Installation of Wind Power into a Weak Power System Considering System Fluctuation and Limitation

[1]JEFF HUANG, [2]ZULATI LITIFU, [1]KEN NAGASAKA
[1]Department of Electrical and Electronic Engineering
Tokyo University of Agriculture and Technology
2-24-16, Nakacho, Koganei-shi, Tokyo 184-8588
JAPAN

[2] Department of Statistics and Information
Xinjiang Institute of Finance and Economics
No. 15 South Beijing Road, Urumqi, Xinjiang
CHINA
weiweihuang88@yahoo.com.tw, zulati@cc.tuat.ac.jp, bahman@cc.tuat.ac.jp

Abstract: - This paper presents the methodology to estimate stable and dynamic operational characteristics of Wind Power Turbines (WPT) in a targeted weak power system under defined local wind condition; and from this to establish the efficient installation process in planning wind power system. In this research, operational characteristics of WPT under regular and irregular wind speeds are considered and verified against power system operational particularities; the losses of power system reactive power and grid voltage drop are calculated to estimate the degree of stability of the local power system; impact current resulting from when WPT connects with the power system and its use for verifying the stiff condition of connecting grid. Electric particularities under the short circuit condition of WPT and weak power system are simulated so that to satisfy power system demand after the WPT is installed, and the maximum capacity of wind power generation that can be safely introduced into the targeted local power system is determined by considering the fluctuation range of grid voltage. This paper provides a synthetic way to judge the operational characteristics of WPT when installed into a weak power system; and could be applied to the existing weak power system in the rural region. This will demonstrate the value of WPT in a practical application.

Key-Words: - WPT, Weak Power System, Operational Process, Electric Fluctuation, Wind Power Limitation

1 Introduction

In the past ten years, wind energy has been one of fastest growing electricity generation technologies. According to the Press Release "New World Record in Wind Power Capacity" by World Wind Energy Association, the globally installed capacity of wind power energy grew from 7475MW in 1997 to 73904MW by the end of December 2006, and is expected to keep growing and reach 160000MW by the end of 2010 [8]. Since wind power energy has a more important role in electricity generation today, therefore it is important to analyse the operational characteristics of Wind power turbine and the effect on the connected power system before wind power turbine installation.

The author previously investigated research related to the wind power system and the result of that research play an important role leading to the research discussed in this paper.

For the installation method of wind power systems, the previous research deals with two vital problems with the installation of wind power generation in an existing power system. One is determining the optimal installation bus and the other one is estimating the maximum limitation of wind power generation that can be safely introduced into the power system. Here, Domain-Link Method is used for forming applicable domains based on the structural characteristic of a power system; consequently Maximizing Decision Method is used for ensuring the best bus inside selected domain using operational indices of environment, economy, reliability and stability. The limitation of wind power generation is estimated after connecting wind power system to the selected bus based on system steady constrains. The result is illustrated using the IEEE 30-Bus test system. Successive installation of wind power generation may be conducted with the same procedure satisfying new power system constrains resulted from the previous installation.

In the previous research, the author also investigated the fluctuation of WPT when connected with the target power system. This research presents a realization process of a hybrid system consisting of biomass and wind as well as solar power generation on the ground of Ashikaga Intitute of Technology located in Ashikaga City of Tochiki Prefecture. The installation principle and procedure are introduced based on the conditions of natural energy such as wind speed and solar rediation degree. The output characteristics from 20kW biomass generator is explained and analyzed in according to cooperational possibility with the wind power and solar power system. The operation characteristics of 40kW wind power turbine is provided based on the practical operation data collected within three years and the simulated results obtained from the software calculation. The operation conditions of 20.6kW solar power system is also anaylzed based on the solar irrediance desity in the located site. The general efficiency of this triple hybrid power system in ecomomic and environment aspects is also studied by using and comparing the simulation methodology and the data in practical operation.

Our previously reseach also covered the analysis of reliablity and control of wind power turbine when connected with the local weak power system. In this research, Wind power generation is expected to be used as a power reserve to improve the reliability degree and reduce line loss of power system 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 that represents bus energy supply ability in a short critical time and Reliability Index in Energy Supply that represents bus average energy supply ability during annual time are applied. Appropriate type of wind power turbine is selected according to Percentage Rate of Availability Index and Percentage Rate of Utilization Index derived from Monthly Average Wind Speed through the target region. Operational reliability and stability are analyzed based on form.

The previous research gave us some valuable information in relation to the behaviour and operational constraint of a wind power turbine when connected to the target power system. But the detail of the installation procedure and operational characteristic of a wind power turbine when connected with a power system has not yet been investigated therefore these are the main features of the research in this paper.

In planning the installation of wind power generation in any scaled power system, it is important to examine the operational characteristics of WPT. Furthermore, it is also crucial to examine the possible impact on the connected power system of the installation site.

When WPT is connected to the power system, the grid voltage may fluctuate since the WPT require absorbing reactive power from the connected power system to keep a magnetic exciting field for its operation. Therefore it is utmost important to calculate the maximum capacity of wind power generation that can be install into the targeted power system safely when considering to design the wind hybrid system.

In order to achieve the above, the following installation procedures of WPT to the targeting site are necessary and performed in this research:

- Testing the WPT under regular wind speed at the installation site. Leading to determine the normal operational characteristics of the WPT.
- Testing the WPT under sudden wind speed change at the installation site, leading to determine the characteristic of the WPT in transient process.
- Determining the amount of compensating capacitor that is absorbed by WPT while the power system is stable.
- Determine the impact on the WPT and the connected power system when short circuit occurs.
- Calculate the maximum capacity of wind power generation which is safely installed at the installation site, while the wind power system is stable.

From the result of our research [2], it is indicated when WPT connects with a weak power system, the impact is stronger then compared to connecting with a strong power system. But in particular, it always found in weak power system areas where the wind conditions are best. Thus, weak power system with WPT is discussed in depth in this paper.

2 Background of the installation site

Hybrid wind power system composes of WPT(s) and the targeting power system of the installation site. In this paper, 600kW WPT(s) with fixed rotating speed and a weak power system with capacity of 14MW are involved. The following are more detailed explanation on these two components.

