Estimating Optimal Wind and Storage Capacity to Avoid Conventional Power Plants Expansion Using Monte Carlo Method

S. Shojaeian, H. Akrami

Abstract— **Considering the growing trend of the electric power demand and the global tendency to substitute new renewable energy sources, this paper proposes a Monte Carlo based method to determine an optimal level of this substitution. Because of the limitation of the wind farms in continuous supply of electric power, hydrostatic power storage facilities are used beside them so that the electric power could be stored and fed in a continuous flow into power systems. Due to the gradual exclusion of conventional generators and a reasonable percent annual load growth, Loss Of Load Expectation (LOLE) index was used in order to calculate the amount of the wind power and the capacity of the necessary power storage facility. To this end, Loss Of Energy Expectation (LOEE) index was calculated for the first year as the reference index for the estimation of the amount of wind power and the capacity of the storage facility in consequent years. For the upcoming years, calculations have been made to account for the gradual exclusion of conventional generators in proportion to load increments. The method proposed has been implemented and simulated on IEEE-RTS test system.**

Index Terms— **Hydroelectric Storage, LOLE, Monte Carlo, Reliability, Wind Power**

I. INTRODUCTION

ENVIRONMENTAL concerns, due to the limitations of conventional fossil fuels such as coal, oil and natural gas used in the production of electricity and emissions an pollutions thereof, has elevated the global tendency to use and promote the use of renewable sources of energy. With the advent and development of power generation techniques using renewable sources of energy, and promotion of the use of these techniques in meeting electric power needs of the nations, probing into and assessment of the power generated and fed into the power systems by these sources gains high importance. Wind energy had the fastest growth rate among these renewable sources of energy and has been recognized as the most successful renewable source of energy. A lot of research has been carried out in order to model the wind speed behavior in terms of planning and analysis the reliability of the wind energy conversion system (WECS) or combination power systems including wind power [1,2,3].

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In previous studies, Wind speed distributions are often characterized by Weibull distributions in system evaluation using analytical methods [4]. However, these techniques cannot recognize the chronology in wind speed variation at a geographic location. Given the changes in the wind speed in time, Auto Regressive Moving Average (ARMA) time series model is the right model for simulating the wind speed [1]. The relation between the wind speed and power output of the wind turbine generators (WTGs) is shown by a non-linear equation in the name of wind power curve1 [5].

References [4-17] presented different techniques in order to reliability evaluate of the powers systems include wind power. References [4-9] use analytical techniques in the assessment of the reliability of power systems that include wind power generators.

Sequential Monte Carlo simulation (SMCS) methods are used for the assessment of the reliability of power systems with unpopular storage sources have been introduced in [10 – 17]. References [10-15] use ARMA time series model in the reliability evaluation of the power systems include WTGs based on the Monte Carlo method.

Power systems that include wind power face many restrictions in the absorption of wind energy because of the fluctuations of the wind power. If it is possible to use sources for the storage of the wind energy beside WTGs, this restriction could be largely overcome. There are different methods for the storage of the energy. New battery technologies, such as the Vanadium Redox Battery (VRB) [18], are being considered and successfully tested for large scale on-grid applications of wind energy. In reference [19], the general probabilistic method of a WECS has been used that include wind power generators and energy storage batteries.

This paper uses IEEE-RTS test system that has been used in many studies as the test system. ARMA time series model was used to simulate the hourly wind speed and SMCS simulation technique was used in the calculation of, Loss Of Load Expectation (LOLE) and Loss Of Energy Expectation (LOEE) indices. The kind of storage facility used is the hydraulic storage system. All simulations have been used the MATLAB software.

II. MODELLING OF THE SYSTEM COMPONENTS

A. Basic concepts

The main function of an electric system is to be of an acceptable level of reliability and price [10]. The reliability of a system is defined as its ability to perform its functions within a definite span of time. In general the reliability associated with a power system is a measure of the overall ability of the system to satisfy the customer demand for electrical energy [20].

