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Reliability/cost evaluation of a wind power delivery system

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ABSTRACT

When the geographical locations with good wind resources are not close to the main load centers, it becomes extremely important to assess adequate transmission facility to deliver wind power to the power grid. A probabilistic method is presented to evaluate the contribution of a wind power delivery system to the overall system reliability. The basic model incorporates transmission line connecting a remotely located large wind farm to a conventional grid system. The classical generation system adequacy evaluation model is extended to incorporate limited transmission system. The mean Capacity Outage Probability Table (*mean-COPT*) concept is used to increase the computational efficiency as it allows determination of *EUE* (expected unserved energy) and *LOLE* (loss of load expectation) simultaneously in calculation of reliability indices of the generating system. The wind farm generation model is obtained by superimposing simulated wind speed, obtained from developed *ARMA* time series model, on power curve of *WTG*. An apportioning method has been used to reduce the number of states in the resulting model, obtaining an equivalent reduced 5-state model. Applying transmission line constraints result in wind generation model ranging from 2- to 5-state models. The study recognizes benefits from fuel offset by wind power, reliability worth and environmental improvement and determines appropriate transmission line capacity based on its contribution to the overall system risk and associated transmission system cost. The paper illustrates results using a real wind farm. The presented methods and discussions should be useful to power system planners and policy makers.

1. Introduction

Renewable energy policies, such as the Renewable Portfolio Standard (*RPS*), arising from increase of environmental concerns have set very ambitious targets for wind power penetration in electric power systems throughout the world. Many jurisdictions around the world are implementing or are in the process of implementing the *RPS* either voluntarily or mandatory. Different jurisdictions have made commitments to generate renewable energy from 5% to 25% of the total electricity generation within a decade.

Wind power has to be built in areas with good wind potential. The best conditions for installation of wind power are, thus, in remote areas free of obstacles, and consequently with low population density. Reliability benefits, environmental benefits and operating cost savings from wind power integration should be compared with the associated investment costs in order to determine optimum transmission facility for wind power delivery.

Wind is a highly variable energy source, and therefore, transmission system planning for wind delivery is very different from conventional transmission planning. Deterministic methods ('$n-1$' criterion) [1] cannot recognize the random nature of wind variation that dictates the power generated from wind power sources.

Significantly high wind penetration in power systems can introduce serious problems in adequate system planning and reliable system operation. Wind power is mainly viewed only as a fuel saver, and is not normally considered in power system planning. Although wind power can help in avoiding new conventional power plants in a system, it is not given any credit in generation planning. Wind power has significant effect in improving system reliability up to a certain level. There has been some work done in resolving adequacy problems associated with planning of generation system including unconventional energy sources [2,3].

Geographical sites with good wind resources are being explored for potential large wind farms in order to meet the high penetration targets set by *RPS*. Many of these sites can be far away from a power grid and need to be connected to the grid with transmission lines. Determining an adequate transmission system to deliver wind power to a power grid is a difficult problem. Wind power generation randomly fluctuates between zero and the wind farm's rated capacity. Designing a transmission system to match the wind farm's installed capacity can lead to over investment. On the other hand, it is important to provide fair access to the power transmission network to all the participating power producers in many power systems. This problem needs to be addressed by applying

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suitable power system reliability evaluation techniques and economic assessment for evaluating transmission system adequacy on wind power delivery. There has not been sufficient work done in this area [4–6]. Ref. [5] suggested few solutions to overcome deficiency of delivery system from wind farms in areas that might not be dimensioned to accommodate additional large-scale power plants. One possibility is to revise the methods for calculation of available transmission capacity. Since wind power production depends on the wind speed, the wind farm utilization time is only 2000–4000 h a year, and power production peaks not necessarily occur during periods with insufficient transmission capacity. Therefore wind energy curtailment may be considered as an alternative for large-scale wind power integration. It is also possible to store excess wind energy during the periods with insufficient transmission capacity. Conventional power plants with possibilities of fast production control (e.g. hydropower plants or gas power plants) may also be employed for this purpose. Ref. [6] presents a reliability evaluation technique that include the transmission of wind power in a load center, based on evaluation of the Loss of Load Expectation index using an analytical technique.

