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OPTIMAL PLANNING OF ENERGY HUBS CONSIDERING RENEWABLE ENERGY SOURCES AND BATTERY ENERGY STORAGE SYSTEM

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ABSTRACT

In the context of multiple energy loads, the energy hub is introduced as a unit where multiple energy carriers can be converted, conditioned, and stored to enhance the energy efficiency of the system. Therefore, this study presents an optimal planning framework, which aims the selection the invested size and time of equipment based on minimizing the life cycle cost considering renewable energy sources (RES) and battery energy storage systems (BESS). The input energies considered include the electrical energy, natural gas, solar radiation and wind that are converted to supply for output energies consisting of electricity, cooling, and heating. The planning framework with the objective function which is minimizing the life cycle cost of the project consists of the investing and operating cost of equipment, cost for purchasing energy from market (electricity, natural gas), the emission taxes cost and the replacement cost or residual value of equipment at the end of the planning period. The constraints as balance energy types, the size limit of equipment integrated into model together with binary variables make a mixed integer nonlinear programming (MINLP) planning problem. The feasibility of the proposed model and the effectiveness of renewable energy sources and BESS in optimal planning of energy hubs are tested by an assumed energy hub with the high-level algebraic modeling software, general algebraic modeling system (GAMS).

Contribution/Originality: This study contributes in existing documents a novel planning framework which considers the RES and BESS. A MINLP planning framework with the LCC objective function and constraints proposed allows determining the installed size and time of equipment during the planning period. The different lifetime and uptime of equipment are examined which improve the accuracy and suitability of problem for the practical.

1. INTRODUCTION

Energy hub concept was introduced for the first time as a result of the vision of future energy networks project presented in Geidl *et al.* (2007). In this model, an interface between consumers, producers, storage devices and transmission devices in different ways is utilized including as directly or via conversion equipment, handling one or several carriers. A matrix model to communicate various energy carriers at the input and output via the coupling matrix of energy hub (EH) concept is also introduced, in which each element represents EH interior features consisting of connection and transform coefficients of the internal components of EH.

In this new context, the structure of traditional energy supply systems that is mainly responsible for generation, transmission and management of an energy carrier has significant changes. The various types of EH structures are summarized and introduced in studies (Mohammadi *et al.*, 2017) that the simplest type is similar to traditional energy supply systems with correlates consumer and producers of energy together through conversions and storage systems. The most widely used structures of EH in the literature consist of a transformer (TR), combined heat and power (CHP), boiler, and storages which can convert between the input energy types and/or loads. In such a structure, a particular demand can be met in various ways and thus the flexibility and reliability in the supply of EH increase because of increasing the degree of freedom in supply and demand, and more flexible maintenance of different components.

The technologies of CHP include the reciprocating engines, gas turbines and micro-turbine where the gas turbines are widely used because of high efficiency achieved when combining both electricity and heat and low emission level (Elmubarak and Ali, 2016). Additionally, the distributed energy resources, especially renewable energy sources (RES) have been widely applied in recent times with various technologies such as solar energy, wind energy, geothermal and bioenergy. These sources are installed near the consumption site due to lower energy costs, with high potentiality of reducing transmission and distribution losses and higher energy efficiency (Elmubarak and Ali, 2016; Vinodh *et al.*, 2016). Particularly, renewable technologies are clean sources of energy and optimal use of these resources decreases the emission and environmental impacts. Therefore, the RES technologies provide an exceptional opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting conventional energy sources (Panwar *et al.*, 2011; Owusu and Asumadu-Sarkodie, 2016). However, the EH with the participation of RES and issues such as the complexity of connections and operation lead to planning, design and operation scheduling with optimal performance of such systems have serious challenges. Besides, the battery energy storage system (BESS) with various technologies used for large-scale energy storage, such as the lead-acid, lithium-ion, nickel-cadmium, sodium-sulfur and flow batteries, as well as their applications, are introduced in studies (Poullikkas, 2013; Zhao *et al.*, 2018). The lead-acid batteries have been widely applied in practice because of the low cost, large power and capacity. However, such batteries slowly charge and have the short lifecycle as well as the lead and sulfuric acid used are also highly toxic and can create environmental hazards. Sodium-sulfur batteries have high efficiency of charge/discharge, large power and capacity, long lifecycle and high operating temperature so they are primarily suitable for large-scale, non-mobile applications such as grid energy storage. Nevertheless, the capital cost of this battery is higher the lead-acid batteries. The different types of batteries as nickel-cadmium batteries, lithium-ion batteries and flow batteries have high efficiency and long lifecycle but the very high capital cost limits application of them in practice.