The most important issue in evaluating the efficacy of a power system including wind power is the ability of the system to supply the power needed to meet the load of the system. Reliability assessment of power systems takes place in the three Hierarchical levels of generation (HL1), transmission (HL2) and distribution (HL3). Considering the fact that failure or fault in generation facilities to the outage of the whole system, the adequacy evaluation of the power systems at the generation level is of particular importance. That is why this study is focused on the reliability of the power systems that include WTGs and storage facilities using the HL1. The transmission and distribution systems are considered as quite reliable in this paper.

Reliability evaluation of the power systems including wind power is carried out using different techniques. Analytical and simulation methods are among the most important techniques used in the evaluation of the reliability of these systems, and as far as simulation techniques are concerned, the Monte Carlo simulation method (MCS), which has been adopted in this study, prevails.

Analytical methods use statistical and mathematical models for the description of the system elements, and risk indices are obtained using mathematical models. The analytical method cannot readily take into account the chronology of the random events and relation between load, wind power, and charge and discharge states of the power storage facilities. On the other hand, the statistical technique is practical and useful for the evaluation of systems that have a great number of random variables.

The Monte Carlo method is a calculative algorithm that uses random sampling for the calculation of the results. The MCS technique provide different methods for the evaluation the reliability indices of the power systems through the simulation of real processes and the random behavior of the system, and takes into account all dimensions and intrinsic probabilities of the system in planning, design and operation of the power systems.

In recent decades, MCS has found widespread uses due to the rapid development of the calculation tools. MCS method involves the sequential and non-sequential techniques. In the sequential technique, the behavior of the system is taken as continuous, whereas in the non-sequential technique, the system's behavior is taken as discrete. Therefore, the sequential method is more precise in terms of the temporal and chronological continuity [21].

B. Generation model

Each power generator within the power systems can be demonstrated by a two-state or multi-state Markov model. In the two-state Markov model the power generation unit is either in a fully functional load or a forced outage rate (FOR) state. As shown in Fig. 1, the generation unit transits between the two states of λ and μ, where λ is the failure rate and μ is the repair rate of the generating unit.

If the failure rate (λ) and repair rate (μ) is available, it is possible to calculate the value of unavailability (U),

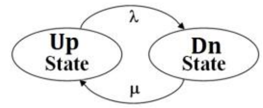

Fig. 1: Two-state model for a generation unit.

availability (A) and FOR of the generator unit with use (1) to (3) [20].

$$U = \frac{\lambda}{\lambda + \mu} \tag{1}$$

$$A = 1 - U = \frac{\mu}{\lambda + \mu} \tag{2}$$

$$FOR = \frac{\sum_i Down\,Time_i}{\sum_i Down\,Time_i + \sum_i Up\,Time_i} \tag{3}$$

C. Load Model

Different load models can be suggested for a system's demand within a definite period of time. The simplest model that can be taken for a load is to use a constant load for the whole period in question. In such conditions, the maximum load of the system is taken as the constant load. Daily peak load variation curve (DPLVC) and load duration curve (LDC) are extensively used as load models in the assessment of the efficacy of the generator units.

The DPLVC is created by arranging the individual daily peak load data, usually collected over a period of one year, in descending order. The LDC is created when the individual hourly peak loads are used, and in this case the area under the curve represents the total energy demand for the system in the given period [1]. In practice, LDC reflects the system load more completely than DPLVC.

Using the hourly load data it is possible to obtain the chronological model of the load. The amount of the load L(t) at time t can be obtained using equation (4).

$$L(t) = L_y + P_w + P_d + P_h(t) \tag{4}$$

Where L_y is the annual peak load, P_w is the percentage of weekly load in terms of the annual peak, P_d is the percentage of daily load in terms of the weekly peak load and $P_h(t)$ is the percentage of hourly load in terms of the daily peak

Using the load conditions on annual, weekly and daily bases, and making use of (4), it is possible to simulate the hourly load for one year. Given the load changes in seasons, months, days and even hours, it will be wrong to consider a fixed amount of load for all hours of a year. That is why this paper load changes in the time spans above have been taken from IEEE-RTS loads with the peak load of 2850 MW for the simulation of the load model. This paper assumes that the load will be increased in 5 percent increments per year...