There has been significant work done for economic assessment of wind energy utilization in power systems [7]. One of the key benefits from wind power application in a conventional power system is the offset in fuel cost. Wind power generation can also contribute to overall system reliability, and help in reducing customer cost of electric power interruption. Offsetting conventional fuel consumption means reducing harmful emissions produced by fuel and therefore, providing environmental benefits. The cost savings due to these benefits can be compared with the investment in the transmission system for wind power delivery. Realistic reliability/cost evaluation techniques should be developed and utilized in determining adequate transmission facilities. This will be important for both vertically integrated system and deregulated power systems in order to determine proper investment in the transmission system.

This paper presents a probabilistic method to evaluate the contribution of a wind power delivery system to the overall system reliability. The basic model incorporates a 220 kV, 56 km, 2 × 300 MW double circuit transmission line connecting, a large wind farm remotely located at Zafarana, Red Sea, Egypt to a conventional Egyptian relatively large grid system at Ein-El'Sokhna substation. The classical generation system adequacy evaluation model is extended to incorporate limited transmission system. The mean Capacity Outage Probability Table (*mean-COPT*) concept [8] is used to increase the computational efficiency as it allows determination of *EUE* (expected unserved energy) and *LOLE* (loss of load expectation) simultaneously in calculation of reliability indices of the generating system. The wind farm generation model is obtained by superimposing simulated wind speed, obtained from developed *ARMA* time series model [9], on power curve of *WTG*. An apportioning method [10] has been used to reduce the number of states in the resulting model, obtaining an equivalent reduced 5-state model. Applying transmission line constraints result in wind generation model ranging from 2- to 5-state models. The study recognizes benefits from fuel offset by wind power, reliability worth and environmental improvement and determines appropriate transmission line capacity based on its contribution to the overall system risk and associated transmission system cost. The presented methods and discussions should be useful to power system planners and policy makers.

2. Incorporating transmission system in adequacy evaluation

The basic model incorporating transmission line in system adequacy evaluation at the HL-I level is shown in Fig. 1, where a remotely located large wind farm, is connected to a conventional generation system in a power grid system through a transmission system.

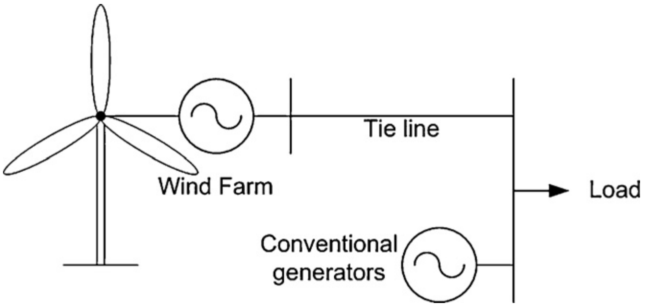

Fig. 1. *HL-I* system model incorporating transmission line.

Generation model of conventional units are typically constructed using recursive unit addition algorithms [11]. Calculation of *EUE* composes the largest computational burden in reliability assessment of generating system. However introduction of the mean Capacity Outage Probability Table (*mean-COPT*) concept [8] increases the computational efficiency as it allows determination of *EUE* and *LOLE* simultaneously.

The classical generation system adequacy evaluation model is extended to incorporate limited transmission system as shown in Fig. 2. A tie line constraint equivalent unit approach [11] is used to develop a generation model that includes transmission system.

System adequacy evaluation considering transmission system is conducted as shown in the model using the following steps.

1. A generation model for the remotely located wind generation plant is first developed in the form of a (*COPT*).
2. The generation model developed in step-1 is modified to include the transmission line constraints. The available generation capacity of the remote plant is constrained by the transmission line capacity and probabilities of the various capacity conditions are weighted by the availability of the transmission line. The modified *COPT* represents a single unit that includes wind generation and transmission system models.
3. The total system generation *mean-COPT* can finally be obtained by adding the equivalent unit model obtained in step-2 to the rest of the generation system using the recursive algorithm. The wind sources are assumed to be base loaded after the larger conventional units in the *EEHC* system.
4. The total system generation model is convolved with system load model to obtain the system risk indices.

