Sustainable Energy Technologies and Assessments 39 (2020) 100687

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

journal homepage: www.elsevier.com/locate/seta

Wind-hydrogen storage in distribution network expansion planning considering investment deferral and uncertainty

Hasan Mehrjerdi[a,*], Reza Hemmati[b]

[a] Electrical Engineering Department, Qatar University, Doha, Qatar
[b] Department of Electrical Engineering, Kermanshah University of Technology, Kermanshah, Iran

ARTICLE INFO

Keywords:
Distribution network expansion planning
Hydrogen storage system
Investment deferral
Stochastic programming
Wind energy

ABSTRACT

With respect to the recent developments of hydrogen storage system (HSS), it is relevant to model these storage units in the network expansion planning. Also, most of the available expansion planning tools consider constant locations and sizing for renewable resources and only study the impacts of renewables on the model. It seems that considering variable location and capacity for renewable energies and finding their optimal levels may result in more flexible model. With regard to these issues, this paper presents distribution network expansion planning incorporating wind power and hydrogen storage. The optimal site and size of wind and hydrogen systems are denoted. The stochastic optimization programming is addressed to minimize the plan budgets. The purpose is to defer the investment and operating budgets. The uncertainty modeling is developed to handle the load-wind errors. The achievements demonstrate that the model finds optimal location, sizing, operation pattern, and setting for wind turbines and HSSs while the planning cost is deferred and minimized.

Introduction

The electrical energy storage systems are helpful to store energy when the energy is not necessary and then restore energy when it is required. The electrical energy may be stored in various forms [1]. The chemical energy storage is one of the new and interesting concepts that converts electrical energy to the chemical gases and stores it in the proper reservoirs. The main model is to convert electrical energy to hydrogen or Methane [2]. Fig. 1 shows the topology of HSSs. In the HSSs, the electrical energy is converted to hydrogen through electrolysis systems like high temperature, Alkaline, or Polymer electrolyte membrane. The produced hydrogen may be stored in large-size storage tanks such as underground storage reservoirs or small-size storage systems such as liquid tanks [3]. The stored hydrogen is afterward utilized for industry applications such as refineries or it may be used for re-electrification in fuel-cells or gas turbines [4].

The hydrogen storage systems have wide applications in the electrical networks. One of the proper applications of hydrogen storage systems is to deal with renewable energies [5]. The renewable energies often comprise intermittency resulting in parameters uncertainty in the systems. The hydrogen storage systems operate as a buffer between the renewable energies and the network [6]. The output power of renewable energies is converted to hydrogen. The hydrogen is afterward re-electrified to produce electrical energy. This procedure removes the uncertainty of renewable energies and adjusts their output powers. The process of converting energy to hydrogen or Methane is known as power to gas process [7]. In such processes, the renewable or non-renewable energy is reformed to the chemical gases (i.e., hydrogen or Methane) and stored or transferred. The power to gas has been presented as an efficient scheme to deal with electrical energy issues like environmental pollutions, uncertainty, and transmission [8].

The energy storage systems, e.g., hydrogen storage, assist the electrical networks to integrate more renewable energies [9]. The renewable energies are widely utilized in the electrical networks. The large-size renewables are integrated in the generation section of electric power systems [10] and the small-size renewables are installed on the distribution networks [11]. Both large-scale and small-scale renewables inject uncertainty into the system [12]. There are some common methods to handle uncertainty in the models, for instance the stochastic programming and robust programming are the frequent techniques to handle such uncertainty [13]. Various types of energy storage systems may be combined to make the hybrid energy storage systems. These technologies are more efficient and can provide both the short and long-term operations. The hybrid storage systems have been broadly discussed and modeled and there are various topologies for hybrid storage systems [14].

The network expansion planning can be integrated with renewables and energy storages. The transmission and distribution network

---

* Corresponding author.
E-mail addresses: Hasan.mehrjerdi@qu.edu.qa (H. Mehrjerdi), r.hemmati@kut.ac.ir (R. Hemmati).

https://doi.org/10.1016/j.seta.2020.100687
Received 1 February 2020; Received in revised form 12 March 2020; Accepted 23 March 2020

Nomenclature

Symbols	*Description*
$B_{i,se,ti}^{hss}$	Binary variable for hydrogen storage operation
B_{i}^{hn}	Binary variable showing number of hydrogen storage units
B_{i}^{wn}	Binary variable showing number of wind turbines
$C_{i,j}^{power}$	Capacity of line (p.u.)
C_f	Unit conversion between hydrogen and electricity
$E_{se,ti}^{price}$	Electricity price ($/kWh)
Fa	Factor to change cost to yearly cost
$F_{sc,i,j,se,ti}^{power}$	Power flow through line (p.u.)
H_{i}^{rp}	Rated power of hydrogen storage (kW)
H^{inv}	Investment cost of hydrogen storage ($/kW)
$H_{i,se,ti}^{ch}$	Consumed power by hydrogen storage (p.u.)
$H_{i,se,ti}^{dch}$	Produced power by hydrogen storage (p.u.)
$H_{i,se,ti}^{gen}$	Produced hydrogen by hydrogen storage (kg)
$H_{i,se,ti}^{com}$	Consumed hydrogen by hydrogen storage (kg)
$H_{i,se,ti}^{s}$	Stored hydrogen in reservoir (kg)
H_{i}^{cap}	Capacity of hydrogen reservoir (kg)
Hn	Number of hydrogen systems
i, j	Symbol of buses
$K_{i,j}^{\exp}$	Number of new installed lines
$L_{i,j}^{length}$	Distance of line (km)
L^{inv}	Investment cost of line ($/km)
$L_{sc,i,se,ti}^{power}$	Load power (p.u.)
L^{growth}	Load growth (%)
N	Set of buses
$P_{sc,se,ti}^{in}$	Power between grid and upstream network (p.u.)
R_{sc}	Probability of each scenario
sc, SC	Symbol and set of scenarios
se, SE	Symbol and set of seasons
T_{se}^{day}	Number of days in one season
ti, TI	Symbol and set of time periods
W_{i}^{rp}	Wind unit power (kW)
W^{inv}	Investment cost of wind unit ($/kW)
$W_{sc,i,se,ti}^{power}$	Power of wind unit (p.u.)
Wn	Number of wind turbines
$Y_{i,j}$	Admittance of line (p.u.)
Z	Objective function of the planning ($/year)
$\theta_{sc,i,se,ti}^{voltage}$	Voltage angle (Radian)
η_{i}^{hss}	Efficiency of hydrogen storage system (%)

expansion planning have been modeled and studied incorporating renewable energies and energy storage systems [15]. It has been demonstrated that the renewable energies make significant changes in the model and it is required to reconfigure the model when the renewables are integrated [16]. The storage devices can defer the expansion plan and investment budget [17].