Because of the above reasons, the optimal planning and operation of EH have been studied extensively in recent years. The studies (Sheikhi *et al.*, 2011; Amiri and Niknam, 2018). Introduced EH planning model that objective consists of energy and air pollution cost with constraints as the balance of loads, equipment size limit and thus the optimal sizes of furnaces, CHP and TR are determined. The investment cost of equipment often has large value but it was ignored resulting in unsecured economic efficiency. A novel optimal planning method, which can determine the optimal generation, conversion and delivery of electricity, heat, cooling of EH, is represented with the objective including the investment cost of energy converters and storage devices and the operating cost (Wanga *et al.*, 2018). Similarly, the capacity configuration problem aims at finding the optimal sizes for the generation units introduced in the study (Deng *et al.*, 2017) the life cycle cost (LCC) is chosen as the minimal objective function of the model. In addition to the investment and operation costs of EH, the problem is added emission cost and lifecycle of equipment. However, only electricity and natural gas are considered in these studies so the energy cost and emission of EH are high. The solar energy and storage systems have been examined in EH planning problems that the objective function is minimizing the cost of energy and emission during the operation period shown in Barmayoon *et al.* (2016); Wanga *et al.* (2017) or the average installation cost, maintenance and operation (M&O), and management

annual fee, which shown at study (Bayod-Rújula *et al.*, 2018). The EH structure considered wind turbine (WT) and energy storages together with a mathematical formulation is developed by Pazouki and Haghifam (2016). Two objective functions are represented to integrate costs associated with investment, operation, reliability and emission of EH. The optimal investment of equipment is selected and thus the optimal structure of EH is also determined. However, most of above optimal planning and design studies failed to take adequate consideration to RES, the growth of the loads, investment time and lifecycle of equipment. To overcome the above disadvantages, this study presents an optimal planning framework, which aims the selection of the investment size and time of equipment based on minimizing the LCC considering RES and BESS. The different technologies of RES are examined simultaneously with conversion equipment and BESS by MINLP problem with binary variables to decide the investment for equipment during the computed time. The change in the value of the loads, the electrical price and out the power of RES according to the daily cycle and the growth of the energy demand during the planning period also taken into consideration in this study. Then, the effects of RES and BESS are investigated in each investment case. This study is organized by sections as follows: Firstly, the proposed EH structure will be introduced in Section 2. Then, a mathematical model for planning EH represented in Section 3 with objectives and constraints. Section 4 compares and discusses the computed results by different cases of EH. Finally, Section 4 draws the conclusions and future research directions.

2. PROPOSED ENERGY HUB STRUCTURE

In an EH, the different forms of energy are received at the input ports connected to the energy infrastructures and the energy are delivered at the output ports. The different energy forms are converted and conditioned by converter technologies such as TR, CHP, absorption chiller (AC), electrical chiller (EC), gas boiler (GB) and energy storages. The demand at output ports of EH often includes the energy forms as electricity, heating and cooling while the energy forms at the input are electricity, natural gas and renewable energies (Geidl *et al.*, 2007; Barmayoon *et al.*, 2016; Deng *et al.*, 2017). Therefore, a schematic diagram of a typical EH is proposed, and depicted in Figure 1 to improve the effectiveness of energy supply. The natural gas and electricity together with RES as PV and WT are input energy forms and they are converted through the equipment to supply for loads consisting of electricity, heating and cooling. The electrical power can be supplied by CHP, RES and the electrical system via TR. Similarly, the heating load can be received from CHP or GB and the cooling load can be converted from electricity by EC or heating through AC. In addition, BESS is considered in EH to store energy and supply for loads at other times because the energy demand, the electrical price and out power of RES largely change in the daily cycle.
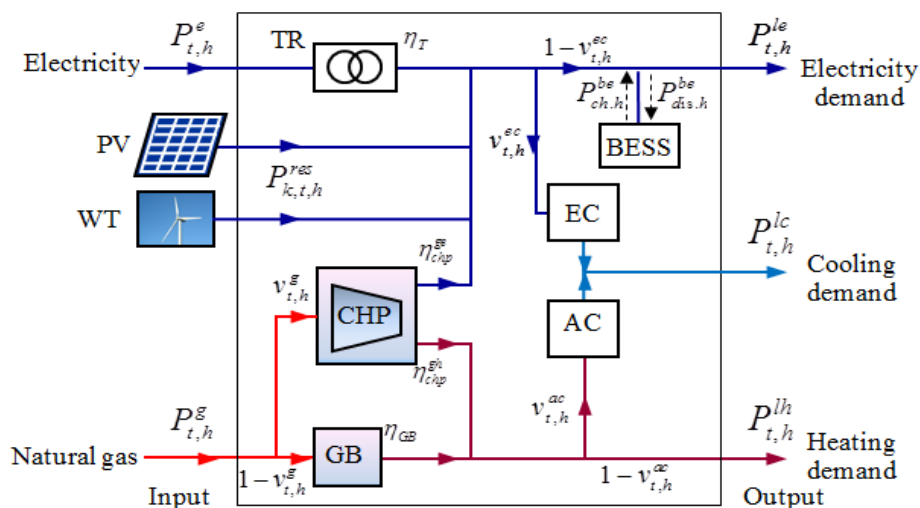

Figure-1. The proposed energy hub structure.

3. MATHEMATICAL MODEL FOR PLANNING ENERGY HUBS

The optimal model consists of an objective function and constraints in which the objective function is minimizing the LCC of the project, the constraints guarantee to make investment decisions and the size limit of equipment together with the operation of EH as following.

