SPECIFICATION
OF
MWT-450
WIND TURBINE GENERATOR
FOR
Villa do Bispo Project / Portugal

No. WM-96-041 Revision 3

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MITSUBISHI HEAVY INDUSTRIES, LTD.
NAGASAKI SHIPYARD & MACHINERY WORKS
1. INTRODUCTION ........................................... 2

2. MWT-450 EQUIPMENT AND COMPONENT ................. 3
   2.1 Rotor ........................................... 3
   2.2 Power Train .................................... 4
   2.3 Yaw System .................................... 5
   2.4 Tower .......................................... 6
   2.5 Control System ................................ 7

3. MWT-450 SPECIFICATION ................................ 12
   3.1 Specifications ................................... 12
   3.2 Standards ...................................... 13

4. SCOPE OF SUPPLY .................................... 16

5. OUT OF SCOPE ....................................... 18

6. AVAILABILITY GUARANTEE ............................ 19

7. WARRANTY ........................................... 21

8. PERFORMANCE ........................................ 22

Attachment 1. OUTLINE OF MWT-450 .................. 25
Attachment 2. POWER FACTOR ......................... 26
Attachment 3. ISO-9001 CERTIFICATE ............... 27
Attachment 4. SECTIONAL DRAWING OF WTG ........ 28
Attachment 5. SINGLE LINE DIAGRAM FOR WTG ...... 31
Attachment 6. WIRING DIAGRAM FOR WTG ........... 32
Attachment 7. INTERFACE OF MONITORING SYSTEM .. 33
Attachment 8. WTG INTERLOCK DIAGRAM ............ 34
1. INTRODUCTION
MWT-450 is the new generation of the high performance MHI wind turbine generators, designed for high annual energy capture at the minimum cost. This is achieved by the most efficient light-weight rotor blades optimized for the actual operating conditions, a 40 meter tower and the high efficiency and low maintenance power train.

The followings are the design features of the MHI wind turbine MWT-450,

a) Upwind, three blade, variable pitch rotor for maximum energy capture and reliable operation.
b) Active yaw system to track the wind direction.
c) High efficiency, light weight planetary/helical gearbox.
d) 500kW, 550V induction generator with a soft starter.
e) High design wind speed.

The quality control of MWT-450's is in accordance with ISO-9001.

The outline of MWT-450 is shown in Attachment 1.
2. MWT-450 EQUIPMENT AND COMPONENT

The main components of a MWT-450 wind turbine are a rotor, a power train, a yaw system, a tower and an electrical system. Each of these components are described below.

2.1 Rotor

The rotor has three blades which can be rotated along its longitudinal axis by a pitch control mechanism for power regulation and aerodynamic braking. The blades are connected to the main shaft through a rigid hub (rotor head).

2.1.1 Blades

The rotor has three GFRP (Grass Fiber Reinforced Plastics) blades. Each blade is 18.3 meters long and employs the modified NASA LS(1)-04XX series airfoil. The construction is similar to the 12 meters blades, approximately 2,500 of which are now under successful operation with MWT-250 wind turbine, with improvements of aerodynamic and structural performance. The airfoil is the modified LS(1)-04XX series airfoil as mentioned above, varying from a 13% thickness ratio at the tip to 30% thickness ratio near the root. The blade has 13.7 degrees twist from the root to the tip. The maximum chord length is 2,000 mm and tapers down to 700 mm at the tip. The blades are mounted to the rotor head at a cone angle of 0 degree.

2.1.2 Rotor Head

The rotor head connects the blades to the low speed shaft (main shaft). The blade loads, static and dynamic wind loads and centrifugal forces, are transferred to the nacelle bedplate through the low-speed shaft bearings. Pitch linkages for blade pitch control are installed in the rotor head.

