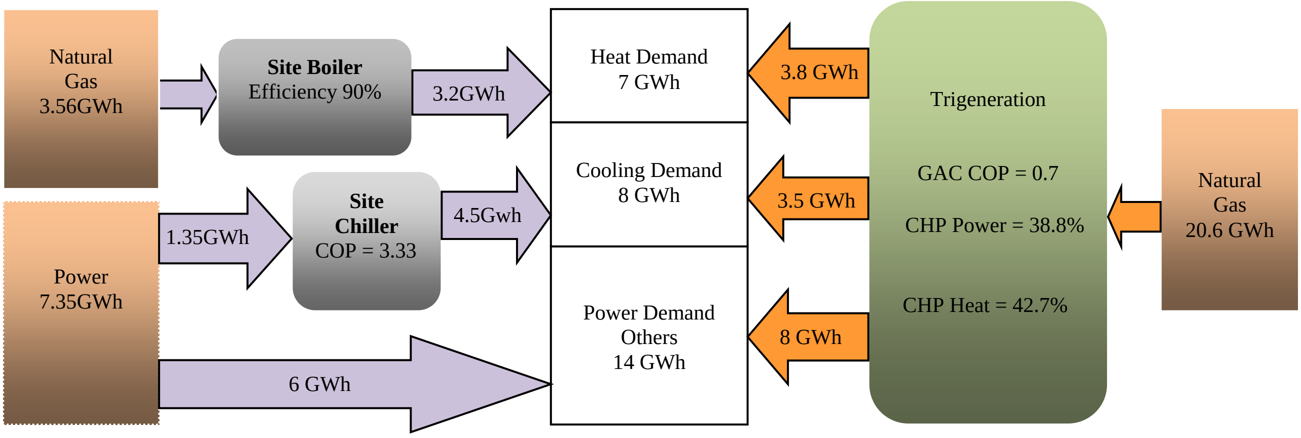


Figure 3. Classical approach along with trigeneration source for load supply [12]

The produced heat is then compared to the thermal demand and the boiler will be turned on in case of deficit to cover remaining thermal demand. Also the extra produced heat (in case of existence) is consumed for covering cooling demand using absorption chiller and the site chiller will be run if this produced cooling is less than the required cooling load. Obviously, there is no available excessive electrical power in this strategy to be sold to the main grid. At the end, components' costs are added and total cost of electrical dispatch is computed. The flowchart in Figure 4 shows the steps of this strategy for one-hour period. Certainly this process can be repeated 24 times for calculating system's total cost in a day.

## B. Thermal Dispatch

Unlike the electrical dispatch, in this strategy the first priority is satisfying required thermal demand and the second priority is taken by electrical power demand. The boiler will start running if produced heat as a byproduct is inadequate to cover the required heating and exceeds unit maximum power. In this situation, since there is no excessive heat to be used in the process of cooling production, the site chiller is employed to cover the needed cooling demand. Excessive produced power can be used to run site chiller otherwise this power is purchased from the main grid. Also it is possible to purchase the remaining required power from the grid. Additionally, if power generated by the system to satisfy required thermal load is more than electrical demand, this extra power can be used to empower site chiller and the rest of excessive power can be sold to the utility.

## C. Hybrid Dispatch

The optimal state of the trigeneration operation is presented in this strategy. In this approach, the unit rated power is selected as a start point and then produced heat is compared to the thermal demand. The boiler can be employed in case of heating power shortage. Cooling demand is also provided by extra produced heat (if it is available otherwise the site chiller will be run to fulfill required cooling load. Electrical power required for running site chiller is first provided by extra power produced by CHCP (in case of availability) and otherwise is provided by the grid. If produced power by the CHCP is inadequate to cover power demand, the remaining required power is imported from the grid.