3.1. Objective Function

The LCC of the project consists of the investment and operating cost of equipment, the cost for purchasing energy from the market (electricity, natural gas), the emission taxes cost and the replacement cost or residual value of the equipment at the end of the planning period as expressed in Equation (1).

$$LCC = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left(C_{I.t} + C_{OM.t} + C_{EG.t} + C_{Emi.t} + C_{R.t} \right) \qquad (1)$$

Where, $C_{I.t}$ is the investment cost and $C_{OM.t}$ is the O&M of the equipment at year t. $C_{EG.t}$ is the cost of energy purchase (electricity and natural gas) from the market. $C_{Emi.t}$ is emission cost of the sources in the EH and $C_{R.t}$ is replacement cost or residual value of the equipment at the end of the project. r is discount rate and T is total planning time.

The structure of EH as Figure 1 shows that the equipment selected of planning problem include the TR, CHP, GB, AC, EC, BESS, PV and WT. Therefore, the total investment cost is computed as Equation (2).

$$C_{I,t} = \sum_{k=1}^{K} C_{I.k}^{res} * P_{I.k,t}^{res} + C_I^{tr} * P_{I.t}^{tr} + C_I^{chp} * P_{I.t}^{chp} + C_I^{gb} * P_{I.t}^{gb} + C_I^{ac} * P_{I.t}^{ac} + C_I^{ec} * P_{I.t}^{ec} + C_{I.P}^{be} * P_{I.t}^{be} + C_{I.E}^{be} * E_{I.t}^{be}$$
$$\forall t \in T \qquad (2)$$

The first part is investment cost of the RES in which $C_{I.k}^{res}$ is capital cost for each technology k, $P_{I.k,t}^{res}$ is selected power of the RES at year t and K is total types of the RES (PV and WT). The second part is the investment cost of TR with capital cost C_I^{tr} and installed power $P_{I.t}^{tr}$. Similarly, the third part is the investment cost of CHP with capital cost C_I^{chp} and selected power $P_{I.t}^{chp}$. The investment cost of GB is forth part consisting of capital cost C_I^{gb} and power $P_{I.t}^{gb}$. The fifth and sixth parts are investment cost of AC and EC in which the C_I^{ac} and C_I^{ec} are capital cost of each equipment corresponding with the power $P_{I.t}^{ac}$ and $P_{I.t}^{ec}$, respectively. The final parts are investment cost of BESS depending on power $P_{I.t}^{be}$ and capacity $E_{I.t}^{be}$ in which the capital cost by power is $C_{I.P}^{be}$ and by capacity is $C_{I.E}^{be}$.

The O&M cost of the equipment as TR, GB, AC, EC and BESS is ignored because of very low value of them. Consequently, the only O&M cost of the RES and CHP is computed as Equation (3). Where, $P_{k,t}^{res}$ is rated power and $k_{k,h}^{res}$ is the out power factor of the RES at year t. Similarly, $P_{t,h}^{chp}$ is the out power of the CHP at hour h and the H is total hour in a day. The coefficients for determining the O&M cost of the RES and CHP are ρ_k^{res} and ρ^{chp}, respectively.

$$C_{OM.t} = 365 * \sum_{k=1}^{K} \sum_{h=1}^{H} P_{k,t}^{res} * k_{k,h}^{res} * \rho_k^{res} + \sum_{h=1}^{H} P_{t,h}^{chp} * \rho^{chp} \qquad \forall t \in T \qquad (3)$$

The cost for purchasing energy consisting of electricity and natural gas at year t is expressed as Equation (4) in which the amount of electricity and natural gas received from the market are $P_{t,h}^e$ and $P_{t,h}^g$, respectively. Besides, the electrical price is denoted by ρ_h^e and the price of natural gas at each hour is ρ_h^e.

$$C_{EG.t} = 365 * \sum_{h=1}^{H} (P_{t,h}^e * \rho_h^e + P_{t,h}^g * \rho_h^g) \ \forall t \in T \tag{4}$$

The emission of the sources includes CO, CO_2, SO_2 and NO_x in which the amount of emission CO_2 is the largest so it is integrated into objective function to decrease the emission taxes computed as Equation (5) (Deng $et\ al.$, 2017). ξ_k, ξ_g and ξ_e are CO_2 emission coefficient from the RES, natural gas and utility grid electricity, respectively. β denotes for the emission tax probably enforced by the government.

$$C_{Emi.t} = 365 * \beta * \sum_{h=1}^{H} \left(\sum_{k=1}^{K} \xi_k * P_{k,t}^{res} * k_{k,h}^{res} + \xi_g * P_{t,h}^g + \xi_e * P_{t,h}^e \right) \qquad \forall t \in T \tag{5}$$

The replacement cost or residual value of the equipment at the end of the planning period is computed by expression Equation (6). At the end of planning time, if the uptime of the equipment is shorter than the lifetime of them, $C_{R.t}$ is residual value and it becomes the replacement cost on the contrary. Where, the lifetime of the equipment consists of $T_{c.k}^{res}$, T_c^{tr}, T_c^{chp}, T_c^{gb}, T_c^{ac}, T_c^{ec} and T_c^{be}.