3. System modeling and evaluation method

The required wind power system evaluation model consists of three major steps:

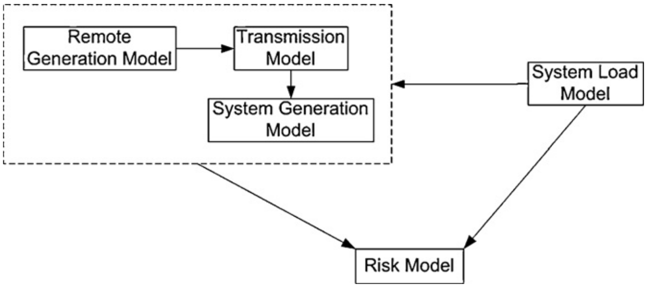

Fig. 2. Evaluation model incorporating transmission system in *HL-I*.

(1) wind speed modeling
(2) *WTG* system modeling
(3) system risk modeling

3.1. Wind speed modeling

Wind power generation is proportional to the cube of the wind speed indicating accurate wind speed modeling is essential for studying wind power effect on system reliability and cost. Wind speed varies continuously with time, and wind regimes vary with geographic conditions. A wind simulation model simulates the variation of wind speed over a specified period of time for the selected geographic site. Hourly wind speeds for the selected wind farm site were simulated using a time series Auto Regressive Moving Average (*ARMA*) model [9], which is mathematically expressed in Eq. (1).

$$y_t = \varepsilon_t + \sum_{i=1}^{p} \varphi_i y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} \tag{1}$$

where y_t is the time series value at time t, φ_i ($i = 1, 2, 3, \ldots, p$) and θ_j ($j = 1, 2, 3, \ldots, q$) are the auto regressive and moving average parameters of the model respectively. $\{\varepsilon_t\}$ is a normal white noise with zero mean and a variance of σ_a^2 (i.e. $\varepsilon_t \in NID(0, \sigma_a^2)$), where *NID* denotes Normally Independently Distributed. The simulated wind speed SW_t at the tth hour can be obtained using Eq. (2) from the historical mean speed μ_t, standard deviation σ_t and the time series values y_t.

$$SW_t = \mu_t + \sigma_t \times y_t \tag{2}$$

The hourly mean wind speed and the standard deviation data for Zafarana site are collected by *NREA* and a computer program was developed using speed data to obtain *ARMA* (p, q) model in order to generate simulated wind speed data. This model represents the first step of wind system modeling.

3.2. Wind system modeling

Zafarana, wind farm composes Gamesa-G-52, Vesta-V47 and En-Ercon *WTG* units totalizing 425.82 MW installed capacity. *WTG* system modeling requires combining the above wind speed model with the *WTG* power generation characteristics of all the *WTG* units.

3.2.1. Wind power generation

The main characteristics that influence the *WTG* generated power are the cut-in speed (V_{ci}), cut-out speed (V_{co}), rated speed (V_r), and the rated power P_r of the *WTG*. Wind power generation varies non-linearly with the wind speed and can be obtained from the power curve of a *WTG* [7] and mathematically expressed by Eq. (3).

$$P_t = \begin{cases} 0, & 0 \le SW_t \le V_{ci} \\ A + B \times SW_t + C \times SW_t^2, & V_{ci} \le SW_t \le V_r \\ P_r, & V_r \le SW_t \le V_{co} \\ 0, & V_{co} \le SW_t \end{cases} \tag{3}$$

where P_t is the wind power output at the tth hour. The constants A, B and C can be found in [12], using V_{ci}, and V_r.

3.2.2. Wind power generation model

The wind farm generation model consists of a number of different power generation states and their corresponding probabilities. The probability p_{wi} of a simulated wind speed SW_i is given by Eq. (4).

Table 1
Wind power generation model.