2.1 Concept of weak power system

The word " weak" in weak power system is used when the substation grid is not stiff enough, such that the grid voltage could not be well-controlled. The substation system in the weak power system usually comprised of several buses, and the bus with valid wind speed is selected for connecting to WPT. In order to reduce the influence on existing power system, the optimal bus must be first selected. Without this step, this research presented in this paper may lose its meaning. However, the task for selecting the optimal bus has been achieved in our previous research [2], hence in this paper the author only make simple explanation to introduce these methods: For large scaled power system, the selection of the optimal bus can be conducted through the Domain-Link Method (DLM), whereas for the small power system, the Weakness Degree in Energy Supply Method (WDES) [3] and Endurace Index of Crisis Hours Method (EICH) [4] can be utilised.

For the purpose of this research, it is assumed that the WPT has already been connected to the optimal bus, and the wind speed at this optimal bus is satisfied to drive WPT. The circuit diagram (Fig.1) below describes the interconnection of wind power farm (located at the optimal bus, which is assumed to exist at the terminal of targeting power system) with the targeting weak power system. This model is typically applied for the interconnection between WPT and weak power system and also been used in this research.

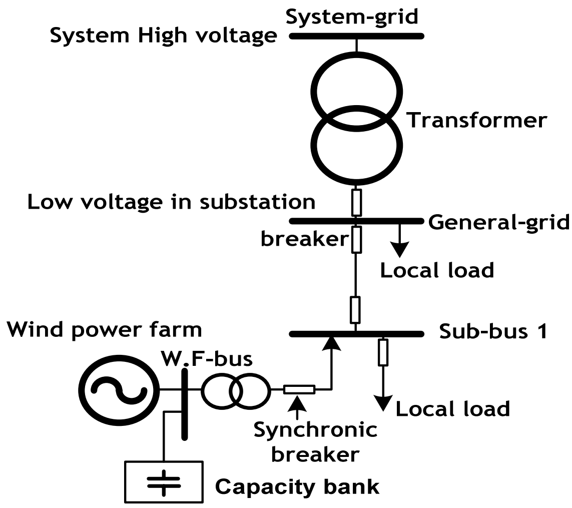

Fig.1. Inter-connection of wind power farm at terminal of a targeting weak power system

The electric parameters of the targeting weak power applied in this research are listed in Table 1.

Table 1: Parameters of targeting weak power system at the defined installation site

Transformer on wind power farm side	690V/22.8kV , 12MVA
Transformer on system high voltage side	22.8kV/69.3Kv , 25MVA
Capacity bank	0.23MVAR
Load on general-grid	2MVA , Power Factor 0.85
System-grid short circuit level	70MVA

2.2 WPT with fixed rotating speed

In this research, a 600 kW WPT with fixed rotating speed is employed. 600kW WPT is chosen because it has been widely applied for weak power system in many countries; and therefore there is strong experience on using this type of WPT. However, like the other WPT, this 600 kW fixed speed WPT does have a property of high starting current and it require to absorb reactive power from the connected power system when it's in operation. As a result, stability of the power system will be affected. The electric parameters of 600kW WPT use in this research are given in Table2.

Table2. Parameter of 600kW fixed speed WPT

capacity	P. factor	Freq.	S. R	S. X
0.6MW	0.912	60Hz	0.0079Ω	0.00017Ω
S. R	S. X	Pole	Cut-in WS	Cut-out
0.0006	0.00017Ω	6	3.2m/s	13.8m/s

Note: P=Power, S=Stator, R=Resistance, Rot=Rotor X=Reactance, Freq=Frequency, WS=Wind speed

3 Operational characteristic of WPT and connected weak power system under different conditions

This section presents the simulation results from the five different installation procedure of WPT mentioned in the introduction.

3.1 Under regular wind speed condition

In most of operational time, WPT works under regular wind speed condition. Hence, it is important to analyze the operational characteristic of WPT and the effect on the targeting power system under this wind speed condition. Also the operation characteristic of WPT under this wind condition not only determines the operational efficiency of WPT, it also determines the service time and economic efficiency of WPT at the targeting installation site.

3.1.1 Equation of WPT under regular wind speed condition

As shown in Fig2, wind power generation highly depends on the wind speed, and the amount of wind power generation is the key factor in determining the stability of the wind power system.

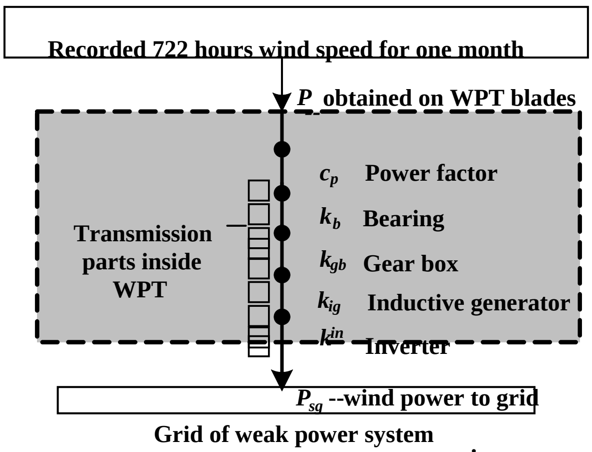

Fig.2. Transmission parts inside WPT connected to weak power system under recorded wind speed

The amount of wind power generation is the key factor in determining the stability of the wind power system. Power transfer from wind kinetic energy to electricity of defined WPT is shown in Fig2.In Fig.2, wind power absorbed by the blade of WPT is given by P, and this kinetic energy P transform to the electrical energy P_{sg} through the transmission part inside of WPT. The equations explain this energy conversion process can be expressed by the following equation (1)

$$\begin{cases} P = 0.5 \rho A V^3 \\ P_{sg} = C_p k_b k_{gb} k_{ig} k_{in} \end{cases} \quad (1)$$

Where; V is regular wind speed, A is cross-section area swept by blades, ρ is air density of installation site and C_p is power factor of defined WPT. All coefficients k form equation (1) is only applied with single WPT, therefore in case a group of WPT, the total generation can be obtained from the sum of each generation of WPT. But, for the losses reactive power and grid voltage drop by a group of WPT, it has no longer linear relation with amount of each WPT. Therefore, it is not possible to estimate these parameters directly from the linear calculation.

