Reliability Considerations in the Utilization of Wind Energy, Solar Energy and Energy Storage in Electric Power Systems

Roy Billinton, *Fellow, IEEE*, and Bagen, *Student Member IEEE*

***Abstract*-- Wind and solar energy are being increasingly used in electric power supply due to environmental concerns and fuel cost escalation associated with conventional energy sources. Wind and sunlight are, however, variable energy sources and behave very differently from conventional energy sources. Energy storage systems are, therefore, often required to smooth the fluctuating nature of these energy conversion systems. This paper presents a method for capacity adequacy evaluation of a power system containing wind energy, solar energy and energy storage.**

***Index Terms*—Electric Power Systems, Energy Storage, Reliability Evaluation, Solar Energy, Wind Energy**

I. Introduction

WORLD-WIDE utilization of wind energy especially in large grid-connected applications has grown rapidly over the last two decades [1]. Solar energy projects have also shown steady growth in the last 15 years [1]. Many of these applications have been driven by the need for electric power from "cleaner energy sources". There is a large potential for wind and/or solar energy projects in grid-connected applications [2, 3]. The rapid growth of wind and solar energy applications and their immense potential for future use in electric power systems dictates the need to quantitatively evaluate the reliability benefits associated with unconventional energy sources.

The wind and sunlight are variable energy sources, and behave far differently than conventional sources. Energy storage systems are, therefore, often required to smooth the fluctuating nature of these energy conversion systems. The actual benefits obtained and the adequacy of power supply associated with such energy systems can be quantitatively assessed using reliability evaluation techniques. This paper employs a sequential Monte Carlo simulation approach to develop a comprehensive technique for generating capacity adequacy evaluation of power systems containing wind energy, solar energy and energy storage. The technique combines the development of the generation model and the chronological load model to determine the reliability indices. An auto-regressive moving average time series model is used to simulate the hourly wind speeds. The available wind power is obtained by applying the relationship between the power output of the wind turbine generators (WTG) and the wind speed. The solar radiation is simulated using a commercially available computer program. The energy storage time series is computed from the generation and load time series and included in the adequacy analysis.

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The proposed method is illustrated using a representative reliability test system containing conventional generating units, wind energy conversion systems (WECS), photovoltaic conversion systems (PVCS) and/or energy storage. The conventional generating unit ratings, reliability data and load model from the Roy Billinton Test System (RBTS) [4] are used. A wind farm is assumed to be composed of a number of identical WTG. A solar park is considered to be composed of a number of identical potovoltaics (PV) generating units composed of a number of panels. Key parameters that influence the reliability contribution, such as the site location, the system load level, the installed WTG and/or PV capacity and the energy storage capability have been considered and are illustrated in this paper. The system reliability is examined in terms of the loss of load expectation (LOLE) and the probability distributions associated with the LOLE index. Additional indices are presented in the initial studies.

II. Evaluation Methodology And Model Considerations

The primary concern in generating capacity adequacy evaluation is to assess the capability of the generation facilities to satisfy the total load demand. In a chronological Monte Carlo simulation approach, the capacity model is the available system capacity at points in time established sequentially, taking into account random unit failures [5].The load model is a chronological hourly load profile. The available system reserve at a point in time is the difference between the available capacity and the load. A negative margin denotes a load loss situation. The system reliability indices [5] can be obtained by observing the available system reserve profile over a sufficiently long period of time.

The basic reliability index calculated and used in this research is the LOLE. An estimate of the LOLE for a number of sample years (N) can be obtained using Equation (1):

$$LOLE = \frac{1}{N}\sum_{i=1}^{n} t_i \tag{1}$$

where t_i =loss of load duration in year i

N =total number of simulated years

The LOLE provides an overall indication of the ability of the generating system to satisfy the total system load. Additional indices [5, 6] such as the loss of energy expectation (LOEE), expected frequency of interruptions (ELOLF) and the expected duration of interruptions (ELOLD) can be obtained from the simulation process. One advantage of the Monte Carlo technique is its ability to provide information related to the probability distributions of the reliability indices in addition to their mean or average values. In order to illustrate the types of results that can be obtained using MCS and the benefits of additional information, reliability index distributions are also introduced and investigated in the studies described in this paper.

