Project Planning for Small and Medium Scale Industries No.28

Wind Power Generation Plant

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JAPAN CONSULTING INSTITUTE

This technical brochure was compiled to help in the drafting of a suitable plan for the construction of a Wind Power Generation Plant.

The production scale and manufacturing process have been described in this brochure on the basis of a typical instance.

The profitability was estimated by fixing certain required conditions, which may differ from country to country.

We hope that the data contained in the brochure will help you to draw up the most suitable plan for the industrialization of your project.

In case a government or public organization requests the Japan Consulting Institute to conduct a feasibility study of the above industry for the purpose of establishing the most suitable plan, it is possible for us to carry this out free of charge.

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1. Introduction

Since the oil crises of the 1970s the depletion of natural reserves of coal, petroleum, and other fossil fuels has become a matter of major concern throughout the world, prompting vigorous efforts for development of alternative sources of energy.

The wind energy conversion system, which takes advantage of wind power, one of the natural energy sources, has come to attract renewed attention as a method of electric power generation free of pollution.

The wind energy conversion system progressed by leaps and bounds since the latter half of the 1970s, when engineering endeavor to devise modern wind power generation plants gathered momentum principally in the U.S. and Europe improving windmill technology already available.

Going into the 1980s many large-scale windfarms were constructed in California, U.S.A., among other places, the installed wind power generating capacity there now reaching 1,400MW. In Europe, Australia, India, and many other countries as well, the wind power plants are being planned or already in practical use.

Broadly, the wind power plant, or the wind turbine generator as is commonly called, has found applications in the following two forms.

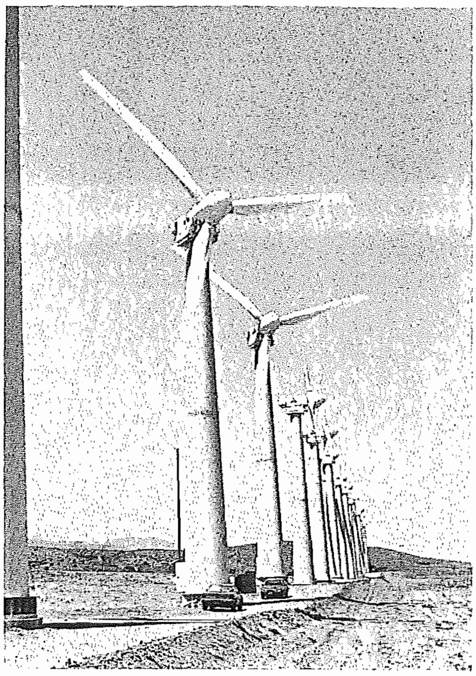


Photo 1. Wind Power Generation Plant

(1) A large-scale windfarm employing several tens to as many as several hundreds of wind turbine generators, which is constructed for the purpose of generating and selling electricity to utility companies.

(2) A small wind-electric installation consisting of only one or several turbine generators at most, which is constructed for remote area or remote island supplying electric power needs of limited population or small industrial plant.

In either instance, employing the wind power generating system can be said to offer the following advantages.

① The use of clean energy source rather than the fossil fuel eliminates the possibility of environmental pollution.
② Utilizing the wind energy contributes to the conservation of fossil fuels.
③ Easy to operate and maintain, the wind-electric plant can serve as accessible and economical means of generating electricity.

The wind turbine generator can be constructed even on barren lands not suitable to the farming, for use in electrified farm-water pumping, etc. thereby serving to promote the regional development.

2. Mechanism of Wind Power Generation and Plant-site Conditions

2.1 Wind Turbine Type Variations and Design Features

2.1.1 Wind turbine type variations

Broadly, the wind turbine types can be classified into the vertical-axis and horizontal-axis types depending on the position in which the rotor shaft is installed.

The vertical-axis types include the Paddle type, Savonius type, Darrieus type, etc.: the horizontal-axis types include the Dutch four-arm type, Multiblade type, Propeller type, etc. (refer to Fig. 1)

The wind turbine operates on the kinetic energy of the wind to drive the generator. However, the density of wind kinetic energy is low at about 75 W per 1 m^2 with the wind speed at 5 m/s and about 600 W per 1 m^2 with the wind speed even at 10 m/s: the power factor (the ratio of recovered energy to the kinetic energy of the wind with a wind turbine of ideal aerodynamic efficiency) is said to be 0.593 with a wind turbine of ideal aerodynamic efficiency at the maximum, as indicated in Fig. 2. When employing the wind turbine for power generation, therefore, how efficiently the machine can collect the kinetic energy of the wind is an important consideration.

The propeller type machine is excellent in aerodynamic characteristic and capable of efficiently collecting the kinetic energy of the wind. Also, being simple in construction, the propeller type wind turbine generator can easily be redesigned and built larger in size and, besides, permits its output to be easily controlled.

The propeller type machine, therefore, now constitutes the mainstream of wind turbine generators and is employed in great numbers ranging in capacity from several watts to several megawatts of power generation. But the propeller type requires to be kept faced in the direction of prevailing wind and hence has to be equipped with the driving unit suitable for that purpose.

The vertical-type Savonius, Darrieus, and other machines are also in use for power generation but are almost invariably limited in capacity, ranging from several watts to several kilowatts.

The Darrieus type, however, has recently undergone engineering improvements, so its larger versions have come to be constructed for power generation.

The vertical units, being omnidirectional, do not require to be turned following the change in wind direction but leave more to be improved as regards the efficiency and starting characteristic.

