International Journal of Electrical and Power Engineering 1 (1): 28-35, 2007

Improving the Reliability of a Weak Power System by Introducing Wind Power Generation

[1]Zulati Litifu, [2]Noel Estoperez and Ken Nagasaka, [3]Yasuyuki Nemoto and [3]Izumi Ushiyama
[1]Department of Xinjiang, Synthetic Research Centre of Ashikaga Institute of Technology, 268-1 Omae-Cho, Ashikaga City, Tochigi, Japan Statistics and Information Institute of Finance and Economics No. 15 North Beijing Road, Urumqi, Xinjiang, China
[2]Electrical and Electronics Department of Tokyo University of Agriculture and Technology, 2-24-16, Nakamachi, Koganei-shi, Tokyo, Japan
[3]Mechanical Engineering Department of Ashikaga Institute of Technology, 268-1 Omae-Cho, Ashikaga City, Tochigi, Japan

Abstract: Granted by research project of Japan Society for the Promotion of Science (JSPS), this research provides planning of installing Wind Power Turbine (WPT) in an existing Local Weak Power System (LWPS). Wind power generation is expected to be used as a power reserve to improve the reliability degree and reduce line loss of LWPS, that suffers from critical load in each summer. Installation buses are selected based on the existing reliability degree derived from system condition in energy service and load demand, two reliability indices namely Weakness Degree in Energy Supply (WDES) that represents bus energy supply ability in a short critical time and Reliability Index in Energy Supply (RIES) that represents bus average energy supply ability during annual time are applied. Appropriate type of WPT is selected according to Percentage Rate of Availability Index (PRAI) and Percentage Rate of Utilization Index (PRUI) derived from Monthly Average Wind Speed (MAWS) through the target region. Operational reliability and stability are analyzed based on formed system characteristics after introducing WPT.

Key words: Local system, load condition, reliability indices, stability and reliability verification

INTRODUCTION

In this study LWPS loads the M.L caused from agricultural activities in summer, WPT is under planning to be introduced on the buses near or directly connected to agricultural load, on the other word, buses with the M.L and low level in reliability are expected to install WPT, this study requests WPT to function as a power reserve to improve the power system reliability. Anyway, in technological convention WPT is usually connected to buses keeping high level in reliability in order to reduce possible influence in stability caused from operation of WPT. To install WPT on buses with low reliability level, such buses should be classified into rank. In this study two system indices of WDES and RIES are taken as main references to denote reliability situation of each bus in both short critical time and long average time.

In deriving WDES, available power supply is considered according to LWPS operational schedule and the load particularity in agricultural season. For the M.L, the happened percentage and continued time are investigated, general time of the M.L is a statistically period obtained from each fraction time in operation. RIES is obtained from average energy supply and constant of yearly average load increment on the each load bus. The buses that simultaneously shows high WDES and low RIES are regarded as the candidates for connecting WPT so as to improve their reliability quality in future operation.

WPT capacity is determined from the range of PRVI and PRUI based on local MAWS. System efficiency of stability and reliability is also verified after new hybrid system is constructed with WPT.

Approach on reliability of LWPS: Figure and Table 1 shows the characteristic of LWPS[1], the main system load comes from agriculture activities, local industry and livestock processing industry. Entire region is consisted by living, industrial and agricultural districts, region suburbs are covered by extending grassland.

Corresponding Author: Zulati Litifu, Synthetic Research Centre of Ashikaga Institute of Technology, 268-1 Omae-Cho, Ashikaga City, Tochigi, Japan Statistics and Information Department of Xinjiang Institute of Finance and Economics No. 15 North Beijing Road, Urumqi, Xinjiang, China

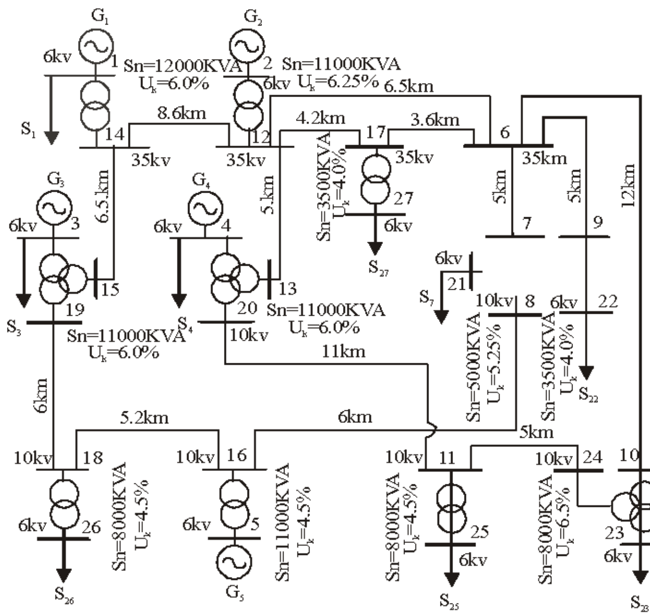

Fig. 1: Diagram of interconnection of target LWPS under planning to introduce WPT