A. Modeling Wind Speed

The simulation of a WECS involves the computation of the hourly wind power generated by one or more WTG for a large number of sample years. The hourly power output of a WTG depends on the hourly wind speed at a specific location. Wind speed varies with time and site and at a specific hour is related to the wind speed of previous hours. In order to incorporate the variable nature of the wind, a time series model referred to as an auto-regressive and moving average (ARMA) model [7] was used to generate synthetic wind data on the basis of measured wind data at a specific site location.

Different site locations usually experience different wind regimes. The ARMA time series models representing different locations, therefore, are not the same. The wind speed models and data from three different sites located in the Province of Saskatchewan, Canada were used in the studies described in this paper. The three ARMA models developed by the Power System Research Group at the University of Saskatchewan are presented in [8].

B. Modeling WTG

After the hourly wind speed is generated, the available power output of a WTG can be determined using the function describing the relationship between the WTG power output and the wind speed. This function is often referred to as the "Power Curve" and is described by the operational parameters of the WTG. The main parameters are the cut-in wind speed (at which the WTG starts to generate power), the rated wind speed (at which the WTG generates its rated power) and the cut-out wind speed (at which the WTG is shut down for safety reasons). A VESTAS V29 225-50 turbine power curve [3] is used in the wind related analyses in this paper. The cut-in, rated and cut-out speeds are 3, 12 and 26 m/s respectively.

C. Simulation of a PV System

The output power from a PV generating unit is mainly determined by the amount of solar radiation at the particular site. Detailed irradiation data are not often available for many locations around the world especially for remote locations. In these cases, it is, therefore, necessary to generate synthetic solar radiation data for adequacy studies of a power system containing solar energy. A widely applied computer program known as WATGEN [9] was used to generate hourly global irradiation and ambient temperature data from monthly mean values at a given location. Atmospheric data from two different sites (Swift Current and Toronto) in Canada have been used in the PV related studies described in this paper. The average monthly weather data for these sites are presented in [10]. The hourly output of a PV unit was then calculated using the method adopted by the Watsun Simulation Laboratory [11]. The PV generating units are assumed to be composed of a number of identical panels. The total power generated by a solar generating unit is the sum of the power generated by all the PV panels in the unit.

D. Simulation of an Energy Storage System

If the system contains an energy storage system, the effect of the storage facility can be incorporated in the evaluation. The operating strategy of an energy storage element is that whenever the generation exceeds the load, the excess energy is stored and used whenever there is a generation shortage. The energy stored in the storage facility is calculated from the load time series and the total generation time series taking into consideration the charging and discharging characteristics of the storage facility [12].

III. System Studies

The relative benefits of adding different types of energy sources to the RBTS have been analyzed. The RBTS is expanded in different ways by adding equal capacity in the form of conventional units, PV and WTG. The total capacity added in each case is 22.5 MW (or 22.5 MW_p) and the annual peak load is 185 MW (unless specifically indicated). The added conventional capacity is in the form of 7.5 MW and 15 MW units with forced outage rate (FOR) of 0.01 and 0.02 respectively. The wind farm consists of identical VESTAS V29 225-50 turbines with FOR of 0.04. The additional PV generating units are composed of identical CANROM30 PV panels with FOR of 0.03. A comparison of the system reliability for different capacity addition cases is shown in Table 1.

TABLE 1
RELIABILITY INDICES FOR THE ORIGINAL RBTS AND DIFFERENT EXPANSIONS

Case	LOLE (h/year)	LOEE (MWh/year)	ELOLD (h/occ.)	ELOLF (occ./year)
Original	1.1470	10.6972	5.3110	0.2160
Toronto (PV added)	0.9748	9.9959	3.5353	0.2693
Swift Current (PV added)	0.9520	9.9641	3.4051	0.2863
North Battleford (WTG added)	0.9205	6.0729	3.7629	0.1996
Saskatoon (WTG added)	0.8742	5.6447	4.3680	0.2001
Regina (WTG added)	0.7512	4.6252	4.6417	0.2005
Conventional unit added	0.0982	0.8217	4.4961	0.0218

It can be seen from Table 1 that the adequacy of the RBTS is improved in each case, but not to the same degree.