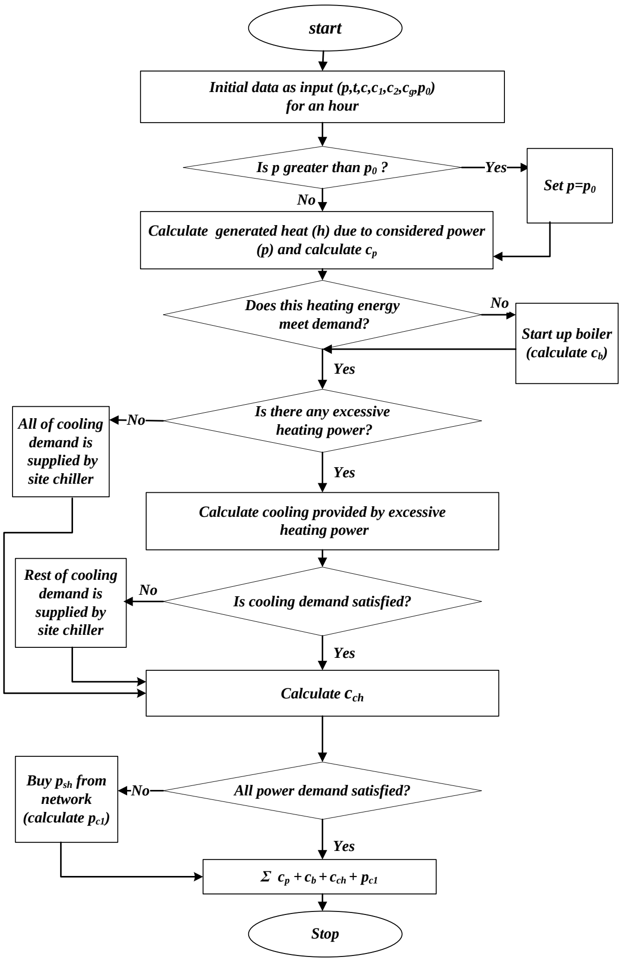


Figure 4. Flowchart of electrical dispatch for an hour

In case extra generated power is available, first it can be used in the cooling process and then the remaining electrical power can be sold to the grid. Generally in hybrid dispatch, all the possible states of components in order to supply power, heating and cooling demands are considered and investigated. Finally a state with the minimum total cost is chosen as the optimal solution. In this paper, all the aforementioned strategies are implemented to find the optimal state and their results are evaluated and compared together. There are some assumptions used for three algorithms as following:

1) Always local load of the consumer such as power, heat and cooling is given the priority.
2) Supply of heating load has priority over cooling load and the excessive heat is used for cooling production.
3) Unit extra power is first used to supply the cooling load and then the remaining power is sold to the grid.

## IV. DESCRIPTION OF THE PROPOSED MODEL

A simulation devoted to the optimal energy management is introduced in this section. This model consists of power systems made by several energy sources such as CHPs, boilers, absorption chillers, and site chillers. The model objective function and related system constrains and also some required data to run the model is presented in part.

### A. Objective Function

Cost function is defined to minimum costs of unit investor as below:

$$\min \mathit{Total\ Cost} = \sum C_{engine\ and\ boiler\ \ fuel} + \\ + C_{electricity\ import} - P_{sale\ of\ \ extra\ \ power} \tag{1}$$

$$\min \sum C_p + C_b + C_{sc} + P_{c1} - P_{c2} \tag{2}$$

Inputs of simulation optimizer in each time interval are consumer's power, heat and cooling needs, price of electricity (TOU prices) at that time and also sale price of electrical power from a typical DG.

### B. Constraints of Model

1) The power balance for electricity is calculated for each hour (t) by means of:

$$P_t^{CHP} + P_t^{GridIn} - P_t^{Chiller} - P_t^{EndUse} - P_t^{GridOut} = 0 \tag{3}$$