Table 1: Characteristic of system generators and type of power plant in LWPS

Gen. No.	Rat. Cap. [KW]	x"	cosϕ	Type of plant
G1	2×3000+2000	0.20	0.85	Ther. Plant
G2	2×3600	0.25	0.85	Ther. Plant
G3	2×2500+2000	0.20	0.85	Ther. Plant
G4	3×2500	0.20	0.80	Ther. Plant
G5	2×3500	0.25	0.80	Ther. Plant

Bus12, 14, 19, 20 and 25 bus are output terminals of power plant, other loads are connected to local transformer substations and system is with the voltage of 6.5, 10 and 35kV, the power network is almost established on the plain terrain.

Analysis on the WDES of LWPS: WDES is defined as a criterion to weight the remain of system service when the M.L is demanded. Here, the system service indicates the available power including system reserve generation corresponding with system dispatching plan and the M.L results from the experienced maximum demand of system load. WDES reflects operational margin of system service for a critical load, based on such idea WDES can be mathematically expressed by Eq. 1:

$$WDES = 1 - \frac{\left[\sum_{i=1}^{n} W_{G\,i} - \left(\sum_{r=1}^{s} \Delta W_{lr} + \sum_{j=1}^{m} W_{ML\,j}\right)\right]}{\sum_{j=1}^{m} W_{ML\,j}} \quad (1)$$

where, n, m and f are respectively the number of generator buses, load buses and transmission lines. $W_{G\,i}$ is regular and potential energy supplied from generator i and $W_{ML\,j}$ is system load demand on bus j, $\Delta W_{1\,r}$ is energy loss on line r. For a system, WDES relates to cumulated $W_{G\,i}$, W_{MLj} and $\Delta W_{1\,r}$ in same period of time T_a. Define T_a as a sum of fraction period of time during which the M.L (or critical load) is existing, then it can be expressed by a series of operational time sections of $a_1+a_2+\ldots a_r\ldots+a_{r-1}+a_s$, then W_G and $W_{ML\,j}$ may be statistically obtained from Eq. 2 and 3:

$$W_{Gi} = \int_0^{T_a} P_{Gi}(t)dt = \frac{1}{S}\sum_{r=1}^{s} \int_0^{a_r} P_{Gi.1}(t)dt \quad (2)$$

$$W_{ML\,j} = \int_0^{T_a} P_{ML\,j}(t)dt = \frac{1}{S}\sum_{r=1}^{s} \int_0^{a} P_{ML\,j1}(t)dt \quad (3)$$

where, s is occurred times of the M.L. Eq. 1 may be applied for any power system like being mentioned in Fig. 1. But for single bus the definition of WDPS should be expanded and enable bus to have system function. First, since the elements in Eq. 1 is experienced operation data under system constrains, the voltage and frequency of each bus is therefore regarded within limited stability margin when the M.L is demanded. Supposing $W_{G\,i}$ and $W_{ML\,j}$ are also cumulative value during time T_a and take $\Delta W_{lr} = 0$, then each bus can be converted to a isolated system with the M.L. Fig. 2a and b show the equivalent models of PV and PQ buses, the equivalent generator represents potential reserve and regular service for a target bus and the M.L may be obtained from the bus operational schedule. Take W_{GI} as Available Power

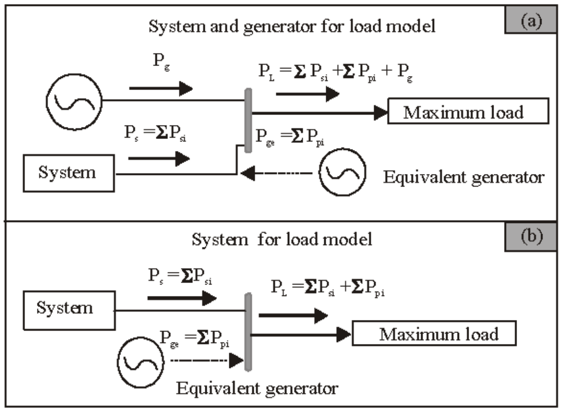

Fig. 2: Basic concept of equivalent models of system for estimating WDES of each bus

