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OPERATION ANALYSIS OF DISTRIBUTION FEEDERS WITH WIND POWER GENERATION

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ABSTRACT
This paper investigates the impact of wind power generation to the distribution systems. The seasonal wind power generated by the wind turbine is calculated by applying the exponential rate and Weibull possibility distribution model according to the actual minutely wind speed data in Hengchun area in Taiwan. The mean value and standard deviation of seasonal wind power output are determined for the design of load shedding scheme when the distribution feeder has been isolated for the islanding operation. A practical distribution feeder of Taiwan Power Company (TPC) is selected for the computer simulation of micro grid system with wind power generator. For the normal operation of test feeder, the system voltage variation is derived by considering the daily load profile of test feeder with wind power generation. For the permanent fault in distribution system, the load shedding scheme is developed for the islanding micro gird so that the stable operation can be restored with the proper pitch angle control of wind power generator.

KEY WORDS
Wind power, distribution system, Weibull.

1. Introduction

With the shortage of fossil energy resources and the consideration of environmental protection to reduce the green house effect introduced by the conventional thermal power generation, the government in Taiwan has set the goal to increase the percentage of renewable generation up to 10% of total generation capacity or 5139 MW by year 2010. As compared to the centralized power generation with large nuclear or thermal units, the dispersed generation (DG) has the advantage of modulated, shorter commission time and it is more close to the load center. With the integration of DG in distribution systems, the power flow may be generated by the small units of photovoltaic or wind power generators, etc, which may introduce the problems of power quality, relay protection, and islanding operation. Besides, the intermittent power generation by DG may impact to the stable operation of power systems. Up to now, there are 181 units of wind power generators (WG) have been installed by Taipower with total capacity of 336 MW. Besides, the independent power producers (IPP) have installed wind power generators with another capacity of 142 MW too. It is estimated that total capacity of 2160 MW will be provided by wind power generators at year 2010 to ensure that 10% of total system generation capacity can be contributed by renewable energy in Taipower. Taiwan is an island state with large wind power resources, especially along the coast of west corridor. To promote the wind power generation, Taipower is revising the tie line regulation and allow the large unit wind power generators to be connected to the distribution feeders directly after executing the system impact analysis to verify the harmonic distortion, voltage sag and drop, load carrying capability, etc.

With much less short circuit capacity and power loading of distribution system as compared to the transmission system, the installation of wind power generator at distribution feeder has to be analyzed. In this paper, the power generation by wind power generators has been simulated according to the mean value and standard deviation of wind speed. A distribution feeder in Taipower has been selected for computer simulation to investigate the transient dynamic response of wind generator for system fault contingency. The proper load shedding has been determined to maintain the stable operation of wind power generators for the islanding operation to serve the critical loads.

2. Wind Power Generator

The wind turbine is used to covert the wind energy into rotating mechanical energy, which can be expressed as the cubic of wind speed in (1):

$$P_m = C_P(\lambda,\beta)\frac{\rho A}{2}v^3 \tag{1}$$

where C_P : coefficient of power conversion

ρ : air density

A : projected airfoil area

V : wind speed

λ : ratio of surface velocity to the wind speed β：angle of the blade

In this paper, a double fed wind generator has been used to connect to the distribution feeder and Fig. 1 shows the configuration of the wind generator. The step up transformer (670V/11.4kV) is applied to tap the output power of the generator to the distribution feeder. Figure 2 shows the relationship of mechanical output power (P_m) and rotating speed of generator at different wind speed. With the variation of wind speed, the power converter of the rotor winding is applied for the speed adjustment of induction generator. By this way, the output mechanical power of the wind turbine will be determined by the loci as shown by A B C D E and F. Figure 3 shows the electric power output vs. the wind speed. The cut in wind speed is 3m/sec and the pitch angle control has to be applied when the wind speed exceeding 14m/sec, so that the rated power output of wind generator can be obtained without being over loaded.