$$C_{R.t} = \sum_{k=1}^{K} \frac{T_{c.k}^{res} - t_{up.k}^{res}}{T_{c.k}^{res}} * C_{I.k}^{res} * P_{I.k,t}^{res} + \frac{T_c^{tr} - t_{up}^{tr}}{T_c^{tr}} * C_I^{tr} * P_{I.t}^{tr} + \frac{T_c^{chp} - t_{up}^{chp}}{T_c^{tr}} * C_I^{chp} * P_{I.t}^{chp} + \frac{T_c^{gb} - t_{up}^{gb}}{T_c^{gb}} * C_I^{gb} * P_{I.t}^{gb}$$
$$+ \frac{T_c^{ac} - t_{up}^{ac}}{T_c^{ac}} * C_I^{ac} * P_{I.t}^{ac} + \frac{T_c^{ec} - t_{up}^{ec}}{T_c^{ec}} * C_I^{ec} * P_{I.t}^{ec} + \frac{T_c^{be} - t_{up}^{be}}{T_c^{be}} * (C_{I.P}^{be} * P_{I.t}^{be} + C_{I.E}^{be} * E_{I.t}^{be}) \tag{6}$$
$$\forall t \in T$$

Similarly, the installed time of them are $t_{I.k}^{res}$, t_I^{tr}, t_I^{chp}, t_I^{gb}, t_I^{ac}, t_I^{ec}, t_I^{be} and the uptime are $t_{up.k}^{res}$, t_{up}^{tr}, t_{up}^{chp}, t_{up}^{gb}, t_{up}^{ac}, t_{up}^{ec} and t_{up}^{be} as represented in Equation (7).

$$t_{up.k}^{res} = T - t_{I.k}^{res}; \qquad t_{up}^{tr} = T - t_{I.k}^{tr}; \qquad t_{up}^{chp} = T - t_I^{chp}; \qquad t_{up}^{gb} = T - t_I^{gb}$$
$$t_{up}^{ac} = T - t_I^{ac}; \qquad t_{up}^{ec} = T - t_I^{ec}; \qquad t_{up}^{be} = T - t_I^{be} \tag{7}$$
$$\forall t \in T$$

3.2. Constraints of Model
3.2.1. Energy Balance Constraints

Based on the structure of the proposed EH at Figure 1 and the matrix representing the energy balance relation in Equation (8) the energy balance constraints include three expressions as the following. The first equation balances the electricity, the second equation balances heat, and the cooling is balanced by the third equation.

$$P_{t,h}^{le} = (1 - v_{t,h}^e) * \left(\eta_{tr} * P_{t,h}^e + \sum_{k=1}^{K} P_{k,t}^{res} * k_{k,h}^{res} + v_{t,h}^g * \eta_{chp}^{ge} * P_{t,h}^g \right) + P_{dis.h}^{be} * \gamma_{dis.h} - \eta_{be} * P_{ch.h}^{be} * \gamma_{ch.h}$$
$$P_{t,h}^{lh} = [v_{t,h}^g * \eta_{chp}^{gh} + (1 - v_{t,h}^g) * \eta_{gb}] * (1 - v_{t,h}^g) * P_{t,h}^g \tag{8}$$
$$P_{t,h}^{lc} = v_{t,h}^e * \eta_{ec} * [\eta_{tr} * P_{t,h}^e + v_{t,h}^g * \eta_{chp}^{ge} * P_{t,h}^g] + [v_{t,h}^g * \eta_{chp}^{gh} + (1 - v_{t,h}^g) * \eta_{gb}] * \eta_{ac} * P_{t,h}^g * v_{t,h}^h$$
$$\forall t \in T, h \in H$$

In the Equation (8) $P_{t,h}^{le}$, $P_{t,h}^{lh}$ and $P_{t,h}^{lc}$ are electricity, heat and cooling load of EH, respectively. Similarly, $v_{t,h}^{e}$, $v_{t,h}^{g}$ and $v_{t,h}^{h}$ are the dispatch ratios of electricity, natural gas, and heat conversion at hour h and year t, respectively. $P_{ch.t,h}^{be}$ is the charge power and $P_{dis.t,h}^{be}$ discharges power of the BESS corresponding with the charge/discharge is expressed through two binary variables $\gamma_{ch.h}$ and $\gamma_{dis.h}$. η_{chp}^{ge}, η_{chp}^{gh} denote for gas-to-electricity and heat conversion efficiency of the CHP. The final, η_{tr}, η_{gb} and η_{be} are the efficiency of the TR, GB and BESS, respectively. η_{ec}, η_{ac} are the efficiency of the EC and AC which are computed based on the coefficient of performance (COP) as equation follows in which the COP_{ec}, COP_{ac} are the coefficient of performance of EC and AC (Barmayoon *et al.*, 2016) respectively.

$$\eta_{ec} = \frac{COP_{ec}}{1+COP_{ec}}; \eta_{ac} = \frac{COP_{ac}}{1+COP_{ac}} \tag{9}$$

3.2.2. Power Constraints of the RES

The technology and size of the RES are limited by constraint Equation (10) that the binary variable $\alpha_{k,t}^{res}$ is utilized to decide the investment time. The selected power depends on the potential of the primary energy source and is limited by the maximum power of each technology denoted by $P_{max.k}^{res}$.

$$P_{I.k,t}^{res} = \alpha_{k,t}^{res} * P_{k,t}^{res}; \ P_{k,t}^{res} = P_{I.k,t}^{res} + P_{k,t-1}^{res}; \qquad \sum_{t=1}^{T} \alpha_{k,t}^{res} \leq 1; \qquad 0 \leq P_{I.k,t}^{res} \leq P_{max.k}^{res}$$
$$\forall k \in K, t \in T \tag{10}$$