The above referenced studies various types of storage systems but the hydrogen storage has not been studied or has been rarely studied in the network expansion planning. With respect to the new developments of hydrogen storage systems, it is relevant to study the hydrogen storage in the network expansion planning. As well, most of the previous studies consider fixed location and sizing for renewable energies. As a result, considering the location and capacity of renewable energies as the design variables and finding their optimal levels may realize a more flexible model.

Some studies have been performed to investigate the mobile distributed generations (DGs) in the grids. Such mobile DGs for example truck-mounted DGs may be utilized for emergency conditions such as power blackout. The main purpose of these devices is to improve the system resilience (e.g., critical load restoration) under disruptions [18]. The electric vehicles and truck-mounted storage units may also be utilized to improve the system resilience under natural disasters [19]. However, such mobile DGs are often applied for emergency conditions and their applications for steady-state energy management is insignificant. In practical steady-state energy management problems, the fixed DGs have broad applications. This paper therefore considers fixed locations for DGs.

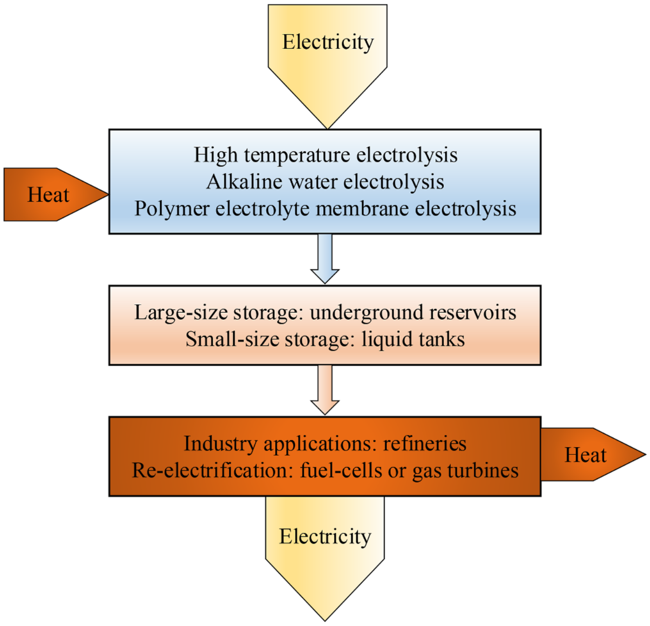

Fig. 1. Topology of hydrogen storage system.

This paper presents distribution network expansion planning incorporating wind power and hydrogen storage. The optimal place and size of wind turbines and hydrogen units are determined by the plan. The plan is presented for optimal investment deferral in the network. The plan minimizes the investment cost on wind turbines, the investment cost on hydrogen storage systems, and the energy cost of the network. The constraints on the operation of wind turbines, hydrogen storage systems, and network are incorporated. The key contributions of the model are highlighted here;

- The distribution network expansion is presented incorporating wind energy and hydrogen storage system under load and wind uncertainty.
- The optimal location, sizing and setting of hydrogen storage systems are determined.
- The optimal place and size of wind generating systems are achieved.

Mathematical formulation of model

Network expansion planning

The objective function of programming is to minimize the investment and operating budgets. The objective function is presented by (1). The first term is the annualized energy cost, the second part signifies the investment cost on new lines, the third part is the investment cost on new wind units, and the final part is the investment cost on hydrogen units.

All the costs in (1) are converted and presented per year. The objective function (1) is therefore presented as annual cost.

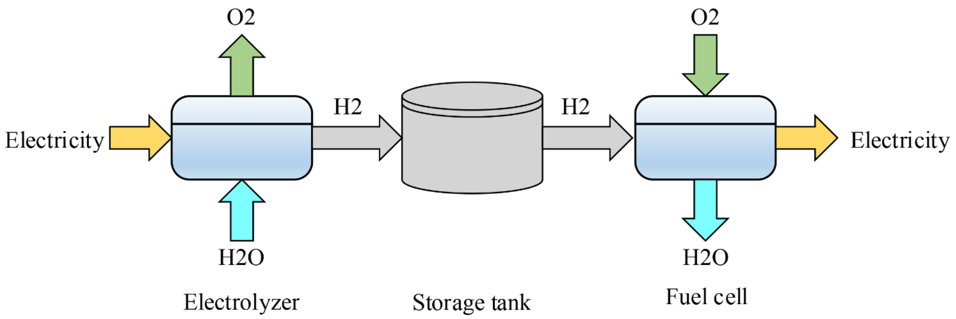

Fig. 2. Structure of hydrogen storage unit.

$$Z = \sum_{sc\in SC}\sum_{se\in SE}\sum_{ti\in TI}(P^{in}_{sc,se,ti}\times R_{sc}\times E^{price}_{se,ti}\times T^{day}_{se}) + \sum_{i\in N}\sum_{j\in N}(K^{\exp}_{i,j}\times L^{length}_{i,j}\times L^{inv}\times Fa) + \sum_{i\in N}(W^{rp}_{i}\times W^{inv}\times Fa) + \sum_{i\in N}(H^{rp}_{i}\times H^{inv}\times Fa) \quad (1)$$

Power flow model

This paper utilizes DC power flow to model the grid operation. The AC power flow is more accurate model but it is a non-linear model and cannot be applied in the linear programming problems. The DC power flow is a linear model and it is properly compatible with linear programming problems. Application of DC power flow creates some errors in the results but reduces the simulation time and facilitates the modelling extensively. The current problem, i.e., network expansion planning, is a long-term plan and the power flow parameters such as voltage magnitude do not make significantly effects on the model and outputs. Therefore, application of DC power flow is acceptable and reasonable.