D. System risk model

The system risk model is obtained by combining the generation model with the load model. Therefore, it is possible to obtain the system risk index of the system using the risk model, that is LOLE and LOEE indexes. LOLE is the number of hours or days in a year when the total power output of the system has failed to meet load demands. LOEE is the loss of energy expectation when the system has failed to meet its demand because the demand outweighs the total power generation capacity. The load model used in sequential Monte Carlo model has been developed in hourly steps; however, it is possible to use it for even lesser time spans. LOLE and LOEE indices can be obtained using (5) and (6). Estimates of the reliability indices for a number of sample years (N) can be obtained using equations (5) and (6).

$$LOLE = \frac{1}{N}\sum_{i=1}^{N} t_i \qquad [days / year] \tag{5}$$

$$LOEE = \frac{1}{N}\sum_{i=1}^{N} e_i \qquad [MWh / year] \tag{6}$$

Where, t_i is loss of load duration in load curtailment i, e_i is energy not supplied in load curtailment i, N is total number of simulated years and n is number of load curtailments. The LOLE and LOEE present an overall status of the system's ability to estimate the power needed by the system.

E. Wind energy conversion model

Methods used for modeling Wind energy conversion model (WECS) fall into the two categories of simulating wind speed data and extraction of the energy conversion systems model. In the first step, the wind speed random variable should be recognized. This random value consists of the right model for the reflection of the status and chronological correlation for a particular geographical location. In the second step, a non-linear relation between the wind turbine generator power output and the wind speed is taken into account. This relation is obtained by using the WTG operational parameters and modeling techniques of the power curve.

E.1. Wind energy conversion model

The power output of the WTG depends on the wind speed at a certain site. The wind speed changes in time and location. Therefore wind speed at a certain hour depends also on the wind speed in previous hours. Numerous studies have been made for the purpose of planning and analyzing the reliability of the wind energy convertors or compound systems that include wind power [1-3].

Using the ARMA time series it is possible to simulate the wind speed with its seasonal or daily distribution. Therefore, this model can be used in power system reliability studies including WECS. Information on wind speed time series for a wind farm from an ARMA model at the level of (n, n-1) is obtained from (7).

$$y_t = \sum_{i=1}^{N} \varphi_i y_{i-1} + \alpha_t - \sum_{j=1}^{N-1} \varphi_j \alpha_{j-1} \tag{7}$$

Where φ_i (i=1,2,…,p) and θ_i (i=1,2,…,q) are autoregressive (AR) and moving average (MA) respectively and α_t is the white noise process with the zero mean and $\sigma_a{}^2$ variance (that is $\alpha_t \epsilon NID(0, \sigma_a{}^2)$ where NID is indicative of the independent normal distribution. The minimum squares method is used in order to estimate the amounts of p, q, ϕ_i and θ_i at ARMA (p, q) [22], and the amount of α_t is calculated from an initially guessed value. The 15-year history of wind speed at Swift Current in the Province of Saskatchewan, Canada has been used for obtaining the ARMA time series model. The information recorded goes back to the height of 10 meters, and the wind speed at this site is approximately 20 km/h. The hourly wind speed information at a 15-year sample from 1989 to 2003 has been used in modeling at ARMA time series. Using the information mentioned above, the ARMA time series for this region is calculated from (8).

$$\begin{aligned} y_t = 0.8782 y_{t-1} - 0.0061 y_{t-2} + 0.0265 y_{t-3} \\ + \alpha_t - 0.2162\alpha_{t-1} + 0.0091\alpha_{t-2} \end{aligned} \tag{8}$$

$$\alpha_t \in NID(0, 0.55792^2)$$

where y_t is the time series value of time t, α_t is the white noise process with a mean of zero and variance of 0.55792^2. The above time series model provides a logical picture of the wind regime. Using the y_t time series the wind speed for the above site can be calculated using the equation (9).

$$SW_t = \mu_t + \sigma_t . y_t \tag{9}$$

Where μ_t and σ_t are the historical hourly mean wind speed and the standard deviation of wind speed respectively for the wind sites.