3.2.3. Power Constraints of the CHP and GB

The power limit of the CHP is presented in Equation (11) with the binary variable α_{t}^{chp} to decide the investment time and the rated power at year t is P_{t}^{chp}. The maximum power can invest of the CHP is limited by P_{max}^{chp}.

$$P_{I.t}^{chp} = \alpha_{t}^{chp} * P_{t}^{chp}; \ P_{t}^{chp} \geq P_{t,h}^{g} * v_{t,h}^{g}; \ P_{t}^{chp} = P_{I.t}^{chp} + P_{t-1}^{chp}$$
$$\alpha_{t}^{chp} \leq 1; \ 0 \leq P_{I.t}^{chp} \leq P_{max}^{chp}; \quad 0 \leq v_{t,h}^{g} \leq 1 \tag{11}$$
$$\forall t \in T$$

Similarly, the investment GB is limited as the constraint Equation (12) in which the installed time is decided by binary variable α_{t}^{gb}, the rated power at year t is P_{t}^{gb} and its maximum power which can be selected is P_{max}^{gb}.

$$P_{I.t}^{gb} = \alpha_{t}^{gb} * P_{t}^{gb}; \quad P_{t}^{gb} \geq P_{t,h}^{g} * (1-v_{t,h}^{g}); \quad P_{t}^{gb} = P_{I.t}^{gb} + P_{t-1}^{gb}$$
$$\alpha_{t}^{gb} \leq 1; \ 0 \leq P_{I.t}^{gb} \leq P_{max}^{gb} \tag{12}$$
$$\forall t \in T$$

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3.2.4. Power Constraints of the EC and AC

The electricity is converted into cooling by EC that its power is limited by maximum power P_{max}^{ec} and electrical load $P_{t,h}^{le}$ as Equation (13). Similarly, the constraint Equation (14) limits the investment power of the AC which converts heat into cooling with maximum power P_{max}^{ac}. The binary variables α_t^{ec} and α_t^{ac} are also utilized to select the installed time of the EC and AC.

$$
\begin{aligned}
&P_{I.t}^{ec} = \alpha_t^{ec} * P_t^{ec}; \quad P_t^{ec} \geq P_{t,h}^{le} * v_{t,h}^e; \quad P_t^{ec} = P_{I.t}^{ec} + P_{t-1}^{ec} \\
&\alpha_t^{ec} \leq 1; \quad 0 \leq P_{I.t}^{ec} \leq P_{max}^{ec}; \quad 0 \leq v_{t,h}^e \leq 1 \\
&\forall t \in T
\end{aligned}
\tag{13}
$$

$$
\begin{aligned}
&P_{I.t}^{ac} = \alpha_t^{ac} * P_t^{ac}; \quad P_t^{ac} \geq P_{t,h}^{lh} * v_{t,h}^h; \quad P_t^{ac} = P_{I.t}^{ac} + P_{t-1}^{ac} \\
&\alpha_t^{ac} \leq 1; \quad 0 \leq P_{I.t}^{ac} \leq P_{max}^{ac}; \quad 0 \leq v_{t,h}^h \leq 1 \\
&\forall t \in T
\end{aligned}
\tag{14}
$$

3.2.5. Power Constraints of the TR and BESS

The transformer connects the EH with utility grid so the its capacity S_t^{tr} at year t must always larger than the amount of electricity purchased from utility grid $P_{t,h}^e$ as shown in Equation (15). Similarly, the power and capacity limit of the BESS as constraint Equation (16) where the rated power and capacity at year t are P_t^{be} and E_t^{be}, respectively. E_h^{be}, E_{max}^{be} are capacity at hour h and maximum capacity of the BESS, respectively. The binary variables α_t^{tr} and α_t^{be} are utilized to decide the investment time of the TR and BESS, respectively. P_{max}^{be} is maximum power of BESS and S_{max}^{tr} is the maximum capacity of TR.

$$
\begin{aligned}
&S_{I.t}^{tr} = \alpha_t^{tr} * S_t^{tr}; \quad S_t^{tr} \geq P_{t,h}^e; \quad S_t^{tr} = S_{I.t}^{tr} + S_{t-1}^{tr} \\
&\alpha_t^e \leq 1; \quad 0 \leq S_{I.t}^{tr} \leq S_{max}^{tr} \\
&\forall t \in T
\end{aligned}
\tag{15}
$$

$$
\begin{aligned}
&P_{I.t}^{be} = \alpha_t^{be} * P_t^{be}; \quad P_t^{be} \geq P_{ch.h}^{be}; \quad P_t^{be} = P_{I.t}^{be} + P_{t-1}^{be} \\
&E_{I.t}^{be} = \alpha_t^{be} * E_t^{be}; \quad E_t^{be} \geq \max_{h \in H}\left(E_h^{be}\right); \quad E_t^{be} = E_{I.t}^{be} + E_{t-1}^{be} \\
&E_h^{be} = E_{h-1}^{be} + P_{ch.h}^{be} - P_{dis.h}^{be}; \quad \alpha_t^{be} \leq 1; \quad 0 \leq P_{I.t}^{be} \leq P_{max}^{be}; \quad 0 \leq E_{I.t}^{be} \leq E_{max}^{be} \\
&\forall t \in T, h \in H
\end{aligned}
\tag{16}
$$