Wind power generation states WP_i (%)	Probability (p_i) associated with wind generation state
0	0.070210
25	0.059460
50	0.116850
75	0.244460
100	0.509020

$$p_{wi} = \frac{N_i}{(N \times 8760)} \tag{4}$$

where N is the number of simulation years, and N_i is the number of occurrences of wind speeds in the range (SW_j, SW_{j+1}), where

$$SW_i = \frac{(SW_j + SW_{j+1})}{2} \tag{5}$$

The power generated P_i by each individual *WTG* in the wind farm was calculated using Eq. (3), and aggregated to obtain the wind farm generation model which consists of the wind farm power generation states WP_i and their corresponding probabilities p_i. WP_i corresponding to wind speed SW_i is given by Eq. (6).

$$WP_i = \sum_{n} P_i \tag{6}$$

where n is the number of *WTG* in the wind farm.

EPO is the long-term average power output, and is a useful power index in adequacy evaluation of a wind farm. It can be expressed by Eq. (7).

$$EPO = \sum_{i=1}^{m} WP_i \times p_i \tag{7}$$

where m is the number of generation states.

However the number of states of the resulting model is large. Apportioning method [10] has been used to obtain an equivalent reduced model for the wind farm. The mean wind speed for this geographic location is ranging from 9 to 9.7 m/s with the hourly mean standard deviation ranging from 3.5 to 3.6 m/s. The cut-in speed, the rated speed and the cut-out speed of each *WTG* are ranging from 2.5, 4 and 4 m/s, 13, 13 and 17 m/s and 25, 19 and 25 m/s respectively. The resulting 5-state wind system/farm generation model is shown in Table 1.

3.2.3. Wind generation/delivery system model

The next step of the evaluation process is to develop the wind farm generation model at the grid access point. This model incorporates the transmission line, its power transfer capability and forced outage probability of which constrains the wind farm generation model. The wind power available at the grid access point WP_{Gi} is constrained by the transmission line capacity T_{cap} as expressed in Eq. (8).

$$\begin{aligned} WP_{Gi} &= WP_i, \quad \text{for} \quad WP_i < T_{cap} \\ WP_{Gi} &= T_{cap}, \quad \text{for} \quad WP_i \ge T_{cap} \end{aligned} \tag{8}$$

The probability p_{Gi} of the generation state WP_{Gi} is given by Eq. (9).

$$\begin{aligned} p_{Gi} &= U_T + (1 - U_T) \times p_i, && \text{for} \quad WP_{Gi} = 0 \\ &= (1 - U_T) \times p_i, && \text{for} \quad WP_{Gi} < T_{cap} \\ &= (1 - U_T) \times \textstyle\sum_{j=1}^{s} p_j, && \text{for} \quad WP_{Gi} = T_{cap} \end{aligned} \tag{9}$$

Table 2
Constrained wind power generation model.

Wing power generation states WP_i (*MW*)	Probability (p_i) associated with wind generation state
2-State model	
0	0.1843
100	0.8057
3-State model	
0	0.1943
130	0.4554
250	0.3503
4-State model	
0	0.1943
130	0.4554
260	0.3117
350	0.0386
5-State model	
0	0.1943
130	0.4554
260	0.3117
390	0.0375
520	0.0012

where U_T is the transmission line forced outage probability, *s* is the total number of *j* generation states constrained by the line transfer capability.

Transmission system failure rate (λ) and average repair time (r) were extracted from Egyptian Electric Holding Company (*EEHC*) data. Transmission system unavailability U_T was calculated 0.066. The constrained wind generation model incorporating transmission line unavailability at the grid access point ranges from 2-state to 5-state model depending upon transmission capacity relative to wind farm installed capacity. The models are given in Table 2 in one computer run.

In this way, Eqs. (6)–(9) were used to determine the different power generation states WP_{Gi} and their corresponding probabilities p_{Gi} at the grid access point. This model was used to determine the *EPO* using Eq. (10).

$$EPO = \sum_{i=1}^{s} WP_{Gi} \times p_{Gi} \tag{10}$$

3.3. System risk modeling

The overall system generation model incorporating conventional and wind generation/delivery systems is finally convolved with system load model to obtain the system risk and energy based indices. The *EEHC* electrical power system load varies with time and that variation can be represented by a load model. Fig. 3 shows the *EEHC* load duration curve model.