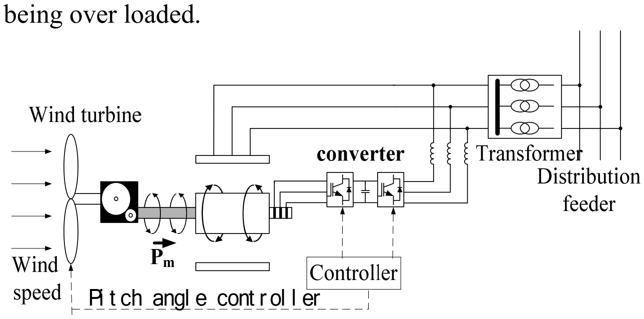

Figure 1. Configuration of double fed induction generators

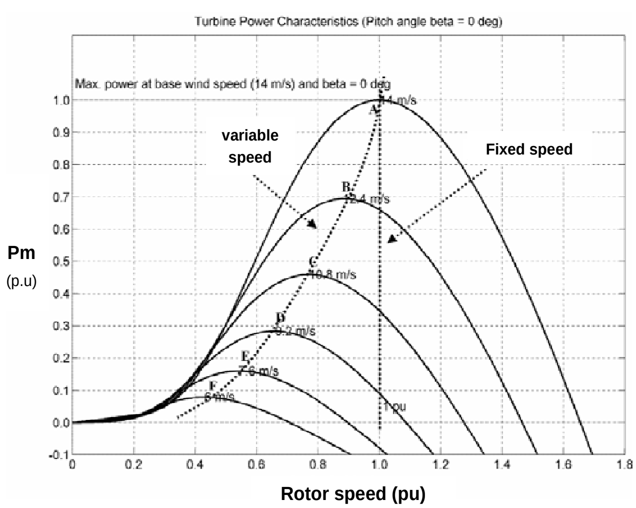

Figure 2. Mechanical output power of wind generators

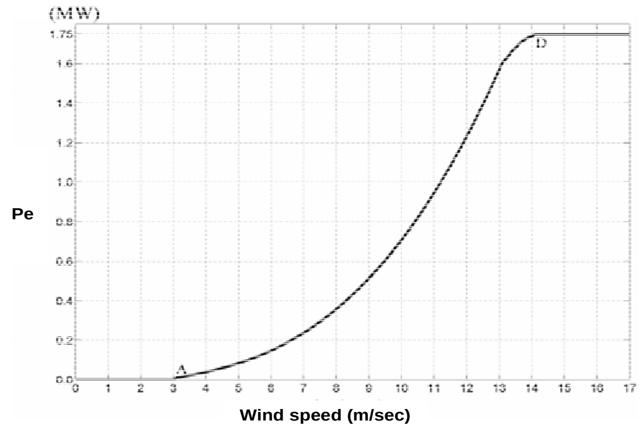

Figure 3. Electrical output power of wind generators

3. Probability Distribution of Wind Speed

The wind speed is introduced by the air flow which will be affected by the roughness of land surface and buildings. The wind speed at height of X can be expressed as Eq(2).

$$V(X) = V(X_{ref})(\frac{X}{X_{ref}})^{\alpha} \qquad (2)$$

where α is the roughness index of land surface, X_{ref} is the height of wind monitoring station as shown in Fig. 4.