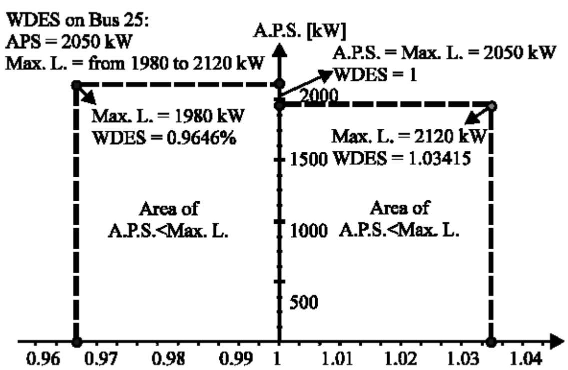

Fig. 3: The changing track of WDES on bus25 under APS = 2050 kW and the M.L = 1980 kW~2120kW

Supply (APS) with reserve and regular serving function and W_{ML_j} is statistic sum of the M.L during T_a, then based on the such definition, WDES on each bus is not beyond system margin and cab be expressed by Eq. 1, 2 and 3.

In application, the performance of the M.L during a defined time is hence no long important, Average Happened Possibility (AHP with average of 31.98% in this research) and Continued Time in One time T_a (CTO with average of 12.66 h in this research) are taken as main target under different state of equivalent model. Fig. 3 denotes the track of WDES on bus25 under APS=2050kW in case of application.

In Fig. 3, WDES<1 means APS (including power reserve) on target bus matching for the M.L, WDES =1 shows the bus under limit critical and WDES>1 indicates the range of APS can not feed the M.L. In this research, the case of DWES<1 is to be regarded based on the existing operation schedule. Table 2 indicates the annual average load and the M.L on each load buses. Since S_1, S_2 and S_4 are industrial load without serious variation and they are supported by adjustable PV buses, the WDES of such buses are not considered here. Load type in Table 2 covers Industry and Processing (Indu and Pro), Industry and Living (Indu and Liv), Agriculture and Living (Agri and Liv) and Complex Load (Com.Loa.). It is obviously that agriculture loads have bigger increment relating to their average load.

Table 2: Characteristic of system generators and type of power plant in existing power system

	Annual average load		Maximum load		
Load No.	P[KW]	Q[KVA]	P[KW]	Q{KVA}	Load type
S1	4420	2750	5800	3850	Irdu. and Pro.
S3	3580	2200	4600	3150	Irdu. and Pro.
S4	4300	2500	5500	3690	Irdu. and Pro.
S21	2600	1650	3435	2085	Com. Lao.
S22	1200	750	1650	1050	Agri. and Liv.
S23	1200	750	1585	950	Agri. and Liv.
S25	1500	920	1980	1200	Agri. and Liv.
S26	3800	2350	5520	3050	Agri. and Liv.
S27	3850	2385	6250	3800	Com. Lao.

Table 3: Simulated result of WDES on load buses

Bus No.	A.P.S.[KW]	C.T.O.[h]	A.H.P.[%]	H.D.M.	WDES[%]
Bus 21	3650	8	16.68	9.10,11	0.93741
Bus 22	1750	8	16.68	9,10,11	0.93939
Bus 23	1650	16	35.00	6,7,8	0.95899
Bus 25	2050	16	50.00	6,7,8	0.96425
Bus 26	5800	16	48.00	6,7,8	0.94928
Bus 27	6950	12	25.50	9,10,11	0.88800

Table 3 shows the simulation result of WDES based on the characteristics of system load and operational schedule, this table shows agriculture buses have relative high WDES in the duration of time that is named by Happened During the Month (HDM). The coloured buses indicate the relative high WDES and those buses may be regarded as the possible candidates to install WPT.

Analysis on the RIES of LWPS: RIES is defined as a criterion to express the average possibility of power supply for an average load on the target bus (the buses without generator). On the other word, RIES represents the increment particularity of the average load and average ability of system service on each bus during an expected time. Here, supplied average power and demanded average load are derived from operation record corresponding with the same period of operational time. In according to above definition, RIES can be mathematically expressed by Eq. 4:

$$\mathrm{RIES} = 1 - \left[(1+k)\frac{1}{Z}\sum_{i=1}^{z} P_{Li}\,\Delta T_i\right] \Big/ \left(\frac{1}{Z}\sum_{i=1}^{z} P_{Gi}\,\Delta T_i\right) \qquad (4)$$

where, $\Delta T_i$is one of the time fractions to make the load being an average amount in interval i and here, the supplied power and demanded load have statistical average particularity. Here, z is number of time fractions, the summing up length of time fractions is determined by the number of periods during which the general system load has obvious increment. In application, the line power loss that equals to 6 to 8% (depends on the range of power flow through the line) of total generation P_G is averagely added to the load on each bus, then the total load on a bus can be expressed by Eq. 5.