3.2.6. Charging/Discharging Constraints of the BESS

The electricity prices and load vary with one-day cycle (24 hours). The electricity price is high at peak hours and vice versa. Besides, the BESS can store the electrical energy at hours that the price or load of the electricity is low then it generates back to supply for the load at peak load hours or times have the high electrical price. In this context, the maximum power of the equipment can decrease the lead to reduce the investment cost together with the cost of purchasing energy from the market. Hence, the constraint on energy balance in the computed cycle of the BESS is expressed as Equation (17) and the charge/discharge of them can be expressed through two binary variables $\gamma_{ch.h}$ and $\gamma_{dis.h}$.

$$\sum_{h=1}^{H} \eta_{be} * \gamma_{ch.h} * P_{ch.h}^{be} = \sum_{h=1}^{H} \gamma_{dis.h} * P_{dis.h}^{be}; \ \gamma_{ch.h} + \gamma_{dis.h} = 1 \qquad \forall h \in H \qquad (17)$$

3.2.7. The Constraints for Purchasing Energy from the Market

The power and energy which can receive from the market is limited by the capacity and energy stored. Consequently, the constraint Equation (18) is utilized in which the maximum allowable power of electrical energy and natural gas are P_{max}^{e} and P_{max}^{g}, respectively.

$$P_{t,h}^{e} \le P_{max}^{e}; \ \ P_{t,h}^{g} \le P_{max}^{g} \quad \forall t \in T, h \in H \qquad (18)$$

Similarly, the total energy purchased from the electricity and natural gas system within each day and year of EH is limited by the energy that can be supplied from the two systems above by the Equation (19). The maximum allowable capacity of electrical energy and natural gas are denoted E_{max}^{e} and E_{max}^{g}, respectively.

$$\sum_{t=1}^{T}\sum_{h=1}^{H} P_{t,h}^{e} \le E_{max}^{e}; \ \sum_{t=1}^{T}\sum_{h=1}^{H} P_{t,h}^{g} \le E_{max}^{g} \quad \forall t \in T, h \in H \qquad (19)$$

The optimization problem with targeted function and binds was based on a programming language GAMS with BONMIN solver (Rosenthal, 2008).

4. RESULTS AND DISCUSSIONS

To investigate the effectiveness of RES and BESS in EH planning, the three study cases have been defined to compare and discuss as Table 1. Each of the cases represents a possible structure for investing the equipment of EH. In the first case, only electricity and natural gas are utilized for input energy converted and conditioned by TR, CHP, GB, EC and AC to deliver for loads (electricity, heating and cooling). The input energies are added the RES in the second case and the final case considers all of the equipment of proposed EH in Figure 1.

Table-1. Computed cases.

Case	TR, CHP, GB, EC, AC	RES	BESS
1	x		
2	x	x	
3	x	x	x

The typical daily curves of loads at base year are assumed as Figure 2 where the growth of electrical, heating and cooling demand are about 5%, 2.5% and 1% annually, respectively. Similarly, the average out power of RES at 24 hours each day is also assumed and represented in Figure 3.
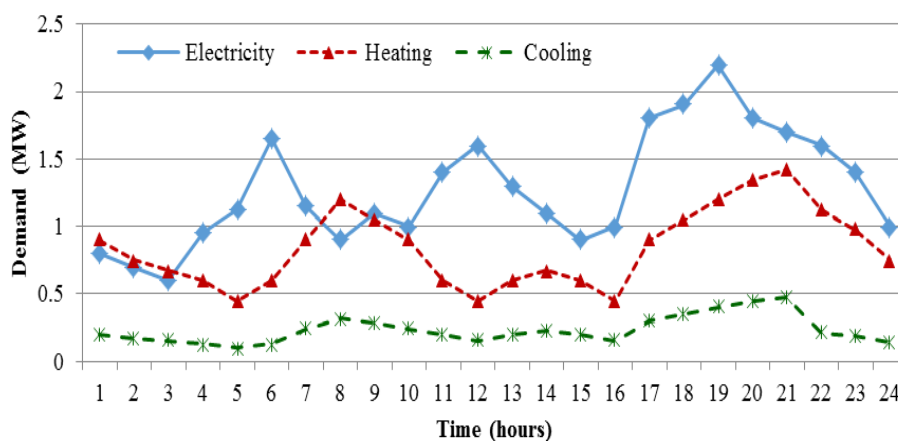