Conventional generators are much superior to PV or WTG when comparing reliability benefits from a given capacity addition. Adequacy comparisons of the non-conventional energy sources show that the maximum improvement occurs by adding a wind farm (with Regina data) to the RBTS while the minimum improvement occurs by adding a solar park (with Toronto data) to the RBTS. The system reliability improvement with the Regina wind data is more significant than that for the other two wind farm locations, as Regina has a higher mean wind speed and, therefore, is a better wind resource. The reliability benefit obtained from the Swift Current solar park is higher than that from the Toronto solar park as the Swift Current site has a higher monthly average solar radiation level than the Toronto site.

The distributions of the loss of load duration (LOLD) created from 6000 replications for the original RBTS and the six different additions are shown in Appendix 1. The distributions are exponential in form and are quite similar to each other. All of the distributions are highly skewed with a very high probability of zero values. Loss of load durations higher than the averages are observed in all cases. The probabilities associated with these higher values are, however, quite small. Although the addition of different energy sources to the RBTS can reduce the average value of the LOLE, it has relatively little impact on the general shape of the distributions of the LOLD. Comparing the LOLD distribution of the original RBTS with those of the other cases, it can be concluded that the distributions of the LOLD are largely dominated by the original RBTS generation and load characteristics.

A noticeable difference in these distributions is the change in the probabilities of zero LOLD as shown in Table 2. It can be seen from Table 2 that the variation in the probabilities of zero LOLD are directly related to the LOLE values shown in Table 1. An implication of this is that the LOLE provides a relatively good indication of the reliability performance in these cases. The reliability benefits of adding conventional generating capacity are also illustrated in Tables 1 and 2.

TABLE 2
PROBABILITIES OF A ZERO VALUES IN THE LOLD DISTRIBUTIONS SHOWN IN FIGURE 3

Case	Probability of Zero LOLD
Original	0.862523
Toronto (PV added)	0.865356
Swift Current (PV added)	0.874021
North Battleford (WTG added)	0.875521
Saskatoon (WTG added)	0.884853
Regina (WTG added)	0.894184
Conventional unit added	0.984839

A. *Incremental Peak Load Carrying Capability*

The LOLE index of the RBTS incorporating WECS and PVCS of 22.5 MW and 22.5 MW_p respectively is plotted as a function of the annual peak load in Figure 1. The annual peak load was varied from 175 MW to 205 MW in 5 MW steps. It can be seen from Figure 1 that there are load carrying capability benefits from the WECS and PVCS additions. This benefit can be presented in terms of the incremental peak load carrying capability (IPLCC) [5]. Simulation results show that the LOLE for the original RBTS with an installed capacity of 240 MW and an annual peak load of 185 MW is approximately 1.1470 hours/year. Figure 1 shows that after 22.5 MW_p PVCS (Toronto data) is added to the RBTS, the combined system can carry a peak load of 186.66 MW at the LOLE of 1.1470 hour/year. The IPLCC in this case is, therefore, 1.66 MW. If 22.5 MW_p PVCS (Swift Current data) is added to the RBTS, the IPLCC increases to 2.09 MW. The IPLCC is approximately 2.52 MW, 2.98 MW and 4.35 MW respectively after the WECS with the North Battleford, Saskatoon and Regina wind regimes are added to the RBTS.

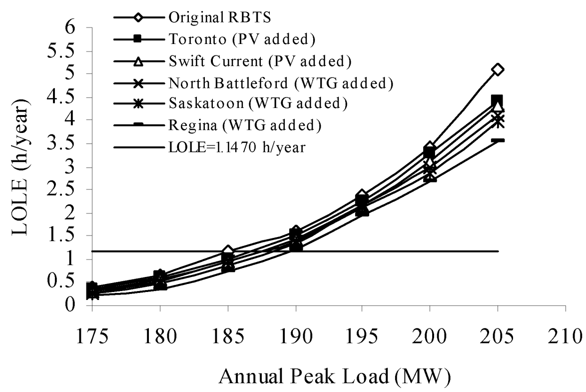


Fig. 1. LOLE versus annual peak load (RBTS)

The changes in the LOLD distributions with annual peak loads for the cases shown in Table 1 were compared. The results show that the system annual peak load has a significant impact on the LOLD distributions. The probability of zero LOLD decreases with increase in the annual peak load. The probabilities associated with longer LOLD increase with increase in the annual peak load. These probabilities become increasingly observable when the peak load exceeds a certain value, which in this case is 190 MW. The decrease in the probability of zero LOLD and the increase in the probability of longer LOLD result in reduced system adequacy and peak load carrying capability. This is in general agreement with the reliability appreciation obtained using the LOLE.

