Short Term Scheduling of Multi Carrier Systems through Interruptible Load and Energy Storage toward Future Sustainable Energy Needs

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Abstract

Greenhouse gas emissions especially CO2 and growing energy needs are developing advance technologies which are subject to emission lower, efficiency enhancement, economic improvement and reliability enhancement in response to future energy needs; electricity, hydrogen, heat, cooling and biofuels. In this paper, Energy Hub (EH) model as a strong solution is extended by smart grid key drivers; Renewable Energy, Combined Heat and Power (CHP), Energy Storage (ES), Demand Response (DR) to balance demand and supply in distribution system. EH is defined a super node in electric power system to utilize renewable and network energy carriers, then based on minimum cost decides how to act; convert, store or directly connect to serve hub required demands. Simulation results are applied on an urban place (Daran) in North-West of Iran where has strong potential to utilize agricultural and renewable resources. Results by Linear Mixed Integer Programming (MIP) model of GAMS software show when and how much of which carrier should be purchased, stored or interrupted to satisfy demands.

1. INTRODUCTION

Technology advances in renewable generation have been key drivers to implement renewable resources over two past decades in response to emission and cost reduction, reliability enhancement and efficiency improvement [1]-[3] toward future energy needs; electricity, hydrogen, heat, cooling and bio fuels [4]. Operation of renewable generation with conventional grid creates new challenges to balance demand and supply [5]. Smart grid provides opportunity for customers to participate in electricity produce. It can be beneficial for power system companies to decline power production in peak demands and costs for transmission lines expansion and power plant establishment. In this paper, we hourly operate the resources toward meeting future energy needs based on energy hub solution.

Several concepts for integrated energy systems have been considered recently: “Micro Grid”, “Virtual Power Plant”, “Hybrid Energy System” and the latest approach has been formulated in VoFEN (Vision of Future Energy Network) project [6]. The first energy hub was designed to produce natural gas and heat from wood chips by gasification and methanation process and a cogeneration plant by a municipal in Switzerland, Regionalwerke AG Baden. The hub receives diverse of solid, gaseous and chemical carriers such as fossil fuels (coal, petroleum product), air, water, hydrogen, biomass/ biogas, geothermal heat, municipal waste, landfill gas, etc. From system view, an energy hub includes: input and output, conversion, storage. Three elements in energy hub are direct connection, converter, and storage. Direct connection is used for transferring a carrier from input to output without any change in carrier quality (voltage, pressure, etc), electric cables, overhead lines, pipelines are good example of direct connection. In contrast, converters change input carriers quality form, e.g. steam turbine, gas turbine, combustion engines, electric machines, fuel cells, compressors, pumps, transformer, power electronic, heat exchanger and etc. Series of places can be modeled as hub [6]: Power plants (co& tri generation), Industrial plants (steel works, paper mills, and refiners), Big buildings (airports, hospitals, shopping malls), Bounded Geographic areas (rural& urban districts, town, cities)

Energy hub approach isn’t restricted to predefined size and elements, the model can be flexibility extended for different problems [7]-[8]. Photovoltaic and storage without DR are employed for an optimal power flow problem in multi carrier energy systems [9]-[10]. Plug in hybrid electric vehicle as ES [11] are used to smooth fluctuations of wind power without DR. Reference [12] investigates DR and ES influence in residential EH which is supplied with photo voltaic. Heat responsive demands are utilized in response to operation costs reduction with different biomasses in [13] and in response to simulated spot electricity price with Monte Carlo in [14]. Renewable resources can be also applied in energy hub [6], [10], [13].

Paper extends an EH in section II and scheduling of the hub in session III. Section IV models an urban hub. Results are debated in section V. Conclusion is discussed in section VI.