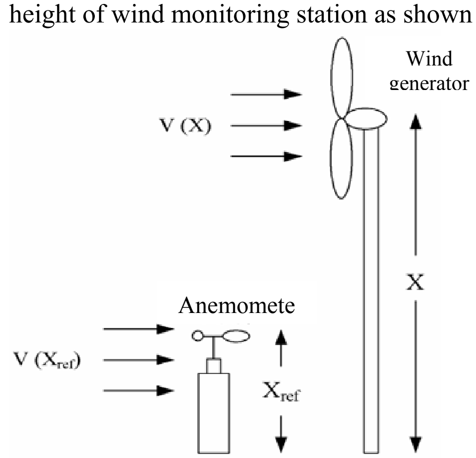

Figure 4. Wind speed calculation for wind generator

With the stochastic distribution of wind speed, the Weibull distribution is used in this paper to represent the wind speed modeling because it can cover a wider variety of wind regimes. The Weibull probability density function is given by Eq (3), where K is the shape factor and C is a scale factor.

$$P(V) = (\frac{K}{C})(\frac{V}{C})^{K-1} \exp[-(\frac{V}{C})^{K}] \qquad (3)$$

The wind speed has been collected over one year period at Hengchun area in Taiwan, at where wind generator is to be installed. Figure 5 shows the variation of wind speed at height of 70m. It is found that the wind speed is larger for the months from Oct. to April as compared to the months from May to Sep. Fig. 6 shows the Weibull probability distribution of wind speed for the winter season with shape factor K=1.8 and mean value of wind speed $\overline{V}$ =6.9 m/sec.

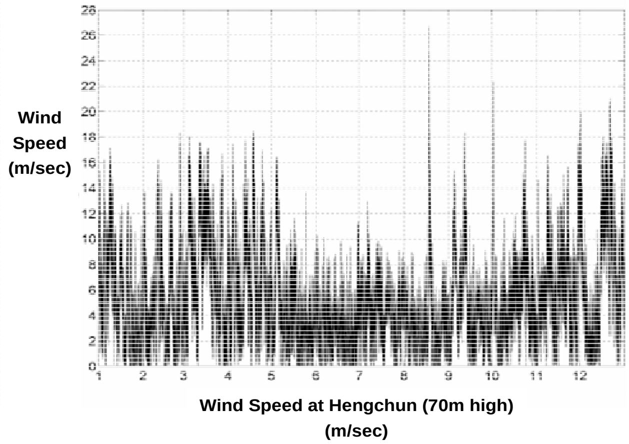

Figure 5. Wind speed at Hengchun (70m high)

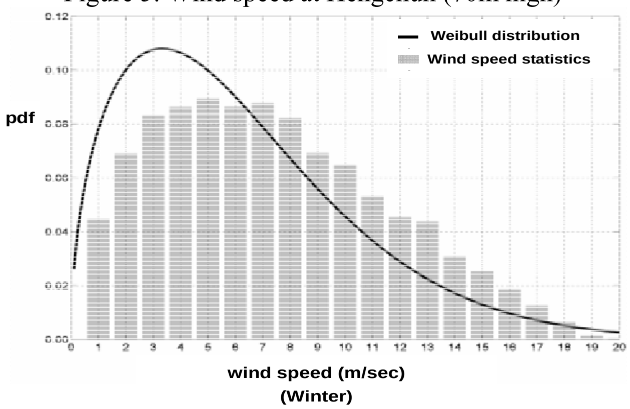

Figure 6 Weibull distribution of wind speed (winter)

4. Computer Simulation of Distribution Feeder

To study the transient dynamic analysis of distribution system with wind power generators, a distribution feeder BX31 in Taipower has been selected for simulation as shown in Fig. 7. It is a 11.4kV overhead feeder which serves the mixture loading of industrial and residential area. Figure 8 shows the daily power loading profile of the test feeder. A double fed induction wind generator (DFIG) has been installed at the end of the feeder with the rated values of capacity of 1.75MW. To simulate the power output of wind generator, the daily wind speed of 2006.12.10 has been recorded as shown in Fig. 9. The maximum wind speed is 17.8m/sec and the minimum wind speed is above 10m/sec. The power output of the wind generator has been solved as shown in Fig. 10 according to the wind speed. It is found that the power output has been limited as the rated value of 1.75 MW when the wind speed becomes larger than 14m/sec.