3.1.2 Regular wind speed at the installation site

In this paper, actual wind speed data recorded from the targeted installation site are entered into the simulation. In comparison with the average wind speed obtained usually by statistical method from *Wind and Generation Matrixes*[1], this real wind speed data allows the result of the simulation to become more realistic in relation to the real operation conditions at the targetting installation site.

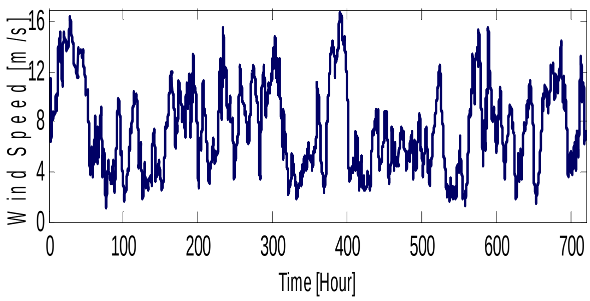

Fig.3. Recorded regular wind speed data used for simulation at the defined installation site

The month selected for wind speed data was the month with the strongest and most volatile wind speeds throughout several year recording at that targeted installation site; this data cover all possible wind condition scenarios which may happen at that installation site. The regular wind speed used for simulation in this research as shown in Fig.3.

3.1.3 Simulation result

Fig.4 shows the simulation result of WPT under regular wind speed condition by including WPT inertia factor. The simulation result indicates that single 600kW WPT operates entirely in fine condition; and has good tracking ability under variation of wind speed condition (compare Fig.3 with Fig.4). According to the result, when wind speed increases, the rotor of WPT begin to rotate faster almost at same time; real power generation increase; and WPT absorbs more reactive power. Real power generation matches for the result obtained from Utilization and Availability Indices of selected WPT. Fluctuation of grid voltage is within ±5%. Through this simulation, monthly generation and economy efficiency may be resulted from simulated numeral result. Hence, yearly synthetic efficiency may be separately resulted from each monthly simulation results based on recorded regular wind condition.

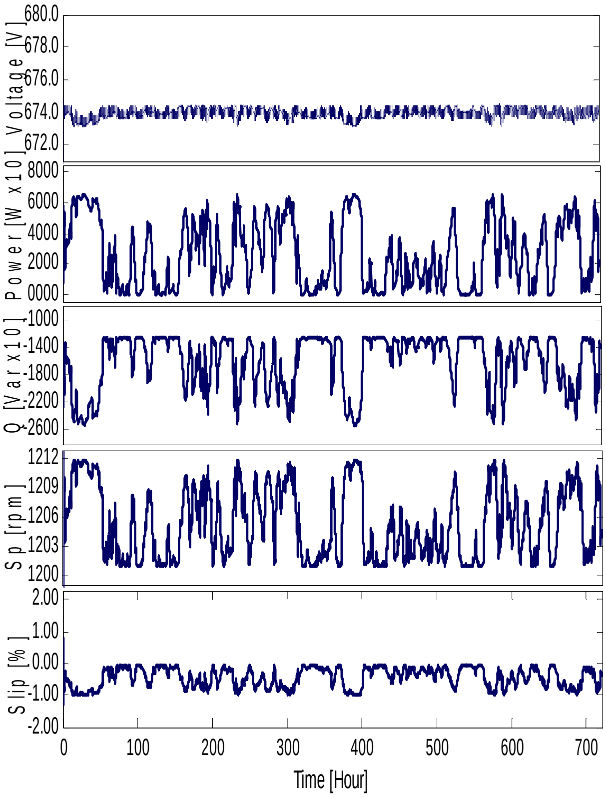

Fig.4. Simulation result of single 600kW WPT under regular wind speed at the defined installation site

3.2 Under sudden changes in wind speed condition

WPT suffers from transient process under sudden changes in wind speed condition. Actually, there are many reasons that lead to transient process of WPT therefore affecting the power system's stability.

From the view of wind speed, small variations in wind speed may be absorbed by WPT blades and inertia without causing transient process, but when large and sharp variations of wind speed that occurs for relatively long period of time, WPT must reach a new operation point through transient process by tracking the control way $dP/d\omega = 0$. The result of this simulation can be used to judge the transient characteristic of WPT and the stability of the connected power system under the transient process.

3.2.1 Equations of WPT in dynamic process

Transient equations are including electrical equation and mechanic equation [5] that derived from basic theory of asynchronous inductive generator. All parameters are converted to DQO candidate system. Uppercase and lowercase letters indicated the parameters of rotor and stator according. ω and ω_1 are synchronous and asynchronous velocity of state magnetic field and generator rotor, the electrical equation of inductive generator can be expressed by equation (2);

$$\left.\begin{aligned} p\psi_d &= R_1 i_d + \omega\psi_q + V_d \\ P\psi_q &= R_1 i_q - \omega\psi_d + V_q \\ p\psi_D &= -R_2 i_D + (\omega - \omega_1)\psi_Q \\ p\psi_Q &= -R_2 i_Q - (\omega - \omega_1)\psi_D \end{aligned}\right\} \qquad (2)$$

where, $p = d/dt$, i, ψ and V are currents, magnetic linkages and voltages. R_1 and R_2 are resistances of stator and rotor. In the view of WPT, define magnetic-electric torque as $T_E = \psi_d i_q - \psi_q i_d$, T_T and T_W are mechanic torque on WPT blade axes and generator input axes. The mechanical equation of inductive generator can be expressed by equation (3)

$$\left.\begin{aligned} ds/dt &= (T_T - T_E)/T_J \\ dT_T/dt &= (T_w - T_T)/T_H \\ d\theta/dt &= \omega_1 \end{aligned}\right\} \qquad (3)$$

where, s is slip of generator, T_H and T_J are inertia time constant of turbine and generator, and θ is angle between stator and rotor. Based on equations (2) and (3), three standard equations that can be used for transient simulation are expressed by matrix equation (4) (refer to reference [5], deriving process is omitted). Where, $p = d/dt$, I, ψ, V and E are respectively current, magnetic linkages, voltages and electrical potential matrixes. A matrix in equation is variable matrix and related to same electric parameters such as current, magnetic linkage, voltage and electric potential. And for B matrix, it is additional matrixes with same degree as A.

$$\begin{cases} p\psi = A\psi + BV \\ pE = AE + BI \\ pI = AI + BV \end{cases} \quad (4)$$