2. PROPOSED ENERGY HUB MODEL

The model (Fig.1) focuses on renewable resources like hydrogen [15] by growth technologies, biomass [16] to prepare biogases for fuel cells [17] and hybrid electric vehicles [18]. Carbon capture technology is located to capture carbon dioxide and release hydrogen from fossil fuels. The technology potential is reducing carbon pollution of hydrogen fuels till 90%. Mature and immature renewable energy resources such as tidal, wave, geothermal, etc could be applied for hub inputs. Smart grid empowers energy consumers to effectively manage their consumption by communication technologies. ES could be utilized to reduce operation costs. Table 1 summarize the hub (Fig.1) performance under technologies. Proposed EH is formulated in(1)-(6).

Hub required demands and ESs are restricted in (1) and (2) in sequence. L and L^{sold} are stated as hub demands and sold power to the grid in sequence. C explains converted power by hub converters. P^{tech}describes imported power to every converter. Discharge and charge power of storage are consequently declared in P^{dis}, P^{ch}matrixes. P^{cut}clarifies curtailed power of hub demands at every hour (t). P^{st}illustrates content power of ES. Equation (3) declares employed matrixes in (1) and (2). Hub demands (1) are supplied by converted power [19]-[21] and ES [20]-[23] and interruptible program [24]-[26] of DR programs.

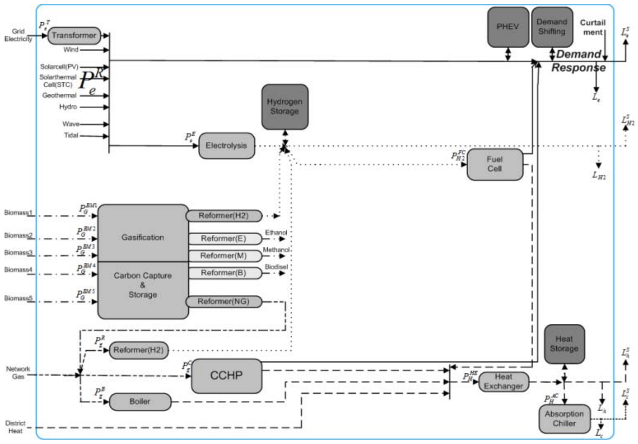

Fig. 1. Proposed energy hub

Additional power is sold to the grid. Energy storage content is restricted in (2) and it is related to content energy at previous time and its charged and discharged power.

$$[L(t)] + [L^{sold}(t)] = [C][P^{tech}(t)] + \left[[P^{dis}(t)][P^{ch}(t)]\right] + [\mathrm{I}][P^{cut}(t)] \quad (1)$$

$$[P^{st}(t)] = [P^{st}(t-1)] + \left[P^{dis}(t)\right] - [P^{ch}(t)] \quad (2)$$

$$P=\begin{bmatrix} P_e^T \\ P_e^R \\ P_e^E \\ P_H^{FC} \\ P_{B1}^G \\ P_{B5}^G \\ P_g^r \\ P_g^{CCHP} \\ P_g^B \\ P_h^{HE} \\ P_c^{AC} \\ P_g \\ P_{DH} \end{bmatrix}, L=\begin{bmatrix} L_e+L_e^S \\ L_H+L_H^S \\ L_h+L_h^S \\ L_c+L_c^S \end{bmatrix}, P^{st}=\begin{bmatrix} P_e^{st} \\ P_H^{st} \\ P_h^{st} \\ 0 \end{bmatrix}, P^{dis}=\begin{bmatrix} P_e^{dis} \\ P_H^{dis} \\ P_h^{dis} \\ 0 \end{bmatrix}, P^{ch}=\begin{bmatrix} P_e^{ch} \\ P_H^{ch} \\ P_h^{ch} \\ 0 \end{bmatrix}, P^{cut}=\begin{bmatrix} P_e^{cut} \\ P_H^{cut} \\ P_h^{cut} \\ P_c^{cut} \end{bmatrix}$$