2) Constraints of Switching Power Between CHP and Main Grid:

$$P_{ex}^{\min} \le \left| P_{ex}^{i} \right| \le P_{ex}^{\max} \tag{4}$$

3) Constraints of Gas Boiler:

$$P_{gb}^{\min} \le P_{gb}^{i} \le P_{gb}^{\max} \tag{5}$$

4) Constraints of absorber chiller:

$$P_{ab}^{\min} \le P_{ab}^{i} \le P_{ab}^{\max} \tag{6}$$

5) Capacity limit of CHP:

$$P_{chp} \le P_0 \tag{7}$$

The optimal dispatch can be summarized in Figure 5. Three mentioned strategies, which are electrical, thermal and hybrid dispatch are run and the best state with less cost and also off-and-on position of all equipment in that state are presented to investor. Time interval in this paper (time scale) is a day (24 hours) while time scale for this program is possible to be set at hour, month and year. Load variations during a twenty four-hour period for a day in mid-season have been shown in Figure 6. It is necessary to extract the amount of demands from the figure to use in modeling. As given in Table 1, these demands are for a moderate day and there is more heating need at the beginning and end of day. Also there is cooling need at midday and heating need always exists due to continuous need to warm water and so on. Required data used in algorithms are given in Table 2.

Table 1. Load demands

| Hour | Power (kW) | Heat (kW) | Cooling (kW) | Hour | Power (kW) | Heat (kW) | Cooling (kW) |
|---|---|---|---|---|---|---|---|
| 1 | 456 | 1500 | 0 | 13 | 522 | 187 | 331 |
| 2 | 395 | 1252 | 0 | 14 | 537 | 122 | 397 |
| 3 | 390 | 1125 | 0 | 15 | 550 | 225 | 328 |
| 4 | 400 | 970 | 0 | 16 | 547 | 243 | 279 |
| 5 | 352 | 830 | 0 | 17 | 517 | 314 | 187 |
| 6 | 322 | 800 | 0 | 18 | 477 | 434 | 107 |
| 7 | 290 | 761 | 0 | 19 | 405 | 510 | 46 |
| 8 | 332 | 692 | 23 | 20 | 311 | 618 | 0 |
| 9 | 383 | 613 | 51 | 21 | 303 | 724 | 0 |
| 10 | 437 | 515 | 82 | 22 | 309 | 802 | 0 |
| 11 | 481 | 380 | 194 | 23 | 367 | 954 | 0 |
| 12 | 504 | 207 | 267 | 24 | 410 | 1172 | 0 |

Table 2. Data used in algorithms

| Parameter | Value |
|---|---|
| $P_0$ | 400 kW |
| $C_g$ | 10.65 cents/kWh |
| $\eta_t$ | 88% |
| $\eta_p$ | 33% |
| $\eta_{ab}$ | 22% |
| $\eta_h$ | 52% |
| $P_{ex}^{\min}$ | --400kW |
| $P_{ex}^{\max}$ | 400kW |
| COP CHCP | 0.7 |
| COP site chiller | 3.33 |
| $P_{gb}^{\min}$ | 0 |
| $P_{gb}^{\max}$ | 900kW |
| $P_{ab}^{\min}$ | 0 |
| $P_{ab}^{\min}$ | 400kW |

In order to reach the most economically optimal state, it is necessary to have TOU prices of power exported to and imported from grid. These prices are given in Table 3 [11]. It is assumed that ISO considers demand response DR programs and encouraging policies and purchases power from the CHP unit by 20% more at peak hours.

Table 3. Sale and purchase prices for a typical distributed generation

| Hour | Network Price (cent/kwh) | Sale Price (cent/kwh) | Hour | Network Price (cent/kwh) | Sale Price (cent/kwh) |
|---|---|---|---|---|---|
| 1 | 1.8 | 1.8 | 13 | 4.2 | 5.04 |
| 2 | 1.8 | 1.8 | 14 | 4.2 | 5.04 |
| 3 | 1.8 | 1.8 | 15 | 3.8 | 4.56 |
| 4 | 1.8 | 1.8 | 16 | 3.8 | 4.56 |
| 5 | 1.8 | 1.8 | 17 | 4.2 | 5.04 |
| 6 | 1.8 | 1.8 | 18 | 2.8 | 2.8 |
| 7 | 2.4 | 2.4 | 19 | 2.8 | 2.8 |
| 8 | 2.4 | 2.4 | 20 | 2.8 | 2.8 |
| 9 | 4.2 | 5.04 | 21 | 3.8 | 4.56 |
| 10 | 3.8 | 4.56 | 22 | 3.0 | 3.6 |
| 11 | 4.3 | 5.16 | 23 | 2.4 | 2.4 |
| 12 | 4.2 | 5.04 | 24 | 1.8 | 1.8 |