$$P_{Li} = \sum_{i}^{n} p_i + \frac{1}{m}(0.06 \sim 0.08)P_G \quad (5)$$

In order to obtain the RIES, the generation characteristics of entire system is also need to be determined. As mentioned in previous section, LWPS has relative bigger load in each summer comparing with other seasons, the RIES in summer is hence taken as the verification target. It is expected to use hydro power as much as possible so as to save the cost for fuel, the thermal power is therefore taken as compensation of the hydro power. Due to maintenance in the period of slack load time, the generation from thermal power plants may averagely reach 85% of total capacity in summer and it is averagely allowed to reach 0.95% for a peak load, the possible operation time under such situation is decided by mechanical condition of each generator. Based on operation performance, system monthly generation and load is shown in Table 3.

The equipment capacity of total system hydro generator is about 14500 kW, the available hydro generation tightly depends on the water discharge obtained from river flow. To simplify the analysis, here all hydro power generators are equalized to one hydro system, then the total generation and water discharge can be indicated by Eq.[2] 6:

$$\begin{cases} Q_{re} = V_{av} S_{av} (1 - k_{ef}) \\ P_{re} = \gamma \eta Q_{re} H = \gamma Q H \eta_r \eta_m \eta_k \end{cases} \quad (6)$$

where, V_{av} and S_{av} stand for the average flow speed and average section at the terminal of water pipe. For this hydro system, main references are: Power Efficiency $\eta = \eta_v \eta_h \eta_m$ (efficiency of Volume 85%, Hydro 82% and Mechanical 90%) = 62.80% and the Average Water Head is H = 38.5 m. The water discharge changes along with the season of year, Fig. 4. shows the characteristic of water discharge from equalized water flow, the full water discharge is about 60.2 m^3/s that is statistic sum from five generators in two hydro plants and the lowest water discharge is 37.21 m^3/s with the yearly average water discharge around 50.17 m^3/s. Since the river flow contains relative high density of red sands, turbine blades are often worn and replaced within about 45 days to 60 days, therefore generators are maintained in shift even in full discharge period and it is difficult to have the working efficiency over 80% of equipment capacity even under the M.L condition.

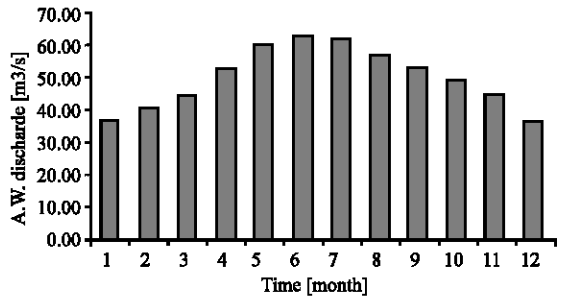

Fig. 4: Estimation of monthly average variation of water discharge from equalized water flow

Table 4: Monthly average generation from hydro (H. Power) and thermal power (T. Power) and general load (G. Load) containing 6~8% of line loss

Month order	January	February	March	April
H. Power [KW]	7155	7225	7325	10115
T. Power [KW]	16745	17185	17075	16350
G. Load [KW]	22415	23025	22985	24995
Month order	January	February	March	April
H. Power [KW]	11585	11625	11595	10655
T. Power [KW]	16085	18870	19675	20085
G. Load [KW]	36132	28750	39150	29050
Month order	January	February	March	April
H. Power [KW]	10875	10150	9525	7250
T. Power [KW]	19715	19435	19550	7255
G. Load [KW]	28350	28150	22515	22500

Table 5: Average increment constant k and RIES of each load bus with 6~8% of line loss

Bus No.	Bus 21	Bus 22	Bus 23
Ave. Inc. Per. K	3.82%	4.15%	4.58%
RIES	0.90012	0.89972	0.89932
Bus No.	Bus 25	Bus 26	Bus 27
Ave. Inc. Per. K	4.61%	5.5%	1.23%
RIES	0.89930	0.89844	0.90255

In Table 4, hydro power plants contribute the average output around 76.68% of the equipment capacity from May to October, actually some times of this period the agricultural load reaches to the maximum demand, even if hydro and thermal plants have not reached the rated equipment capacity, limited by water and operation situation the entire system is operating under critical condition almost without power reserve, any unexpected generator problem may cause the system losing the load[3].