$$C=\begin{bmatrix} \eta_{ee}^T\eta_{ee}^{Con} & -1 & \eta_{He}^{FC} & 0 & 0 & \\ 0 \quad 0 & \eta_{eH}^E & -1 & \eta_{B1H}^G & 0 & \\ 0 \quad 0 & 0 & (1+\eta_{hh}^{HE})\eta_{Hh}^{FC} & 0 & \eta_{hh}^{HE}\,\eta_{gh}^{CHP}\eta_{B5H}^G & \cdots \\ 0 \quad 0 & 0 & 0 & 0 & 0 & \end{bmatrix} \begin{bmatrix} & 0 & \eta_{ge}^{CHP} & 0 & 0 & 0 & 0 \\ \cdots & \eta_{gh}^r & 0 & 0 & 0 & 0 & 0 \\ & \eta_{gh}^{CHP} & \eta_{ge}^{CHP}(1+ & \eta_{hh}^{HE})\eta_{gh}^B & 0\,\eta_{hh}^{DH} & \eta_{gh}^{CHP} & \eta_{hh}^{DH} \\ & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

P_e^T, P_e^R, P_e^E, P_H^{FC}, P_{B1}^G, P_{B5}^G, P_g^r, P_g^{CCHP}, P_g^B, P_h^{HE}, P_c^{AC}, P_g, P_{DH} are respectively expressed as imported electricity to transformer, produced electricity by renewable, imported electricity by electrolysis, imported hydrogen by fuel cell, imported biomass1 to gasification, imported biomass 5 to gasification, imported gas to reformer, imported gas by CHP, imported gas to boiler, imported heat to heat exchanger, imported heat to absorption chiller, imported network gas and imported district heat in matrix [P]. $L_e, L_e^S, L_H, L_H^S, L_h, L_h^S, L_c, L_c^S$ consequently explain hub electricity demand and sold electricity to grid, hub hydrogen demand and sold hydrogen to the grid, hub heat demand and sold heat to grid, cooling demand and sold cooling to grid in matrix [L]. $P_e^{st}, P_H^{st}, P_h^{st}, P_c^{st}$ declare electricity storage content, hydrogen storage content, heat storage content in matrix $[P^{st}]$.$P_e^{dis}, P_H^{dis}, P_h^{dis}, P_e^{ch}, P_H^{ch}, P_h^{ch}$explain discharged power of electrical storage, discharged power of hydrogen storage and discharged power of heat storage, charged power of electrical storage, charged power of hydrogen storage and charged power of heat storage in matrixes $[P^{dis}]$, $[P^{ch}]$in sequence.$P_e^{cut}, P_H^{cut}, P_h^{cut}, P_c^{cut}$respectively describe interrupted electricity, interrupted hydrogen demand, interrupted heat demand and interrupted cooling demand in matrix $[P^{cut}]$.

$\eta_{ee}^T, \eta_{ee}^{Con}, \eta_{eH}^E, \eta_{He}^{FC}, \eta_{hh}^{HE}, \eta_{Hh}^{FC}, \eta_{B1H}^G, \eta_{gh}^{CHP}, \eta_{B5H}^G, \eta_{gh}^r, \eta_{ge}^{CHP}, \eta_{gh}^B, \eta_{hh}^{DH}$ correspondingly express electricity to electricity efficiency of transformer, electricity to electricity efficiency of converter, electricity to hydrogen efficiency of electrolysis, hydrogen to electricity of fuel cell, heat to heat efficiency of heat exchanger, biomass 1to hydrogen efficiency of gasification, gas to heat efficiency of CHP, biomass 5 to hydrogen efficiency of gasification, gas to heat efficiency of reformer, gas to electricity of CHP, gas to heat efficiency of boiler and high temperature heat to normal heat of district heat in matrix converter [c].

Converters are restricted to min-maximum power (4) and ESs are limited in minimum and maximum power (5). Interruptible load program is restricted to curtail power till maximum value (6).