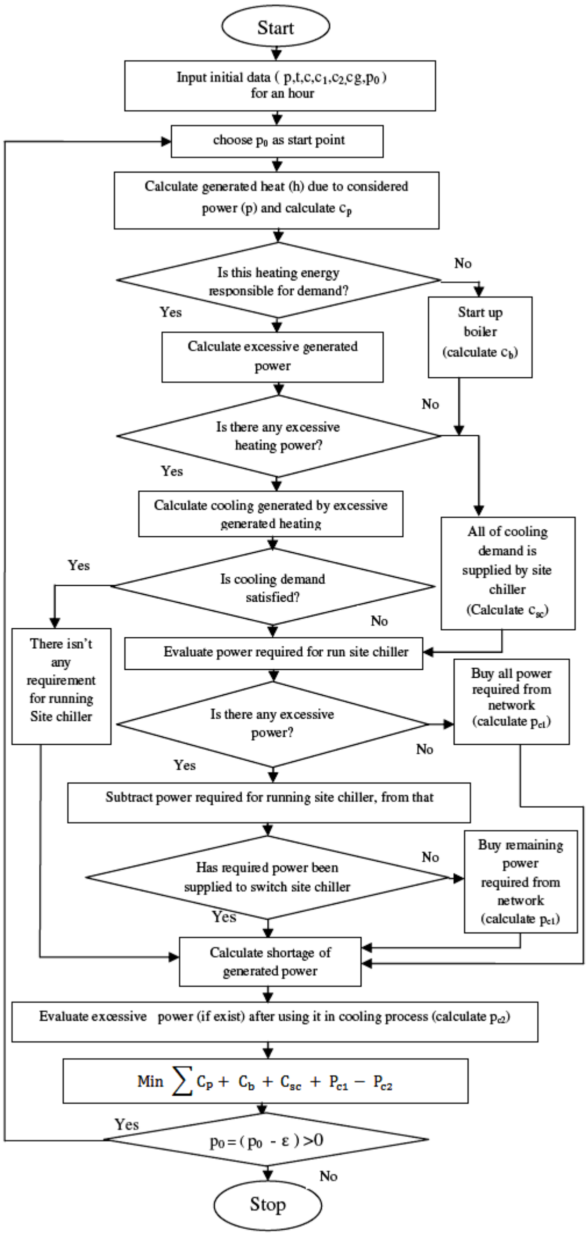


Figure 5. Flowchart of hybrid dispatch for an hour

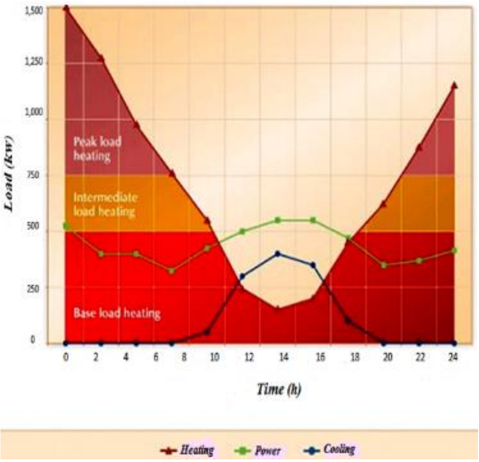


Figure 6. Electrical, heating and cooling load profile

## V. SIMULATION RESULTS

Simulation was run using three algorithms for one-day period and results were extracted. As shown in Figure 7, total cost of hybrid strategy is less than other strategies. So this is the most optimal state.