B. *Renewable Energy Penetration*

Studies have been carried out to investigate the effects on the system adequacy of the wind and solar energy penetration levels. The WTG or PV capacity added to the RBTS was changed and the combined system reliability analyzed using both the mean values and the distributions of the LOLE index.

Figure 2 shows the change in the LOLE as additional WTG or PV capacity is added to the RBTS. It can be seen from Figure 2 that there is a reliability benefit from both WECS and PVCS capacity. The changes in the LOLE are significant in the beginning and tend to saturate when more WTG are added while the decreases in the LOLE are relatively flat with the increases in PV capacity. It can also be seen in this figure that the same WECS produces different reliability contributions in wind farms with different wind regimes. The same PVCS also produces different reliability contributions in solar parks with different atmospheric conditions.

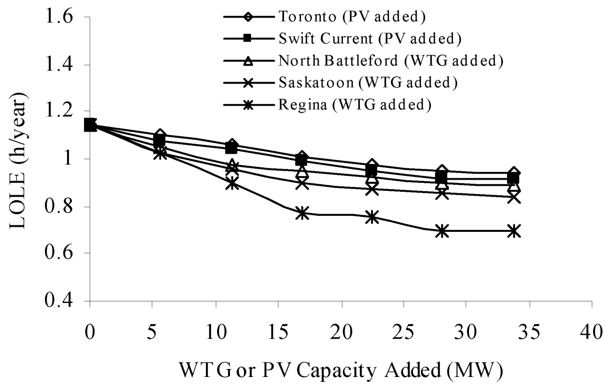


Fig. 2. LOLE versus wind or solar energy penetration (RBTS)

C. *Risk Based Equivalent Capacity Ratio*

Electric power from a WTG or a PV unit is intermittent and non-dispatchable as the outputs of these non-conventional generating units depend strongly on the site resource availability. Previous discussions show that a 1 MW WTG or a 1 MW_p PV cannot carry the same amount of load as a 1 MW conventional generating unit. This effect can be further examined by adding different units in the RBTS or replacing different units in the RBTS by the required number of WTG or PV units while maintaining a specific reliability criterion [13]. The system LOLE in the original RBTS is 1.1470 hours/year.

One of the 5 MW hydro units is removed from the RBTS and replaced by WTG or PV units. Figure 3 shows the variation in the LOLE as a function of the added WTG or PV capacity for different locations. The LOLE increases from 1.1470 hours/year to 1.6491 hours/year after the 5 MW hydro unit is removed. Figure 3 shows that the LOLE decreases with increasing WTG or PV capacity. The degree of decrease is, however, not the same when adding wind or solar capacity at different locations. The required WTG (or PV) capacities to replace a 5 MW hydro unit are also different for different energy sources and different site locations. When the Regina wind data is used, the LOLE is restored to 1.1470 hours/year if 42.16 MW of WTG is added. This indicates that 42.16 MW of WTG is able to replace a 5 MW conventional generating unit if the wind farm is assumed to be located at the Regina site. The equivalence between a conventional unit and a WTG (or PV) can be represented by the ratio of WTG (or PV) capacity to the conventional unit capacity. This ratio is referred to as the risk-based equivalent capacity ratio (RBECR) in this paper.

The LOLD distributions of the combined RBTS assuming that a 5 MW Hydro unit is removed were compared with the distribution for the original RBTS. The distributions were created by replacing the 5 MW conventional unit with the required WTG or PV capacities presented in Table 3. The results show that although the average value of the LOLE is essentially the same, the loss of load duration distributions are slightly different in each case. The LOLD distributions for each case are similar to those discussed previously and therefore similar conclusions can be drawn.