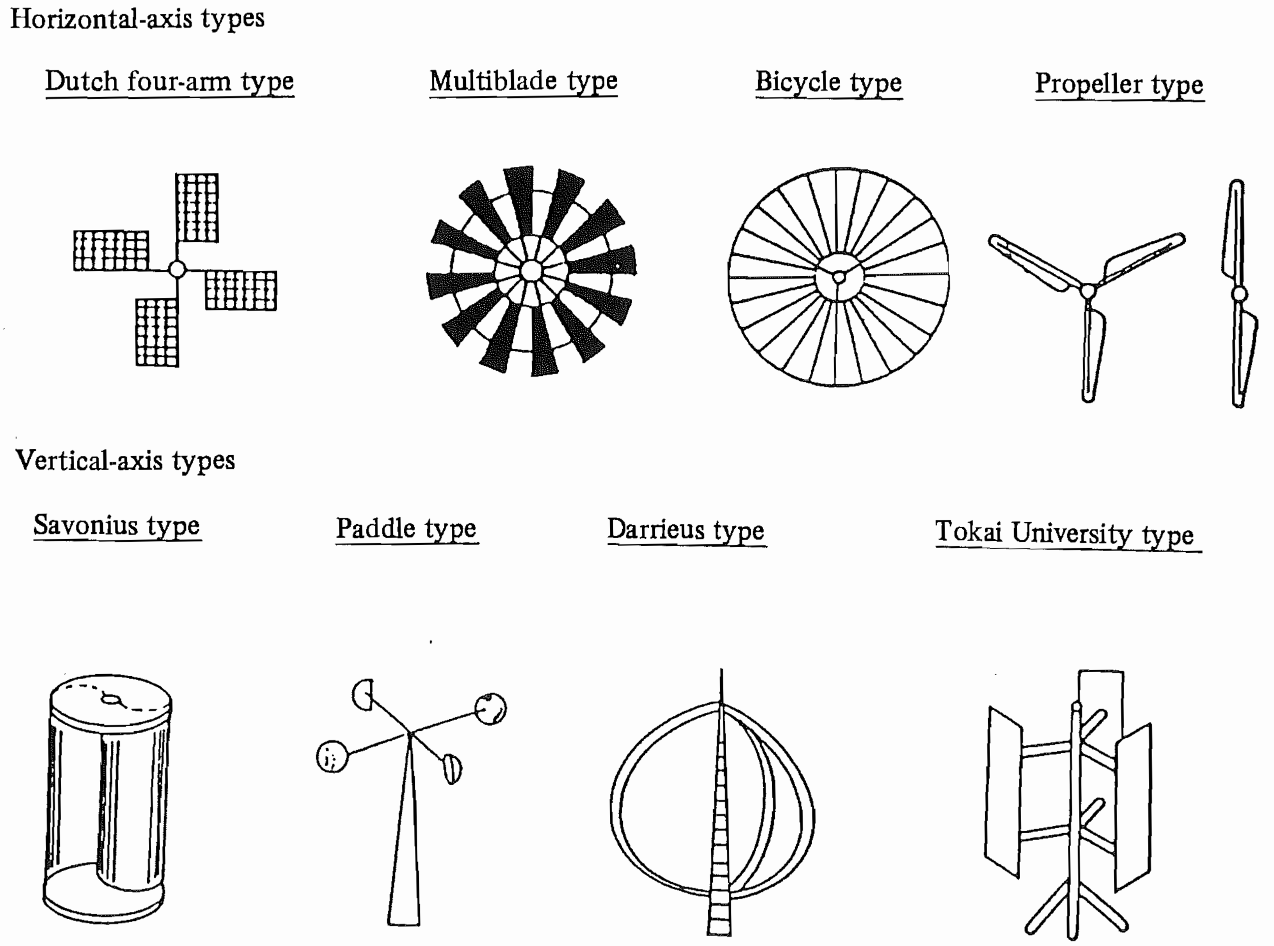


Fig. 1 Wind Turbine Type Variations

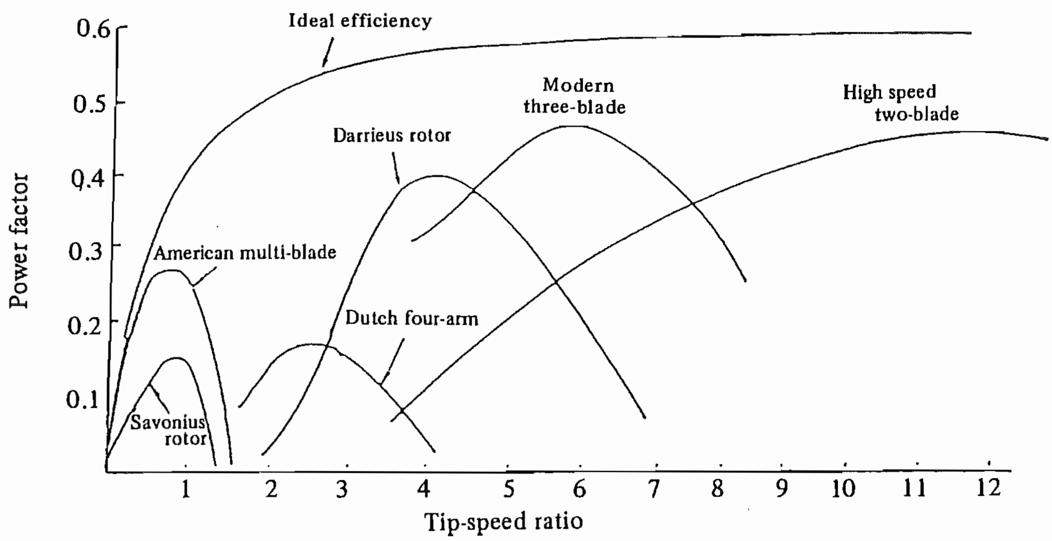


Fig. 2 Wind Turbine Type of Power Factor

2.1.2 Type classification by location of rotor

The horizontal-axis machines can be divided into the downwind type and upwind type depending on the location of rotor relative to the support column, or tower. The downwind type is employed principally for small units, while the upwind design becomes predominant as the machine size increases.

(a) Downwind type

The rotor is located on the downwind side of the tower, enhancing nacelle-wind directional controllability (matching of the nacelle with the direction of wind). Therefore, the yaw control system (a drive system that turns the nacelle in keeping with changing direction of wind) is either not required or can be designed small in capacity.