3.3.1. Adequacy evaluation method and risk indices

Fig. 4 shows the pictorial representation of the software applied in overall system adequacy evaluation. The software provides system reliability indices such as the loss of load expectation (*LOLE*) and energy indices, such as the loss of energy expectation (*LOEE*) and expected energy supplied (*EES*) by each generating unit [11]. These indices are used for evaluating reliability and cost associated with wind power integration with a conventional system through a transmission system.

3.4. Evaluation of reliability/cost indices

There are number of benefits associated with utilization of wind energy in a conventional power generation system. These are:

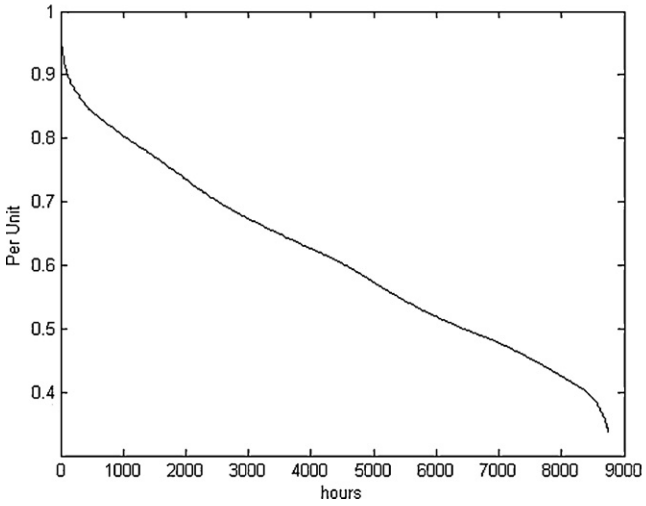

Fig. 3. Annual load duration curve for the *EEHC*-power system.

3.4.1. Fuel offset by WTG

The savings in fuel cost can be obtained by determining the energy offset from burning conventional fuel. The energy offset is equal to the expected energy supplied by wind sources *EES*. The energy supplied by the wind farm offsets the conventional fuel cost, and can be calculated by Eq. (11).

$$FOW = EES_w \times FC \tag{11}$$

where *FOW* = fuel offset by wind energy; EES_w = expected energy supplied by *WTG* in MWh; *FC* = average fuel cost in \$/MWh.

3.4.2. Environment benefits from WTG

Wind power technology and cost of electricity generated from wind are costlier than power generation from most conventional sources. Wind Power Production Index (*WPPI*) recognizing the environmental benefits of wind power is assumed as 1 ¢/kWh. The monetary value of the environmental benefits can be calculated using Eq. (12).

$$BOI = EES_w \times WPPI \tag{12}$$

The *BOI* index stands for benefits obtained from incentive in dollars.

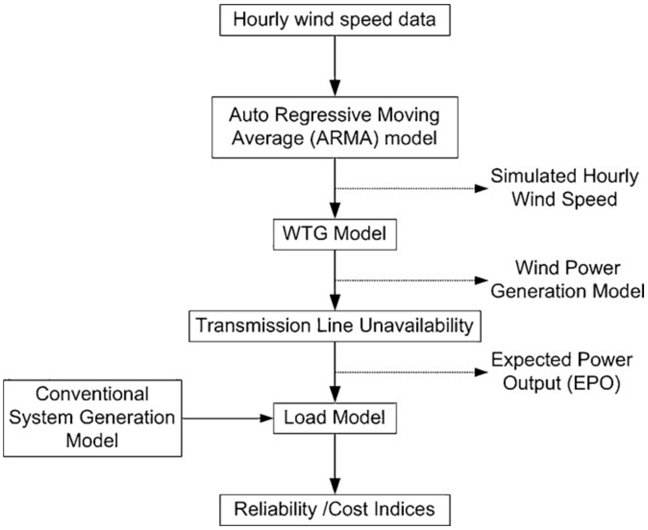

Fig. 4. Flow chart of evaluation approach.