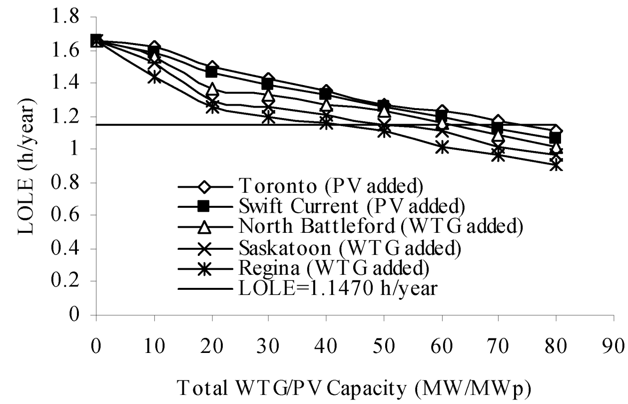


Fig. 3. LOLE versus total WTG or PV capacity assuming a 5 MW hydro unit is removed from the RBT

Table 3 shows the WTG or PV capacity required to maintain a LOLE of 1.1470 hours/year and the corresponding RBECR values.

TABLE 3
WTG OR PV UNIT CAPACITY RELATIVE TO A 5 MW CONVENTIONAL GENERATION UNIT

Cases	Capacity needed (MW or MW_p)	RBECR (WTG or PV Capacity/ 5)
Toronto (PV added)	73.33	14.67
Swift Current (PV added)	67.87	13.57
North Battleford (WTG added)	62.13	12.43
Saskatoon (WTG added)	51.11	10.22
Regina (WTG added)	42.16	8.43

D. *Site Resource Independence*

The previous analyses deal with the adequacy assessment of combined systems containing a single wind farm or solar park. This section investigates the adequacy of combined systems containing multiple independent wind farms or solar parks. Wind data from the Regina and Saskatoon sites and solar data from the Swift Current and Toronto sites are used in the following analyses. The RBTS was modified by adding two wind farms or solar parks or a wind farm and a solar park to compare the relative reliability benefits. The total capacity added in each case is 22.5 MW. The total capacity is shared equally at each site for the multiple site cases. A description of the different system configurations designated as A, B, C, D, E, F, G and H and the site data used in the simulations are presented in Table 4.

TABLE 4
COMBINED RBTS WITH DIFFERENT SYSTEM CONFIGURATIONS

Case	System Configuration	Site Data
A	Original system	N/A
B	Single solar park	Swift Current
C	Two solar parks different atmospheric conditions	Swift Current Toronto
D	Two solar parks same atmospheric condition	Swift Current
E	Two wind farms different wind regime	Regina Saskatoon
F	Single wind farm	Regina
G	A wind farm and a solar park	Regina Swift Current
H	Two wind farms same wind regime	Regina

Table 5 shows the basic adequacy indices for the eight different system configurations shown in Table 4. It can be seen from Table 5 that after adding a single wind farm with the Regina data (Case F), the LOLE decreases from 1.1470 hour/year (Case A) to 0.7512 hour/year. Table 5 also shows that if the WTG units are located at two independent sites (Case H) which have the same wind regime (Regina) as in Case F, the LOLE decreases to 0.6959 hour/year. The reliability benefits obtained from the two wind farm case, but with different wind regimes (Case E), is lower than those obtained from Cases G and H mainly due to the lower mean wind speed at the Saskatoon site. This example clearly illustrates the reliability benefits of wind energy independence. Similar conclusions can be drawn for the RBTS cases containing solar energy (Cases B, C and D). When a wind farm and a solar park using data from the Regina and Swift Current sites respectively are added to the RBTS (Case G), the LOLE decreases from 1.1470 hour/year (Case A) to 0.7355 hour/year. The LOLD distributions for each case shown in Table 4 are quite similar to those discussed previously and therefore similar conclusions can be drawn.

TABLE 5
RELIABILITY INDICES FOR THE RBTS BEFOR AND AFTER 22.5 MW WTG OR PV UNITS (SINGLE AND MULTIPLE CASE COMPARISION)

Case	LOLE (h/year)	LOEE (MWh/year)	ELOLD (h/occ.)	ELOLF (occ./year)
A	1.1470	10.6972	5.3110	0.2160
B	0.9520	9.9641	3.4051	0.2863
C	0.9282	9.5182	3.4151	0.2718
D	0.9220	9.0559	3.3945	0.2716
E	0.7802	4.8235	4.0927	0.1906
F	0.7512	4.6252	4.6417	0.2005
G	0.7355	4.5361	2.8151	0.2613
H	0.6959	4.2620	3.3328	0.2088

Wind and solar energy independence can make a positive reliability contribution to a power system utilizing non-conventional energy sources. It is quite possible that there is no wind or sunlight at a specific time at a given site. All of the WTG or PV units at the specific location make no contribution to the system under these circumstances. If the units are located at two different independent sites, the probability of there being no wind or sunlight simultaneously at both sites is much less and therefore, the probability of no WTG or PV power is decreased substantially. Distributing WTG or PV at independent sites is of considerable benefit in improving the reliability of a power system utilizing wind and/or solar energy.