(b) Upwind type

The rotor is located on the upwind side of the tower. Although the yaw control system commensurate with the size of machine is required for nacelle-wind direction control, the rotor, being located on the upwind side of the tower, is not affected by the tower wake and thus offers an advantage of reducing the rotor blade stress fluctuation, noise, etc.

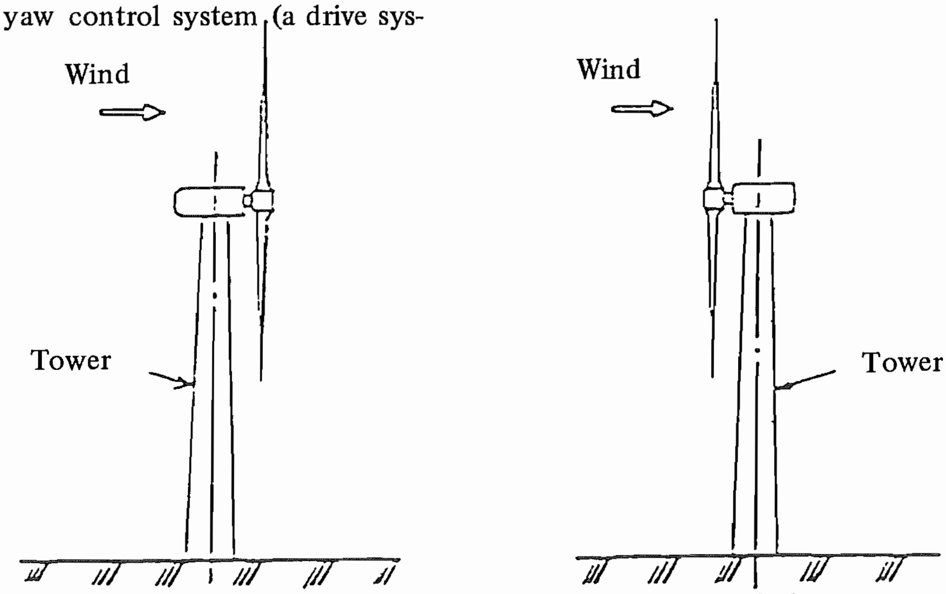


Fig. 3 Type of Downwind and Upwind

2.2 Mechanism of Wind Power Generation

The mechanism of power generation with the propeller type wind turbine generator, which is the mainstream of wind power generating plants is as follows.

The propeller type wind turbine generator consists of ① the blades which collect wind energy, ② the nacelle consisting of the rotor, the speed-increasing gear, the generator, the yaw control system, etc., and ③ the tower that carries the nacelle.

The kinetic energy of the wind is collected by the rotor blades as rotational energy, which is then transmitted to the rotor head, the main shaft, speed-increasing gear, and flexible coupling, to drive the generator for power generation.

(1) Nacelle construction

The nacelle contains the aforementioned equipment plus the blade pitch control mechanism in the case of pitch control type.

Generally, maintenance work of each equipment contained in the nacelle is carried out in the nacelle. The nacelle, therefore, is designed with adequate working space inside and the equipment housed in it are arranged compactly, yet with consideration toward minimizing the outside dimensions.

Also, for the medium- and large-sized wind turbines and the upwind type turbine which require the nacelle-wind direction control system, a yaw bearing is provided at the connection between the nacelle and tower so that the nacelle with the rotor can be turned by the yaw control equipment following the change in wind direction.

(2) Power generating system

Natural wind constantly changes its speed, causing the rotor to change its rpm in response. Therefore, when the synchronous generator is employed, it is necessary to control the rotor rpm by the function of the blade pitch control system.

Since completely controlling the rotor rpm in the changing wind speed is extremely difficult, however, the DC link system is employed in many instances, which enables the AC current from the synchronous generator to be converted into DC current and reconverted back into the AC current again by means of inverter with the current controlled to constant voltage and frequency by the inverter.

Also, in cases where the induction generator is employed, parallel operation with an integrated utility system is prerequisite. In such an instance, the rotor rpm should be in a range so that the frequency attained may accord with the utility system frequency.

Although the abovementioned provision prevents the rotor rpm from fluctuating due to change in wind speed, the changing wind speed directly results in changing power output. In the high wind speed region, therefore, the power output has to be controlled to within the rated level.

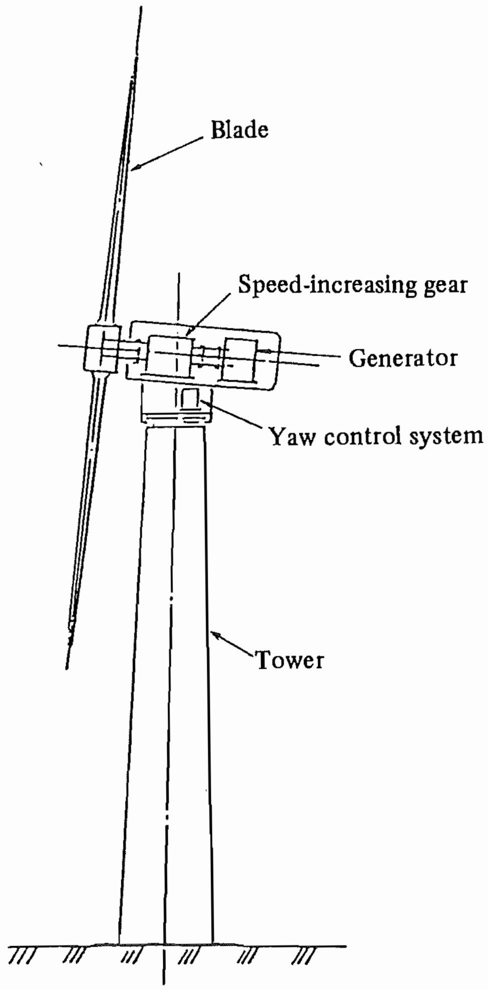


Fig. 4 Propeller Type Wind Turbine Generator

2.3 Site Conditions

(1) Wind and weather conditions at site

The wind power generating plant is meant to serve the purpose of transforming the kinetic energy of the wind into electric energy. When constructing the wind power generating installation, therefore, the state of winds blowing at the projected construction site requires to be thoroughly evaluated to make sure that the suitable wind for starting and operating wind speed and rated wind speed is available at all times with the stability in wind direction. It is to be fully realized that the amount of electricity generated by the plant and the economics that goes with it vastly vary with the state of winds blowing at the site.

