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Optimal energy distribution and storage in a wind-based renewable electricity supply chain

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Abstract

Nowadays, utilization of renewable energies for satisfying electricity demand has received more interest, and renewable electricity generation has been growing in the world. This study addresses the operational planning of a renewable electricity supply chain over a multi-period planning horizon. The purpose of this study is to maximize total profit and to optimize the operational decisions related to power transmission and storage in a wind-based electricity supply chain. The applicability of the developed model is demonstrated by a case study. Due to the wind intermittency and demand variations, some probable scenarios are considered. Sensitivity analysis provides several managerial insights. Numerical results indicate that line capacity expansion can make a good promotion in each scenario by reducing unmet demand and making more profit. Moreover, incorporating an electricity storage system in wind farms improves demand covering in peak load hours.

Keywords: Renewable energies, electricity supply chain, operational planning, electricity storage.

1- Introduction

Nowadays, the widespread usage of fossil fuel despite the limitation of its resources in the world has made the human to look for alternative energy sources in order to meet life demands (Ekren and Ekren, 2009). Additionally, increasing global warming as a result of releasing huge quantities of greenhouse gases (GHGs) emissions due to the excess use of fossil fuel is another reason for attempt to develop alternative resources (Banos et al., 2011). Being clean, inexhaustible and environment-friendly are among the advantages of potential resources of renewable energies, which encourage the human to follow this path (Ekren and Ekren, 2009). Recently, power generation on the foundation of renewable energies has been shown to be significant (Ramandi et al., 2016). These sources of energy can satisfy a significant portion of the United States electricity needs, which brings economic efficiency, and also leads to benefits such as safeguarding the environment and diminishing dependence on fossil fuels (Osmani and Zhang, 2014).

Recent researches show that renewable energies are capable of providing up to 20% of total electricity needed for the United States by 2030. In 2012, the portion of renewable energies in electricity generation was 11% in the United States (Osmani and Zhang, 2014).

Wind energy is one of the most considerable types of renewable energy sources for electricity generation in the United States (Osmani and Zhang, 2014, Osmani et al., 2013).

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Wind power generation is increasing rapidly in this country because of its environmental and economic benefits and availability of wind energy (Ramandi et al., 2016). Also, wind technology is commercially available in the United States (Lindenberg, 2009).

Wind intermittency is a noticeable issue to the integration of wind-based electricity into the existing power grid (Osmani et al., 2013). The biggest problem is finding the most economic and most efficient way to supply electricity from various and interspersed wind farm sites to different electricity demand zones. Zubo et al. (2016) presented a comprehensive review on planning of a distribution network integrated with renewable electricity generators. In order to enhance the demand satisfaction and reliability of the generated electricity from renewable, upgrading the transmission lines between wind farms and demand zones is of necessity so as to be able to deal with the additional electric load to be transmitted by the power grid (Osmani and Zhang, 2014).

Recently in power systems, storage devices have grown rapidly. Storage systems are integrated into energy distribution systems to achieve several purposes such as satisfying power demand in peak demand load hours, smoothing output power of generation sites, increasing system reliability and economical efficiency, etc. (de Quevedo et al., 2015). Storing excess amount of generated electricity in off-peak load periods can lead to the decrease of electricity losses cost in generation sites.

Various aspects of renewable power generation and transmission networks have been studied in literature. Zhu and Tomsovic (2007) proposed an optimal distribution power flow strategy. The proposed approach decomposes the formulation problem into two components: economic dispatch of energy and minimizing the distribution network losses, in a single period planning horizon. The proposed algorithm is an effective algorithm for a distribution system in medium size. Ekren and Ekren (2009)developed a simulation model for a hybrid energy system. In this model, photovoltaic and wind turbine sizes as well as batteries capacity are optimized for an extended period of time. Toole et al. (2010) presented a simulation-optimization algorithm with the purpose of upgrading the existing power grids. The location of renewable generators and decisions related to transmission network expansion are determined. Zhou et al. (2013) suggested a model for distributed energy system design, consisting of wind, solar and biomass energies as renewable sources. Electricity, as well as cooling and heating energies is among the system productions. Technology selection, amount of production, and storage are the main decisions that are optimized in a multi-period context. The model is applied to the planning of a distributed energy system in a hotel. Osmani and Zhang (2014)developed an integrated model for power generation and transmission network design to satisfy a portion of off-peak demand load without any storage system. Renewable energies including wind and biomass are integrated to generate electricity in a yearlong planning horizon. Locations of renewable generators, production and transmission capacity, as well as electricity flow are optimized. Mohammadi et al.(2014)presented a model for operation management of micro grids. This system consists of renewable energies and full cells for power generation. State of micro grid units and electricity flow are related decision variables that are optimized in a multi-period context with hourly periods. Because of short distance between demand points and generation units in micro grids, the transmission lines use low voltage electricity for power transmission. Therefore, in these systems, load demand of faraway demand points cannot be covered. Zhou et al. (2015)proposed a bi-objective model for the planning of a regional energy system in the province of British Columbia, Canada. The system is a combination of renewable energies and fossil fuel for power and heat generation. Planning of capacity expansion in a multi-period planning horizon is a strategic decision of this model. Every period includes a 5-year time interval. Environmental protection and cost efficiency are considered as objective functions. Bukhsh et al. (2016) presented an approach for multi-period power flow optimization. In this model, operating point of conventional electricity generators and amount of renewable generations are determined. The results show that considering demand side flexibilities can result in more profit. Ji et al. (2015)developed a model for energy management in micro grids. In this model, power scheduling is optimized in order to minimize operating costs in a short period of time. PV plans, wind turbines, and the energy storage system are incorporated for electricity demand satisfaction. Nojavan and Allah Aalami (2015) addressed energy procurement for a large electricity market. Bilateral contracts are used for purchasing power in this electricity network. They investigated the impact of demand response program on the energy procurement. The capability of the proposed model was illustrated by four case studies. Hu et al. (2016)studied a local energy management system. The number of different facilities including PV, wind turbines, batteries and fuel cells and power flow are optimized for maximizing total profit. The proposed model is applied to a case study in Taiwan. De Quevedo et al. (2016)proposed a model for optimization of renewable energy generation and power storage in distribution systems under islanding condition (with no relation to other networks).They investigated the effect of power storing by solving the model with and without the storage system.