Table 5 gives the derived RIES result of each load bus. Since system shows no load increment in the months around winter, RIES only takes summer period from May to October as the expected time. *Average Increment*

Percentage k (Ave. Inc. Per. *k*) indicates constant of load increment under system available power supply for target bus, other data for computation also relates to summer period.

Now, the reliability situation of target buses may be identified by the list proposed in Table 3 and Table 5, that shows Bus23, 25 and 26 have high WDES and low RIES that need to be improved. In tables, Bus25 shows higher WDES and RIES than Bus26, since this research takes WDES as the most serious reference in bus selection, Bus25 is therefore the first candidate to be considered for installing WPT.

Approach on installation of WPT: The original MAWS in Table 6 is the data obtained from 10 m high wind speed meter, considering the plain land and extended prairie in target region, the wind condition is regarded as having averagely distributed characteristic in horizontal (within level land boundary) and vertical (below 60 m) directions, MAWS at a height of 10m is therefore can be directly converted to MAWS at a height of 38 m[4], that is an average height of middle sized WPT to be considered in this study, by using Eq. 7:

$$V_r = (h_r/h_b)^{\frac{1}{n}} V_b \qquad (7)$$

where, V_r and V_b are respectively indicate basic MAWS and converted MAWS at height h_r and h_b, value of constant n is 5-8 for plain land and grassland, here middle value 6.5 is applied. Table 6 also gives the converted MAWS at an average height of middle sized WPT of 38 m, this result can be re-derived based on the height of selected WPT:

It is necessary to indicate that the MAWS in Table 6 belongs to good level and also well matches for the large sized WPT over 1000kW, however, the load increment is not centralized on one bus but distributed on several buses far from each other, large sized WPT may cause power loss in tracking load. On the other hand, middle sized WPT causes small electric fluctuation in start and operation, this point is extremely essential for a weak power system such as LWPS in this study. Here, 200 KW (31.5 m), 350 KW(35.5 m) and 500 KW (42.5 m) are taken as candidates, the final selection should be determined by availability and utilization indices of each candidate WPT, the characteristics of wind condition is therefore concerned. We know the probability distribution of a defined wind speed V is usually expressed by Weibull Eq. 8[5]:

$$f(V) = \frac{k}{c}\left(\frac{V^{k-1}}{c}\right)\exp\left[-\left(\frac{V}{c}\right)\right]^k \qquad (8)$$

Table 6: Monthly MAWS of 10 m and the converted monthly MAWS at the height of 38. [m/s]

Height	January	February	March	April	May	June
10 m	6.90	5.70	7.10	6.40	6.20	5.50
38 m	7.50	6.20	7.70	7.00	6.70	6.00
Height	July	August	Sept.	October	Nove.	Dece.
10 m	5.20	5.50	5.70	6.30	7.20	6.60
38 m	5.60	6.00	6.20	6.90	7.80	7.20

where, c is scale parameter and k is shape parameter. Based on Eq. 8, the cumulative distribution of wind speed V can be solved by Eq. 9:

$$F(V) = \int_0^{\infty}\frac{k}{c}\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)^k\right]dv = 1-\exp\left[-\left(\frac{V}{c}\right)^k\right] \qquad (9)$$

From Eq. 8 and 9, the scale parameter and shape parameter are respectively determined as c = 2.85 and k = 2.0. Consequently, the operational efficiency namely the Percentage Rate of Availability Index (PRAI), that indicates available working probability under the valid wind speed under which WPT operates with power system, can be obtained from Eq. 10:

$$PRAI(\%) = V_{AFR\,in}(\%) - V_{AFR\,out}(\%) \qquad (10)$$

where, *PRAI* is between the $V_{AFR\,in}$ (cumulative rate over cut-in wind speed) and $V_{AFR\,out}$ (cumulative rate over cut-out wind speed). Similarly, the available power generation from a WPT during an expected time (usually indicates one year or one month) may be determined by Eq. 11:

$$W_{WPT} = \sum_{i=1}^{n}[P_i(V_i)\times f_i(V_i)\times 8760] \qquad (11)$$

where, n is annually number of valid fractions of operation time, P_i is output power that may obtained from the Curve of Output and Wind Speed of WPT under wind speed V_i and f_i denotes the probability distribution of wind speed V_i decided by Eq. 8. Hence, the Percentage Rate of Utilization Index (PRUI) may be easily obtained from Eq. 12:

$$PRUI(\%) = [W_{WPT}/(P_n\times n)]\times 100 \qquad (12)$$

Based on the wind speed data with one meter interval and Eq. 9 and 10, the *PRAI* of 200KW, 300KW and 500KW WPT are shown in Fig. 5.