When constructing the wind power plant in a frigid area, successful starting of the plant has to be ensured by protecting the equipment against freezing, providing the governor-oil and lubricant-oil pipelines with adequate thermal insulations, etc.

(2) Power generating system

The wind power generating plant operates on natural winds, whose wind speed changes at every moment. Since the wind power plant output is proportional to the cube of wind speed, it follows that the plant power output also constantly varies with the changing wind speed.

When integrating the plant into an adjoining utility system, therefore, it is to be ensured that such a utility system is adequate in capacity not to be disturbed by the change in plant power output. Generally it is said that the utility system should have the minimum load capacity 10 times or more as large as the wind power plant rated output.

(3) Environmental consideration

Adverse environmental effects that can conceivably be exerted by the wind power plant include the jamming and noise.

Although it is said that the plant is nearly harmless in terms of jamming the radio or communication wave, its adverse effects on television or radio carrier wave are not deniable. Actually, however, the wind power installations are constructed in places far removed from residential areas where no jamming can take place in the majority of instances.

In cases where there are regulations restricting the noise, it is desirable that with the consideration toward the noise of plant operation, the plant be erected an adequate distance away from the residential area.

3. Outline of a Model Plant

3.1 Size of Windfarm

Generally, a decision on how many wind turbine generators to instal at a given construction site is function of demands for electricity existing in that district and installed power generating capacity available there, plus the state of winds at the construction site.

A study is made here of a windfarm consisting of 10 wind turbine generators rated at 275 kW each by way of example. The windfarm, therefore, has a total generating capacity of 2,750 kW in this instance.

3.2 Basic Design Conditions

An important consideration when constructing a windfarm is to engineer a wind turbine generator suitable to wind speed available at the construction site.

In other words, the engineering goal is to be set at designing and building the machine capable of a high level of efficiency in a range of low wind speed when the construction site is located in the area of relatively low wind speed: if the construction site is located in the area of high wind speed, the machine requires to be designed capable of a high level of efficiency in a range of high wind speed.

For use in the model windfarm referred to, the wind power generator was designed to suit the following conditions.

① Atmospheric temperature : 0 to 40 deg. C
② Atmospheric pressure : 1,013.3 mb
③ Air density : 1.2 kg/m^3
④ State of winds : Annual average wind speed of 7.5 m/s (wind-speed distribution was selected in accordance with Weibull distribution, with the shape parameter at 2.0.)
⑤ Seismic factor : 0.3 G
⑥ Long-term soil bearing capacity : 10 $tons/m^2$

3.3 Wind Turbine Generator

The wind turbine generator employed for the windfarm referred to is rated at 275 kW as mentioned earlier, measuring 28 m in rotor diameter. Its external views are illustrated in Fig. 5, and its outline specification is indicated in 3.3.1.

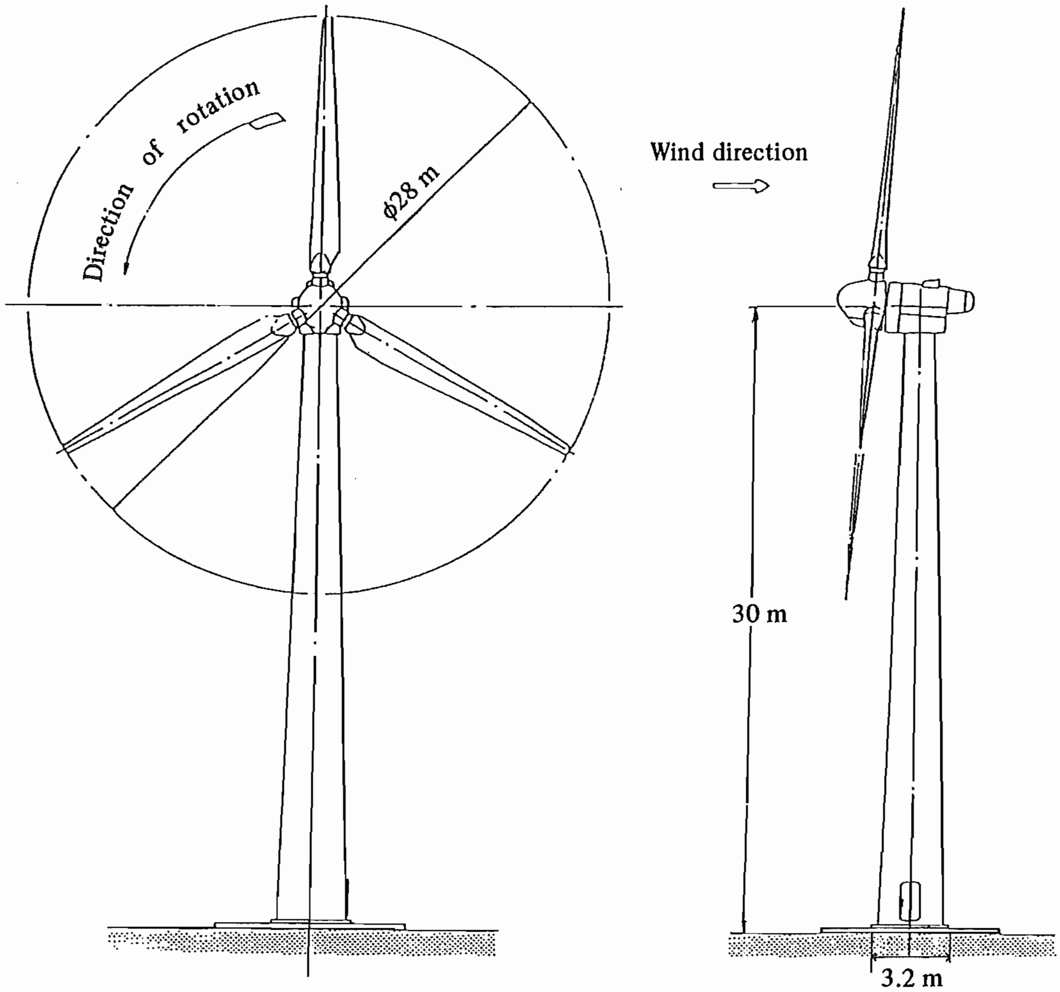


Fig. 5 275 kW Wind Turbine Generator External Views

3.3.1 **Outline specification**

The 275 kW wind turbine generator specification is outlined below.