Table 1. Proposed energy hub elements

Conversion Technology Process	From Hub Input Carrier	To Hub Output Carrier
1.Absorption chiller	High Heat	Cooling
2.Boiler	Natural Gas	Heat
3.CCHP	Natural Gas	Electricity, Heat, Cooling
4.Electrolysis	Electricity+ Water	Hydrogen
5.Fuel Cell	Hydrogen	Electricity, Heat, Cooling
6.Gasification	Biomass+ Oxygen	Hydrogen, Natural Gas
7.Heat Exchanger	High Temp Heat	Heat
8.Transformer	Electricity	Electricity
9.Reformer	Natural gas, Biomass	Hydrogen, Ethanol, Methanol, Biodiesel, Gas
10.Renewable:Wind, PV,STC,Geothermal ,Wave,Hydro,Tidal	Renewable	Electricity
Energy Storage Device	**From Charging State**	**To Discharging State**
11.Heat Storage	Heat	Heat
12.Hydrogen Storage	Hydrogen	Hydrogen
13.PHEV (V2G)	Electricity	Electricity
Demand Response	**From**	**To**
14. Interruptible load	Electrical load	Curtailed load

Constraints:

$$P^{min} \le P^{tech}(t) \le P^{max} \quad (4)$$

$$P^{stmin} \le P^{st}(t) \le P^{stmax} \quad (5)$$

$$0 \le P^{cut}(t) \le P^{cutmax} \quad (6)$$

3. PROPOSED ENERGY HUB SCHEDULING

Hub is optimally scheduled based on minimum operation costs of objective function (7) and its constraints (1)-(6) in 24 hours a day to provide hub required demands. Hub receives renewable power with zero cost or could purchase network energy carrier at every hour L(t) with its price (π) and hub could sell additional produced power at every hour ($L^{sold}(t)$) to network with its cost (π^{sold}) as follow:

$$\text{Of}=\sum_{t=1}^{24}(\pi L(t) - \pi^{sold}L^{sold}(t)) \quad (7)$$

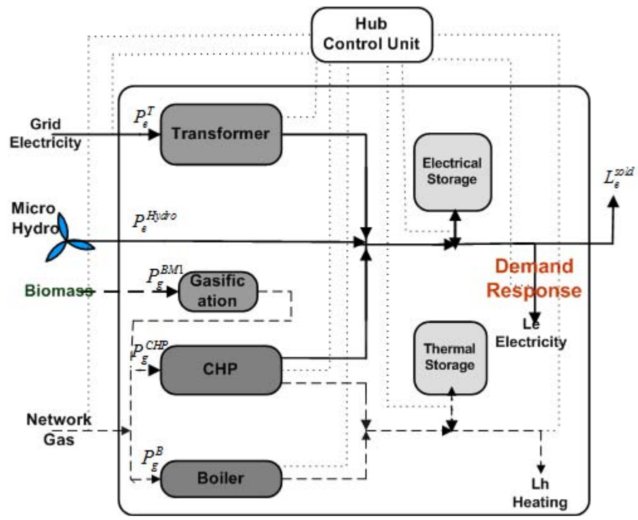

Fig. 2. Case study of Daran urban by grid gas and electricity carriers, micro hydro, biomass, electrical and thermal storage, interruptible DR