The flow of active power in the lines is computed by (2) and the thermal limitation of each line is limited by (3) [20].

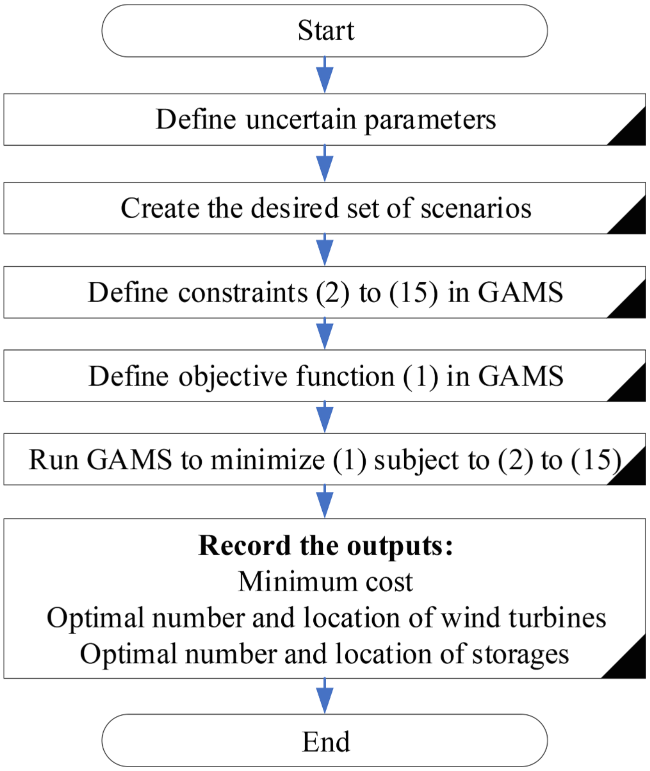

Fig. 3. Solution process of the given problem.

$$F^{power}_{sc,i,j,se,ti} = [(\theta^{voltage}_{sc,i,se,ti} - \theta^{voltage}_{sc,j,se,ti})\times Y_{i,j}]$$
$$\forall\, sc\in SC,\ i\in N,\ j\in N,\ se\in SE,\ ti\in TI \quad (2)$$

$$|F^{power}_{sc,i,j,se,ti}| \leqslant C^{power}_{i,j}\times(K^{\exp}_{i,j}+1)$$
$$\forall\, sc\in SC,\ i\in N,\ j\in N,\ se\in SE,\ ti\in TI \quad (3)$$

The power balance in the network is addressed by (4). The generated power by wind turbines and the generated-consumed powers of hydrogen storage systems are incorporated.

$$L^{power}_{sc,i,se,ti}\times L^{growth} + \sum_{j\in N} F^{power}_{sc,i,j,se,ti} + H^{ch}_{i,se,ti} - W^{power}_{sc,i,se,ti} - H^{dch}_{i,se,ti} = 0$$
$$\forall\, sc\in SC,\ i\in N,\ se\in SE,\ ti\in TI \quad (4)$$

The produced power by wind turbines is limited by rated power as shown in (5). The dispatched power to the upstream grid is modeled by (6).

$$W^{power}_{sc,i,se,ti} \leqslant W^{rp}_{i}$$
$$\forall\, sc\in SC,\ i\in N,\ se\in SE,\ ti\in TI \quad (5)$$

$$P^{in}_{sc,se,ti} = F^{power}_{sc,i,j,se,ti}$$
$$\forall\, sc\in SC,\ i\in[1],\ j\in[2],\ se\in SE,\ ti\in TI \quad (6)$$

Hydrogen storage system

Fig. 2 depicts the structure of HSS containing electrolyzer, storage tank, and fuel-cell. The electrolyzer converts the electricity to hydrogen and stores it the tank. The hydrogen is fed into the fuel-cell to produce electricity. The hydrogen may be stored in the reservoir for long-term periods [2].

The operation of HSS is modeled here. In (7), it is confirmed that the HSS can either work on charging or discharging at each time interval [6].

$$\{H^{ch}_{i,se,ti}\times B^{hss}_{i,se,ti} + H^{dch}_{i,se,ti}\times(1 - B^{hss}_{i,se,ti})\} < \{H^{ch}_{i,se,ti} + H^{dch}_{i,se,ti}\}$$
$$\forall\, i\in N,\ se\in SE,\ ti\in TI \quad (7)$$

When the hydrogen storage operates on charging state, it converts electricity to hydrogen and produces hydrogen. The generated hydrogen is calculated by (8). Once the hydrogen storage operates on discharging state, it consumes hydrogen to produce electricity. The consumed hydrogen is calculated by (9).

$$H^{gen}_{i,se,ti} = H^{ch}_{i,se,ti}\times C_f$$
$$\forall\, i\in N,\ se\in SE,\ ti\in TI \quad (8)$$

$$H^{com}_{i,se,ti} = H^{dch}_{i,se,ti}\times C_f$$
$$\forall\, i\in N,\ se\in SE,\ ti\in TI \quad (9)$$

The powers of hydrogen storage are limited by (10) and (11).

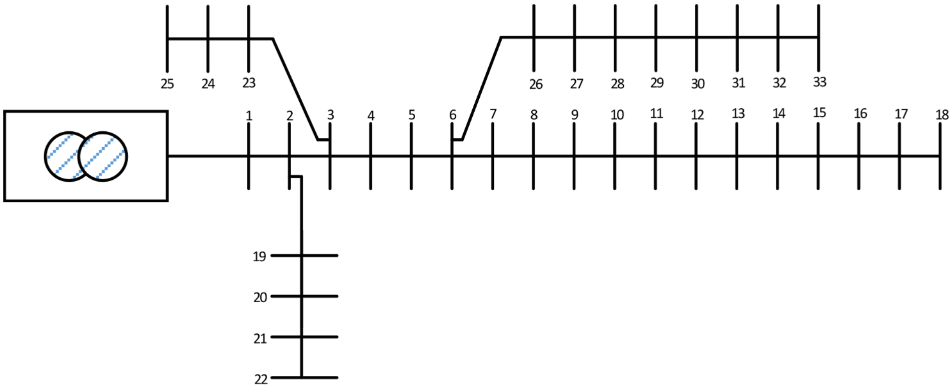

Fig. 4. Single line diagram of test network.