(a) Wind turbine

Type	:	Upwind-controllable pitch blade
Rated output	:	275 kW
Rotor diameter	:	28 m
Rated rpm	:	48 rpm
Number of blades	:	3 (FRP)
Rated wind speed	:	12.9 m/s
Cut-in wind speed	:	5 m/s
Cut-out wind speed	:	24 m/s
Max. allowable wind speed	:	60 m/s

(b) Generator

Type	:	Induction generator
Rated output	:	275 kW
Voltage	:	480 V
Phase	:	3-phase
Frequency	:	60 Hz

(c) Tower

Type	:	Monopole
Height (to nacelle center)	:	30 m

(d) Control system

– Blade pitch control system

– Yaw control system

(e) Protection system (Safety interlocks)

– Overspeed

– Low governor oil pressure

– Heavy nacelle vibration

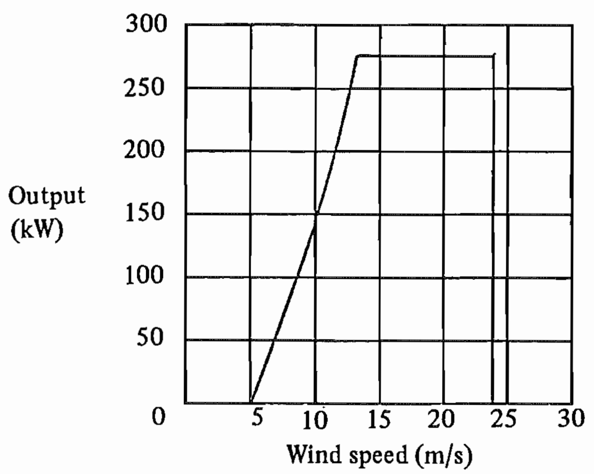
– Generator overcurrent

–Disorder control system

3.3.2 **Performance**

An expected performance curve drawn for the 275 kW wind turbine generator in the standard atmospheric condition (pressure: 1,013.3 mb and temperature: 20 deg. C) is shown in Fig. 6.

The diagram shows the relation between the wind speed and generator output. The power generation is started at the wind speed of 5 m/s, and the rated output of 275 kW is reached at the rated wind speed of 12.9 m/s: in the high-speed range beyond that wind speed, the blade pitch control is initiated so that the output can be controlled to the rated level of 275 kW. With the instant max. wind speed reaching 24 m/s, the turbine is automatically brought to a halt (cutout wind speed).



Atmospheric pressure : 1,013.3 mb
Atmospheric temperature : 20 deg. C

Fig. 6 275 kW Wind Turbine Generator Expected Performance Curve

The relation between the annual average wind speed and annual expected rate of power generation in the standard atmospheric condition (pressure: 1,013.3 mb and temperature: 20 deg. C) is shown in Fig. 7. The wind-speed distribution is in accordance with Weibull's distribution, with its figurative constant at shape parameter 2.0.

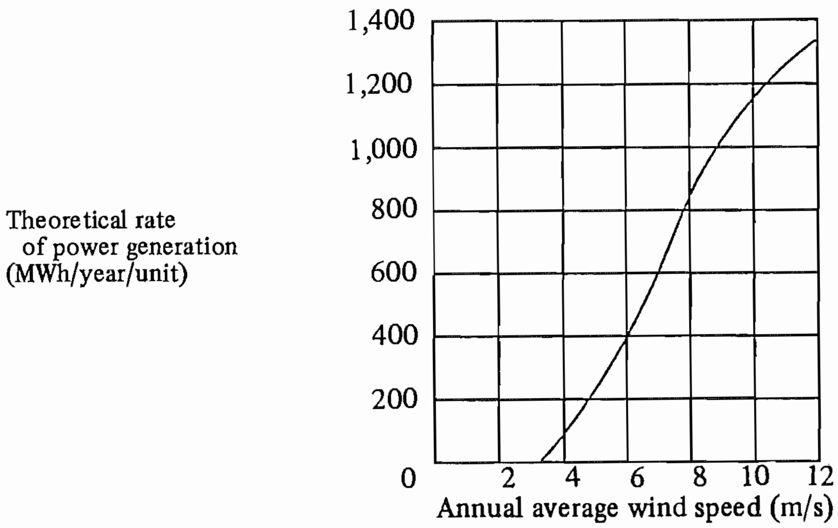
Also, the curve represents the theoretical gross output and does not include various kinds of losses. Under the model-case wind condition, assuming the annual average wind speed to be 7.5 m/s and allowing for various kinds of losses, power generation of about 600 MWh per turbine annually is expected.

3.4 Erection Procedure

The method of transporting the wind turbine generator varies with the size of machine. The small- and medium-sized machines generally are transported separately by the rotor, nacelle, tower, and control panels. The tower is divided into sections of suitable dimensions for transportation.

It therefore follows that at the construction site, all these components require to be assembled into a wind turbine generator in an efficient manner with an aid of small and heavy-duty construction machines.

For example, the 275 kW wind turbine generator erection procedure is illustrated in Fig. 8.