3.4.3. Reliability worth

Incorporating wind power to conventional system can be useful in supplementing energy to system and in reducing expected customer interruption cost (*ECOST*) [11]. The simplest way of estimating *ECOST* without introducing great inaccuracies is presented by Eq. (13) [13,14].

$$ECOST = IEAR \times LOEE \tag{13}$$

The *IEAR* represents interrupted energy assessment rate and assumed as 3.63 $/kWh of unsupplied energy. *LOEE* is also known as the expected energy not supplies (*EENS*). The addition of wind power to a power system will normally improve the overall system reliability. This can be quantitatively measured by the reduction in system *LOEE*, which can be obtained by using Eq. (14).

$$\Delta LOEE = EENS - EENS_w \tag{14}$$

where $\Delta LOEE$ is the reduction in system LOEE as a result of wind energy utilization; *EENS* = expected energy not supplied before adding wind power; $EENS_w$ = expected energy not supplied after adding wind power.

The reduction in outage cost to the customer or the benefit available from saving in *ECOST* can be estimated using Eq. (15).

$$BOC = IEAR \times \Delta LOEE \tag{15}$$

where *BOC* represents benefits from saving in *ECOST* in dollars.

The total benefit (B_w) from wind power can be obtained using Eq. (16).

$$B_w = EES_w(FC + WPPI) + IEAR \times \Delta LOEE \tag{16}$$

4. Reliability contribution of WECS through a transmission system

The *EEHC* power system consists of 165 conventional generating units with a total generating capacity of 21,516 MW. The annual peak load is 19,700 MW. System data and relevant reliability data for all the generation units in the *EEHC* system is provided in Table 3. Zafarana farm composes a wind power penetration of 1.979%.

The developed methodology (Fig. 4) of reliability evaluation is used to find the optimum transmission system capacity. The basic indices obtained from the process are *EPO*, *LOLE*, *LOEE* and *EES*.

4.1. Effect of transmission line capacity

The reliability of the *EEHC* system is improved by the integration of Zafarana wind farm. The reliability contribution of the wind system, however, depends on the tie line connecting it to the system. Fig. 5 shows the increase in system reliability with an increase in the tie line capacity. The incremental reliability, however, decreases with increase in line capacity. The figure shows that the *EPO* for 150 MW line capacity is about 127.848 MW, and for 600 MW line

Table 3
EEHC generating system data.

Unit size (MW)	Unit type	Number of units	FOR	MTTF (h)	MTTR (h)
11.30	G	1	0.78384	126.14400	457.42616
11.60	G	1	0.78395	126.14400	457.70780
14.28	H	6	0.05633	5135.11200	306.54618
16.00	H	4	0.05633	5135.11200	306.54618
23.96	G	2	0.60355	183.960000	280.05672
24.50	C	12	0.06941	3836.00400	286.12865
24.60	G	1	0.60371	183.96000	280.24123
24.72	C	8	0.06666	3836.00400	273.98078
26.50	S	1	0.09369	4239.84000	438.29941
30.00	S	5	0.09369	4239.84000	438.29941
32.30	G	5	0.60371	183.96000	280.24123
33.00	S	2	0.09369	4239.84000	438.29941
33.30	G	4	0.60371	183.96000	280.24123
33.50	G	3	0.60371	183.96000	280.24123
45.92	C	1	0.09381	4239.84000	438.91242
45.94	C	1	0.06666	3836.00400	273.98078
46.00	H	7	0.04728	4920.49200	244.19637
50.00	G	1	0.32611	400.33200	193.72776
55.00	C	1	0.06666	3836.00400	273.98078
58.00	C	3	0.06666	3836.00400	273.98078
60.00	S	4	0.09369	4239.84000	438.29941
65.00	S	3	0.09369	4239.84000	438.29941
67.50	H	4	0.04728	4920.49200	244.19637
87.50	S	4	0.09369	4239.84000	438.29941
110.00	G	3	0.32586	400.33200	193.72776
110.00	C	1	0.06666	3836.00400	273.98078
110.00	S	4	0.07624	5745.68400	474.21369
132.00	C	6	0.06666	3836.00400	273.98078
136.00	C	3	0.06666	3836.00400	273.98078
150.00	S	10	0.07624	5745.68400	474.21369
175.00	H	12	0.04728	4920.49200	244.19637
210.00	S	2	0.09066	6547.22400	652.71720
250.00	C	16	0.06666	3836.00400	273.98078
300.00	S	3	0.05929	6230.98800	392.72067
311.00	S	1	0.05929	6230.98800	392.72067
312.00	S	2	0.05929	6230.98800	392.72067
315.00	S	4	0.05929	6230.98800	392.72067
320.00	S	6	0.05929	6230.98800	392.72067
330.00	S	2	0.05917	6230.98800	391.84406
341.25	S	4	0.05929	6230.98800	392.72067
627.00	S	2	0.06649	6806.52000	484.80407