Based on the Eq. 11, the monthly power generation from the each WPT is derived from hourly local wind

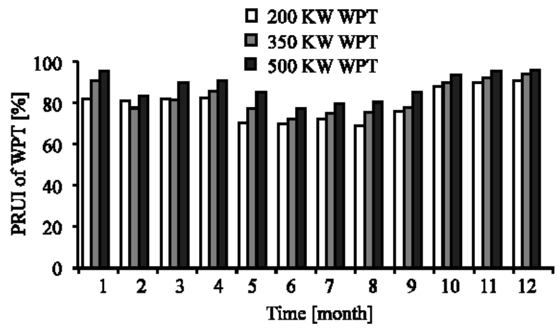

Fig. 5: Simulated result of monthly *PRAI* from three candidate WPT and AWS

Table 7: Available power generation from three types of WPT based on local wind condition

Month	200 kW WPT	300 kW WPT	500 kW WPT
1	62931	99246	171965
2	39349	66028	111227
3	62012	97290	170832
4	50636	82979	141098
5	46132	74037	131622
6	39244	64283	110936
7	35575	60409	101025
8	27252	49735	81978
9	35929	64141	105597
10	58587	92298	159117
11	70471	108201	191797
12	60382	98174	168640

speed, it is a sum of average generation from available operating h. Mechanical characteristic of WPT and natural physic particularity of air are also considered. Table 7 shows available monthly power generation from three WPT candidates:

Figure 6 denotes the simulated result of monthly *PRUI* based on the Table 7 and Eq. 12, in this figure 500 kW WPT shows high possibility in producing more PRUI than WPT of 200kW and 350kW WPT. In application, the annual average value of PRUI and PRAI are also need to be considered except for the monthly average indices.

Table 8 shows the annual value of PRUI and PRAI derived from the monthly indices. With the synthetically comparing by Fig. 5, Fig. 6 and Table 8, the 500 kW WPT is finally selected for installation and it is necessary to indicate that 500kW WPT is also efficient in economy due to its larger capacity.

Efficiency after installing WPT: After installation of WPT, a hybrid power system is constructed based on the original system shown in Fig. 1. Figure 7 shows the structure and interconnection of formed hybrid LWPS that is to be used for the verification of system stability (the characteristics of each reactance and resistance are omitted here), R.I.C indicates the Rectifier and Inverter Controller. As first stage, two 500kW WPT are installed on the Bus26 and Bus25.

Table 8: Annual average value of *PRUI* and *PRAI* based on monthly indices for three WPT candidates

Target indices	200 kW WPT	300 kW WPT	500 kW WPT
Annual *PRUI* (%)	34.06	36.90	38.10
Annual *PRAI* (%)	79.67	82.67	88.00

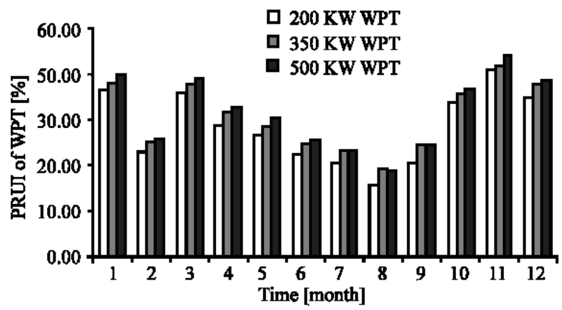

Fig. 6: Simulated result of monthly *PRUI* from three WPT candidates based on local wind condition

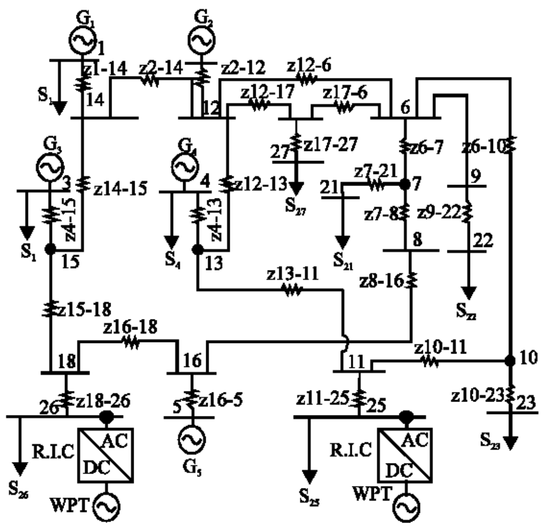

Fig. 7: Structure and interconnection of the hybrid LWPS after installing 2×500 kW WPT