E. Energy Storage

Energy storage facilities have a significant positive impact on the reliability of small isolated power systems [8, 10, 12]. The reliability of such systems can be greatly enhanced by the provision of energy storage facilities. It is also financially viable to use energy storage in small off-grid applications. Large scale on-grid applications of wind and/or solar energy may not include storage facilities due to economic considerations. It is, however, of interest to investigate the possible impacts of energy storage in on-grid systems that utilize significant amount of wind and/or solar energy. Figure 4 presents the LOLE in hours/year for the cases shown in Table 1 as a function of the energy storage capability. It is assumed in this analysis that there are no restrictions on the energy storage charging and discharging capability.

It can be seen from this figure that the LOLE decreases with the addition of more storage capacity. Figure 4 indicates that significant reliability benefits can be obtained by utilizing energy storage in on-grid applications. These benefits will, however, have to be evaluated by incorporating the costs and practicality of creating the required storage facilities. The reliability benefit degrades considerably when restrictions are placed on the maximum charging and discharging rate of the energy storage facility.

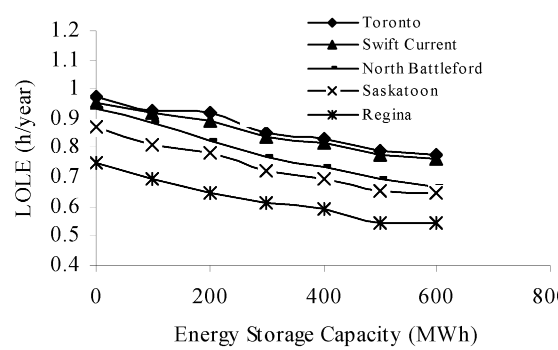


Fig. 4. LOLE versus energy storage capacity

IV. SUMMARY AND CONCLUSIONS

A simulation methodology for the generating capacity adequacy evaluation of power systems containing wind energy, solar energy and energy storage is presented. The system adequacy is investigated using the mean values and the distributions of the LOLE indices. The results obtained using the RBTS show that the contributions of a WECS or PVCS to the reliability performance of generation system are highly dependent on the site resource conditions. WECS or PVCS can make a significant reliability contribution at a site with high wind speed or solar radiation levels. The WTG capacity or PV capacity required to maintain a given reliability criterion will, however, be considerably higher than that normally associated with a conventional generating unit. Site resource independence and energy storage also has positive impacts on the reliability performance of power systems containing WECS and PVCS. The LOLD distributions associated with the RBTS are largely dominated by the load/capacity characteristics of the original system. The sensitivities of the LOLD distributions to changes in the selected parameters are more noticeable when comparing the changes in the probability of zero LOLD values. The LOLD distributions provide additional insight into the adequacy of a generating system and complement the information provided by the basic LOLE index.

V. References

[1]. A. Filion, "Renewable energy options-overview and trend", Proceedings of the 28th Annual National Conference of the Solar Energy Society of Canada, Kingston, August 2003.

[2]. RETScreen International Renewable Energy Decision Support Centre Website: www.retscreen.net

[3]. Danish Wind Energy Association Website: www.windpower.org

[4]. R. Billinton, S. Kumar, N. Chowdhury, K. Chu, K. Debnath, L. Goel, E. Khan, P. Kos, G. Nourbakhsh and J. Oteng-Adjei, "A reliability test system for educational purposes-basic data", *EEE Transactions on Power Systems*, Vol. 4, No.3, 1989, pp.1238-1244.

[5]. R. Billinton and R. Allan, *Reliability evaluation of power systems*, 2nd Edition, Plenum Press, New York, 1996.

[6]. R. Billinton and W. Y. Li, *Reliability assessment of electrical power systems using Monte Carlo method,* Plenum Press, New York, 1994.

[7]. R. Billinton, H. Chen and R. Ghajar, "Time-series models for reliability evaluation of power systems including wind energy", *Microelectron. Reliability*, Vol. 36, No. 9, 1996, pp. 1253-1261.