Total number of units = 165; total install capacity = 21,516 MW; peak load = 19,700 MW; FOR = forced outage rate; MTTF = mean time to failure; MTTR = mean time to repair; G = gas turbine; H = hydro unit; C = combined cycle unit; S = steam turbine.

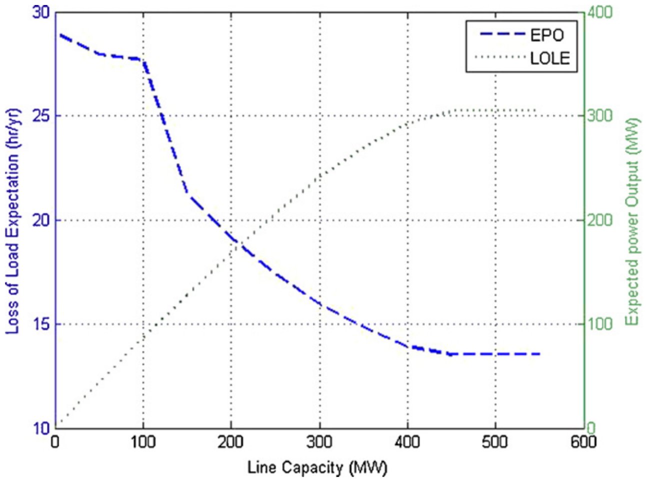

Fig. 5. System risk versus line capacity.

capacity is 304.642 MW. The zero line capacity in Fig. 5 represents the system without any connection to the wind farm. The corresponding 28.98813 h/yr is the LOLE of the original *EEHC* system with no wind power. Fig. 5 shows that increasing the tie line capacity beyond 450 MW do not result in a significant increase in system reliability.

5. Economic assessment of a transmission system delivering wind power

The ultimate decision on the appropriate transmission system will require a trade-off between the system cost and the system reliability. The monetary benefits from the wind delivery system are compared to the investment costs of the transmission system with different power transfer capabilities in order to determine appropriate sizing.

The investment in transmission line will generally increase linearly with the increase in transmission line capacity. The investment cost of 220 kV, 300 MW transmission line is assumed at 0.69 million $/km. A linear interpolation was used to estimate the cost per km for transmission lines of various transfer capabilities. The Annuity of capital investment on the line is calculated over an average life of 45 years with 8% cost of money. The conventional fuel offset due to wind application was evaluated assuming the wind sources to be base loaded after the larger conventional units in the *EEHC* system. The average of fuel cost (*FC*) of 3.75 $/MWh was used in the studies considering different types of conventional generating units in the system. This study considers 0.01 $/kWh as *WPPI* towards wind energy supplied by a wind farm. The value of *IEAR* for the *EEHC* system is assumed to be 3.63 $/kWh. The overall cost benefits were calculated using Eq. (16).

5.1. Effect of transmission line expansion

The marginal net benefit in expanding the transmission line capacity above 50 MW is shown in Fig. 6. The benefits of connecting wind power through a transmission line were calculated using Eq. (16). The net benefit is obtained by subtracting the total investment costs from the total benefits from wind power.