To the best of our knowledge, most of the studies in the literature have focused on network design and strategic decisions in power generation of renewable energies, while in practice, operational planning in the existing supply chain can improve system capability by considering real-time demand and supply variations. Moreover, according to load demand variations in several hours of a day, consideration of a multi-period planning approach in a power transmission network could be valuable, which has been ignored in previous works. This study addresses the planning of a renewable electricity supply chain. The purpose of this study is to maximize total profit (electricity selling incomes minus expenses including batteries operation and maintenance costs, shortage cost, and purged cost) and optimize the operational decision related to power transmission and storage in a wind-based electricity supply chain. The main contributions of this study can be summarized as follows:

- Considering different demand load periods (off-peak, shoulder, and peak load) in order to incorporate demand variations in different hours of a day.
- Integrating storage systems in supply zones to improve demand covering in peak load periods and store the excess generated power in off-peak hours.
- Considering different scenarios based on changes in demand and wind speed.
- Providing managerial insights of different sensitivity analyses on the transmission lines capacity and the cost of deficit.

This study is organized as follows: Section 2 describes the mathematical formulation of generation and storage model. Section 3 defines the notations and mathematical model. Section 4 explains the case study and discusses the model results. Section 5 consists of sensitivity analysis results and finally, conclusion is presented in Section 6.

2- Problem description

The electricity supply chain that is studied in this research consists of several production and distribution facilities, from wind farms to demand zones, as shown in figure 1. The purpose of design and optimization of this supply chain is utilization of renewable energies in order to satisfy some of electricity demand. The demand zones can be defined as aggregated demand of consumers that are located in the same geographic area. The location of wind farms and grid stations, capacity of wind farms and transmission lines as well as amount of electricity production are determined. An important assumption in this formulation is that the overall investment costs have already been minimized in a previous planning phase where the best locations for wind farms and storage systems have been selected. The main operational planning decision includes electricity flow and amount of power storage in wind farms. High voltage alternating current (HVAC) power lines are used for generated electricity transmission to near demand zones and grid stations. Electricity transmission over distances greater than 300 miles via HVAC power lines has significant line losses (Lindenberg, 2009). Therefore, using high voltage direct current (HVDC) power lines for transmitting electricity to faraway demand zones is more preferable. Grid stations are middle points that receive electricity via HVAC power lines and transmit electricity using HVDC power lines. HVDC power lines are applicable for transmitting electricity over distances up to 1000 miles without considerable line losses (Pattanariyankool and Lave, 2010). Moreover, the transmission capacity of HVDC power lines is more than traditional HVAC power lines capacity, although the investment cost of HVAC line setup is lower than that of HVDC (Lindenberg, 2009).

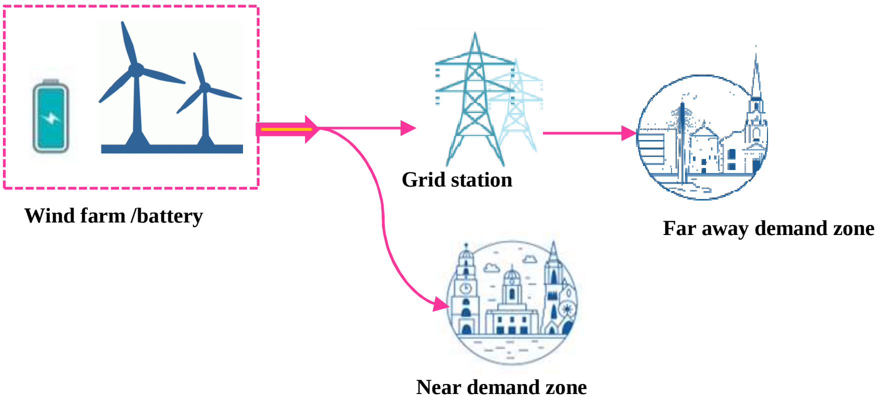

Figure 1. The electricity supply chain

There exist three different periods in a day related to power load demand including off-peak, shoulder and peak periods (Adilov et al., 2004). A day began with a shoulder period, followed by one peak and finally, one off-peak period. The duration of these periods is not equal and the beginning time of each period varies in different seasons.(Leadbetter and Swan, 2012).In this model the operational planning is conducted for 24-h duration.