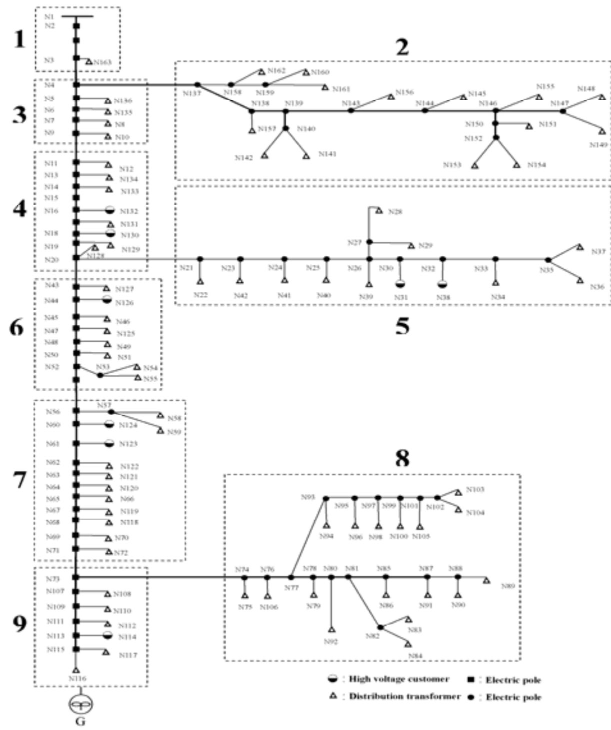

Figure 7. Configuration of test feeder BX31

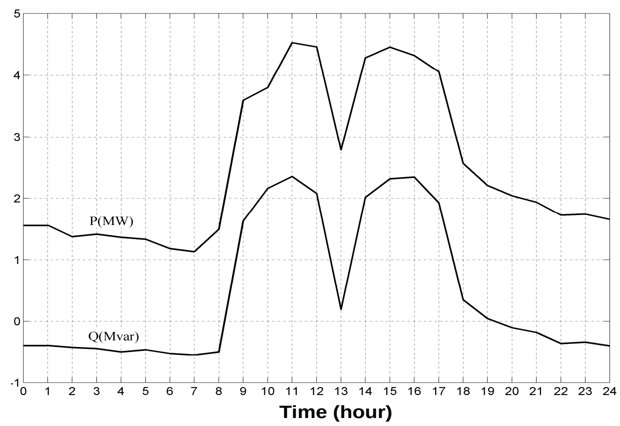

Figure 8. Daily load profile of test feeder BX31

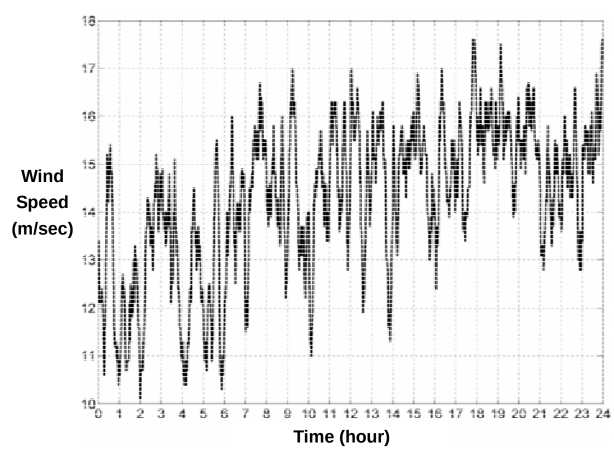

Figure 9. Daily wind speed profile

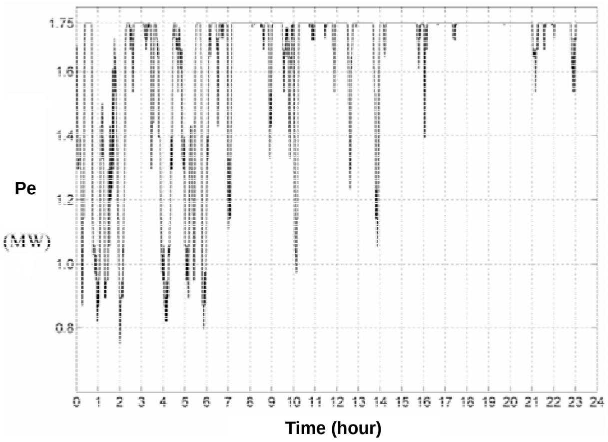

Figure 10. Daily wind power generation

4.1 Voltage Variation of Test Feeder

To investigate the voltage variation of the distribution feeder with daily loading in Fig. 8 and wind power generation in Fig. 10, the load flow analysis has been executed in this paper. Figure 11 shows the voltage level at the end of the feeder. Without the wind generator, the voltage has been reduced to be 0.96pu for the system peak loading at 11AM and 3PM. With the voltage control provided by the wind generator, the voltage profile has been improved with the reactive power compensation.

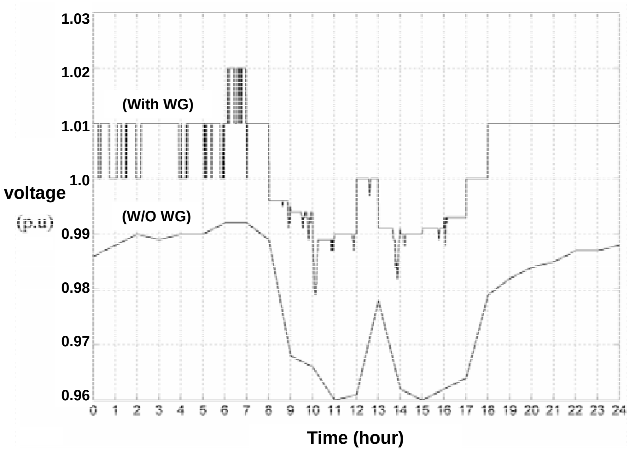

Figure 11. Voltage variation of test feeder

4.2 Transient Stability Analysis for Fault Contingency

To support the micro-grid operation of distribution feeder with wind generators, various fault contingencies have been studied in this paper. Figure 12 gives a simplified distribution feeder with wind generator. Two study cases have been executed to know the impact of wind generator on the dynamic responses of distribution when a fault contingency occurred.

4.2.1 Case 1

In this case, a 3-ϕ fault occurs at Bus B1 and is cleared by Breaker 2 after 0.28 second. The transient response of the feeder with and without the installation of synchronous condenser (SC) has been executed by Matlab/Simulink. Figures 13 and 14 give the terminal voltage and the power output of the wind generator, respectively. Without the installation of SC, the terminal voltage can recover more quickly and the output power can reach the stable value of 1.37 MW after little oscillation for 2 seconds. With the installation of SC, the terminal voltage oscillates between 0.4 p.u. and 0.85 p.u. and restores to 1.0 p.u. after 2 seconds. In addition, the power output of wind generator is varied greatly and recovered slowly as compared to the case without the installation of SC. Due to the long fault clear time, the dynamic responses have been deteriorated when the SC is installed in the system.