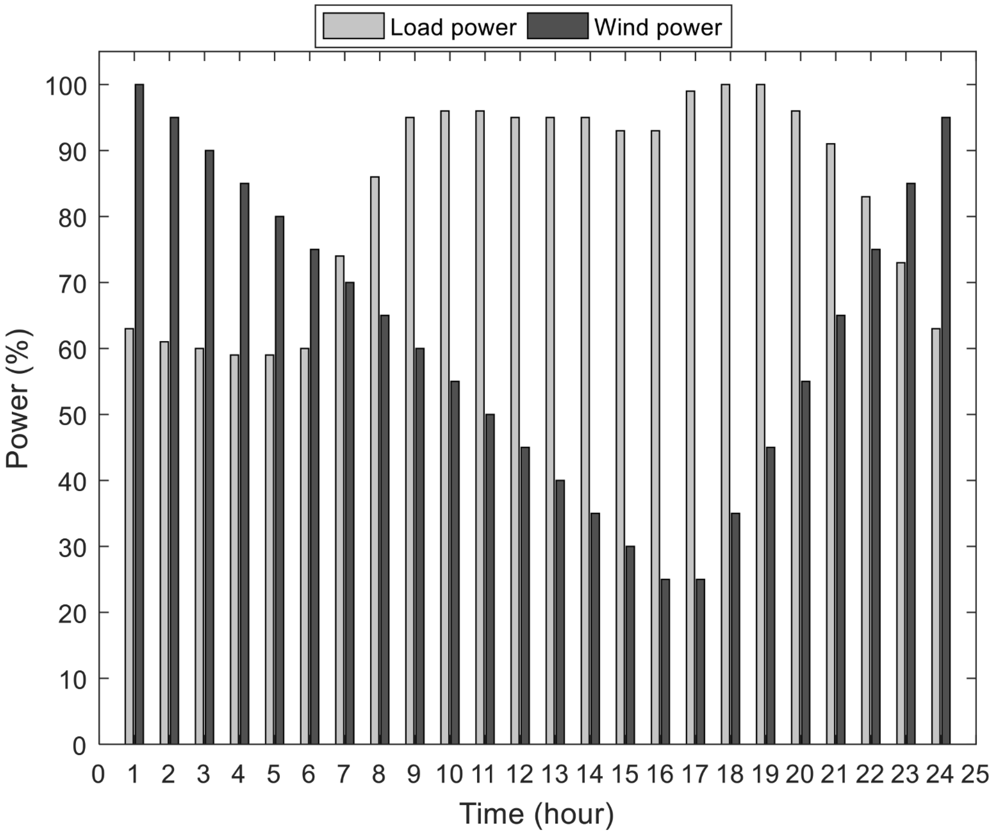

Fig. 5. 24-hour pattern for load and wind powers.

$$H^{ch}_{i,se,ti} \leqslant H^{rp}_{i} \quad \forall\ i \in N,\ se \in SE,\ ti \in TI \tag{10}$$

$$H^{dch}_{i,se,ti} \leqslant H^{rp}_{i} \quad \forall\ i \in N,\ se \in SE,\ ti \in TI \tag{11}$$

The stored hydrogen in hydrogen reservoirs is specified by (12) and capacity of the reservoirs is limited by (13) [3].

Table 1
The price of electrical energy.

Hour	Electricity price ($/kWh)
1–8	0.05
10–15	0.1
16–22	0.2
23–24	0.1

Table 2
Seasonal profile of wind and load.

Season	1	2	3	4
Wind level	0.85	0.90	1.00	0.95
Load level	0.85	1.00	0.95	0.75

$$H^{s}_{i,se,ti} = H^{s}_{i,se,ti-1} + \left[{}^{(H^{gen}_{i,se,ti} - H^{com}_{i,se,ti})}\Big/_{\eta_i^{hss}} \right] \quad \forall\ i \in N,\ se \in SE,\ ti \in TI \tag{12}$$

$$H^{s}_{i,se,ti} \leqslant H^{cap}_{i} \quad \forall\ i \in N,\ se \in SE,\ ti \in TI \tag{13}$$

The mathematical model indicates that hydrogen storage system has a constant operating pattern under all scenarios of performance. In other words, the charging-discharging operation of hydrogen storage system is designed to be robust and feasible under all uncertainties of the system.

Location and number of wind turbines and storages

As it was discussed, the plan finds optimal number and location of wind generating systems and HSSs. In (14), number and locations of hydrogen storage systems are determined and (15) finds number and locations of wind turbines.

$$\sum_{\forall i \in N} B_i^{hn} \leqslant Hn \tag{14}$$

$$\sum_{\forall i \in N} B_i^{wn} \leqslant Wn \tag{15}$$

Solution process

Fig. 3 shows the solution process of the given problem. First, the uncertain parameters of the model are defined. In this paper, the load and wind powers are measured as the uncertain parameters and modeled by Normal distribution. Then the Monte Carlo sampling is applied to create a large-set of scenarios and the backward scenario-reduction process is employed to decrease scenarios to the required number. The constraints of the model (Eqs. (2)–(15)) are defined in GAMS software. These constraints model the feasible operating pattern of the components. The objective function (Eq. (1)) is then modeled in GAMS software. The final model is realized by mixed integer linear programming. The GAMS software is run to solve the optimization programming. The achieved outputs are recorded including minimum cost, optimal number and locations of wind turbines, and optimal number and locations of hydrogen systems.