Stability verification: In the view of stability, the verification should cover the both states of normal operation and transient dynamic process of power system, this study only deals with the verification of normal operation, the verification about system dynamic performance including capacity compensation and relay protect system will be done as the special project in the next research based on the simulation method denoted by Litifu[6]. Fluctuation of voltage and frequency is taken as main verification target in normal operation so as to know if each bus works within or beyond allowed electric margin, the LWPS in Fig. 7 is used for the simulation. Table 9 indicates the related parameters of selected 500 kW WPT:

Table 9: Related parameters of 500kW WPT for simulation of LWPS stability

Reted capacity	Reted voltage	Reted velocity	Reted frequency	Reted factor
500 KW	600 KV	1518 r min^{-1}	50 Hz	0.9
loss in stator	loss in rotator	loss in excitement	Resistance on stator	Efficiency
3.908 KW	5.522 KW	2.732 KW	0.01656Ω	95%

Table 10: Power flow (P.F.) reduction, voltage and frequency on each PQ bus after installing WPT. [p.u]

Case 1: P (WPT) = 500 KW under AWS over 12.5 m/s		
P.F. Reduction (bus to bus)	4.68% (B.10-B.11).	1.89% (B.13-B.11)
Bus voltage	0.9537 (bus22 in Min.)≤ V ≤ 0.9992 (bus12 in Max.)	
Bus frequency	49.9762 (bus14 in Min.) ≤ f ≤ 49.9885 (bus12 in Max.)	
Case 2: P (WPT) = 132 KW under AWS over 6.73 m/s		
P.F. Reduction (bus to bus)	12.50% (B.10-B.11).	1.89% (B.13-B.11)
Bus voltage	0.9531 (bus22 in Min.)≤ V ≤ 0.9993 (bus12 in Max.)	
Bus frequency	49.9742 (bus14 in Min.) ≤ f ≤ 49.9756 (bus12 in Max.)	
Case 3: P (WPT) = 0 KW under AWS over 3.5 m/s		
P.F. Reduction (bus to bus)	0.0104(B.10-B.11).	0.0218 (B.13-B.11)
Bus voltage	0.0193 (bus22 in Min.)≤ V ≤ 0.9981 (bus12 in Max.)	
Bus frequency	49.9742 (bus14 in Min.) ≤ f ≤ 49.9756 (bus12 in Max.)	

Driving by random wind speed, the generation from WPT changes in a certain degree. Since influence of stability caused from WPT on a power system tightly depends on existing WPT generation in this system, here all possible WPT generation have to be considered in simulation. In this study, three kinds of WPT generation that can represent the influence caused from all other WPT generation are used in simulation. If system is stable under these three WPT generation, it will therefore be stable under all other WPT generation. These three generation are denoted as: the full WPT generation of 500 kW corresponding with the wind speed over 12.5 m/s, the average WPT generation of 132kW corresponding with the MAWS of 6.73 m/s and also the zero WPT generation corresponding with the wind speed below the cut in wind speed of 3.5 m/s. Take 100MVA and 6.6 KV as the system basis of per unit and allowed system margins are given with bus voltage±5% and system frequency±2%. Table 10 shows simulated results of the bus voltage and system frequency by using the derived computation program and Power Flow Software.

From simulation result, it is known that the voltage and frequency are within the proposed margin in normal operation. The increment of WPT generation makes system frequency dropping, the reason is that WPT absorbs system reactive power (given negative value in simulation) in operation so as to reduce certain amount of active power, in application the capacity compensation is necessary. Since WPT are directly installed on load bus, power flow and line loss on related lines have been reduced, in Table 10 only the reduced values of nearest lines are given.

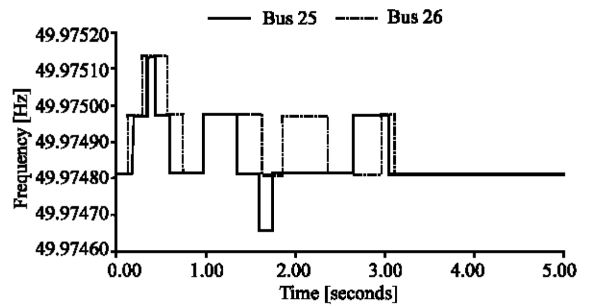

Fig. 8: Frequency fluctuation when WPT on Bus25 and Bus26 start to operate

Table 11: RIES and WDES of LWPS under three WPT generation after installing WPT

Bus Number	0 KW	132 KW	500 KW
RIES under three WPT generation			
Bus 21	0.90012	0.90329	0.90329
Bus 22	0.89972	0.90207	0.90290
Bus 23	0.89932	0.90169	0.90251
Bus 25	0.89930	0.90082	0.90166
Bus 26	0.89844	0.90484	0.90249
Bus 27	0.96255	0.90484	0.90564
WDES under three WPT generation			
Bus 21	0.93741	0.93741	0.93741
Bus 22	0.93939	0.93939	0.93939
Bus 23	0.95899	0.95899	0.95899
Bus 25	0.96465	0.89646	0.71212
Bus 26	0.97928	0.92536	0.87681
Bus 27	0.88800	0.88800	0.88800