Comparing numerical results of costs in each strategy with a situation in which CHCP has not been used (power, heat and cooling demands comes from grid, boiler site chiller respectively) is illustrated in Table 4. Consequently the cost of load supply during a day decreases from 420.5$ to 188.9$ when CHCP unit is used in its best performance. In addition, the best state is to follow the electrical dispatch at midday because the amount of thermal load is low and following thermal dispatch is not economically justifiable though this action is suggested at the beginning and end of the day.

Table 4. Numerical results of total costs in each strategy

| Strategy | Total cost (cent) |
|---|---|
| Cost Without CHCP | 420503.67 |
| Cost With CHCP (Thermal dispatch) | 330745.78 |
| Cost With CHCP (Electrical dispatch) | 202763.04 |
| Cost With CHCP (Hybrid dispatch) | 188931.40 |

As demonstrated in Figure 8, electrical dispatch tracks the power need but its output is limited to the unit rated value at midday. Also thermal dispatch tracks the heating need but increases CHP output at the beginning and end of the day when thermal load is high and decreases CHP output at midday. The hybrid strategy shows the best state because unit must operate nearly at its rated power during the day.

In terms of boiler output, all strategies behave such that boiler is off at midday when thermal load is low as seen in Figure 9. When this load increases at the beginning and end of the day, boiler output increases as well and therefore, optimal state (i.e. hybrid dispatch) is identical to thermal dispatch. Figure 10 shows the site chiller output and since the goal of the thermal dispatch is supplying thermal load, thus excessive heat won't be available for cooling process. The chiller must supply the rest of the cooling load when the unit works at its rated power at midday. In hybrid strategy there is no need to use site chiller except little amount at midday when cooling load is high.

The amount of purchased power from the network is illustrated in Figure 12. The result in this figure is related to CHP output in figure 8. In both hybrid and electrical strategies, CHP output is limited to its rated power at midday and its power shortage is purchased from the network to fully cover the available electrical load profile (refer Figure 7). Thermal strategy makes CHP unit output reduce due to thermal load drop at midday and it must buy significant amount of power from the utility to supply the electrical load, which it is not economically suitable.