The benefit is maximized at line capacity of about 350 MW. Fig. 6 shows that the net benefit decreases rapidly as the line capacity is further increased. It was also shown in Fig. 5 that there was no reliability benefit in expanding the line capacity above 450 MW. The decision on a particular line capacity should also take into consideration future system expectations.

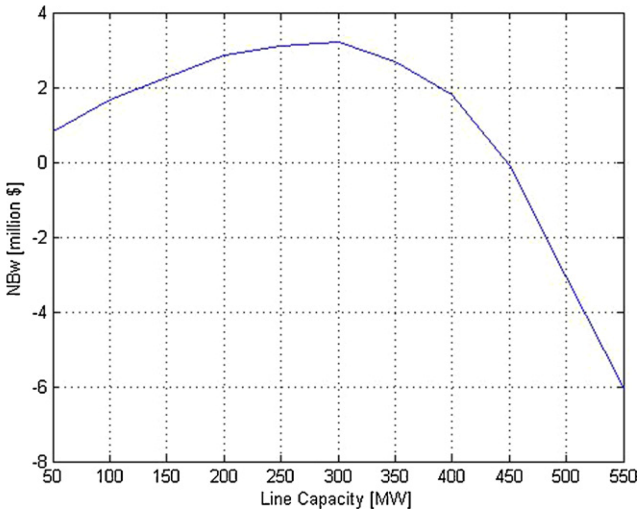

Fig. 6. Net benefit with transmission line expansion.

Table 4
Cost-effective line sizing at different wind power penetration.

Wind farm		Transmission line	
Penetration in percentage	Installed capacity in MW	Capacity in MW	% of wind farm rated capacity
1.979	425.82	300	70.45
2.540	546.52	350	64.04
3.490	750	550	73.33
4.648	1000	650	65.00
6.972	1500	1050	70.00
9.295	2000	1450	72.50

5.2. Effect of wind penetration

The studies described in the previous sections consider a 1.979 (~2.0) % wind penetration by integrating a 425.82 MW rated wind farm to the *EEHC* system. This study considers four different wind penetration levels at 2.54%, 3.49%, 4.648%, 6.972% and 9.295% (i.e. connecting 546.52, 750, 1000, 1500 and 2000 MW wind farms respectively) to the *EEHC* through 56 km transmission system. Each wind penetration case is studied separately considering various tie line capacities.

Table 4 shows the cost-effective line size for various wind power penetration levels. Columns 3 and 4 of the table show the cost-effective line size in MW and in percentage of wind farm rated capacity respectively. It can be noticed from column 4 that the cost-effective line capacity, expressed in percent of the rated wind farm capacity, do not increase at same rate as the increase rate in wind power penetration. This is a result of the relative decrease in the wind benefits compared to the investment cost of the transmission line.

6. Conclusions

The '$n-1$' deterministic criterion for transmission system planning cannot recognize the random variation in wind power generation, and therefore is not suitable for power system planning considering wind power. A probabilistic method is presented for evaluating the contribution of wind transmission system to overall system reliability, using reliability and cost evaluation techniques.

System model and techniques are presented for incorporating limited transmission line in the HL-I study using tie line constraint equivalent unit approach. Wind generation model at grid access point was integrated with *EEHC* conventional system. A computer program was developed, based on the analytical technique developed, to obtain direct numerical solutions for system reliability evaluation. The basic indices obtained from the process are *EPO*, *LOLE*, *LOEE* and *EES*.

EEHC system reliability increases with the transmission line size when wind power is integrated to a conventional system. The incremental reliability benefits are however decreased with increasing line capacity.

Wind power offsets conventional fuel, helps in reducing system down time and also reduces environmental degradation. Reliability cost/benefit analysis shows that the benefits are justified up to a certain limit of transmission line capacity.

The wind penetration level after a certain point cannot fully contribute to the system load, and therefore the relative benefits tend to decrease with further increase in wind penetration in the system.

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