Test system for expansion

Fig. 4 demonstrates the test network. The IEEE 33-bus distribution grid is considered as cast study. The base apparent power is 10 MVA and the base voltage magnitude is 12.66 kV. The load and wind powers are shown in Fig. 5 and the electricity price is presented in Table 1 [21].

Table 2 lists the seasonal profile of wind energy and loads. Table 3 lists the parameters of wind turbines, hydrogen storage systems, and lines. The discount rate is set on ten percent and the load growth is set on thirty percent. The line length is assumed equal to one kilometer. The unit conversion between electricity and hydrogen is 40 kWh [4]. The maximum number of wind turbines and hydrogen storage systems is assumed equal to four.

Results and discussions

Table 4 summarizes the optimal locations of new lines, wind turbines, and hydrogen storage systems on the network. The planning installs five new lines, four wind turbines, and four hydrogen storages to deal with load growth. The locations and sizing of the components are determined by the planning.

The operation of the HSS is optimized by the contributed strategy.

Table 3
Parameters of wind turbines, hydrogen storage, and lines.

Parameter	Level
Line life time (year)	15
Wind life time (year)	8
Hydrogen life time (year)	4
Investment cost of line ($/km)	50,000
Investment cost of wind ($/kW)	1000
Investment cost of hydrogen ($/kW)	400
Hydrogen system efficiency (%)	60

Table 4
Optimal locations of new lines, wind turbines, and hydrogen storages.

Variable	Optimal level
Lines	One line from bus 2 to 3 One line from bus 4 to 5 One line from bus 5 to 6 One line from bus 23 to 24 One line from bus 26 to 27
Wind turbines	100 kW wind turbine on bus 25 110 kW wind turbine on bus 29 100 kW wind turbine on bus 30 90 kW wind turbine on bus 31
Hydrogen storage	100 kW on bus 2 with 30 kg storage capacity 100 kW on bus 5 with 30 kg storage capacity 100 kW on bus 13 with 30 kg storage capacity 100 kW on bus 28 with 30 kg storage capacity

Fig. 6 shows such optimal operation for the storage unit fixed on bus 2. It converts electricity to hydrogen and stores hydrogen when the electricity is cheap (hours 1–15) and discharges hydrogen to produce electricity when the electricity price is high (hours 16–21).

Fig. 7 demonstrates the operation of hydrogen storage on bus 5. It stores electricity in hydrogen form when the electricity is inexpensive and the hydrogen is then re-electrified when the electricity is expensive.

Figs. 8 and 9 indicate that the similar operation is seen for the hydrogen storages on buses 13 and 28. They shift electrical energy from off-peak time periods to on-peak time intervals with the intention of cost reduction. The produced power by wind turbines is generated at night-time and shifted to the day-time by HSS.

Fig. 10 represents the stored hydrogen in the hydrogen tanks. It is obvious that all the hydrogen systems store the hydrogen inside their reservoirs under initial hours and discharge the hydrogen under on-peak hours from hour 15 to 21. After hour 21, the hydrogen tanks are empty and they are ready for next day operation. The hydrogen tank on bus 2 needs the largest capacity and the hydrogen tank on bus 5 needs the smallest capacity.

Comparing the model

The presented model is compared to the other models given in the literature as itemized in Table 5. The first case in Table 5 indicates the proposed model including wind energy and storage units. The second case presents the model with wind energy but without storage units. The presented model presents better outputs compared to case 2. The third case gives the model with storage units but without wind energy. This case also shows more cost compared to the given model by this paper. Eventually, the fourth case is the plan without both the storage units and wind energy. This model is the most expensive case because it is not benefited from the storage units and wind energy.

Sensitivity analysis

The accuracy and correctness of the simulations are verified through error analysis as addressed by Table 6. The results confirm that increasing the investment cost rises the annual cost of the model. The electricity price is the most important economic parameter in the model and increasing the electricity price by 10% rises the annual cost considerably.

System scalability

The load growth is the key factor in the expansion planning. The larger load growth needs more expansion and reinforcement on the grid. Table 7 lists the planning outputs under different load growth in the network. Under the 10% load growth, the plan can successfully defer the network expansion and the load growth is only dealt by

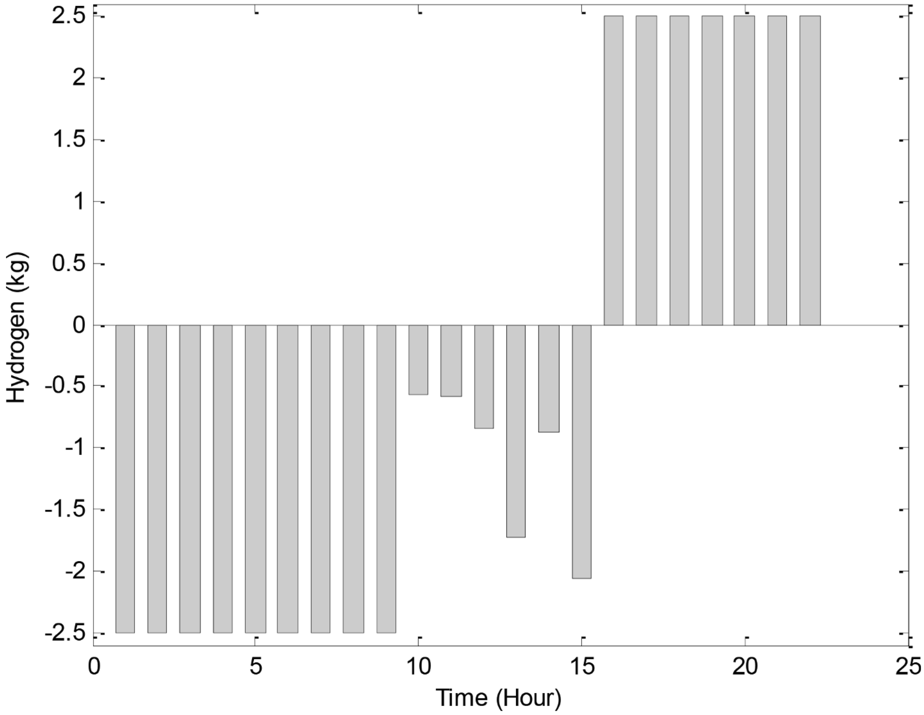

Fig. 6. Hydrogen storage on bus 2 at season 2.