Shortfall in electricity demand is possible, and it occurs in case the generated electricity or transmission line capacity is not sufficient. The shortfall results in high penalty cost (Osmani and Zhang, 2014).If the generated electricity is more than electricity requirement, the excess amount is stored in batteries for use in peak load periods. Moreover, the excess amount may be greater than batteries capacity, which causes purging (Osmani and Zhang, 2014). Electricity purge can be defined as power loss in generation site due to lack of storage capacity.

The power output in the wind production model depends on the wind speed. Wind speed considered as the input of this system is transformed into the power, during a determined methodology. The base of this method is linearization of power curve. Figure 2 indicates that power is produced when the wind speed is between10 m/h and50 m/h. The speed below 10 m/h and above 50 m/h does not result in power output. Additionally, in the mentioned domain, power curve consists of two parts. The first part is almost linear and when the wind speed increases from 10 m/hto30 m/h, amount of power increases almost linearly. In the second part, the output power level remains in its maximum value. When the wind speed is above 50 m/h, power production cuts off to have the wind turbines protected from damage in gale force conditions (Osmani and Zhang, 2014).

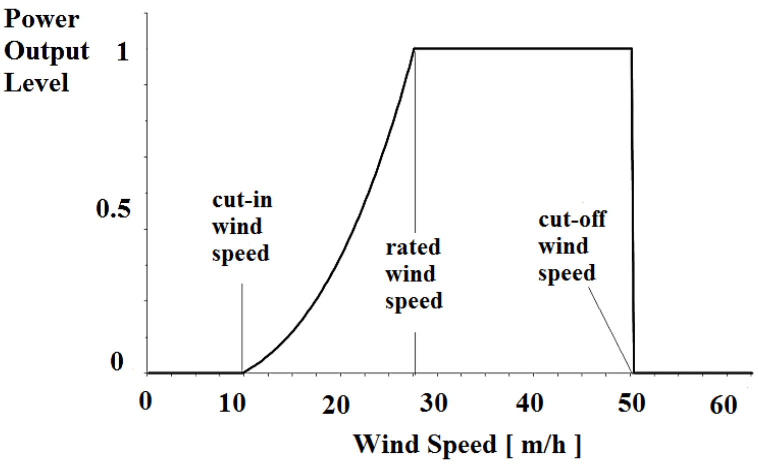

Figure 2. Power output level in different wind speeds.

The power curve is formulated as a first order function as follows:

$$\eta_i = \begin{cases} 0 & \varphi_i < S_I \\ \dfrac{\varphi_i}{S_R - S_I} + \left(1 - \dfrac{S_R}{S_R - S_I}\right) & S_I \leq \varphi_i < S_R \\ 1 & S_R \leq \varphi_i < S_O \\ 0 & \varphi_i \geq S_O \end{cases} \tag{1}$$

Where η_i is power output level (as ratio of maximum power output) of wind farm in location i,$\varphi_i$is the wind speed (m/h), $S_R$is the rated wind speed (m/h), $S_I$is the cut-in wind speed (m/h) and$S_O$is the cut-off wind speed (m/h) (Montoya-Bueno et al., 2015).

3- Mathematical formulation

In this section, mathematical formulation is modeled. This model tends to maximize the total profit in a renewable electricity supply chain. The notations used in problem formulation are as follows:

Sets

I	Existing wind farms, indexed by$i \in I$
J	Existing HVDS grid stations, indexed by $j \in J$
K	Near electricity demand zone, indexed by $k \in K$
E	Faraway electricity demand zone, indexed by $e \in E$
T	Time periods, indexed by $t \in T$
O	Existing transmission lines, indexed by $(i,j),(i,k),(j,e) \in O$

Parameters

bc_i	Storage capacity of battery *i*(MW)
pc_i	Electricity production capacity of wind farm *i*(MW)
lc_{ij}	Maximum capacity of HVAC electricity line *i-j*(MW)
lc_{ik}	Maximum capacity of HVAC electricity line *i-k* (MW)
lc_{ie}	Maximum capacity of HVDC electricity line *j-e*(MW)
omb_i	Operation and maintenance cost of battery *i* ($ / MWh)
γ	Penalty cost of unmet renewable electricity demand ($ / MWh)
α_i	Renewable electricity generation tax credit in location *i* ($ / MWh)
β_k	Sale price of electricity in demand zone *k* ($ / MWh)
β_e	Sale price of electricity in demand zone *e* ($ / MWh)
n_i	Total number of batteries in wind farm *i*
d_k^t	Renewable electricity demand of demand zone *k* in time period *t* (MWh)
d_e^t	Renewable electricity demand of demand zone *e* in time period *t* (MWh)
φ_i	Hourly wind speed in location *i*(mph)
η_i	Electricity production level in wind farm *i*
Rp_i^t	Hourly amount of electricity production in wind farm *i* in period *t* (MWh) $Rp_i^t = \eta_i pc_i$
	Duration of time period *t*