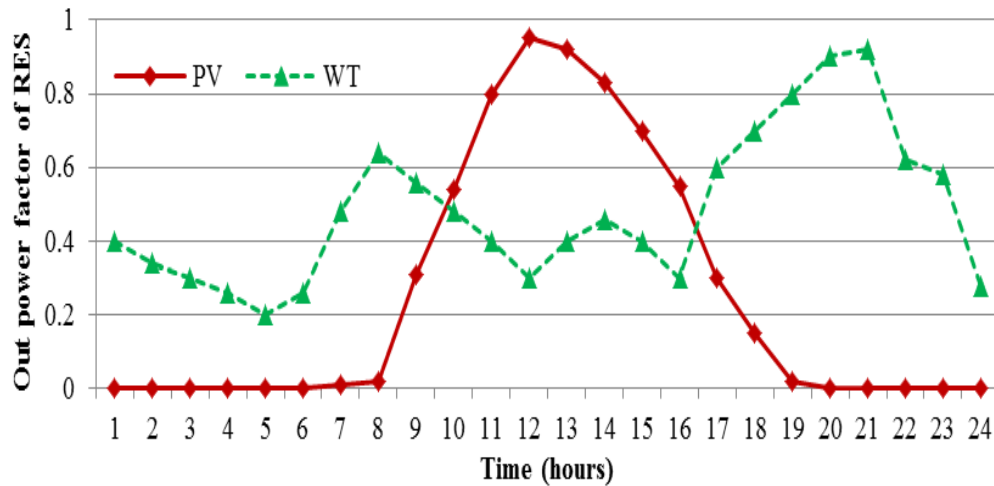**Figure-2.** Electricity, heating and cooling demands at 24h, a day.

Figure-3. Electricity, heating and cooling demands at 24h, a day.

The computed parameters of equipment are assumed as Table 2. In addition, the CO_2 emission coefficient of electricity from the utility source and natural gas are about 0.623 kg/kWh and 0.184 kg/kWh, respectively. The CO_2 emission tax probably enforced by the government is 4.12 \$/ton (Deng *et al.*, 2017; Wanga *et al.*, 2017). The simulation period is 5 years and the discount rate is 10%.

Table-2. Computed data of equipment.

No	Equipment	Parameters	Value	Parameters	Value
1	PV	$C_{I.k}^{res}$ (\$/kW)	1050	$P_{max.k}^{res}$ (MW)	2.0
		ρ_k^{res} (\$/MWh)	22	ξ_k^{res} (kg/kWh)	0.02
		$T_{c.k}^{res}$ (year)	30		
2	WT	$C_{I.k}^{res}$ (\$/kW)	1250	$P_{max.k}^{res}$ (MW)	2.0
		ρ_k^{res} (\$/MWh)	30	ξ_k^{res} (kg/kWh)	0.025
		$T_{c.k}^{res}$ (year)	25		
3	CHP	C_I^{chp} (\$/kW)	815	$P_{max.k}^{res}$ (MW)	5.0
		ρ^{chp} (\$/MWh)	7.8	T_c^{chp} (year)	20
		η_{chp}^{ge}	0.4	η_{chp}^{gh}	0.45
4	TR	C_I^{tr} (\$/kVA)	500	S_{max}^{tr} (MVA)	2.0
		η_{tr}	0.95	T_c^{tr} (year)	20
5	GB	C_I^{gb} (\$/kW)	800	P_{max}^{gb} (MW)	2.0
		η_{gb}	0.9	T_c^{gb} (year)	20
6	EC	C_I^{ec} (\$/kW)	881	P_{max}^{ec} (MW)	1
		η_{ec} (COP = 4)	0.8	T_c^{ec} (year)	20
7	AC	C_I^{ac} (\$/kW)	726	P_{max}^{ac} (MW)	1.0
		η_{ac} (COP = 1.68)	0.63	T_c^{ac} (year)	20
8	BESS	$C_{I.P}^{be}$ (\$/kW)	226	P_{max}^{be} (MW)	0.5
		$C_{I.E}^{be}$ (\$/kWh)	176	E_{max}^{be} (MWh)	1.0
		η_{be}		T_c^{be} (year)	5

Recent, the electricity prices often vary largely in day cycle depending on the market. In this study, the typical daily curve of electricity price is shown in Figure 4. In contrast, the gas prices changed a little in the short term so

in a typical day it is an instant and is about 0.055 $/kWh (Pazouki and Haghifam, 2016; Wanga *et al.*, 2017; Bayod-Rújula *et al.*, 2018).
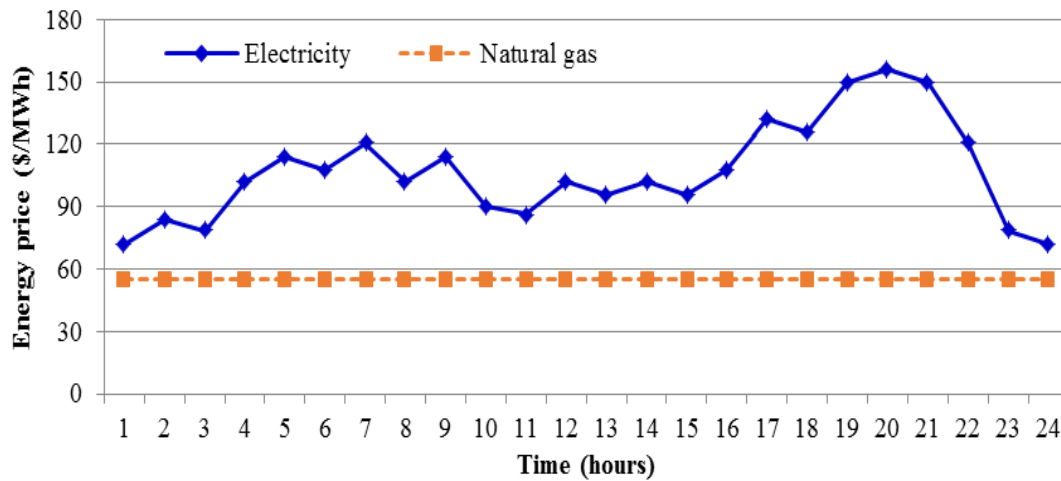

Figure-4. Electricity and natural gas at 24h, a day.