Wind-velocity distribution : Weibull's distribution (shape parameter: 2.0)

Atmospheric pressure : 1,013.3 mb

Atmospheric temperature : 20 deg. C

Fig. 7 Annual Expected Power Generation Curve

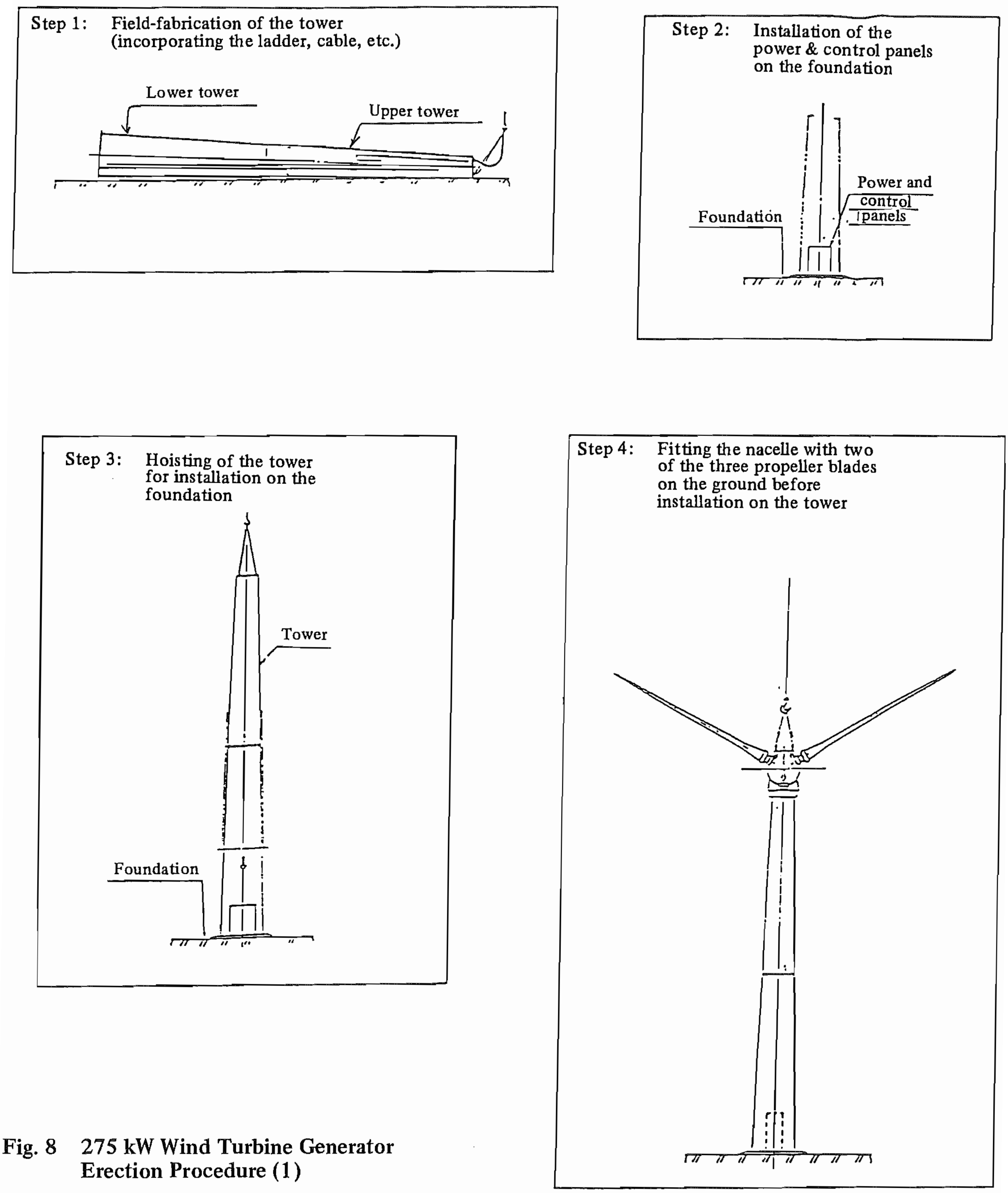
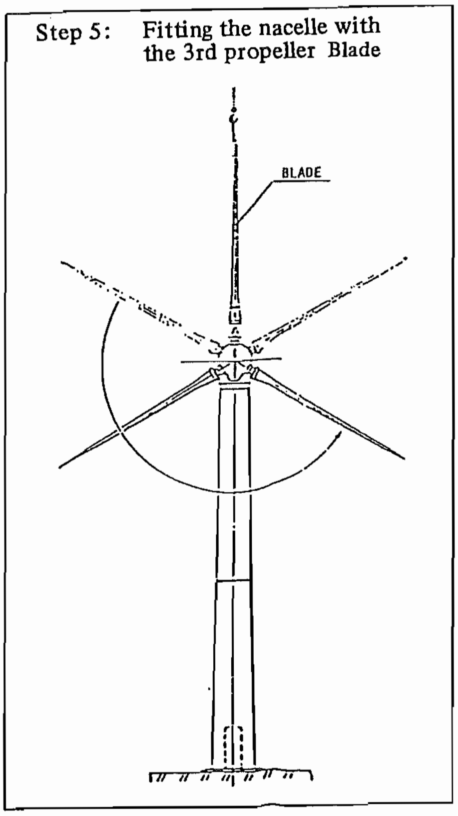


Fig. 8 275 kW Wind Turbine Generator Erection Procedure (1)



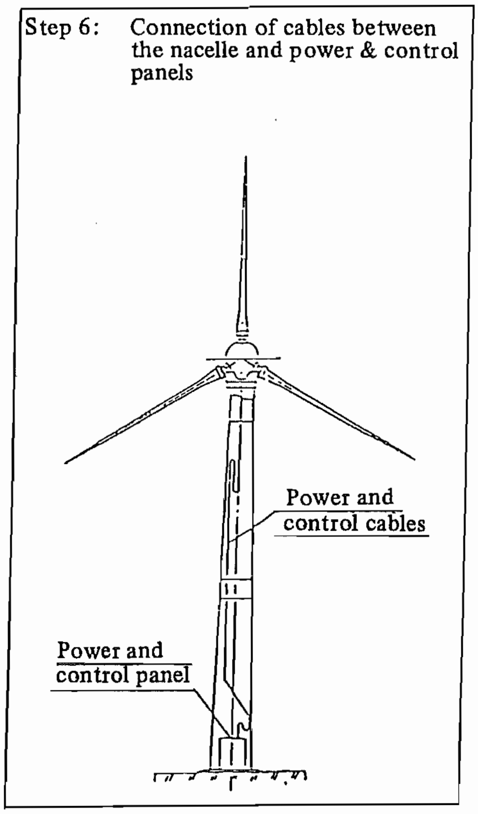


Fig. 8 275 kW Wind Turbine Generator Erection Procedure (2)

Photo 2. Propeller Type Wind Turbine Generator

3.5 Windfarm Layout

When installing many wind turbine generators, the layout of windfarm they constitute requires due consideration.