Decision variable

Rs_i^t	Hourly amount of electricity stored in wind farm *i* in period *t* (MWh)
Rsi_i^t	Hourly amount of electricity input in battery *i* in period *t* (MWh)
Rso_i^t	Hourly amount of electricity output from battery *i* in period *t* (MWh)
Re_i^t	Hourly amount of electricity production that is purged in wind farm *i* in period *t* (MWh)
Rf_i^t	Hourly amount of electricity transmitted from wind farm *i* in period *t* (MWh)
Ef_{ij}^t	Hourly amount of electricity transmitted from wind farm *i* to grid station *j* in period *t* (MWh)
Ef_{ik}^t	Hourly amount of electricity transmitted from wind farm *i* to demand zone *k* in period *t* (MWh)
Ef_{je}^t	Hourly amount of electricity transmitted from grid station *j* to demand zone *e* in period *t* (MWh)
U_e^t	Hourly amount of electricity requirement of demand zone *e* that is not supplied in period *t*(MWh)
U_k^t	Hourly amount of electricity requirement of demand zone *k* that is not supplied in period *t* (MWh)
Xs_i^t	Equal to 1, if battery *i* is in charging state, 0 otherwise
Xd_i^t	Equal to 1, if battery *i* is in discharging state, 0 otherwise

3-1- Objective function

Objective function maximizes total profit as Equation 2.

$$max\,\Psi = \sum_t \Delta t \left[\sum_{i,k} \beta_k Ef_{ik}^t + \sum_{j,e} \beta_e Ef_{je}^t - \sum_i \alpha_i Re_i^t - \sum_i omb_i Rs_i^t - \sum_k \gamma U_k^t - \sum_e \gamma U_e^t \right] \tag{2}$$

In equation 2, the first part is total income earned from selling electricity in demand zones. The costs of this model are related to purged electricity, batteries operation and maintenance and unmet electricity demand.

3-2- Constraints

The model constraints including capacity constraints, balance, and storage constraints are as below:

3-2-1- Capacity constraints

$$Rsi_i^{t-1} + Rsi_i^t \leq n_i bc_i \qquad \forall i \in I, t \in T \tag{3}$$

$$Ef_{ij}^t \leq lc_{ij} \qquad \forall i \in I, j \in J\ t \in T \tag{4}$$

$$Ef_{ik}^t \leq lc_{ik} \qquad \forall i \in I, k \in K\ t \in T \tag{5}$$

$$Ef_{je}^t \leq lc_{je} \qquad \forall j \in J, e \in E\ t \in T \tag{6}$$

Constraint (3) states that stored electricity from last period and input power should be lower than total storage capacity in a wind farm. Constraints (4-6) are transmission lines capacity constraints.

3-2-2- Balance constraints

$$Rf_i^t + Rsi_i^t + Re_i^t = Rp_i^t \qquad \forall i \in I, t \in T \tag{7}$$

$$Rsi_i^{t-1} + Rsi_i^t - Rso_i^t = Rs_i^t \qquad \forall i \in I, t \in T \tag{8}$$

$$Rf_i^t + Rso_i^t = \sum_j Ef_{ij}^t + \sum_k Ef_{ik}^t \qquad \forall i \in I, t \in T \tag{9}$$

$$\sum_i Ef_{ij}^t = \sum_e Ef_{je}^t \qquad \forall j \in J, t \in T \tag{10}$$

$$\sum_i Ef_{ik}^t + U_k^t = d_k^t \qquad \forall k \in K, t \in T \tag{11}$$

$$\sum_j Ef_{je}^t + U_e^t = d_e^t \qquad \forall e \in E, t \in T \tag{12}$$

Constraint (7) represents that total electricity production is transmitted, stored or purged in generation site. Constraint (8) implies that total stored electricity is equal to remaining electricity from the last period plus the difference between input and output power flow in the present period. Constraint (9) ensures that total electricity flow from wind farms is equal to total flow in transmission lines. Constraint (10) indicates the equality between input and output power flow in each grid station. Constraints (11) and (12) imply that total transmitted electricity from supply zones plus amount of unmet demand is equal to electricity demand in each demand zone.

3-2-3- Storage constraints

$$Xs_i^t + Xd_i^t \le 1 \qquad \forall i \in I, t \in T \tag{13}$$

$$Xs_i^t \le Rsi_i^t \qquad \forall i \in I, t \in T \tag{14}$$

$$Rsi_i^t \le Xs_i^t M \qquad \forall i \in I, t \in T \tag{15}$$

$$Xd_i^t \le Rso_i^t \qquad \forall i \in I, t \in T \tag{16}$$

$$Rso_i^t \le Xd_i^t M \qquad \forall i \in I, t \in T \tag{17}$$

$$\begin{aligned} &Xs_i^t, Xd_i^t \in \{0,1\} \\ &Rs_i^t, Rsi_i^t, Rso_i^t, Re_i^t, Rf_i^t, Ef_{ij}^t, Ef_{ik}^t, Ef_{je}^t, U_e^t, U_k^t \ge 0 \end{aligned} \tag{18}$$

Constraints (13-17) are related to correlation of charging/discharging state of the battery and input/output variables. Battery cannot be charged and discharged simultaneously in any time that these limits are forced in Constraint (13) (Zhang and Jia, 2016). Constraints (14) and (15) show that power input variable can be positive if battery is in charging state. Similarly, Constraints (16) and (17) are about battery discharging state. Finally, Constraint (18) represents the type of decision variables.

4- Case study

In this section, application of the developed model is evaluated by conducting a case study in the typical Midwestern state of the ND (North Dakota) in the United States (Osmani and Zhang, 2014). The existing supply chain network consists of four wind farms which are supply zones located in the ND. Within a wind zone, the average wind speeds are similar and correlated. However, the wind speeds across different wind zones are not correlated. Moreover, two grid stations have been established in order to satisfy Denver and Chicago electricity requirement (see figure 3).