4. CASE STUDY

An urban place (Daran) with 353 people which is situated in North-West of Iran and has strong potential to receive renewable energy resources such as wind, hydro and agricultural biomasses are applied as energy hub as case study. Electricity and heat demands are most hub energy needs. Technologies which are employed for this place including micro hydro in front of a waterfall which is 5 kilometer far from Daran, biomass which are produced by agricultural and animal (Most people jobs are agriculturalist), CHP, boiler and transformer and gasification converters are utilized to convert carriers, thermal and electrical storages together interruptible load program of demand response are implemented as complement technologies. The objective (8a), (8b) is minimizing operation costs with corresponding to its constraints (9)-(14f). The objective function (*of*) is minimized based on energy carriers (grid electricity$P_e^{Net}(t)$, network gas for CHP $P_g^{CHP}(t)$and boiler $P_g^B(t)$, biomass$P_{BM1}^G(t)$ and interrupted electricity demand$P_e^{cut}(t)$ and their costs; network electricity price $\pi_e^{Net}(t)$, grid gas cost π_g, biomass price π_B, interrupted demand cost π_e^{cut}in sequence. Hub has potential to sell additional electricity $L_e^{sold}(t)$to the grid as revenue (8a).Biomass$P_{BM1}^G(t)$ is most provided till $P_{BM1}^1$by customers and zero prices are applied on cost. If more biomasses (more than P_{BM1}^1) are required, it will be purchase and its price is considered (8b).The hub employs micro hydro$P_e^{Hydro}(t)$, electricity network $P_e^{Net}(t)$through electricity efficiency of transformer $\eta_{ee}^T$and produced electricity by CHPP_g^{CHP}through gas to electricity efficiency of CHP $\eta_{ge}^{CHP}$to produce electricity demand$L_e(t)$ (9). Electrical storages$P_e^{dis}(t), P_e^{ch}(t)$ and interruptible demand program$P_e^{cut}(t)$ would be also applied in (9). Network gas and biomass are also used to feed CHP through gas to heat efficiency of CHP η_{gh}^{CHP} and boiler through gas to heat efficiency of boiler $\eta_{gh}^B$to provide heat demands (10b). Thermal storage store additional energy $P_h^{ch}(t)$to utilize in $P_h^{dis}(t)$required times (10b). Imported gas for CHP and boiler are produced by network gas and gasificated biomass (10a). Electrical and thermal storages constraints are situated in (11a)-(11e), (12a)-(12e) in sequence. Electrical and thermal energy storages $P_e^{St}(t), P_h^{St}(t)$ are charged $P_e^{ch}(t), P_h^{ch}(t)$and discharged $P_e^{dis}(t), P_h^{dis}(t)$ based on previous content power in $P_e^{St}(t-1)$, $P_h^{St}(t-1)$ in (11a), (12a). Electrical and thermal storage is restricted between minimum $\alpha_e^{min}, \alpha_h^{min}$and maximum $\alpha_e^{max}, \alpha_h^{max}$factors of their maximum powerP_e^M, P_h^M in (11b), (12b). Charge and discharge power of electrical and thermal storages are restricted by minimum and maximum factors of maximum power of the storages and their charge $\eta_e^{ch}, \eta_h^{ch}$and discharge $\eta_e^{dis}, \eta_h^{dis}$ efficiencies in (11d), (11c) and (12d), (12c). Binary variables of charge and discharge of electrical $I_e^{ch}(t)$, $I_e^{dis}(t)$ and thermal storages $I_e^{ch}(t), I_e^{dis}(t)$ are employed to prevent charge and discharge of storages at the same time in (11e) and (12e).Interruptible demand is restricted in (13) with load participation factor of electrical load LPF^{cut}.Network gas (14a) and electricity (14b) and converters; CHP (14c), boiler (14d), transformer (14e), biomass (14f) could be also limited till $P^{Net}, P^{CHP}, P^{Boil}, P^T, P_{BM1}^G$in sequence as follow:

$$OF = \sum_{t=1}^{24} \begin{matrix} \pi_e^{Net}(t)P_e^{Net}(t) + \pi_g\left(P_g^{CHP}(t) + P_g^B(t)\right) + \\ \pi_B P_{BM1}^G(t) + \pi_e^{cut}P_e^{cut}(t) - \pi_e^{Net}(t)L_e^{sold}(t) \end{matrix} \tag{8a}$$

$$\pi_B = \begin{cases} 0 & 0 \le P_{BM1}^G(t) \le P_{BM1}^1 \\ \pi_B P_{BM1}^1 \le P_{BM1}^G(t) \le P_{BM1}^2 \end{cases} \tag{8b}$$

Electrical Demand Constraint:

$$L_e(t) = P_e^{Hydro}(t) + \eta_{ee}^T P_e^{Net}(t) + \eta_{ge}^{CHP} P_g^{CHP}(t) + P_e^{dis}(t) - P_e^{ch}(t) + P_e^{cut}(t) \tag{9}$$