Equation (4) can be feasibly used in according to the simulation target and it also expressed by (5):

$$\left.\begin{aligned} \Delta pX_i &= \frac{\partial f_i}{\partial X_1}\Delta x_1 + \ldots + \frac{\partial f_i}{\partial X_n}\Delta x_n + \frac{\partial f_i}{\partial U_1}\Delta u_1 + \ldots + \frac{\partial f_i}{\partial U_r}\Delta u_r \\ \Delta Y_j &= \frac{\partial F_j}{\partial X_1}\Delta x_1 + \ldots + \frac{\partial F_j}{\partial X_n}\Delta x_n + \frac{\partial F_j}{\partial U_1}\Delta u_1 + \ldots + \frac{\partial F_j}{\partial U_r}\Delta u_r \end{aligned}\right\} \quad (5)$$

where, n is the order of system and r is the number of input, above equation can be written as following equation (6):

$$\left.\begin{aligned} \Delta pX &= A\Delta X + B\Delta U \\ \Delta Y &= C\Delta X + D\Delta U \end{aligned}\right\} \quad (6)$$

here, C is output constant matrix; D is constant matrix related to input. Equation (6) is linearization state of (5) and enables to represent the states denoted by (5) in defined time range, therefore these two states are the equivalent states. Equation (6) is able to be linked to SIMULINK program and calculated by numeral method. Supposing the time period is defined, the linearization form of equation (6) can be realized by equation (7):

$$\left.\begin{aligned} \dot{X} &= AX + BU \\ Y &= CX + DU \end{aligned}\right\} \quad (7)$$

Fig.5 describes the simulation procedure. Wind speed data and initial matrixes are given by $P_1, P_2 \ldots P_n$.

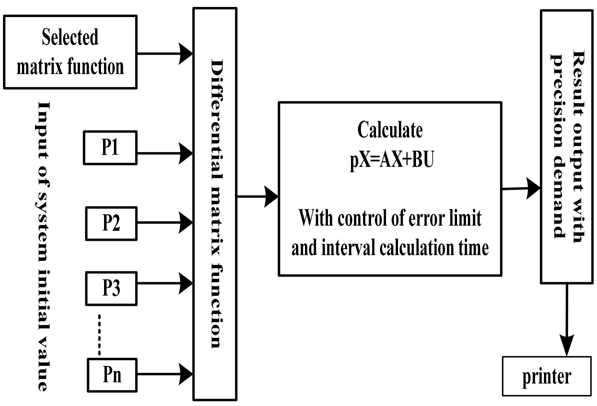

Fig.5. Diagram of simulation procedure for sudden changes in wind speed condition

Simulation result

The result of the simulation indicates a 600kW fixed speed WPT operates in stable condition and has good tracking ability during the sudden change in wind speed condition at the targeted installation site.

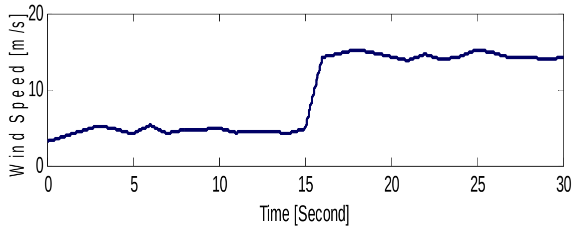

Fig.6. Wind speed that increases from 3.5m/s to 13.8m/s at the defined installation site

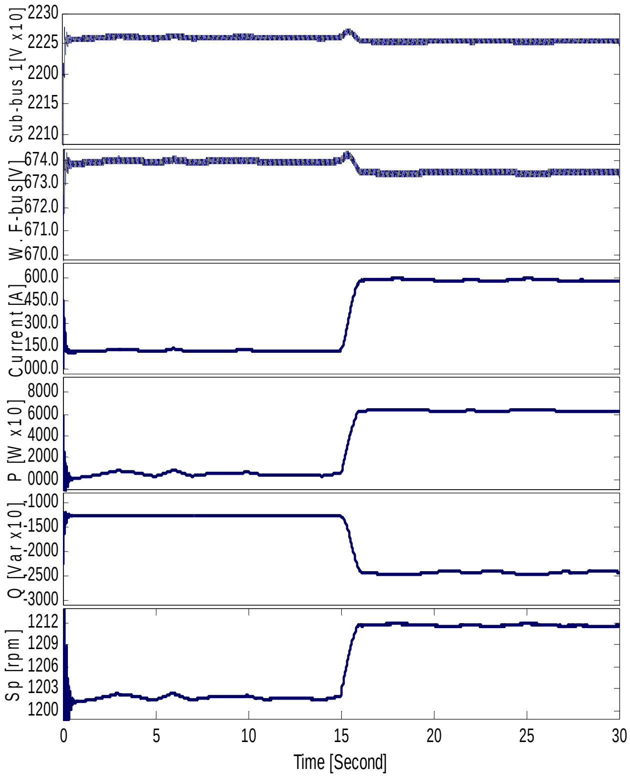

Fig.7. Simulated results of 600kW WPT related to wind speed shown in Fig.6 at defined installation site.

According to the simulation result, when wind speed was suddenly increased from 3.5m/s to 13.8m/s (cut-out wind speed of WPT), all the mechanical and electrical parameters show stiff stable ability, and the WPT also showed good tracking ability during the sudden increase in wind speed conditions at the targeted installation site. Since the fixed compensating capacitor used in this research is sufficient to supply only one WPT's reactive power need in this case, therefore this is the reason the grid voltage only fluctuated by a small amount during this situation. But in the case when the compensating capacitor is not available, or in the case when the capacity of WPT is increased, then the reactive power required for WPT will be absorbed from the connected power system, and this may result on a grid voltage drop. This type of voltage drop phenomenon will be exacerbated if the weak power system is in the application. Therefore it is very important to determine the required capacity of the compensating capacitor bank needed for the capacity of the targeting power system when WPT is applied, and this procedure especially important when weak power system is in the application.

3.3 Connecting process of WPT with system grid

This section explains the concept of connection process between WPT and a targeting weak power system, and also presents the simulation result of this connecting process of our research.

3.3.1 Concept of connection process

Differing from synchronous generator, WPT will connect to the power system when cut-in wind speed level is reaches; and disconnect from the power system when it reaches to cut-off wind speed level. Because of these kinds of automatic connection activities, the WPT creates a transient process.