Figure 3. American Midwest, location of supply and demand zones.

In this network, the existing transmission lines from wind farms to grid stations (*i-j*) and near demand points (*i-k*), and also the HVDC electricity line between grid stations and faraway demand points (*j-e*) are according to table 1. In different wind farms, wind speed is not the same, so when the wind speed is low in a supply site, low power generation can be compensated by other supply sites in where the wind speed is high. There exist some batteries in every wind farm for storing power in off-peak period and releasing it in peak load period. Main parameters are listed in tables 2-4and the other ones are available in reference (Osmani and Zhang, 2014).

Table 1. Existing transmission lines

Transmission line	*i-j*	1-1	1-2	2-2	3-1	3-2	4-2
	i-k	2-1					
	j-e	1-2	2-1				

Table 2. Electricity demand (MWh)

		t = 1	*t* = 2	*t* = 3
demand zone (*k*)	1	310	323	339
demand zone (*e*)	1	2312	2417	2580
	2	662	675	689

Table 3. Electricity transmission line capacity (*i-j*, *i-k*) (MW)

Line capacity	grid station (*j*)		demand zone (*k*)
Supply zone (*i*)	*j*=1	*j*=2	*k*=1
1	790	223	0
2	0	1114	320
3	391	783	0
4	0	1787	0

Table 4. Electricity transmission line capacity (*j-e*) (MW)

Line capacity (*j-e*)	demand zone (*e*)	
grid station (*j*)	*e*=1	*e*=2
1	0	685
2	2511	0

The Mixed integer linear programming model has been implemented using CPLEX solver within GAMS 24.1 software in a personal computer with Intel Core i7-640 M CPU (2.8 GHz), with 8.00 GB of RAM. The solving time of this problem with GAMS software has been 5 seconds. The model results are expressed in Tables 5-9. Tables 5-7 show the electricity flow in the distribution network via the existing HVAC and HVDC transmission lines.

Table 5. Amount of electricity transmission (*i-j*) (MWh)

Ef_{ij}^{t}		period		
Supply zone (*i*)	Grid station (*j*)	*t*=1	*t*=2	*t*=3
1	1	172	284	228
1	2	223	223	223
2	2	1114	1114	1114
3	1	391	391	391
3	2	783	783	783
4	2	17.4	177.4	97.4

Table 6. Amount of electricity transmission (*i-k*) (MWh)

Ef_{ik}^{t}		period		
Supply zone (*i*)	Demand zone (*k*)	*t*=1	*t*=2	*t*=3
2	1	310	320	320

Table 7. Amount of electricity transmission (j-e) (MWh)

Ef_{je}^{t}		period		
Grid station (j)	Demand zone (e)	t=1	t=2	t=3
1	2	563	675	619
2	1	2137	2297	2217

Tables 8 and 9 are related to electricity storage and purge. As is explained, when the battery is in charging (discharging) state, the amount of electricity output (input) is equal to zero. Excess generated power in first period in wind farms 1 and 4 (off-peak period) is stored and used in second period for meeting the demand. According to table 8, the purged electricity in these wind farms in the period 1 is zero. The input power in the second period is stored in battery and remains in third period, which means the generated power in the third period is sufficient, and there is no need to use the batteries. In addition, the input power in this period in all the wind farms is zero. In the wind farms 2 and 3, due to the full batteries, power input is impossible. Therefore, the excess power in the wind farms 2 and 3 is purged. Note that although there is no input power and batteries are empty during the first period in the wind farms 2 and 3, electricity is purged; this is attributed to that the batteries need capacity for power input in the second period.

Table 8. Amount of battery input, output and storage (MWh)

Supply zone (i)	Rsi_{i}^{t}			Rso_{i}^{t}			Rs_{i}^{t}		
	period			period			period		
	1	2	3	1	2	3	1	2	3
1	56	0	0	0	56	0	56	0	0
2	0	50	0	0	0	0	0	50	50
3	0	60	0	0	0	0	0	60	60
4	80	0	0	0	80	0	80	0	0

Table 9. Amount of purged electricity (MWh)

Re_{i}^{t}	period		
Supply zone (i)	1	2	3
1	0	0	0
2	175.7	115.7	165.7
3	673	613	673
4	0	0	0

5- Sensitivity analysis

In order to examine the effect of key parameters on the supply chain operation, some sensitivity analyses have been conducted. Transmission lines are critical to the distribution network. The capacity of the transmission lines has been optimized in the network design stage. Due to the demand growth, capacity expansion might be needed. This change can be implied by technical approaches such as increasing the number of transmission lines or exchanging old lines. As capacity increases, capital cost per unit of capacity increases in the form of non-linear. Indeed when capacity is doubled, the capital cost is not doubled and increases by a factor of $2^{0.9}$(Osmani and Zhang, 2014). Figures 4-8 illustrate the results of sensitivity analyses. Figure 4 shows that the cost of capacity expansion increases incrementally. It can be seen that total profit has a concave diagram versus line capacity expansion, which reaches its maximum point in 20% capacity expansion. It means that, capacity expansion up to 20% can be profitable and after that, the profit decreases because of capacity expansion cost. Figure 5 shows the effect of capacity expansion on the purged electricity cost and the shortage cost. The profit can be increased by decreasing purged electricity and its costs, and increasing satisfied demand through capacity expansion. By increasing the lines capacity by up to 15%, all the demands are satisfied and the amount of unmet demand as well as shortage costs reaches zero.As can be seen in figure 5, the rate of shortage cost reduction versus capacity expansion is high. It should be valuable for managers to realize that transmission network development is possible by spending cost and maximally using available resources, which results in profit enhancement as well as considerable demand satisfaction increase.