[8]. R. Billinton and Bagen, "A sequential simulation method for the generating capacity adequacy evaluation of small stand-alone wind energy conversion systems", IEEE CCECE02 Proceedings, ISBN: 0-7803-75149-9, Vol. 1, 2002, pp.72-77.

[9]. Watsun Simulation Laboratory, WATGEN User's Manual, University of Waterloo, 1.0-August. 1992.

[10]. Bagen, R. Billinton and R. Karki, "Reliability evaluation of isolated solar-diesel power systems using a time series simulation model", Proceedings of the 28th Annual National Conference of the Solar Energy.

[11]. Watsun Simulation Laboratory, *Watsun-PV 5.1 user's manual and program documentation*. University of Waterloo, 1995.

[12]. R. Billinton, Bagen and Yu Cui, "Reliability Evaluation of small stand-alone wind energy conversion systems using a time series simulation model", IEE Proceedings-Generation, Transmission and Distribution, Vol. 150, 2003, pp.96-100.

[13]. R. Billinton and G. Bai, "Generating capacity adequacy associated with wind energy" *IEEE Transactions on Energy Conversion*, Vol. 19, No. 3, September 2004, pp.641-646.

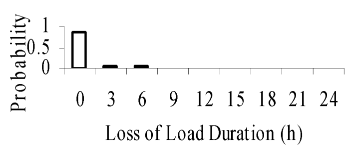
VI. Biographies

Roy Billinton received the B.Sc. and M.S.c. degree from the University of Manitoba and the Ph.D. and D.S.c degree from the University of Saskatchewan. Worked for Manitoba Hydro in the System Planning and Production Divisions. Joined the University of Saskatchewan in 1964. Formerly Head of the Electrical Engineering Department, Associate Dean of Graduate Studies, Research and Extension and Acting Dean of the College of Engineering. Author of papers on Power Systems Analysis, Stability, Economic System Operation and Reliability. Fellow of IEEE, the EIC and the Royal Society of Canada and a P.Eng. in the Province of Saskatchewan.

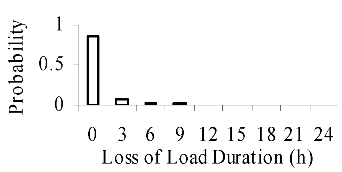
Bagen was born in Inner Mongolia, P. R. China. He received a B.Sc. degree from Inner Mongolia University for Nationalities in 1989 and the M.S.c. and Ph.D. degrees from the University of Saskatchewan respectively in 2001 and 2005. Worked as an electrical engineer for the Inner Mongolia Electric Power Group and as a lecturer for the Inner Mongolia Electric Power College from 1994 to 2000. Currently he is working for Manitoba Hydro in the System Planning Department.

VII. Appendix 1

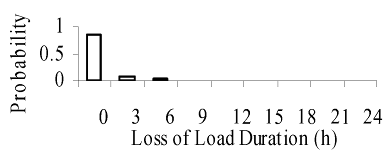
Distributions of the loss of load duration for different RBTS cases shown in Table 1



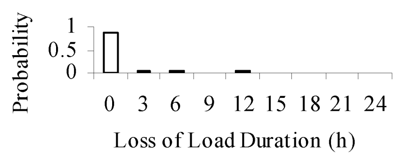
(a) Original system



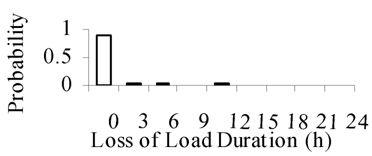
(b) RBTS containing PV, Toronto data



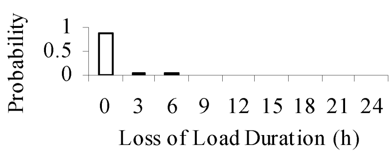
(c) RBTS containing PV, Swift Current data



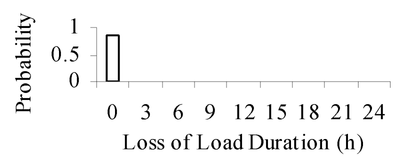
(d) RBTS containing WTG, North Battleford data



(e) RBTS containing WTG, Saskatoon data



(f) RBTS containing WTG, Regina data



(g) RBTS with the addition of conventional units