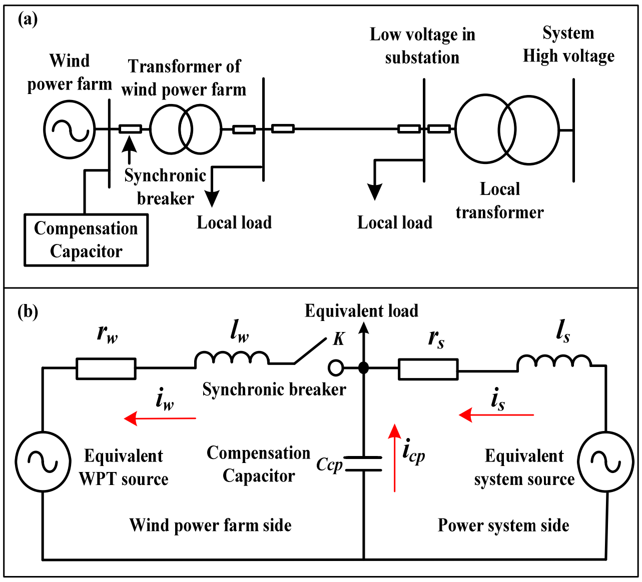

Fig.8. (a) Interconnection of power system and wind farm (b) Equivalent transient circuit of connection process

Usually the transient response of the WPT takes into account the fluctuation on the grid voltage, reactive power and active power. There are two key factors which influence the transient response on most WPT, the capacity of the targeted power system it connects to and the amount of WPT generation. For example, when WPT connects with a strong power system with a stiff grid, the fluctuation level of the transient response may not have much influence on the wind power system. But on the other hand, if the WPT connects with a weak power system, then the fluctuation of transient response will be more obvious. When a WPT with capacity less than 100kW connects with a power system, the transient processes can be approximately solved by the power flow calculations [6], and fluctuation of each parameter can be estimated directly from the equivalent circuit (shown in (b) Fig.8). But, in the case of large WPT, the fluctuation parameters are much more complex and involve non-linear properties. Hence the simulation by using Simulink will be much more efficient than by using the power flow calculations.

3.3.2 Simulation result

When WPT connects with a power system, it results in a momentary in-rush of current as the magnetic field is energized, and this high impact in-rush current can be limited but not eliminated. One of the methods to minimize this impact current is by controlling rotor speed of WPT when it connects with the targeting power system. Usually a WPT's rotor with zero speed connecting with the targeting power system may create a heavier transient process compared to the WPT's rotor with near rated operational speed.

For this part of the simulation, parameters are set as follows: rotor speeds of 600kW fixed speed WPT equal to zero (Fig.9.(a)) and 95% of rated operational speed(Fig.9.(b)) when connected with the targeting power system. As the result of the simulation indicated, the peak value of in-rush current was 3400Amp and the duration time of this in-rush current was about 0.85 seconds when rotor speed of WPT equal to zero when connected to the targeted power system. Compared with this, the simulation result indicated the in-rush current was smaller (2900A) and the duration time of this current also much shorter if WPT connected with the targeted power system with rotor speed of WPT at 95% of rate operational speed.

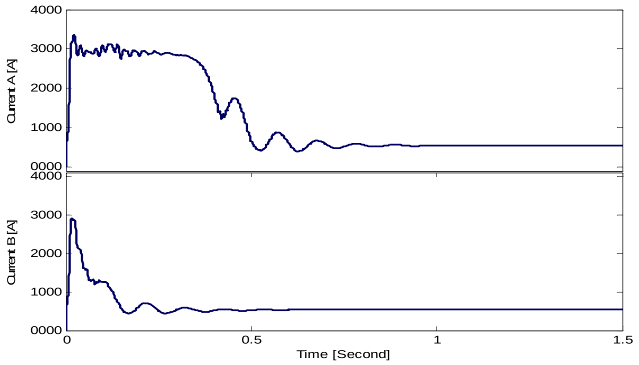

Fig.9.Imapct current on 600kW fixed speed WPT; when connected with targeted power system grid with the rotor speed of WPT at (a) at zero (b) at 95% of synchronous speed

In order to see the performance of the WPT when it connects to the targeted power system at rotor speed of WPT near or equal to rated operational speed, we set the WPT connected to the targeted power system at t=6second in this simulation.

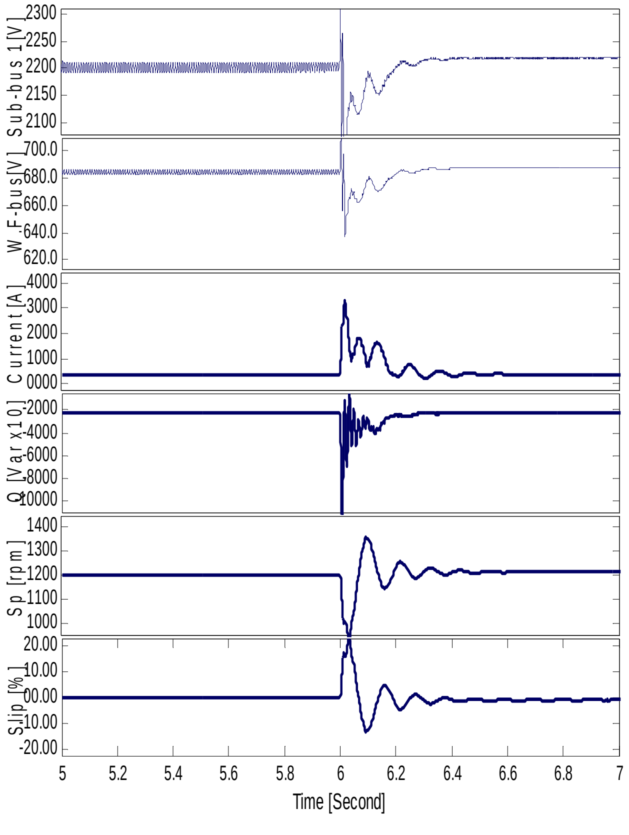

Fig.10. Simulated result of 600kW WPT when it connected to targeted power system grid with rated operational speed at t=6s

From the simulated result as shown in Fig.10, it indicated the voltage at W.F-bus drop instantaneous and recovers back in about 0.4 second. The percentage of instantaneous voltage vibration on this bus is about -4.5%. The main cause of this instantaneous voltage vibration is the transformer (690V/6.9kV) on the WPT side. This transformer is required to absorb the reactive power from connected power system when connecting with grid. In addition, because the compensating capacitor used in this simulation; the voltage on any bus of the wind power system are not fluctuated. But in the case where a compensating capacitor is not available, the grid voltage is expected to drop in a certain degree since the WPT is required to absorb reactive power from the connected power system. Fig.9 also provided the time range of the transient connection current, which is basic reference to determine the synchronic breaker shown in Fig.1.