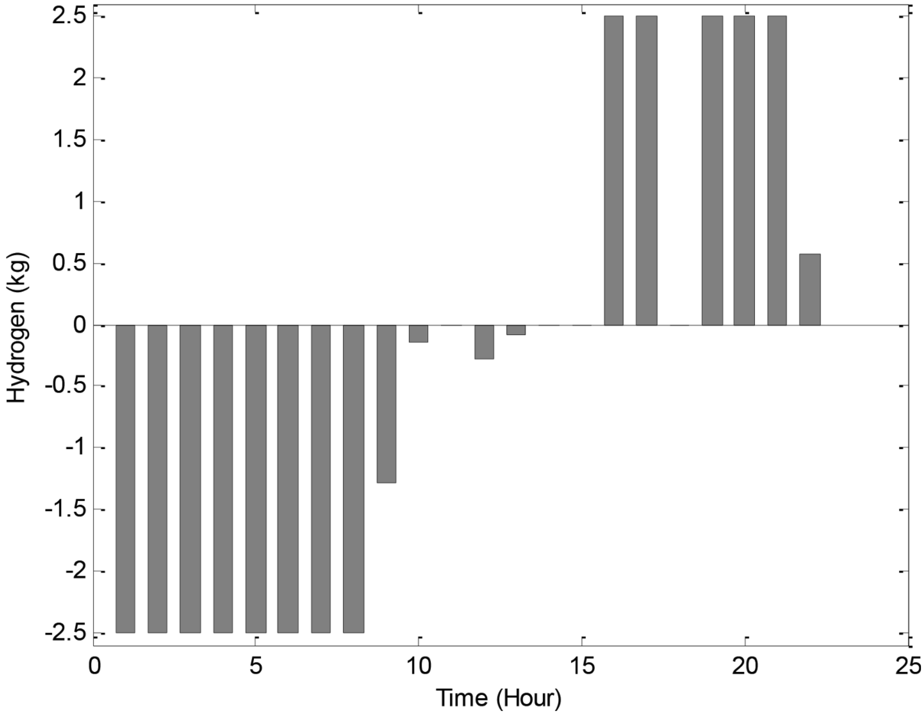

Fig. 7. Hydrogen storage on bus 5 at season 2.

connecting wind units and HSSs. Under the higher levels of load growth, the system needs all equipment (lines, wind units, and HSSs) to deal with load growth.

Dispatched power with upstream network

The load demand is already given in Fig. 5 and the peak load is occurred at hours 17–20. The system therefore needs to receive the maximum energy from the upstream network under these on-peak load demands. However, the hydrogen storage systems properly help the system to shift energy over day hours. The system therefore is able to receive the maximum energy during off-peak periods and store it until the on-peak periods when required. This point is depicted in Fig. 11 and the maximum power is received during off-peak periods (10–15) and it

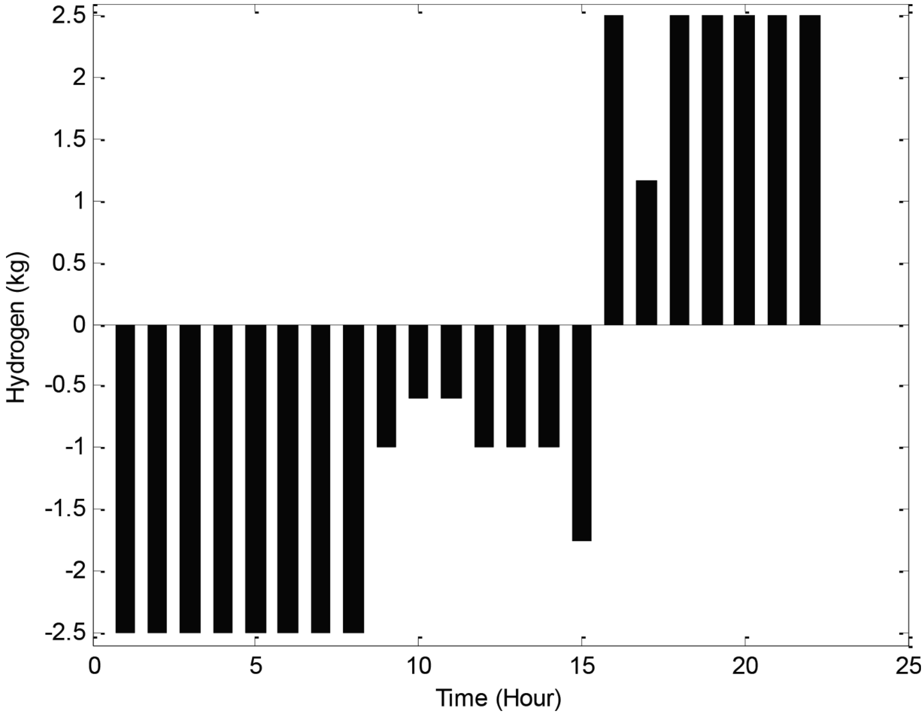

Fig. 8. Hydrogen storage on bus 13 at season 2.