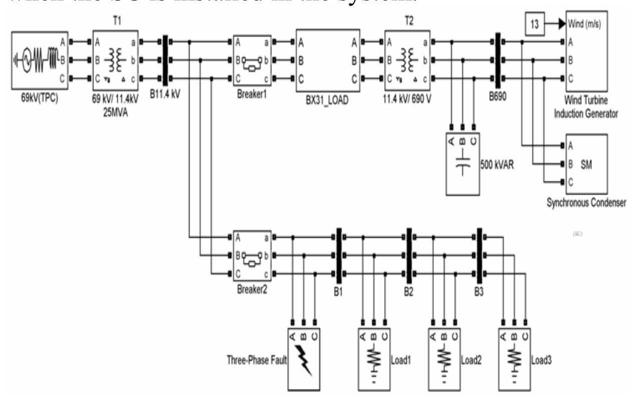

Figure 12. Configuration of distribution feeder with wind generator

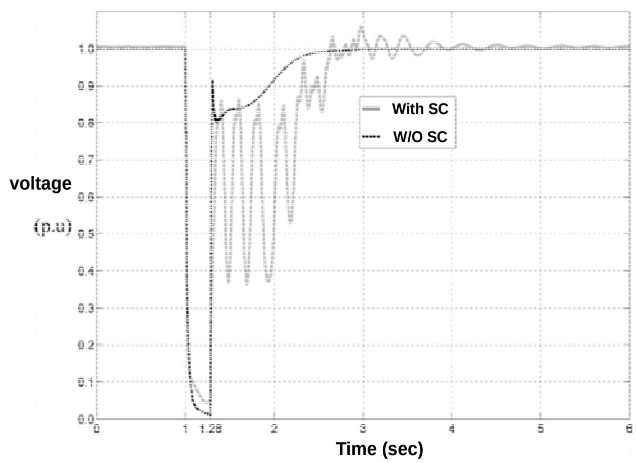

Figure 13. Terminal voltage of wind power generator (Case 1)

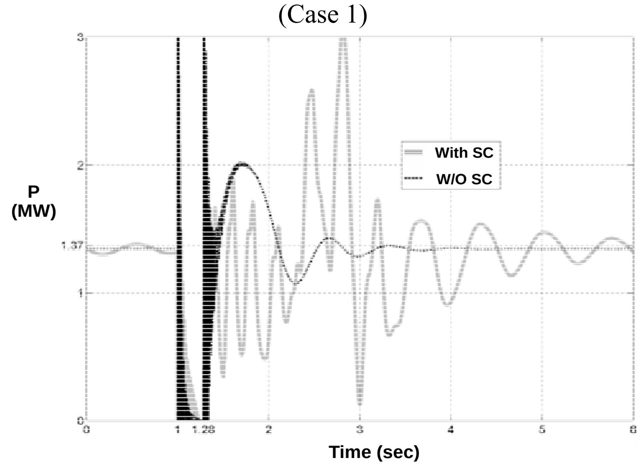

Figure 14. Power output of the wind generator (Case 1)

4.2.2 Case 2

For the permanent fault at B11.4kV in Fig. 12, the Breaker 1 is opened for fault isolation after 0.25 seconds. With the peak loading of 4.0 MW for the feeder and wind power generation of 1.0 MW, the load shedding has to be executed to prevent the collapse of the islanding system. Figure 15 shows the terminal voltage of the wind generator. After opening the Breaker 1, the first stage load shedding is activated to disconnect 2.43 MW of loads. The terminal voltage is increasing and then starts to decrease. The second stage and third stage of load shedding are activated at 0.42 sec and 0.62 sec after the fault with load of 0.56 MW to be disconnected respectively. By this way, the terminal voltage has been restored to be 0.95 pu at one second after the fault. Besides, the pitch angle control of wind turbine has been performed to restore the stability of rotor speed as shown in Fig. 16. After the transient disturbance, the power output of wind generator reaches the stable value of 0.45 MW as shown in Fig. 17.

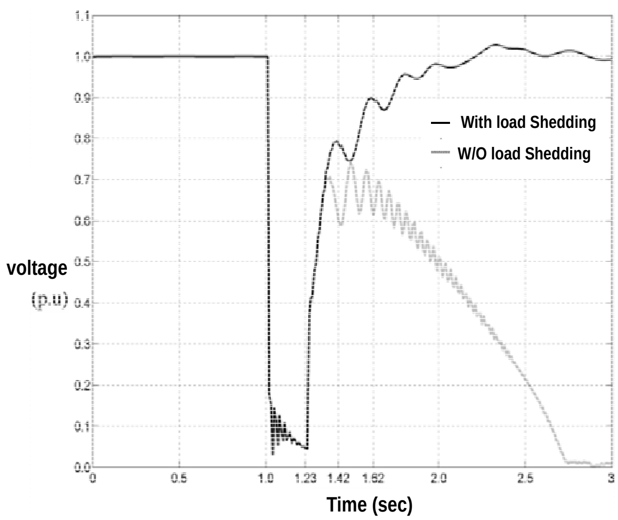

Figure 15. Terminal voltage of wind generator (Case 2)