3.4 WPT under short circuit condition

This section explains the concept of WPT under short circuit condition, and also presents the simulation result of the WPT connected with weak power system under short circuit condition of our research.

3.4.1 Concept of WPT under short circuit condition

Before installing a WPT into new site, it is also necessary to test the dynamic stability of the wind power system under the short circuit condition. When a short circuit occurs in wind power system, a large amount of impact current will be expected to flow from WPT and power system into the short circuit dot, and the grid voltage will also drop in initial time since reactive power of the power system cannot respond immediately. The grid voltage drop situation will be more obvious if short circuit happens in a weak power system. Therefore choosing the right fault protection system to ensure all part of wind power system are able to bear this impact current is extremely important. In order to solve this problem, it is necessary to determine the range of the impact current when designing WPT into the new site.

Generally, there are two types of short circuit situations that might happen in wind power system. The first one is a short circuit inside the WPT related to the stator coil. This problem can be easily solved by using Matlab simulation tools. The second type of short circuit happens at the connection part where the WPT terminal connects with the power system grid(see (a) and (b) in Fig.11). This type of short circuit is usually caused by animals or mistake during the manufacture, and occurs usually in wind power system.

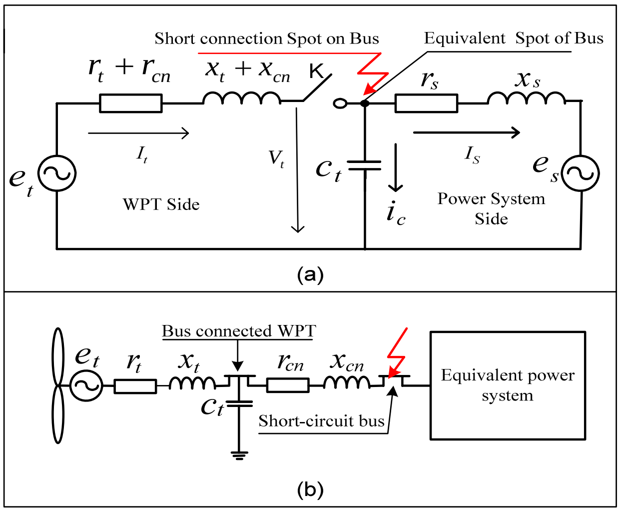

Fig.11.(a)Equivalent circuit of connection system, (b)Typical connection system of WPT system.

When a short circuit happens in wind power system, the connected power system grid usually feeds a much bigger impact current to short circuit dot than WPT due to the capacity difference. Simultaneously, grid voltage will drop sharply due to a loss of reactive power. It is also known that when a short circuit occurs on any part of the connected system, the range of impact current depends mainly on the remaining reactance from the generator to the short circuit point. Regarding to high frequency of current, impedance created by compensating capacitor may be ignored. Therefore the general short circuit power and impact current may be expressed by equation (8):

$$\begin{cases} S_{gsc} = k_1 \dfrac{U_s^2}{Z_s} + k_2 \dfrac{U_{wpt}^2}{Z_{wpt}} \\ I_{gsc} = S_{gsc} \big/ \sqrt{3} U_{ar} \end{cases} \qquad (8)$$

where, S_{gsc} is short circuit power; I_{gsc} is short circuit current; Z_s is remained reactance; U_s is voltage on system grid, Z_{wpt} and U_{wpt} are remained reactance and rated voltage of WPT. From Fig.11 it can derivate $Z_s = r_s + j x_s$ and $Z_{wpt} = r_s + r_{cn} + j(x_s + x_{cn})$, And if short circuit happened at the output terminal, then $Z_{wpt} = X_d'' = x_d'' . U_{wpt}^2 \big/ S_{wpt.s}$ .Here, U_{ar} is average rated voltage on power line. k_1 and k_2 are constant, k =1.1 or 1.05 according to high or low grid voltage.

3.4.2 Simulation result

Fig.12 shows the simulated results when short circuit happened at t = 1s. The results show that, when the 3-phase fault occurred in the sub-bus1 at t=1 second (see Fig.1). The voltage, current, real power, and reactive power of W.F-bus all dropped sharply and reached zero in approximately 0.2 seconds. The speed of the WPT rotor also increased sharply. In order to prevent damage to the WPT from this over-run condition, it is necessary for WPT to be disconnected from the power system within 0.2s by using the relay protection system.

The fault happened in this kind of wind power system is barely caused by hard equipments of wind power system, instead of system equipments the animals are one of the important reasons to make this fault. From the other hand, the power system manufacturer is also one reason to cause this kind of fault. It is therefore suggested that the suitable signal and relay protect system is essential for whole connection system between wind power turbine and existing power system. The characteristics of fault current shown in Fig.12 is important reference to estimate the capacity and thermal limit in selecting the relative equipment in the connection system, especially in selecting the transmission power line of wind power turbine and power system.