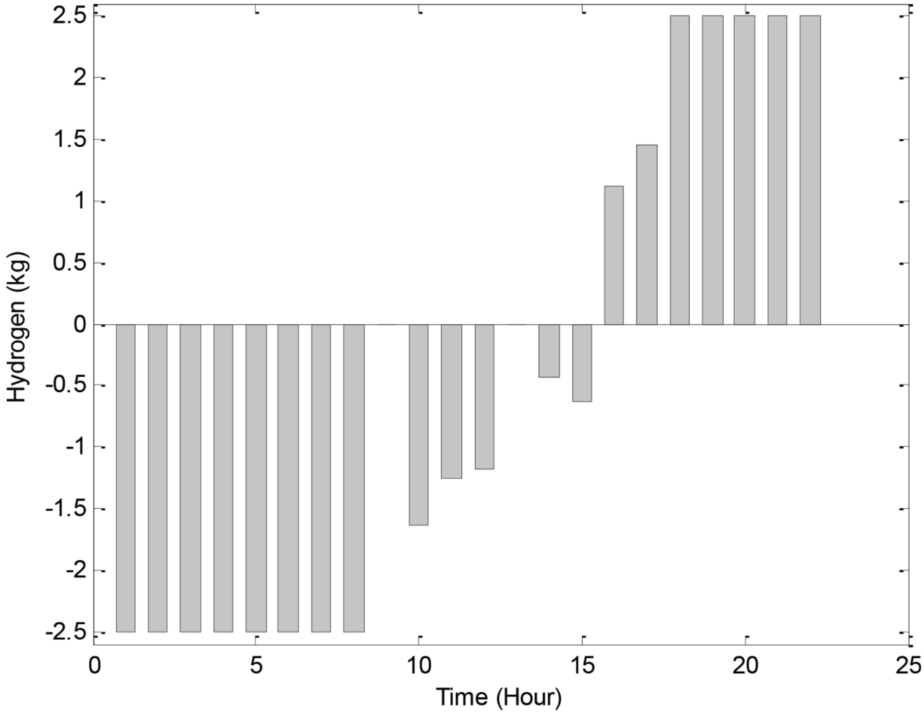

Fig. 9. Hydrogen storage on bus 28 at season 2.

is stored in the HSSs. The on-peak load is afterward supplied by HSSs. As a result, the figure shows that the received power from the grid during on-peak hours is less than the off-peak periods. The wind energies also produce power during initial hours of the night and the received energy form the main grid is decreased at these time periods.

Conclusions

This paper addressed the distribution network expansion planning incorporating wind energy and hydrogen storage system. The model installs 5 new lines, 4 wind turbines and 4 hydrogen storage systems to deal with 30% load growth. The hourly operation of the hydrogen

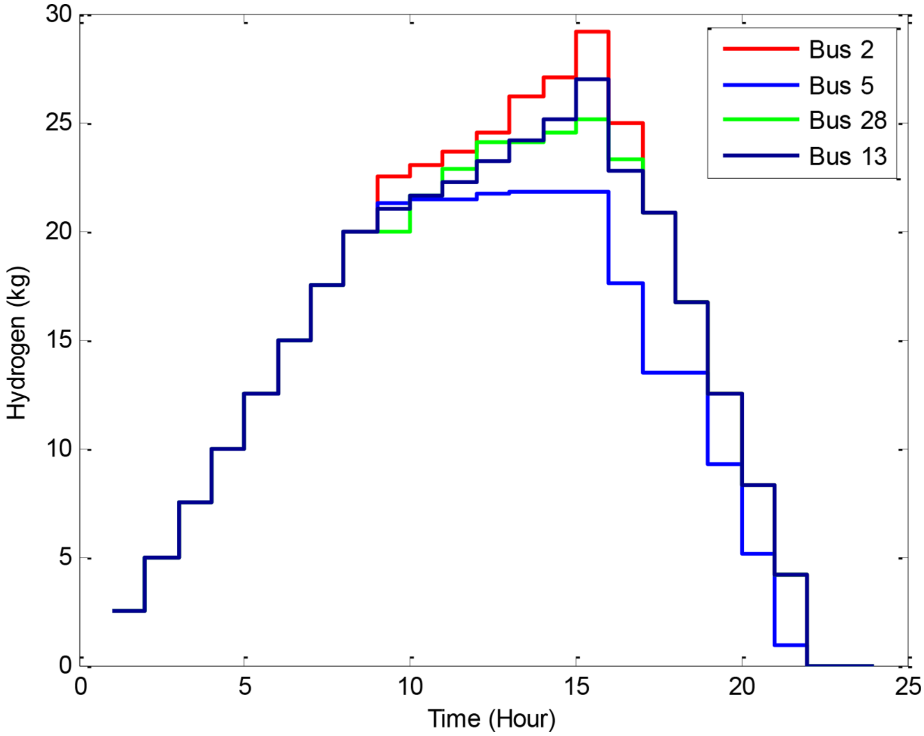

Fig. 10. Stored hydrogen in hydrogen storage systems.

Table 5
Comparing the planning with the other methods.

		Wind power (kW)	Hydrogen storage system	Number of new lines	Annual cost (10^6 $/year)
Case 1	The proposed model	400	400 kW and 120 kg capacity	5	3.323
Case 2	Expansion plan with wind without storage	400	–	8	3.381
Case 3	Expansion plan without wind with storage	–	400 kW and 120 kg capacity	6	3.441
Case 4	Expansion plan without wind and storage	–	–	11	3.495

Table 6
Error analysis on the model parameters.

Test item	Annual cost of model (10^6 $/year)
Nominal operating condition	3.32
Price of lines is increased by 10%	3.34
Price of wind unit is increased by 10%	3.34
Price of hydrogen unit is increased by 10%	3.34
Electricity price is increased by 10%	3.62

storages is also optimized. The hydrogen storage systems are installed on buses 2, 5, 13, 28. All the hydrogen storage systems store hydrogen inside their reservoirs under initial hours and discharge the hydrogen under on-peak hours from hour 15 to 21. The error analysis reveals that the electricity price is the most important economic parameter in the model. It is verified that the plan can successfully defer the network expansion under 10% load growth.

Table 7
Different load growth in the network.