Figure 8 shows the fluctuation of frequency when two WPT on Bus25 and Bus26 are simultaneously cut in system, it is also within limited margin. The voltage fluctuation during the connection process is covered by the values shown in Table 10.

Reliability verification: In the view of WDES and RIES, the reliability of LWPS may be increased after installing WPT. Since system reliability also relates to the WPT generation, WDES and RIES respectively under the full WPT generation, average WPT generation and zero WPT generation are taken as verification targets. Just as stability simulation, WDES and RIES under other WPT generation produced from wind speed between average and full wind speed may be represented by full power generation, this means the highest level of WDES and RIES on each bus corresponds with the full WPT generation but not beyond that.

Table 11 shows the simulated results of WDES and RIES. It is obvious that the RIES of each bus has been increased so that the reliability of entire power system is improved too. Actually, even in the view of the annual average generation (under the average wind speed in Table 6), the RIES of all PQ buses are over 0.9000, this indicates that the reliability of each bus at least has over 10% of the average generation in normal operation.

It is also know from Table 11, WDES on Bus25 and Bus 26 are reduced, the best value is near 0.70 on Bus25 under 500 kW WPT generation and the value under average WPT generation of 132 kW is around 0.89, this indicates that Bus25 still has the ability to serve for the capacity that equal to 5 to 25% of the maximum load while system keeps 5% reserve of power generation. Consequently, the target of this research to improve the reliability of LWPS by installing WPT is realized during both the periods of critical load and average load.

CONCLUSION

This research has reached the target to improve reliability of LWPS and reduce the power loss on lines by installing WPT. WDES and RIES are respectively reduced and improved in a certain degree. Derived WDES may be applied for any bus or system and it can completely reflect the bus weakness range in any period of critical time. Reduction of WDES indicates the improvement of reliability in driving the maximum load. RIES averagely indicates the reliability level of a bus or system during an average time, RIES may be also taken as a supplement of WDES. In application, WDES and RIES essentially provide a complete appraisal for operation condition of a power system and hopefully may become a basic reference in installing WPT and making operation planning after installing WPT, these two indices shows their feasibility in application, especially in analyzing the reliability condition of weak and small sized power system standing alone like the power system mentioned in this research.

The fluctuation of system voltage and frequency after installing WPT is within proposed limitation of LWPS, this means system is operating under stable state. However, the condition of reactive power in a power system need to be seriously verified in following WPT installation because the operation of WPT may change the distribution of reactive power that proportional with the capacity of installed WPT, extra WPT capacity may cause the voltage and frequency of a power system or a bus beyond the expected operational margin.

On the other hand, the verification of dynamic state is very important and this procedure may provide more serious limitation than any stable verification for a power system. In application, dynamic instability problem of a hybrid power system can be solved by adjusting the distribution and compensation of system reactive power or applying available relay protect system with appropriate clearing time. Since LWPS in this study is currently without any large sized electric equipment that needs much reactive power for starting and operation, the stability limitation under system dynamic condition may be easily satisfied.

REFERENCES

1. Wind Power Company, 2001. Investigation on Bur Jing Regional Power System, in Burjing Region, Quequek, Tech. Report.
2. TCDC, 2001. International SHP, Technology of Small Typed Hydropower System, Hang Zhou Publishing House.
3. Billinton, R. and R.N. Allan, 1984. Reliability Evaluation of Power System, Piman Publication, pp: 16-52.
4. Department of Developing Renewable Energy, 2000. Investigation of Wind Condition, Tokyo, pp: 25-38.
5. Mukund R. Patel, 1999. Wind and Solar Power System, CRC Publication LLC, Boca Raton, Florida, pp: 35-55.
6. Litifu, Z., Noel Estoperez, Mostafa Al Mamun and Ken Nagasaka, 2005. Planning of Micro-grid Power Supply Based on the Weak Wind and Hydro Power Generation, IEEE Power Society (IEEE), PES-06GM0973.