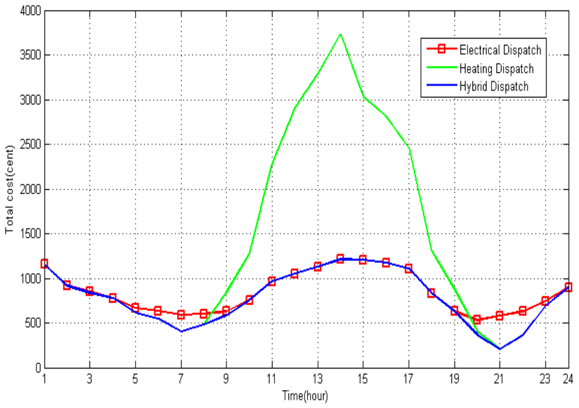


Figure 7. Total cost during a day

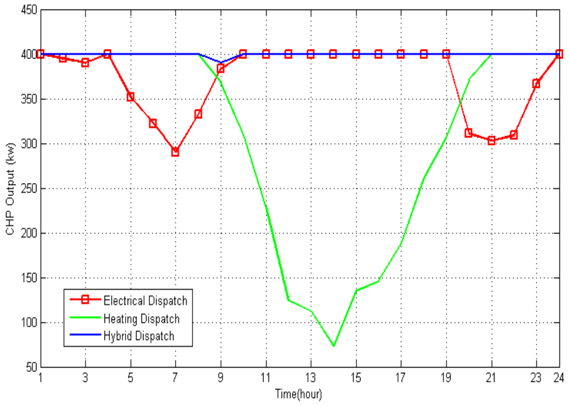


Figure 8. CHP output during a day

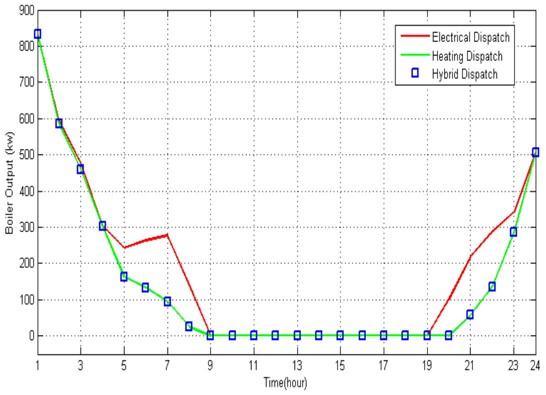


Figure 9. Boiler output during a day

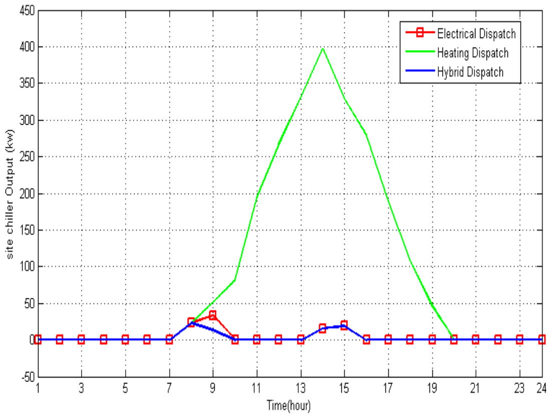


Figure 10. Site chiller output during a day

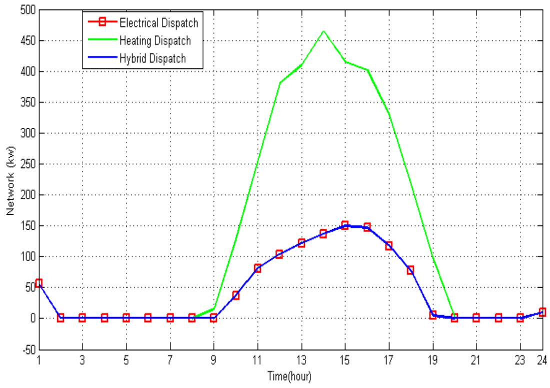


Figure 11. Network price during a day

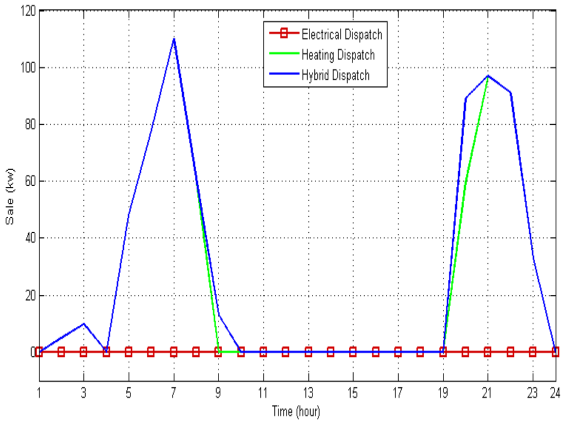


Figure 12. Sale price during a day

The amount of power sold to network is shown in Figure 13. Profile of optimal state or hybrid is under the other profiles in those figures that is known as cost for unit such as Figure 7 to Figure 11 but it is known as profit in Figure 12 and therefore. The area under hybrid strategy profile is higher than other profiles, which means bringing more profits to the system.

It is also clear that electrical dispatch doesn't generate any extra power for sell due to tracking the electrical load. In other two states it is necessary to produce more power to cover the thermal load and the excessive power is sold to the grid.

## VI. CONCLUSIONS

In this paper, three energy dispatch algorithms (thermal, cooling, and hybrid) have been proposed and developed for a CHCP system. The hybrid or optimal algorithm provides trigeneration unit with the operational signals leading to minimization of energy costs for entire system. Data used for this simulation are considered for a moderate weather, which contains both thermal and cooling loads in addition to electrical load. Simulation results indicate that hybrid dispatch is financially optimal state in comparison with other dispatches and the case where the system operates without CHCP unit.