Load growth	Number of lines	Number of wind turbines	Number of hydrogen storage systems	Annual cost (10^6 $/year)
10%	0	4	4	2.72
30%	5	4	4	3.32
50%	13	4	4	3.87

CRediT authorship contribution statement

Hasan Mehrjerdi: Supervision, Writing - review & editing, Writing - original draft, Conceptualization, Methodology. **Reza Hemmati:** Writing - review & editing, Validation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

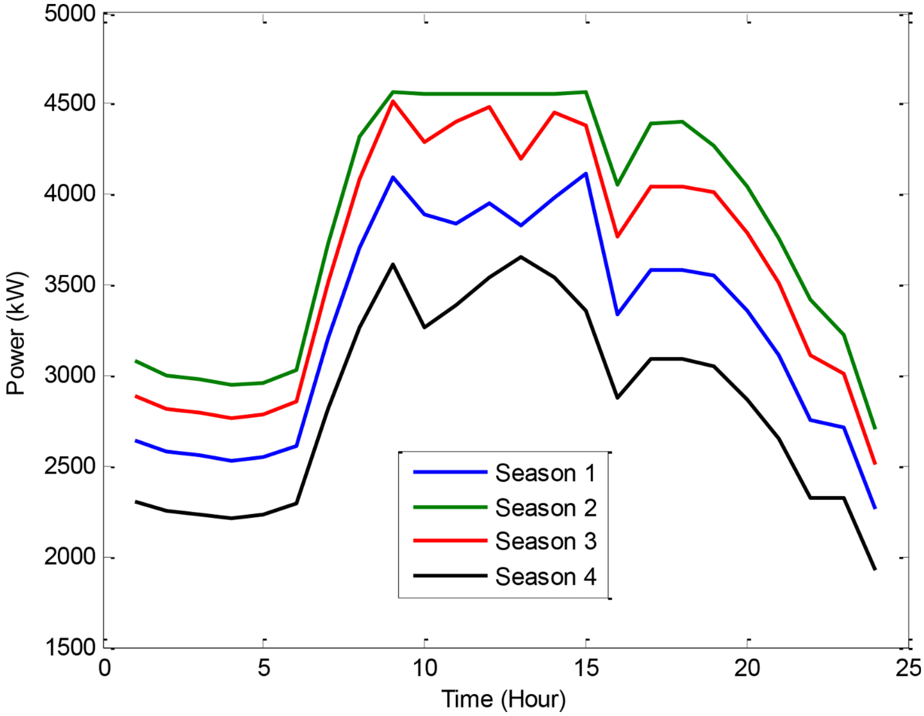

Fig. 11. Seasonal power received from the grid.

References

[1] Gbadegesin AO, Sun Y, Nwulu NI. Techno-economic analysis of storage degradation effect on levelised cost of hybrid energy storage systems. Sustainable Energy Technol Assess 2019;36:100536.

[2] Mehrjerdi H. Optimal correlation of non-renewable and renewable generating systems for producing hydrogen and methane by power to gas process. Int J Hydrogen Energy 2019;44(18):9210–9.

[3] Tarkowski R. Underground hydrogen storage: Characteristics and prospects. Renew Sustain Energy Rev 2019;105:86–94.

[4] Mehrjerdi H. Off-grid solar powered charging station for electric and hydrogen vehicles including fuel cell and hydrogen storage. Int J Hydrogen Energy 2019;44(23):11574–83.

[5] Appl Energy 2017;202:308–22. https://doi.org/10.1016/j.apenergy.2017.05.133.

[6] Energy Convers Manage 2017;150:725–41. https://doi.org/10.1016/j.enconman.2017.08.041.

[7] Blanco H, Faaij A. A review at the role of storage in energy systems with a focus on Power to Gas and long-term storage. Renew Sustain Energy Rev 2018;81:1049–86.

[8] Bailera M, Lisbona P, Romeo LM, Espatolero S. Power to Gas projects review: Lab, pilot and demo plants for storing renewable energy and CO2. Renew Sustain Energy Rev 2017;69:292–312.

[9] H. Mehrjerdi A. Iqbal E. Rakhshani Torresb JR. Daily-seasonal operation in net-zero energy building powered by hybrid renewable energies and hydrogen storage systems Energy Conversion and Management 2019; 201, 112156.

[10] Jannati M, Hosseinian S, Vahidi B, Li G-J. A survey on energy storage resources configurations in order to propose an optimum configuration for smoothing fluctuations of future large wind power plants. Renew Sustain Energy Rev 2014;29:158–72.

[11] Varasteh F, Nazar MS, Heidari A, Shafie-khah M, Catalão JPS. Distributed energy resource and network expansion planning of a CCHP based active microgrid considering demand response programs. Energy 2019;172:79–105.

[12] Shaterabadi M, Jirdehi MA. Multi-objective stochastic programming energy management for integrated INVELOX turbines in microgrids: a new type of turbines. Renew Energy 2020;145:2754–69.

[13] Uzuncan E, Hesamzadeh MR, Balkwill A. Optimal transmission access for generators in wind-integrated power systems: stochastic and robust programming approaches. IET Gener Transm Distrib 2017;11(6):1345–59.

[14] Jing W, Lai CH, Wong WSH, Wong MLD. Dynamic power allocation of battery-supercapacitor hybrid energy storage for standalone PV microgrid applications. Sustain Energy Technol Assess 2017;22:55–64.

[15] Rastgou A, Moshtagh J, Bahramara S. Improved harmony search algorithm for electrical distribution network expansion planning in the presence of distributed generators. Energy 2018;151:178–202.

[16] Hemmati R, Saboori H, Siano P. Coordinated short-term scheduling and long-term expansion planning in microgrids incorporating renewable energy resources and energy storage systems. Energy 2017;134:699–708.

[17] Sardi J, Mithulananthan N, Gallagher M, Hung DQ. Multiple community energy storage planning in distribution networks using a cost-benefit analysis. Appl Energy 2017;190:453–63.

[18] Lei S, Wang J, Chen C, Hou Y. Mobile emergency generator pre-positioning and real-time allocation for resilient response to natural disasters. IEEE Trans Smart Grid 2018;9(3):2030–41.

[19] Lei S, Chen C, Zhou H, Hou Y. Routing and scheduling of mobile power sources for distribution system resilience enhancement. IEEE Trans Smart Grid 2019;10(5):5650–62.

[20] Montoya OD, Grisales-Noreña LF, González-Montoya D, Ramos-Paja CA, Garces A. Linear power flow formulation for low-voltage DC power grids. Electr Power Syst Res 2018;163:375–81.

[21] Mehrjerdi H, Hemmati R. Coordination of vehicle-to-home and renewable capacity resources for energy management in resilience and self-healing building. Renew Energy 2020;146:568–79.