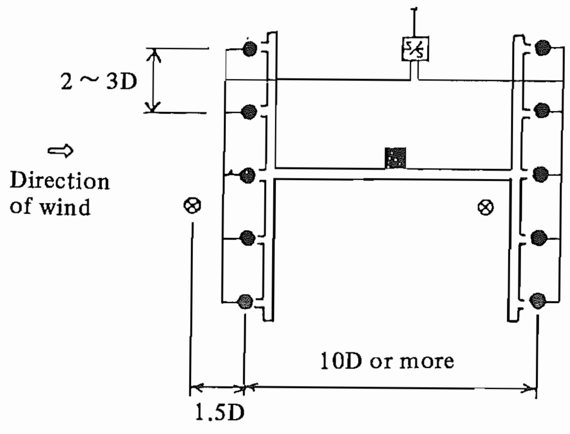
The windfarm layout is to be decided taking into account the distribution of wind directions so that the energy of winds can be exploited to the maximum possible extent.

In cases where the direction of wind is stabilized, it is a good practice to arrange the machines in lines perpendicular to the direction of wind. In this instance the machines are to be spaced by 2 to 3D side by side and to be distanced by 10D or more in the direction in which the wind blows.

When defining the direction of prevailing wind is impossible, it is deemed necessary that an adequate distance be provided between adjoining units.

Examples of model windfarm layouts with the stabilized direction of wind and otherwise are illustrated below.

(1) With stabilized direction or wind



D : Rotor diam.

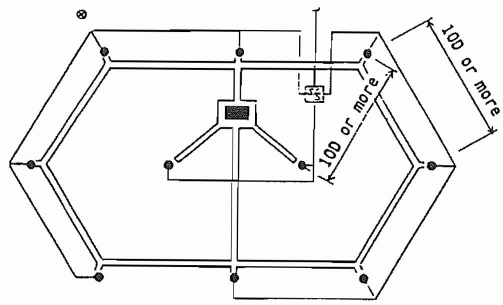
● : Wind turbine generator

⊗ : Anemoscope/anemometer

■ : Control room

⊠ : Substation

(2) With unstabilized direction of wind



3.6 Maintenance and Operation

The 275 kW wind turbine generator standard maintenance requirements and operation follow.

(1) Daily check

① Check of operation record

② Visual check of external appearances

③ Repair of disorders

(2) Monthly check and trimonthly check

The following are to be checked every month for three months from the commencement of operation and every three months thereafter.

① Visual check of external appearances (from the ground)
- Noise of operation
- Oil leakage
- Vibration

② Visual check and adjustment of hydraulic oil pressure

③ Filter check (cleaning and renewal)

④ Check of oil level for governor oil and lubricant oil

⑤ Others (safety interlock trip system)

(3) Check every six months

Check for bolt tightness by hammering or using torque wrench as necessary.

(4) Annual check

① Rotor head internals
- Slip ring
- Potentiometer
- Rotary joint
- Hydraulic oil cylinder
- Hydraulic oil piping
- Link mechanism

② Filter renewal

③ Check for oil level

④ Grease supply check

⑤ Brake-pad check

⑥ Paint check

⑦ Others

The wind turbine generator is controlled by automatic control system so that it will perform all such operations as the start, stop, output control, yaw control, etc. according to the state of wind encountered.

3.7 Site and Building Areas

The site for a windfarm employing many wind turbine generators has to be selected with consideration toward the aforementioned layout plan. Even with one wind turbine generator, since the machine rotates 360 deg. depending on the direction of wind, the site is required to be suitable for this situation as well as for need of space for working and materials handling operations performed at the time of windfarm construction.

In addition, a building that houses materials and working equipment as well as spare parts which are required in making the daily or periodic inspection of the wind-electric generating facilities is also a must. The largest of all the spare parts are propeller blades, and the building must be spacious enough to accommodate this particular item. With due reference to typical examples of windfarms actually constructed so far, the site and building for the model windfarm under study here may be defined as follows.

(1) Windfarm site area
  (a) With 10 wind turbine generators:
    ① When the direction of wind is stabilized: Approx. 150,000 m^2.
    ② When the direction of wind is indefinable: Approx. 750,000 m^2.
  (b) With 2 wind turbine generators: Approx. 24,000 m^2
(2) Building area Approx. 300 m^2

3.8 Number of Personnel Required

The wind power generators normally are operated on the unmanned basis. But nevertheless some maintenance personnel are required for daily and periodic inspections as well as for servicing and other maintenance activities.

Even though the number of personnel required may vary with site, weather, and many other conditions imposed on each individual windfarm, for the windfarm under study here it is assumed that the 10 wind turbine generators employed there are tended by one regular and two temporary maintenance personnels are stationed. It goes without saying that for major maintenance operations (as, for example, propeller blade replacement, etc.), an appropriate number of personnel will have to be provided accordingly.

4. Power Generation Cost

Estimating the cost of wind power generation requires due consideration toward particular general situations that exist in each individual country where the windfarm is constructed and operated, making it extremely difficult ot offer any reasonable generalization.

For the windfarm under study here as a model, the cost of wind power generation involved was estimated based on the following premises.