Heat Demand Constraint:

$$P_g(t) + \eta_{BM1g}^G P_{BM1}^G(t) = P_g^{CHP}(t) + P_g^B(t) \tag{10a}$$

$$L_h(t) = \eta_{gh}^{CHP} P_g^{CHP}(t) + \eta_{gh}^B P_g^B(t) + P_h^{dis}(t) - P_h^{ch}(t) \tag{10b}$$

Electrical Storage Constraint:

$$P_e^{St}(t) = P_e^{St}(t-1) + P_e^{ch}(t) - P_e^{dis}(t) \tag{11a}$$

$$\alpha_e^{min} P_e^M \le P_e^{St}(t) \le \alpha_e^{max} P_e^M \tag{11b}$$

$$\alpha_e^{min}\eta_e^{dis} P_e^M I_e^{dis}(t) \le P_e^{dis}(t) \le \alpha_e^{max}\eta_e^{dis} P_e^M I_e^{dis}(t) \tag{11c}$$

$$\alpha_e^{min} \frac{1}{\eta_e^{ch}} P_e^M I_e^{ch}(t) \le P_e^{ch}(t) \le \alpha_e^{max} \frac{1}{\eta_e^{ch}} P_e^M I_e^{ch}(t) \tag{11d}$$

$$0 \le I_e^{ch}(t) + I_e^{dis}(t) \le 1 \tag{11e}$$

Thermal Storage Constraint:

$$P_h^{St}(t) = P_h^{St}(t-1) + P_h^{ch}(t) - P_h^{dis}(t) \tag{12a}$$

$$\alpha_h^{min} P_h^M \le P_h^{St}(t) \le \alpha_h^{max} P_h^M \tag{12b}$$

$$\alpha_h^{min}\eta_h^{dis} P_h^M I_h^{dis}(t) \le P_h^{dis}(t) \le \alpha_h^{max}\eta_h^{dis} P_h^M I_h^{dis}(t) \tag{12c}$$

$$\alpha_h^{min} \frac{1}{\eta_h^{ch}} P_h^M I_h^{ch}(t) \le P_h^{ch}(t) \le \alpha_h^{max} \frac{1}{\eta_h^{ch}} P_h^M I_h^{ch}(t) \tag{12d}$$

$$0 \le I_h^{ch}(t) + I_h^{dis}(t) \le 1 \tag{12e}$$

Demand Response Constraint:

$$0 \le P_e^{cut}(t) \le LPF^{cut} L_e(t) \tag{13}$$

Network and Converter Constraint:

$$0 \le P_g^{Net}(t) \le P_g^{Net} \tag{14a}$$

$$0 \le P_e^{Net}(t) \le P_e^{Net} \tag{14b}$$

$$0 \le P_B^{CHP}(t) \le P^{CHP} \tag{14c}$$

$$0 \le P_B^B(t) \le P^B \tag{14d}$$

$$0 \le P_e^T(t) \le P^T \tag{14e}$$

$$0 \le P_{BM1}^G(t) \le P_{BM1}^G \tag{14f}$$

5. SIMULATION RESULTS

Simulation is applied on objective function (8a), (8b) and its constraints (9)-(14f) based on grid electricity and network gas price