## NOMENCLATURES

### A. Acronyms

| | |
|---|---|
| *CHCP* | Combined Heat, Cooling and Power |
| *CHP* | Combined Heat and Power |
| *COP* | Coefficient of Performance |
| *DG* | Distributed Generation |
| *CEC* | Compression Electrical Chiller |
| *CHG* | Combustion Heat Generator |
| *GAC* | Gas Absorption Chiller |
| *IFAC* | Indirect-Fired Absorption Chiller |
| *EDC* | Engine Driven Chiller |
| *I ISO* | Independent System Operator |
| *DR* | Demand Response |
| *DER* | Distributed Energy Resource |
| *TOU* | Time of use |

### B. List of Symbols

Subscripts used for symbols represent the types of energy. ($p =$ power, $t =$ thermal, $g =$ gas, $c =$ cooling)

| | |
|---|---|
| $p$ | Electricity demand |
| $t$ | Thermal demand |
| $c$ | Cooling demand |
| $c_1$ | Network electricity cost |
| $c_2$ | Price of electricity sold by DG |
| $c_p$ | Cost of electricity generated by CHP |
| $\eta_e$ | Electrical efficiency of conventional power plant |
| $\eta_{ab}$ | Efficiency of absorption chiller |
| $\eta_t$ | Thermal efficiency of boiler |
| $\eta_p$ | Electrical efficiency of CHP unit |
| $\eta_h$ | Thermal efficiency of CHP unit |
| $c_g$ | Gas cost |
| $h$ | Heat produced by the CHP unit |
| $P_0$ | CHP rated power |
| $P_{chp}$ | CHP output power |
| $c_b$ | Cost of boiler |
| $e_{sc}$ | Electricity required for site chiller start up |
| $P_{ex}$ | Excessive power generated by CHP unit |
| $p_{sh}$ | Shortage of power related to demand |
| $\varepsilon$ | A very small value |
| $c_{sc}$ | Cost of site chiller |
| $p_{c1}$ | Price of electricity purchased from network |
| $p_{c2}$ | Price of electricity sold to network (profit) |
| *total* | Total cost for CHCP unit after subtracting profit |
| $P_{ex}^{\min}$ | The minimum value of switching power between CHP and main grid |
| $P_{ex}^{\max}$ | The maximum value of switching power between CHP and main grid |
| $P_{gb}^{\min}$ | Minimum limits of gas boiler (kW) |
| $P_{gb}^{\max}$ | Maximum limits of gas boiler (kW) |
| $P_{ab}^{\min}$ | Minimum limits of absorption chiller (kW) |
| $P_{ab}^{\max}$ | Maximum limits of absorption chiller (kW) |
| $P^{GridIn}$ | Power imported from grid |
| $P^{GridOut}$ | Power exported to grid |
| $P^{EndUse}$ | Power consumed in end uses |

## REFERENCES

[1] H. Moradi, A. Abtahi, M. Esfahanian, “Optimal Operation of a Multi-Source Microgrid to Achieve Cost and Emission Targets”, IEEE Power and Energy Conference at Illinois (PECI), pp. 1-6, Urbana, IL, 2016.

[2] H. Cho, R. Luck, S.D. Eksioglu, L.M. Chamra, “Cost-Optimized Real-Time Operation of CHP Systems”, Energy and Buildings Journal, Vol. 41, No. 4, pp. 445-451, April 2009.

[3] P.K. Adhvaryyu, P.K. Chattopadhyay, A. Bhattacharjya, “Economic Emission Dispatch of Wind Power Integrated Combined Heat and Power System”, Power Systems Conference (NPSC), Eighteenth National, pp. 1-6, Guwahati, 2014.

[4] M. Brenna, F. Foiadelli, M. Roscia, D. Zaninelli, “Short Circuit Currents Evaluation in Combined Heat Cooling and Power (CHCP) Systems”, IEEE Power & Energy Society General Meeting, pp. 1-5, July 2009.

[5] G. Chicco, P. Mancarella, “From Cogeneration to Trigeneration: Profitable Alternatives in a Competitive Market”, IEEE Tran Energy Conversion, Vol. 21, No. 1, pp. 265-272, March 2006.