4.1 Premises for Estimation

(1) Windfarm construction cost
  (a) The land cost to be excluded.
  (b) The cost for constructing the control room and other buildings to be U.S. \$400/m^2.
  (c) The equipment cost (including the cost for spare parts) to be based on the price FOB Japan of 1989.
  (d) The freight and insurance cost to be 5% of equipment FOB price.
  (e) The foundation work cost to be 10% of equipment FOB price.
  (f) The erection and electrical work cost to be 40% of equipment FOB price.
  (g) The supervision fee to be 2% of equipment FOB price.
  (h) The trial operation and training costs to be 1% of equipment FOB price.
  (i) The contingency to be 5% of equipment FOB price.

(2) Power generation cost

(a) The annual amount of electricity sold to be 600 x 10^3 kWh.

(b) The labor cost to be U.S. \$5,000/man/year.

(c) The maintenance cost to be 2% of equipment FOB price.

(d) The depreciation to be 5% annually by fixed installment method.

(e) The general insurance cost to be 1% of building construction cost and equipment FOB price.

(f) Half of the windfarm construction cost to be covered by a long-term loan at the annual interest rate of 10%.

(g) The exchange rate to be U.S. \$1 = ¥140.

4.2 Capital Required

The model windfarm construction cost as estimated on the premises set forth in 4.1 is as follows. The windfarm size is 2,750 kW in power generating capacity.

Item	U.S. \$
Land cost	–
Building construction cost	120,000
Data recording/process system	200,000
Power generating facilities	
– Equipment cost (incl. spares)	3,000,000
– Freight & insurance costs	160,000
– Foundation work cost	320,000
– Erection & electrical work costs	1,280,000
– Supervision fee	64,000
– Trial operation & training costs	32,000
Contingency	160,000
Total	U.S. \$5,336,000

The capital required is estimated to be U.S. \$5,336,000.

4.3 Power Generation Cost

Based on the premises of 4.1, the annual wind power generation cost may be calculated as follows.

Item	U.S. \$
Labor cost	5,000
Maintenance cost (labor cost & spare parts cost)	64,000
Depreciation	266,800
General insurance cost	33,200
Interest	266,800
Total	U.S.\$635,800

The power generation cost per kWh, therefore, is given as follows.

$$\frac{\text{U.S. \$635,800}}{\text{6,000,000 kWh}} = \text{U.S. \$0.11/kWh}$$

4.4 Annual Amount of Power Generation and Power Cost

The relation between the annual amount of power generation and power cost is shown in Fig. 9.

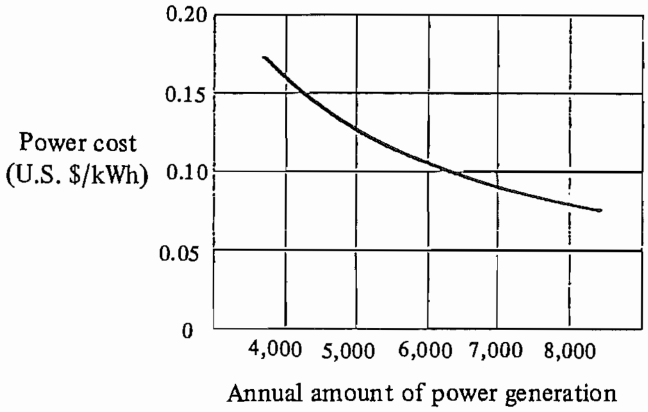


Fig. 9 Amount of Power Generation and Hourly Power Cost

5. Conclusion

The wind power generation has made great strides in its technology in recent years and has earned a high reputation for its enhanced reliability, with consequent reduction in cost. There is in fact no doubt that the wind power generating system will prove to be a highly promising means of power generation especially in remote areas or remote islands where fuel cost remains high or in regions where the preservation of environment is a persistent demand.

The wind power generation plant can be erected even in barren desert areas and hence will help raise the living standard of population there through electrification. The electricity generated by wind power generating system can be used for irrigation or industrial activities, thereby promoting the agricultural production as well as the produce-processing industry.

The wind power generation plant is advantageous also from the environmental point of view since the power generation is based on "clean energy." The jamming and noise problems can also be resolved by carefully selecting the construction site so as to minimize or eliminate the adverse effects of wind power plants.

It is expected from the above that the wind power generating system will find increasingly more prevalent applications in future.

Project Planning for Small and Medium Scale Industries

No. 1 Rice Milling Plant and Rice Bran Oil Manufacturing Plant
No. 2 Plastic Woven Bag Manufacturing Plant
No. 3 Container Board Manufacturing Plant
No. 4 Plastic Blow Bottle Manufacturing Plant
No. 5 Concrete Block Manufacturing Plant
No. 6 Glassware Manufacturing Plant
No. 7 Galvanized Iron Sheet Manufacturing Plant
No. 8 Fishing Net Manufacturing Plant
No. 9 Ice Making, Refrigeration and Cold Storage Plant
No.10 Starch and Syrup Manufacturing Plant
No.11 Instant Noodle Manufacturing Plant
No.12 Surimi and Surimi-Based Food Manufacturing Plant
No.13 Polyethylene Shopping Bag Manufacturing Plant
No.14 Retreading Tire Manufacturing Plant
No.15 Husk Fired Thermal Power Plant
No.16 Fishmeal Manufacturing Plant
No.17 Assorted Animal Feed Manufacturing Plant
No.18 Sanitary Napkin Manufacturing Plant
No.19 Sanitary Ware Manufacturing Plant
No.20 Toilet Tissue Manufacturing Plant
No.21 Powder Milk Manufacturing Plant
No.22 Mosquito Coils Manufacturing Plant
No.23 Solar Pond Power Generation Plant
No.24 Manufacturing Plant of Textile Products for Medical Use
No.25 Ceramic Tableware Manufacturing Plant
No.26 Manufacturing Plant of Ethanol for Medical Use
No.27 Match Manufacturing Plant
No.28 Wind Power Generation Plant

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Japan Consulting Institute (JCI)

Sumitomo Fudosan Kudanshita Bldg. 3 F
Kanda-Jinbocho 3-5, Chiyoda-ku Tokyo
101-0051 Japan

TEL +81-3-3222-8100
FAX +81-3-3222-8101
URL : http://jci-plant.or.jp

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