Computed results for assumed cases with different participations of RES and BESS in EH determine the invested size and time of equipment represented in Table 3. The installed power of TR, CHP and EC significantly reduce when RES and BESS are selected in case 2 and case 3. In case 2, WT is invested in the first year with power 1.0 MW while the power of PV only is selected at the second year with power 0.44 MW. The BESS investment in case 3 with power 0.33MW and capacity 0.7 MWh decreases the cost of purchasing electricity at peak hours lead to improving the effectiveness of RES. Therefore, the PV invested with power is 1.2 MW and WT selected with maximum power is 2.0 MW though installation time is similar to case 2. In case 2 and case 3, the CHP power reduces 7.45% and 38.22% compared with case 1, respectively. Similarly, power TR and EC in case 3 in comparison with case 1 decrease 58.33% and 73.58%, respectively. However, the invested power of GB creases 0.99 MW at case 2 and 1.28 MW at case 3 in comparison with case 1. Similarly, the power of EC installed at case 2 and case 3 also reduce 47.37% and 73.68%, respectively.

Table-3. The invested decision of EH.

No	Equipment	Case 1		Case 2		Case 3	
		Installed size	Planning year	Installed size	Planning year	Installed size	Planning year
1	PV	-	-	0.44 MW	2	1.2 MW	2
2	WT	-	-	1.0 MW	1	2.0 MW	1
3	CHP	4.61 MW	1	3.85 MW	1	2.57 MW	1
4	TR	1.2 MVA	1	1.13 MVA	1	0.5 MVA	1
5	GB	0.14 MW	1	1.13 MW	1	1.42 MW	1
6	EC	0.19 MW	1	0.1 MW	1	0.05 MW	1
7	AC	0.50 MW	1	0.53 MW	1	0.53 MW	1
8	BESS	-	-	-	-	0.33 MW 0.7 MWh	1

Comparison of economic and emission indicators between cases represented in Table 4 shows the effectiveness of RES and BESS in EH planning problem. The LCC of EH reduces 0.47 M$ in proportion to 5.85% in comparison with case 1 when RES is invested in case 2 through the invested cost of equipment increases 2.12 M$ at net present value. Similarly, the both RES and BESS are considered in case 3 lead to decrease LCC 1.03 M$ corresponding with 12.81% in comparison with case 1. However, the capital cost in this case creases 3.03M$ in proportion to 64.44%.

In addition to reducing LCC of the project, the CO_2 emission of EH when both RES and BESS are invested decreases about 11,980.0 tons corresponding with 46.4% in comparison with case 1. Hence, the emission tax reduces 19,170.0 \$ in case 2 and 49,330.0 \$ in case 3.

Table-4. Comparison of economic and emission indicators of EH.

Economic and technical indicators	Case 1	Case 2	Case 3
Total life cycle cost, M\$	8.04	7.57	7.01
Invested cost, M\$	4.63	6.75	7.66
CO_2 emission, 10^3 tons	25.82	21.17	13.84
Emission taxes cost, 10^3 \$	106.37	87.2	57.04

The computed results show significant effectiveness of RES and BESS in EH planning at both economic and emission indicator because of reduction the LCC and emission. Moreover, the flexibility in maintenance and operation equipment together the reliability of EH is enhanced because of the portion of power flows to supply for loads.

5. CONCLUSIONS

The optimal planning of EH considering RES is necessary of multi-energy combination exemplary projects in the context of rapid exhaustion of traditional energy sources and climate change today. Therefore, this study proposes an EH structure and optimal planning framework based on minimizing LCC of the invested project. The significant conclusions of this study are given below:

- A typical EH structure integrated RES and BESS is proposed to improve the effectiveness of energy supply for loads. Input energy forms consist of natural gas and electricity together with RES are converted through the equipment to supply for electricity, heating and cooling loads.

- A MINLP planning framework is proposed with the LCC objective function and constraints allow to determine the installed size and time of equipment during the planning period. The different lifetime and uptime of equipment are examined which improve the accuracy and suitability of problem for the practical.

- The simulation results demonstrate how the high efficiency of the RES in planning grid-connected micro-grid because the RES could promote the reduction of LCC and the cost of purchasing electrical energy from the utility grid. Particularly, the emission of micro-grid significantly decreases and that has great significance in the context of climate change today.

- The results show that the proposed optimal planning framework is beneficial to improve energy utilization efficiency and the practical application of RES and BESS in EH. Additionally, the emission significantly reduces when RES and BESS are invested and that is of large significance in the context of climate change today.

The cases study has illustrated the feasibility of the proposed model and effectiveness of RES and BESS. However, the future works on the planning of EH can consider to discrete parameters as rated power and capacity of equipment to enhance the practical application of EH.

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