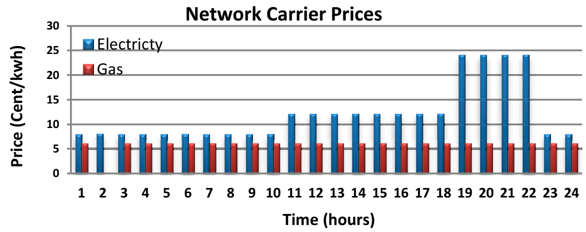

Fig. 3. Network electricity and gas prices at 24 hours a day

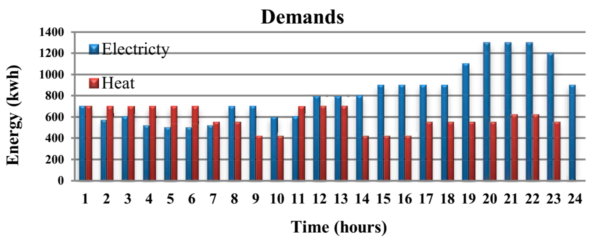

Fig. 4. Hub electricity and heat required demands

Table 2. Proposed hub parameters values

π_B	0.5	η_h^{dis}	0.9
π_e^{cut}	20	η_h^{ch}	0.9
P_{BM1}^1	800	$\alpha_h^{min}\alpha_h^{max},$	0.1,0.9
P_{BM1}^2	1200	P_e^M	400
η_{ee}^T	0.9	P_h^M	300
η_{ge}^{CHP}	0.45	LPF^{cut}	0.1
η_{BM1g}^G	0.75	P_g^{Net}	1000
η_{gh}^{CHP}	0.4	P_e^{Net}	1500
η_{gh}^B	0.9	P^{CHP}	800
η_e^{dis}	0.9	P^B	800
η_e^{ch}	0.9	P^T	1500
$\alpha_e^{min}, \alpha_e^{max}$	0.1,0.9		

(Fig.3) and hub parameters of Table 2 in order to supply hub electricity and heat required demands (Fig.4). Hub operation costs evaluate (Fig.5) in various cases. Imported powers in order to supply hub electricity (Fig.7) and heat (Fig.8) required demands are compared with and without renewable (micro hydro, biomass), converter (CHP), storages (electrical and thermal) and interruptible program (Fig.6).

Simulation results (Fig.5) shows operation costs of hub in different cases. Supplying electricity and heat demands with network energy carriers and without any distributed energy resources (case1) applies high operation costs. Imported network electricity and imported grid gas for boiler are illustrated in (Fig.6). Increasing hub electricity and heat (Fig.4) demands are rising up imported network electricity and imported gas powers (Fig.6) to supply hub electricity and heat required demands. Hence, demands increase together with its prices increases hub operation costs. Integrating CHP to hub (case 4) declines hub electricity and heat demand to one source (network electricity) and one converter (boiler). Therefore, hub operation costs decrease. Integrating renewable resources; micro hydro and biomass (case 5) reduce CO_2 emission and sensibly enhance hub operation costs. Combining electrical and heat storages (case 3) and interruptible demand program of demand response (case 2) decline

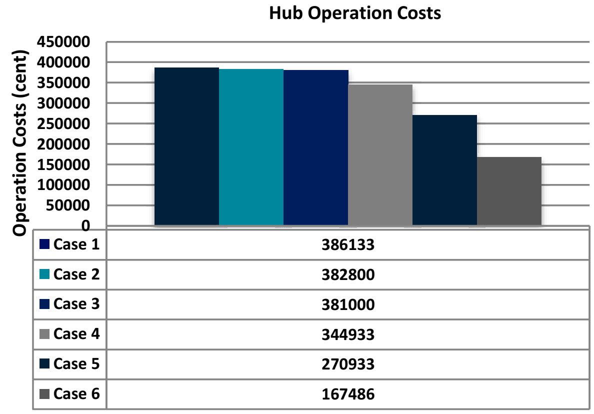

Fig. 5. Hub operation costs at case1, case 2, case 3, case 4, case 5, case 6

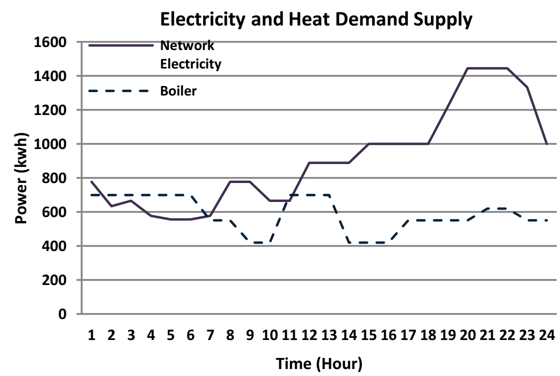

Fig. 6. Imported network electricity and imported network gas for supplying electricity and heat demands in case 1

hub operation costs. Integration of all technologies to hub is expressed as (case 6). Operation costs sensibly reduce hub operation costs according to comparison with (case 1). Effect of integrating different technologies to hub is compared in Fig.5.