E.2. WTG model

The power output of the WTG is different from that of the conventional generators. The conventional power generator units can provide a constant power output for all times. One of the most effective factors on the WTG's power output is the wind speed. There is a nonlinear relation between the power output of the WTG and wind speed that is shown by the power

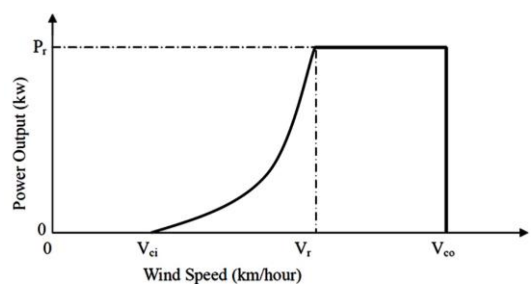

Fig. 2: Power curve of a typical WTG unit.

curve in Fig. 2.

The relation of this curve with the power output becomes clear by describing the operational parameters of the WTG. The important parameters of this relation are: the cut-in wind speed, rated wind speed, and the cut-out wind speed. A WTG starts generating power at the cut-in wind speed. WTGs have their power output rate (P_r) between the rate speed and cut-out speed. As soon as the wind speed reaches the Cut-out speed, WTG units are shut down for safety reasons.

Equation (10) is used for the calculation of the power output of the wind turbine. This equation is the mathematical expression of the power curve. So using (10) and the simulated wind speed, it is possible to simulate the power output of the WTG.

$$P(\mathrm{SW}_t) = \begin{cases} 0 & , 0 < SW_t \le V_{ci} \\ (A + B.SW_t + C.SW_t{}^2) P_r & , V_{ci} < SW_t \le V_r \\ P_r & , V_r < SW_t \le V_{co} \\ 0 & , V_{co} < SW_t \le 0 \end{cases} \tag{10}$$

where P_r, V_{ci}, V_r and V_{co} are the rated power output, the cut-in wind speed, the rated wind speed and the cut-out wind speed of the WTG respectively. The constants A, B, C are determined by V_{ci}, and V_r as expressed in (11) [5]. The cut-in, rated and cut-out wind speed values used in this paper are 14.4, 36, and 80km/hour respectively [24].

$$\begin{aligned} A &= \frac{1}{(V_{ci}-V_r)^2}\left\{V_{ci}(V_{ci}+V_r)-4V_{ci}V_r\left[\frac{V_{ci}+V_r}{2V_r}\right]^3\right\}, \\ B &= \frac{1}{(V_{ci}-V_r)^2}\left\{4V_{ci}V_r\left[\frac{V_{ci}+V_r}{2V_r}\right]^3-(3V_{ci}+V_r)\right\}, \\ C &= \frac{1}{(V_{ci}-V_r)^2}\left\{2-4\left[\frac{V_{ci}+V_r}{2V_r}\right]^3\right\} \end{aligned} \tag{11}$$

With used equation (11), the constants A, B and C for the WTG were calculated to be equal to 0.0311, - 0.00215 and 0.0013. This paper assumes that all WTG units are the same and with the same output rate of 1MW. In a particular geographical location, each WTG has been assumed to have been subjected to the same wind regime and all WTGs have been assumed to deliver a constant power output during a certain period of time.

III. Evaluation of the Reliability of Power Systems with Wind Power and Energy Storage

A. *Strategy statement*

Wind penetration expressed as the ratio of the installed wind capacity relative to the system generation capacity in many power systems around the world is rapidly increasing. The output power of WTGs is widely different from that of conventional generators. The WTGs wind power is random and cannot be used as a constant source in meeting the load of the system except where it is used together with a storage facility. Different kinds of storage techniques have been proposed for the improvement of the performance of power systems. Investigating the effect of energy storage on the reliability large power systems that include a considerable portion of wind power is very important. Storage facilities are very popular and useful where the system faces difficulties in meeting the load.

The main purpose of adding storage facilities in conventional power systems that include wind power is to level out the fluctuations created by WTGs. In practice, usually, the surplus energy of conventional power sources is not stored. The model shown in Fig. 3 stores surplus energy produced by WTGs and delivers it back to the system at low powers (low winds). Energy storage facilities are located adjacent to the wind farms and are connected to the system through a connection line.