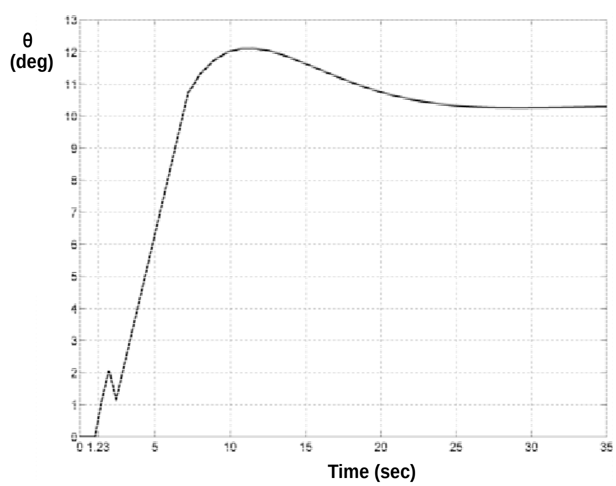

Figure 16. Pitch angle of wind turbine (Case 2)

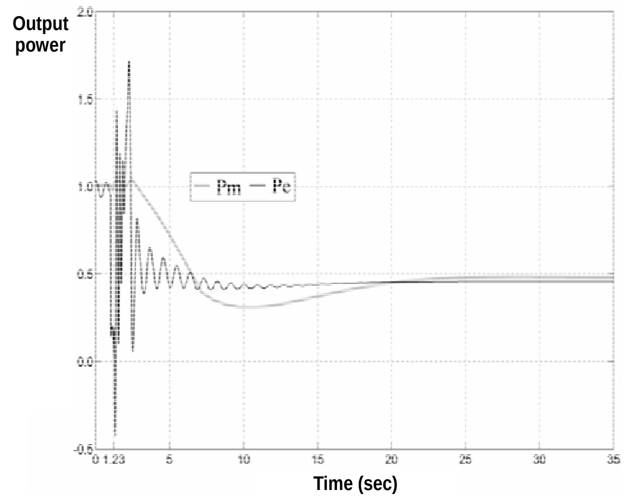

Figure 17. Output power of the wind generator (Case 2)

5. Conclusion

In this paper, the wind speed at the planning site of wind power generator in Taipower has been recorded over one year period. The Weibull probability distribution is then applied to represent the profile of wind speed. The modeling of a double fed induction wind power generator (DFIG) is considered with the power generation according to the wind speed. To investigate the impact of wind generators to distribution system operation, a practical distribution feeder in Taipower has been selected for computer simulation. By installing the wind generator at the end of the feeder, the voltage variation has been solved by load flow analysis based on the feeder loading and wind power generation. It has been illustrated that the voltage drop problem can be improved with the power injection by the wind power generator. To study the dynamic operation of distribution systems with wind power generators, the transient stability analysis of test feeder has been executed by including the mathematical modeling of wind generators in the simulation of Matlab/Simulink program. For a fault contingency of test feeder, the oscillation of terminal voltage of wind power generator during the transient period has been solved, which can be used to define the ride through Capability of wind power generator. For a permanent fault at the outlet of test feeder, the islanding operation of isolated power system has been formulated after the tripping of feeder circuit breaker. After the execution of three stages of load shedding scheme and control of pitch angle of wind power generator, the microgrid becomes stable to maintain the power service of critical loads in the distribution feeder.

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