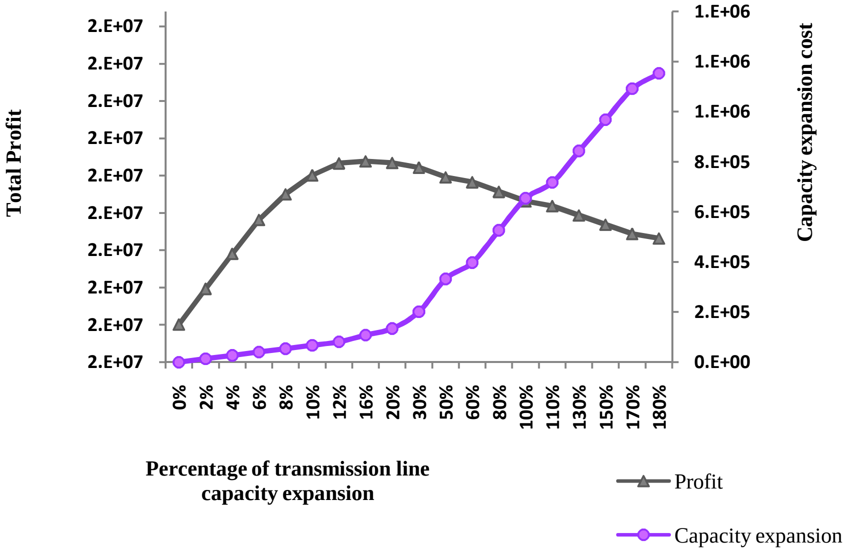

Figure 4. The effect of capacity expansion on the total profit

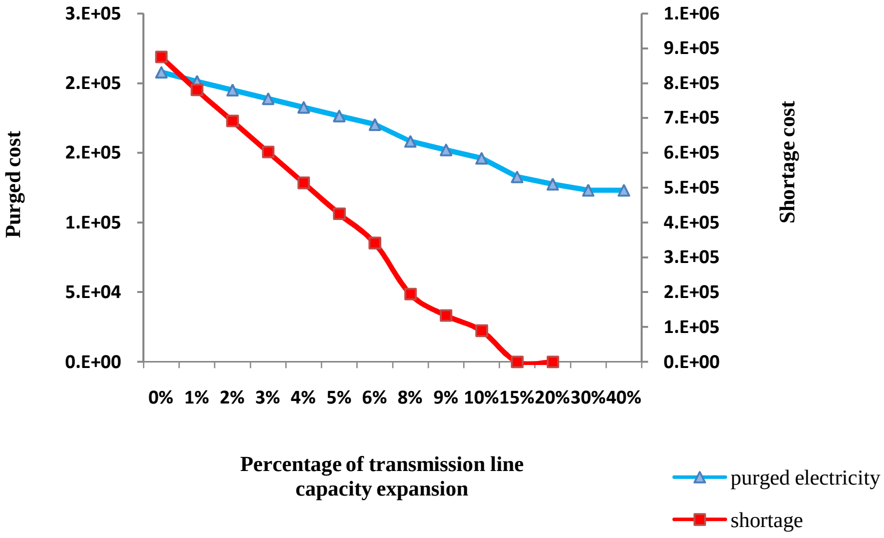

Figure 5. The effect of capacity expansion on purged and shortage cost

In figure 6, the comparison between total income, profit, and different cost variation (purged, shortage and O&M cost) with percentage of line capacity expansion is depicted. As previously explained lines capacity expansion results in considerable reduction in shortage and purged costs.