When the wind portion is relatively low with little effect on the system's performance, the priority in delivering load services is given to the wind power. In such conditions the whole wind power produced by wind farms is absorbed by the system. The ability of power systems in absorbing wind energy is reduced by the increase in the wind power portion due to the system's need for the stability of power supply. When a great portion of the system load is to be met by the wind power, the probability of system's being unstable goes up. Therefore, due to the limitations created by the system's instability, only part of the power needed by the system can be provided by the wind power. This limitation occurs when a definite percentage of the whole system load is borne by the wind power. When the sum of the wind and conventional powers is not enough to answer the system load, the stored energy is used to meet the load and supplement the system's power supply.

B. *Hydro-electric units*

Hydroelectric units are able to change their power output rapidly. On the other hand WTG power output is quite variable and random, and their extensive use in the system can lead to the instability of the system. Coordination between WTGs and hydroelectric units, most of the constraints of the application of wind power in the system in a continuous manner will be overcome. Limited hydroelectric units are used to investigate into the advantages of these units in terms of the reliability of power systems incorporating wind power and coordinate wind and hydroelectric powers. This paper assumes the use of two reservoirs or dams for the storage of electric power.

C. *Using two water reservoirs or two consecutive dams as micro-hydroelectric power storage facilities*

Here, two consecutive dams or two voluminous reservoirs are used for storage purposes. During the period when there is surplus wind energy available, this energy is stored by pumping up water to the upper reservoir to be used when there is a shortage of energy. It is assumed some of water can be added in to reservoir from rain and snow. The potential energy in the water stored in a reservoir is transformed into electrical energy by means of hydro turbines and generators.

When there is a shortage of energy, water flows from the upper reservoir to the lower reservoir and produces energy. This paper assumes 70 percent efficiency for the motor state and 80 percent efficiency for the generator state. The basic data of the project and the constrictions of the hydroelectric units are shown in Table 1.

TABLE I
MEAN VALUE OF WATER IN-FLOW

Number of hydro units		6
Maximum output capacity		62.5
Generator efficiency		0.8 p.u.
Motor efficiency		0.7 p.u.
Maximum water head (m)		180
Reservoir coefficients	a	0.00241
	b	0.111
	c	2
Maximum water volume (Mm^3)		100
Minimum water volume (Mm^3)		5
Initial water volume (Mm^3)		80
Maximum discharge rate (m^3/sec)		53
Minimum discharge rate (m^3/sec)		10.6
Maximum flow area (m^2)		1.1

D. *Energy limited hydroelectric unit model*

The power outputs from hydroelectric units are depending on the capacity and condition of the reservoir. The potential energy is stored in the water reservoirs and later on it is converted to the electric power by turbines. The water inflow to the upper reservoirs mainly comes from precipitation (which is largely dependent on weather conditions) and pumped from downer reservoir. Three model of weather conditions are shown in Table 1. In this paper the dry state is default and a year is divided into 13 equal parts each 672 hours with similar weather conditions. The water in-flow data in the three weather conditions are shown in Table 2.

TABLE II
MEAN VALUE OF WATER IN-FLOW

Period	Wet (Mm^3)	Dry(Mm^3)	Normal (Mm^3)
1	20.5	12.0	12.5
2	34.0	14.5	19.5
3	46.0	23.5	30.0
4	57.0	29.0	42.0
5	31.0	14.0	20.0
6	24.0	11.0	16.0
7	18.0	8.0	12.0
8	12.0	5.0	8.0
9	12.0	5.0	8.0
10	12.0	4.0	7.0
11	18.0	8.0	10.0
12	18.0	10.0	16.0
13	28.0	12.0	18.0

The hourly water in-flow (I_i, i=1, …, 8736) into the reservoir can be obtained using (12).

$$I_i = \frac{Z_j}{672} \quad (12)$$

The amount of water spilled from reservoir (S_i) and the amount of water existing in the reservoir (V_i) in the beginning of the i^{th} hour is calculated using (13) to (15).

$$V_{pi} = V_{i-1} - R_{i-1} + I_i \quad (13)$$

$$S_i = \begin{cases} 0 & , V_{pi} \le V_{\max} \\ V_{pi} - V_{\max} & , V_{pi} > V_{\max} \end{cases} \quad (14)$$

$$V_i = \begin{cases} V_{pi} & , V_{pi} \le V_{\max} \\ V_{\max} & , V_{pi} > V_{\max} \end{cases} \quad (15)$$

where, V_{pi} is volume of the reservoir at i^{th} hour before the spillage of extra water, V_{max} is the maximum reservoir volume, R_{i-1} is the water utilized to generate electricity during $(i-1)^{th}$ hour, S_i is the water spilled during i^{th} hour.