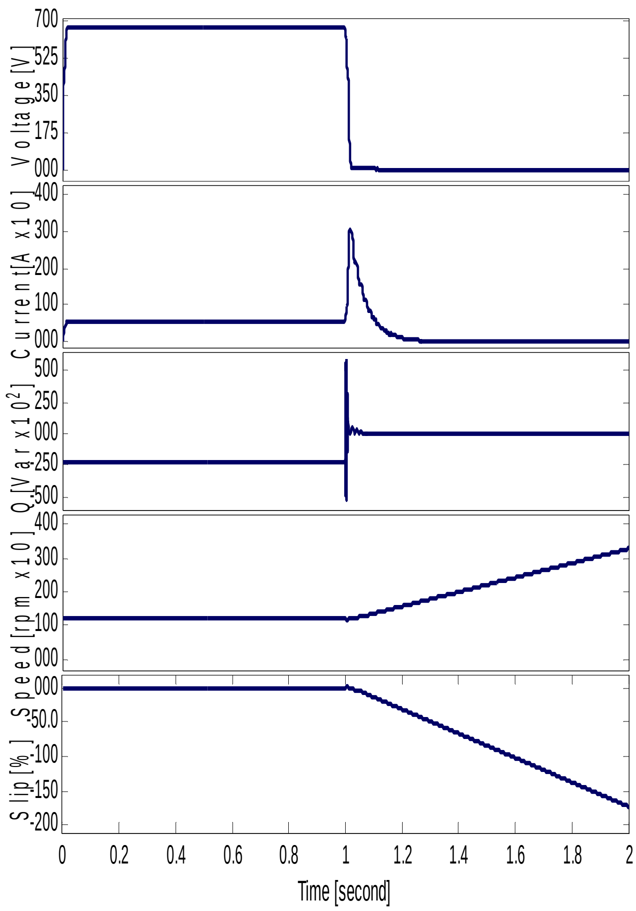

Fig.12. Simulation result of 600kW WPT connected with weak power system under the shot circuit condition happened at t=1 second

3.5 Limitation of wind power capacity in the targeting weak power system

This section explains the concept on limitation of wind power capacity installed to the targeting power system, and also presents the simulation result of the maximum wind power generation which is allowed to be safely installed at the targeting weak power system of our research.

3.5.1 Concept of wind power capacity limitation

Since WPT is based on the principal of induction machine, hence it would absorb reactive power from either the connected power system or from the compensating capacitor during its operation. Even though compensating capacitor is able to stabilise the grid voltage without consuming too much reactive power from the connected power system, but the device itself is costly, therefore, the compensating capacitors are not usually used in a weak power system, such as those found in the small sized rural regions.

As mentioned previously, WPT would consume reactive power from the connected power system when its operation. When large numbers of WPT are applied, the effect to the power system will be much more serious, for example grid voltage fluctuation. Therefore in order to solve this problem; the limitation problem of WPT capacity is occurred in here. The limitation indicates the calculation of the maximum capacity of wind power generation which is allowed to be safely installed at the targeting power system. This procedure is especially important when wind power generation being considered for install into the weak power system.

There are several methods that could be used for calculating the maximum capacity of wind power generation install in the targeting installation site. However, the most efficient way to solve this problem is by consider the range of grid voltage fluctuation. In this research, the voltage in every bus of the wind power system is closely monitored. Furthermore, the simulation is terminated once any of the bus voltage fluctuation falls outside the ±5% range of the rate bus voltage respectively.

3.5.2 Simulation result

To determine the maximum wind power capacity of the targeting installation site, we analyse the effect on the wind power system when we gradually increase the number of WPT in the installation site. According to the simulation result, when increasing the generation capacity of WPT by increasing number of WPT in the wind power system, it indicates the WPT require absorbing more reactive power in its operation. For example, one 600kW fixed speed WPT requires to absorb 228kVAR of reactive power, and five of this same WPT together will require 1140kVAR of reactive power for its operation. But since the compensating capacitor used in this wind power system of our research is only provides 219kVAR of reactive power, which only sufficient to compensate for the reactive power require of one WPT for its operation. Hence when there is more than one WPT in application, the insufficient reactive power will be absorbed from the connected power system. For example, when five 600kW WPT are installed, the total reactive power required is 1140kVAR. However the amount of this, only 216kVAR will be absorbed by the compensating capacitor; and the remaining will be received from the connected power system, and this is a main reason which leading to the problem of the grid voltage fluctuation.

The simulation result also indicated that 7 WPTs (4200kW) provides the maximum wind power generation capacity allowed at this targeted installation site of our research. The WF -bus voltage falls outside the ±5% range of rate W-F bus voltage (-5.5%) when 8 WPTs are installed at this targeted installation site (Fig.14.), and this is not acceptable according to our defined stability standard of power systems.

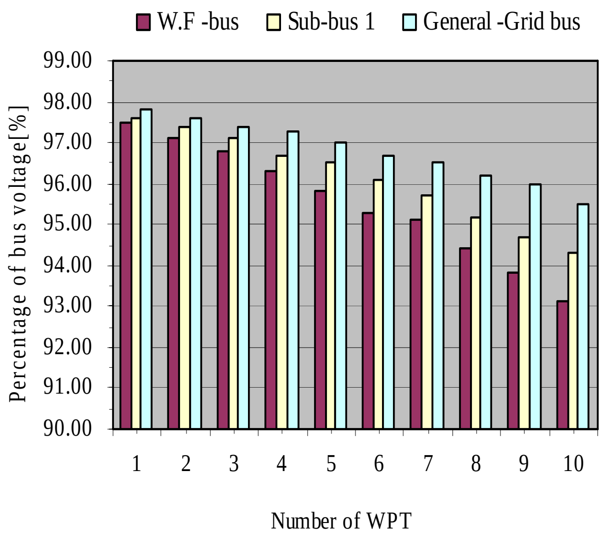

Fig.14.Percentage of the rate bus voltage when difference numbers of WPT are installed at the defined installation site

4 Conclusion

The applicable installation procedure for WPT to the weak power system was proposed and simulated in this research. The installation process proposed in this research can be use for any type of WPT into the targeted power system. WPT installation procedure may be summarized in the three steps. The first step is the estimation of Wind Matrix and Generation Matrix that are derive from the targeted WPT installation region. The second step is to select the optimal bus of targeted power system for WPT to connect with. And the final step is the calculation of the maximum capacity of wind power generation which is allowed to be safely installed at the targeted power system. The installation procedure is the same for WPT installed either to the strong or weak power system, the only minor difference is in the step two of the installation procedure which mention in above.

The simulation result provided by this paper is based on the full generation capacty of wind power turbine, the reason to do this is to make it possible to verify stability of whole power system under the most dangerous condition. If the wind power system and connected power system are able to sustain from the impact by the full generation that is driven from the full wind condition, then it is possible to be say the WPT will able to sustain any influence that caused by the other wind speed conditions. From this concept, the result from this paper is vaulable and can be used in real practical applicaton.