[6] H. Liang, L. Ba, H. Li, W. Xiao, “Study on Environmental and Economic Dispatching of Combined Cooling, Heating and Power Microgrid”, International Conference on Renewable Power Generation (RPG 2015), pp. 1-5, Beijing, 2015.

[7] M.R. Soderlund, “Cogeneration Dedicated to Heating and Cooling”, Ph.D. Dissertation, Georgia Inst. Technol., Atlanta, April 2001.

[8] R. Hashemi, “A Developed Offline Model for Optimal Operation of Combined Heating and Cooling and Power Systems”, IEEE Tran Energy Conversion, Vol. 24, no. 1, pp. 222-229, March 2009.

[9] A. Canova, C. Cavallero, F. Freschi, L. Giaccone, M. Repetto, M. Tartaglia, “Operational Planning of an Integrated Trigenerative System”, IEEE Industry Applications Magazine, March/April 2009.

[10] J. Li, S. Zhu, J. Zheng, X. Wang, “Combined Economic Operation Research of CCHP System and Energy Storage”, International Conference on Information Science, Electronics and Electrical Engineering (ISEEE), pp. 574-578, Sapporo, 2014.

[11] H. Alami, G.R. Yousefi, M.P. Moghaddam, “A MADM-Based Support System for DR Programs”, IEEE Universities Power Engineering Conference, September 2008.

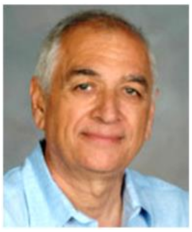
[12] http://www.arizonaenergy.org/Analysis/Builders/chp_basics.htm.

[13] A. Soltani-Sobh, K. Heaslip, R. Bosworth, R. Barnes, D. Yook, “Aggregated Panel Data Analysis to Model Electric Vehicle Adoption Rates”, Transportation on Research Board, 95th Annual Meeting, No. 16-4010, 2016.

[14] H.A. Shayanfar, A. Ghasemi, N. Amjady, O. Abedinia, “PSO-IIW for Combined Heat and Power Economic Dispatch”, International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 11, Vol. 4, No. 2, pp. 51-55, June 2012.

## BIOGRAPHIES

**Hadis Moradi** received the M.Sc. degree in Power Electrical Engineering from Tarbiat Modares University, Tehran, Iran in 2010. She is currently a Ph.D. candidate in Electrical Engineering at Florida Atlantic University, Boca Raton, USA since 2013. Her research interests are power and demand side management, smart grid, renewable energy, photovoltaic new technologies, optimization, cogeneration systems, microgrid financial analysis and distributed energy storage units. She is a member of International Electrical and Electronic Engineers (IEEE) and Society of Women Engineers (SWE).



**Amir Abtahi** received the Ph.D. degree in Mechanical Engineering from Massachusetts Institute of Technology, Cambridge, USA in 1981. Currently, he is a Full Professor at Mechanical Engineering Department, Florida Atlantic University, Boca Raton, USA. He has been working in solar energy as a teacher, inventor, developer and businessman for over 40 years. He is a Registered Professional Engineer in the State of Florida and also holds a LEED Certification by the US Green Building Council. He won the Florida Governor's Award in the state's low-cost solar panel competition. His research interests are fuel cell design and optimization, energy and thermal systems, system dynamics, modeling, renewable resources, microgrid, energy conversion and energy storage. He is a member of American Society of Mechanical Engineers (ASME), the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) as the faculty Advisor, the Society of Automotive Engineers (SAE) and International Electrical and Electronic Engineers (IEEE).

**Mahdi Esfahanian** received the B.Sc. degree in Mechanical Engineering from the Isfahan University of Technology, Isfahan, Iran, in 2005 and the M.Sc. degree in Aerospace Engineering from the Khaje Nasir Toosi University of Technology, Tehran, Iran, in 2009 and the Ph.D. degree in Electrical Engineering from Florida Atlantic University, Boca Raton, USA, in 2014. He is currently working in a bio company as Chief Research Scientist and data analyst in Florida, USA. His research interests lie in the areas of bioacoustics, digital processing of signals, energy systems, optimization, machine learning, and control systems.