The net head H_i of the hydro plant at hour i is then calculated using the following approximate equation (16) when V_i is greater than the minimum reservoir volume (V_{min}):

$$V_i = c + bH_i - aH_i^2 \quad (16)$$

where a, b, and c are constant coefficients of the model. When the power output from WTG and conventional units are enough to answer the system load, the hydroelectric units are not in use. In these conditions the water is stored in the reservoirs. When the power output of the other units (conventional and WTG units) are not enough to meet the load, a right number of the hydroelectric units (K_r) join the circuit to meet the load. The power output of the hydroelectric unit (P_{hi}) is obtained using (17) and (18).

$$P_{hi} = g\beta H_i Qs / 10^6 \quad (17)$$

$$Q_t = G\sqrt{2gH_i} \quad (18)$$

where, g is gravitational constant (in m/sec^2), β is overall efficiency of the hydro plant, Q is turbine discharge rate (in m^3/sec), s is specific weight of water in (10^3 kg/m^3), G is opening area of the guide for each hydro turbine in (m^2). The water used at the I^{th} hour (R_i) is calculated using (19).

$$R_i = 3600 K_r Q \quad (19)$$

The basic data of the project and the constrictions of the hydroelectric units are shown in Table 1.

IV. SIMULATION AND RESULTS

In the reliability evaluation of power systems using the SMCS in the two-state Markov model, the system's generation considers the forces outage rate and it is fully probability.

In the MCS technique, first a value with the normal distribution is selected the within the span of [0, 1]. This value shows the state of the system for the fully functional state or FOR. In this state the value thus produced is compared with FOR value and in case the value is greater than to that of FOR value, the system is in the 'Up' state, and in case the selected value is smaller than or equal to that of FOR value, the system is in the 'Down' state. This process is repeated for all of the power generator units of the system, and after the state of the whole units has been determined, the production output of all units are summed up and total generation (C_c) is delivered to the comparison section for collation. In the comparison section the total production output of the system (C_c) is compared with the system load (L) and in case the total generation does not meet the load of the system, the unmet load is calculated and the counter adds one unit to the number of hours the load has not been met. This procedure is repeated until the reliability indices used are convergent enough. As mentioned before, this trend is quite random, and is of high importance for finding a reliable answer, and for attaining this convergence in the process of simulation. Fig. 4 shows the Monte Carlo convergence process of the LOEE index for the IEEE-RTS.

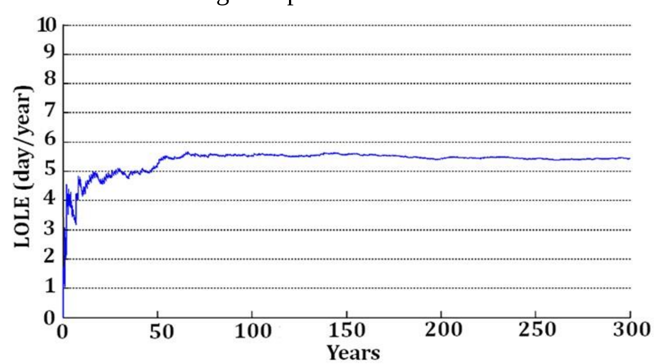

Fig. 4: convergence process of LOEE

Then, given the load growth rate of 5 percent per year, the LOLE index at each stage is calculated and compared with the reference index and wind power generation capacity and the storage needed is calculated. It has been assumed that in the fifth year, one of the conventional 400 MW generator unit and in the eighth year a conventional 350 MW generator unit will be excluded from the circuit and the power requirement will be supplied from the WTG and power storage facility. The hydraulic storage facilities store the excess wind energy at high winds and use it at low winds. Table 3 shows an example of the calculation of the wind power needed and the needed capacity of the hydraulic wind energy storage facility.