This paper only presents the result of computing simulation to the readers, but in reality, some factor which affect the practical situation have not been mentioned in this research. For example the wind speed condition at the targeted installation site. Although the wind condition at the targeted site is able to be estimated by computational model, the detail of the wind speed characteristics still remain as a complex problem. The characteristc of land shape and turbulent wind flow will affect on our simulation result, but this is usually ignored by the research in the WPT installation problem; and this also is not mentioned in this paper. Sometimes it is possible to increase the WPT generation by considering the land shape in the targeted installation site. Different sections of the land shape will provide different wind speed conditions, and this will lead to different amount of WPT generation available in different sections of the targeted power system. This could be the next research topic for the authors to investigate.

References:

[1] Zulati Litifu, Ken Nagasaka, Yasuyuki NEMOTO, Izumi Ushiyama, “Optimal Arrangement Of Wind Power Turbine On Complex Land Considering Economical And Environmental Efficiency”, Proceeding of International Conference on Renewable Energy, Chiba, Japan, 2006.

[2] Zulati Litifu, Ken Nagasaka, C. Kelvin, "Applicable Installation Method of Wind and Solar Power in Power System," Power Society (IEEE), PSO-7803-8465-2. Jun, 2003.

[3] Zulati Litifu, Noel Estoperez, Ken Nagasaka, “Improving the Reliability of a Weak Power System by Introducing Wind Power Generation,” International Journal of Electrical and Power Engineering, Medwell Journals, Vol. 1, No. 1, pp. 28-35, 2007

[4] Zulati Litifu, Ken Nagasaka, Yasuyuki NEMOTO and Izumi USHIYAMA, “Innovative Methodology for Planning and Installing Wind Power Generation in a Rural Power System,” Submitted and under review by International Journal of Electrical Power and Energy System (IJEPES), May. 2007.

[5] Zulati Litifu, Ken Nagasaka, "Steady State and Transient Operation Analyses of Wind Power System", International Journal of Electrical Power and Energy System (IJEPES), Vol. 27. pp. 284-292, May. 2005.

[6] Zulati Litifu, Noel Estoperez, Mostafa Al Mamun, Ken Nagasaka, Yasuyuki Nemoto, Izumi Ushiyama, “Introduction of MWPT and MHPP into A Rural Power System by Developing Weak Natural Energy”, WSEAS Transations on Environment Development, USA, Vol. 2, Issue 6, pp. 719-728. , June, 2006.

[7] Shu-Chen Wang and Pei-Hwa Huang, “Description of Wind Turbine Power Curve via Fuzzy Modeling,” *WSEAS Trans. on Power Systems*, Vol. 1, No. 5, pp. 786-792, 2006. (EI) (ISSN 1790-5060)

[8] Zulati Litifu, Ken Nagasaka, Yasuyuki NEMOTO and Izumi USHIYAMA, “A Research on Electric fluctuation and System Limitation of Wind Power Generation in a Weak Power System,” International Journal of

Electrical and Power and Engineering (IJEPE), Vol. 2, No. 1, January 2008.

[9] Shu-Chen Wang and Pei-Hwa Huang, "Fuzzy c-means clustering applied to direct power system coherency identification," *WSEAS Trans. on Power Systems*, Vol. 1, No. 9, pp. 1634-1640, 2006. (EI) (ISSN 1790-5060)

[10] Shu-Chen Wang and Pei-Hwa Huang, "Power System Output Feedback Controller Design Using Fuzzy C-Means Clustering Reduced Model," *WSEAS Trans. on Systems*, Vol. 6, No. 3, pp. 475-480, 2007. (EI) (ISSN 1109-2777)

[11] Shu-Chen Wang, Pei-Hwa Huang, and Chi-Jui Wu, "Application of Fuzzy C-Means Clustering in Power System Model Reduction for Controller Design," *Proceedings of the 5th WSEAS International Conference on Computational Intelligence, Man-Machine Systems and Cybernetics (CIMMACS '06)*, pp.223-227, Nov. 20-22, 2006. (EI) (ISSN 1790-5095) (ISBN 960-8457-56-4)

Biographies:

Jeff Huang received the B.S degree in electrical engineering in 2005 from the University of New South Wales, Australia. He is currently the student in the Tokyo University of Agriculture and Technology. His research interests include wind power system application, renewable energy application, electricity industry restructuring.

Zulati Litifu was born in July 15, 1959 in Xingjiang, China. He obtained his B.S, M.S and PhD degrees in Electrical Engineering from Xingjian University (1982), Huazhong University (1998) and Tokyo University of Agriculture and Technology (2004). He worked as a Associate Lecturer (1982-1987), Assistant Professor (1987-1996), Associate Professor (1996-present) at Xingjiang University He is a Visiting Scholar in Department of Mechanical Engineering of Ashikaga Engineering University of Japan (2000-2001). Special Lecturer (2004-2005), Special Researcher (2005) in Tokyo University of Agriculture and Technology. Presently, he is a Special Researcher of Japan Society for Promotion of Science (JSPS).

Ken Nagasaka was born in Kermanshah (Iran) in 1956. He obtained his B.S, M.S and PhD degrees in Electrical Engineering from Nihon University (1985) and Tokyo Metropolitan University (1987, 1990), Tokyo, Japan. He worked as a Chief Researcher for Computer Software Development Company, Tokyo, Japan (1990-1991). He became a Visiting Professor at the University of Manitoba, Winnipeg, Canada (1991-1994). Then he worked as a Scientist at the Central Research Institute of Electric Power Industry (CRIEPI), Tokyo, Japan (1994-1998). He worked as an Associate Professor at the Department of Electrical Engineering of Tokyo Metropolitan University (1995-1998). Currently, he is an Associate Professor of Graduate School of Engineering at Tokyo University of Agriculture and Technology. Prof. Nagasaka has published more than 370 scientific papers and one of his papers won a Paper-Prize of the Institute of Electrical Installation Engineers of Japan in 1991. Prof. Nagasaka also obtained three awards from the PSC in 2001, 2002 and 2006. Also in 2006, he received the Medal of the University of Tehran for his contribution to the First Conference of Control and Management of Energy Systems. His current research projects concern environmental energy engineering particularly power system analysis, power deregulation, wind power, micro-grid, load forecasting, and application of intelligent systems to power systems. Prof. Nagasaka is a member of IEE, IEIE of Japan and a member of IEEE, International Neural Network Society of U.S.A.