Integration of the technologies to the hub (case 6) are depicted and discussed in (Fig.7) and (Fig.8) in this part. Electricity demand (Fig.7) is supplied by constant power of micro hydro, network electricity, produced electricity by CHP, electrical storage and interruptible demand service. Due to zero cost, micro hydro supplies electricity demand all the times. CHP is committed more than other technologies due to biomass and gas fewer cost comparison with grid electricity. Electrical storage is charged in low price time and in low electricity demand and it is discharged in high price time and in high electricity demand. Interruptible service is utilized in high price time and in high electricity demand. Hub produces more electricity with the technologies and it could be able to sell its additional electricity to the grid for receiving revenue. Hub heat demand (Fig.8) is served by CHP because CHP works all of the times to produce electricity. Boiler is employed when heat demand is high. Thermal storage is charged and discharged more than boiler as CHP back up in order to reduce operation costs. Integration of the technologies to the hub (case 6) comparison with (case 1) shows effect of the technologies to decline operation costs because demands are most prepared by the technologies and network carriers are imported less than (case 1).

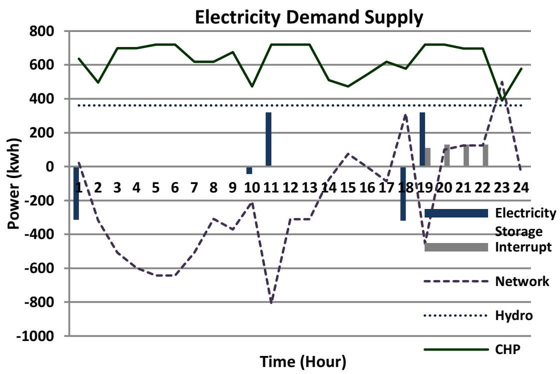

Fig. 7. Electricity demand supply by technologies at 24 hours

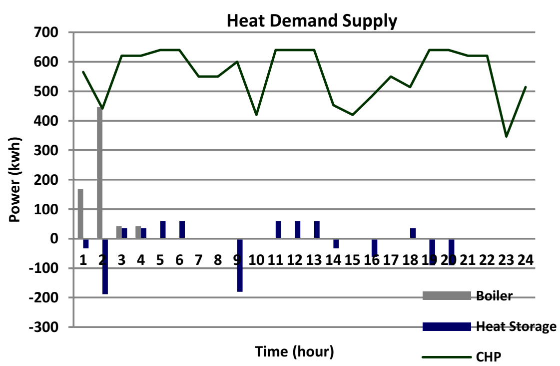

Fig. 8. Heat Demand supply by technologies at 24 hours

6. Conclusion

In this paper, energy hub as multi carrier energy system is extended through renewable resources and distributed technologies in order to decline operation costs and CO2 emission reduction and reliability enhancement in novel power electrical system; smart grid. Proposed hub mathematically formulated under the technologies. An urban place with strong potential of renewable resources utilization is extracted in response to economic and environmental benefit. Extracted hub is mathematically formulated and optimally operated through MIP model of CPLEX solver of GAMS software. Results show the effect of integration of the technologies to decrease operation costs, reliability improvement and CO2 emission reduction. Hub operation costs were illustrated and compared with integrating different technologies; renewable resources (micro hydro, biomass), multi carrier converter (CHP), energy storages (electrical and thermal), interruptible demand program of demand response program. Hub was economically scheduled. Results endorsed when and how much of which technologies should be committed in response to minimize operation costs in proposed energy hub.

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