Figures 5 and 6 show the wind power needed and the storage facility, and the amount of load increments for each reduction of conventional power reductions during the eight-year simulation period.

TABLE III
CAPACITY OF WIND POWER AND HYDRODYNAMIC STORAGE FACILITIES REQUIRED IN THE LOLE CONSTANTS TERMS IN EIGHT YEARS

Year	Base load	Conventional generation	Wind power	Hydrodynamic storage capacity	LOLE
1	2850	3405	300	0	5.68
2	2993	3405	420	100	6.06
2	2993	3405	425	107	5.8
2	2993	3405	400	111	5.72
2	2993	3405	383	114	5.69
2	2993	3405	385	114	5.68
3	3143	3405	450	130	12.56
3	3143	3405	730	200	6.12
3	3143	3405	740	205	6.01
3	3143	3405	744	210	5.69
3	3143	3405	745	211	5.67
4	3300	3405	457	150	26.43
4	3300	3405	1107	300	7.47
4	3300	3405	1157	320	6.32
4	3300	3405	1162	327	5.78
4	3300	3405	1083	332	5.68
5	3465	3005	865	597	17.34
5	3465	3005	1400	690	7.42
5	3465	3005	1420	700	6.61
5	3465	3005	1445	735	5.85
5	3465	3005	1449	740	5.67
6	3638	3005	873	607	42.29
6	3638	3005	1523	757	13.74
6	3638	3005	1823	832	8.1
6	3638	3005	1873	852	7.03
6	3638	3005	1922	884	5.68
7	3820	3005	882	617	96.79
7	3820	3005	1532	767	34.5
7	3820	3005	2182	917	12.6
7	3820	3005	2532	1012	6.74
7	3820	3005	2547	1035	5.67
8	4011	2655	1241	987	139.94
8	4011	2655	1891	1137	53.77
8	4011	2655	2541	1287	19.18
8	4011	2655	3191	1437	6.11
8	4011	2655	3160	1446	5.68

V. CONCLUSION

This paper examined the wind power and the hydraulic storage facility needed for the gradual exclusion of the conventional power generation units and annual 5 percent load increments. The simulations and calculations were carried out on the basis of the LOLE index obtained in the first stage and the amount of the wind power generation and storage were calculated and assessed on the basis of the initial LOLE index. All of the operations mentioned above were tested and the values were extracted successfully in IEEE-RTS system.

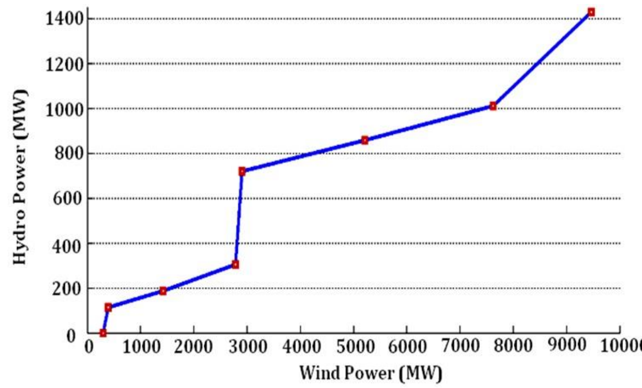

Fig. 5: required the wind power and hydrodynamic storage capacities in the LOLE constants terms

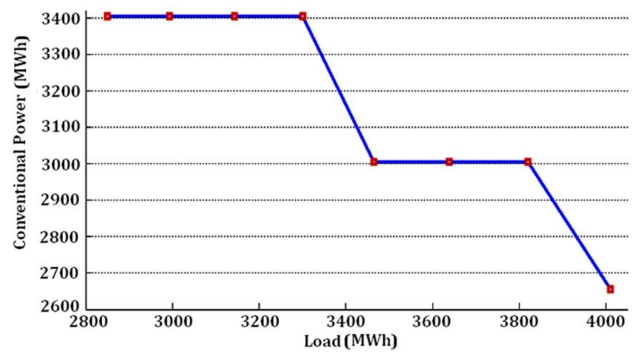

Fig. 6: process of the load growth and reduce of the conventional power in the next eight years

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