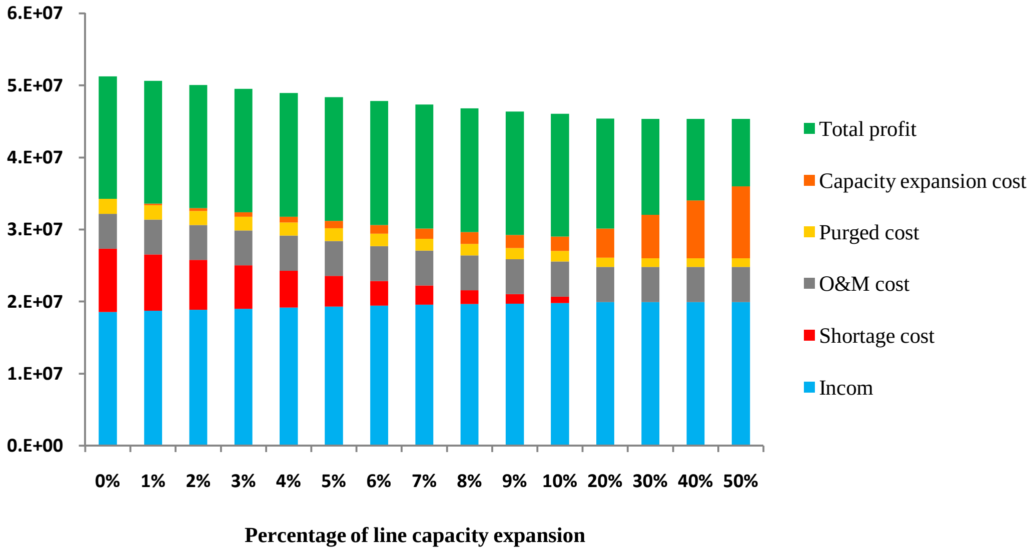

Figure 6. The effect of capacity expansion on the income costs and profit

This problem can be addressed in different load demands and wind speed scenarios. Demand variations can be modeled under low, medium, and high scenarios (Hu et al., 2016). In addition, an unstable wind speed can be considered in three scenarios including low, medium and high wind speed. Therefore, a combination of the load demand and the wind speed variations can make nine scenarios. The sensitivity analyses about capacity expansion and shortage cost are carried out in each scenario. Finally, the results of the six scenarios are depicted in figures 7 and 8. It is noticeable that by expanding transmission lines capacity in each scenario, total profit reaches a maximum value and after that, it is reduced because of capacity expansion costs. In figure 7, maximum profit variation against capacity expansion is related to the scenario 5.In the scenario 5, in addition to the increase in wind speed, electricity demand has increased. Thus, line capacity expansion results in increased demand satisfaction, reduced power losses in generation sites as well as enhanced profit. Minimum variations in profit value are related to the scenario 1,as the demand is low in this scenario. Consequently capacity expansion does not affect profit value in the scenario1 considerably. Managers can make suitable decisions about spending cost in the capacity expansion by considering probable scenarios. The aims of these examinations are improvement in demand satisfaction and profit enhancement. The effect of penalty cost has been shown in figure 8. By increasing penalty cost, the profit is reduced in each scenario.

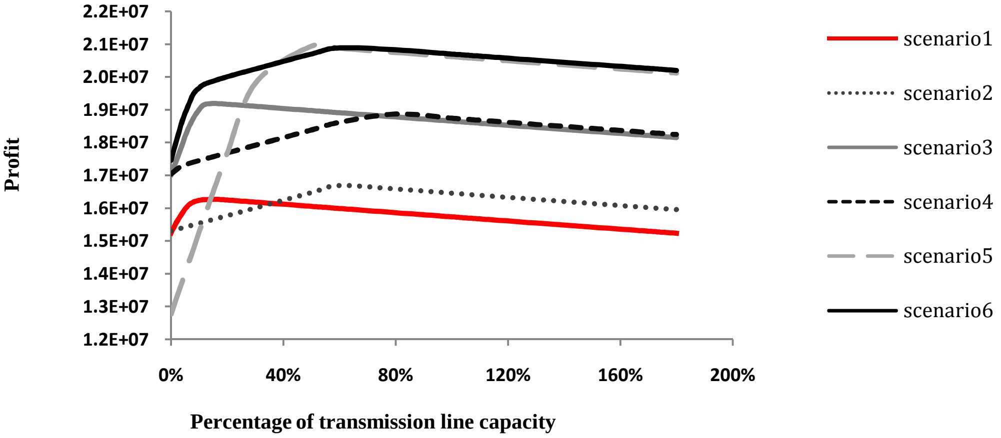

Figure 7. The effect of capacity expansion on the profit in each scenario

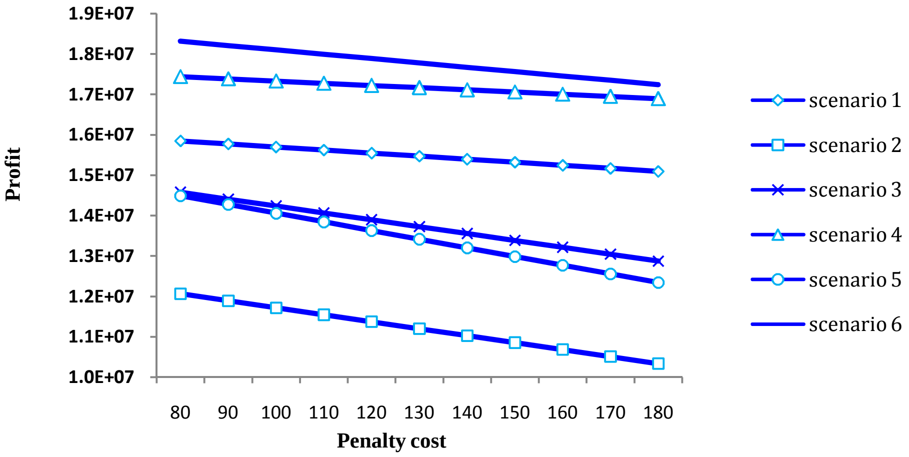

Figure 8. The effect of penalty cost variations on the profit

6- Conclusion

This study addresses the optimization of operational decisions in a renewable electricity supply chain, which are related to power transmission and storage. By considering the determined location of wind farms and transmission facilities, the problem is how to respond to different load demands in an efficient manner and to reduce the amount of unmet demand in a multi-period context. Due to the load demand variations in several hours of a day, three different time intervals including off-peak, shoulder and peak periods have been considered. In order to achieve beneficial managerial insights, some probable scenarios are organized according to variations of parameters including electricity demand and wind speed. The effect of the main parameters on the optimized solution has been investigated by sensitivity analyses in several scenarios. The capability of the proposed model is demonstrated by a case study. Results show that line capacity expansion made a good promotion in each scenario by reducing unmet demand and making more profit. Moreover, incorporating an electricity storage system in the wind farms improved demand covering in peak load hours and decreased power losses of generation sites in off-peak periods. This work has some limitations that provide directions for future work. Other renewable energies such as solar and biomass energy can be incorporated in this model. Modeling the uncertainty of some parameters such as prices, in various methods can be valuable and enhance model effectiveness.

References

Adilov, N., Schuler, R. E., Schulze, W. D. & Toomey, D. E. The effect of customer participation in electricity markets: an experimental analysis of alternative market structures. System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on, 2004. IEEE, 10 pp.

Banos, R., Manzano-Agugliaro, F., Montoya, F., Gil, C., Alcayde, A. & Gómez, J. 2011. Optimization methods applied to renewable and sustainable energy: A review. Renewable and Sustainable Energy Reviews, 15, 1753-1766.

Bukhsh, W. A., Zhang, C. & Pinson, P. 2016. An integrated multiperiod OPF model with demand response and renewable generation uncertainty. IEEE Transactions on Smart Grid, 7, 1495-1503.

De Quevedo, P. M., Allahdadian, J., Contreras, J. & Chicco, G. 2016. Islanding in distribution systems considering wind power and storage. Sustainable Energy, Grids and Networks, 5, 156-166.

De Quevedo, P. M., Contreras, J., Rider, M. J. & Allahdadian, J. 2015. Contingency assessment and network reconfiguration in distribution grids including wind power and energy storage. IEEE Transactions on Sustainable Energy, 6, 1524-1533.

Ekren, B. Y. & Ekren, O. 2009. Simulation based size optimization of a PV/wind hybrid energy conversion system with battery storage under various load and auxiliary energy conditions. Applied Energy, 86, 1387-1394.

Hu, M.-C., Lu, S.-Y. & Chen, Y.-H. 2016. Stochastic programming and market equilibrium analysis of microgrids energy management systems. Energy, 113, 662-670.

Ji, Y., Wang, J., Yan, S., Gao, W. & Li, H. Optimal microgrid energy management integrating intermittent renewable energy and stochastic load. Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), 2015 IEEE, 2015. IEEE, 334-338.

Leadbetter, J. & Swan, L. 2012. Battery storage system for residential electricity peak demand shaving. Energy and buildings, 55, 685-692.

Lindenberg, S. 2009. 20% Wind Energy by 2030: Increasing Wind Energy¿ s Contribution to US Electricity Supply, Diane Publishing.

Mohammadi, S., Soleymani, S. & Mozafari, B. 2014. Scenario-based stochastic operation management of microgrid including wind, photovoltaic, micro-turbine, fuel cell and energy storage devices. International Journal of Electrical Power & Energy Systems, 54**,** 525-535.

Montoya-Bueno, S., Muoz, J. I. & Contreras, J. 2015. A stochastic investment model for renewable generation in distribution systems. IEEE Transactions on Sustainable Energy, 6, 1466-1474.

Nojavan, S. & Allah Aalami, H. 2015. Stochastic energy procurement of large electricity consumer considering photovoltaic, wind-turbine, micro-turbines, energy storage system in the presence of demand response program. Energy Conversion and Management, 103, 1008-1018.

Osmani, A. & Zhang, J. 2014. Optimal grid design and logistic planning for wind and biomass based renewable electricity supply chains under uncertainties. Energy, 70, 514-528.

Osmani, A., Zhang, J., Gonela, V. & Awudu, I. 2013. Electricity generation from renewables in the United States: Resource potential, current usage, technical status, challenges, strategies, policies, and future directions. Renewable and Sustainable Energy Reviews, 24, 454-472.

Pattanariyankool, S. & Lave, L. B. 2010. Optimizing transmission from distant wind farms. Energy Policy, 38, 2806-2815.

Ramandi, M. Y., Afshar, K., Gazafroudi, A. S. & Bigdeli, N. 2016. Reliability and economic evaluation of demand side management programming in wind integrated power systems. International Journal of Electrical Power & Energy Systems, 78, 258-268.

Toole, G. L., Fair, M., Berscheid, A. & Bent, R. Electric power transmission network design for wind generation in the western United States: Algorithms, methodology, and analysis. Transmission and Distribution Conference and Exposition, 2010 IEEE PES, 2010. IEEE, 1-8.

Zhang, Y. & Jia, Q. S. 2016. Operational Optimization for Microgrid of Buildings with Distributed Solar Power and Battery. Asian Journal of Control.

Zhou, X., Huang, G., Zhu, H., Chen, J. & Xu, J. 2015. Chance-constrained two-stage fractional optimization for planning regional energy systems in British Columbia, Canada. Applied Energy, 154, 663-677.2

Zhou, Z., Zhang, J., Liu, P., Li, Z., Georgiadis, M. C. & Pistikopoulos, E. N. 2013. A two-stage stochastic programming model for the optimal design of distributed energy systems. Applied Energy, 103, 135-144.

Zhu, Y. & Tomsovic, K. 2007. Optimal distribution power flow for systems with distributed energy resources. International Journal of Electrical Power & Energy Systems, 29, 260-267.

Zubo, R. H., Mokryani, G., Rajamani, H.-S., Aghaei, J., Niknam, T. & Pillai, P. 2016. Operation and planning of distribution networks with integration of renewable distributed generators considering uncertainties: A review. Renewable and Sustainable Energy Reviews.