2.1.3 Pitch control mechanism

The pitch control mechanism consists of a hydraulic power unit, servocorel valves, linear actuators and linkages. The hydraulic power unit is mounted in the nacelle.
2.2 Power Train
The gearbox transmits the power from the rotor to the generator. A low speed (25 rpm) shaft connects the rotor head to the input shaft of a 1:60.0 gearbox. The gearbox employs planetary / helical gears, which increases the rotational speed to 1500 rpm. All gears are hardened and ground to provide long service life.
The output shaft of the gearbox is connected to the generator through a flexible coupling. A rotor brake is equipped on the high speed shaft and used primarily to secure the rotor from rotation during maintenance works.
The power train axis is inclined 5 degrees (tilt angle) from the horizontal.
The gearbox is mounted on a nacelle bedplate, which is designed to be a light weight main structural member.
The generator is a 550 V, 4 poles, 50 Hz, AC induction type, rated at 500 kW with a power factor of 0.95 (with capacitor) at rated output and the synchronous speed of 1500 rpm. The power factor is shown in Attachment 2.

2.3 Yaw System
In order to follow the shifts of wind direction, a four-point bearing with a bullgear is mounted between the nacelle and the tower. The nacelle to be rotated (yawed) by the electrically powered yaw drive.
A yaw brake system locks the nacelle to the tower whenever the turbine is not yawing, and provides yaw drag force when yawing.

2.4 Tower
The tower which supports the nacelle is a taper monopole, approximately 40m tall, which is supported by reinforced concrete foundation. The tower is designed to withstand the wind speed of 59.5 m/s (Instantaneous) at hub height.
2.5 Control System
The wind turbine generator control system is provided for the automatic, safe and reliable operation of the wind turbine generator at a remote, unattended site. The control system automatically performs the following functions.

1. Power regulation over a wide range of wind speeds including start-up, shut-down, and generator grid connection.
2. Yaw control.
3. Protection against damages due to abnormal operating conditions and/or extreme environmental conditions.

2.5.1 Blade pitch control
The power output of the turbine is regulated by blade pitch control system, using the data from the anemometer and generator.
When the wind speed is below cut-in wind speed or above cut-out wind speed, the blades are feathered to prevent the rotor from excessive rotation.
At wind speeds between rated and cut-out, the blade pitch is controlled to maintain a constant power output (rated power).

2.5.2 Yaw control
Wind speed and yaw error, which is the angle between the nacelle direction and the wind direction, are sensed by the anemometer and wind vane sensor.
During the turbine operation, the yaw error is continuously monitored by the control system. The turbine is yawed, when the yaw error exceeds 15 degrees.

2.5.3 Safety system
The safety system, which enables automatic shut-downs, operates independently of all other wind turbine controls to protect the turbine from catastrophic failure.
Various sensors monitor key parameters, such as the rotor speed, generator current, electrical load, nacelle vibration, yaw error, pitch control system hydraulic pressure, controller failure, and so on.
If any sensor signal deviates from the normal operating range, the safety system automatically shuts down the wind turbine.

2.5.4 Handy Terminal

Yaw and pitch are able to be controlled manually by a handy terminal.

Following data are able to be read on the display of the handy terminal.

1) Trouble name
2) Cumulative power output in kWh
3) Power output in kW (average & instantaneous)
4) Wind speed (average & instantaneous)
5) Cumulative generator on-off cycles
6) Cumulative operation time
7) Yaw error (wind difference angle)
8) Cumulative yaw right turn cycles
9) Cumulative yaw left turn cycles
10) Current nacelle direction
11) Pitch angle (command & actual)
12) Current rotational speed

2.5.5 Power and Control Panel

Power and control panel is located at the base of the tower of each wind turbine. An operator is able to start up the turbine from this panel in accordance with adequate start up manual.

Universal controller with high performance CPU is mounted in the control panel of each wind turbine.

2.5.6 Computer Monitoring System

The computer monitoring system at remote, unattended site is provided as shown on attachment 7.

Also we can provide the RS485 interface of computer communicate cable if you want.
WIND TURBINE CONTROL SYSTEM

*Auto synchronous controller and controller are installed in power and control panel.*
YAW CONTROL SYSTEM

- Yaw error exceeds 15°
- Yaw error exceeds 25°
- WTG is running
- Yawing command
- Yaw driving speed is very low

YAW MOTOR DRIVE

WTG SHUTS DOWN

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>AND</td>
<td></td>
</tr>
<tr>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>NOT</td>
<td></td>
</tr>
<tr>
<td>TIMER</td>
<td></td>
</tr>
</tbody>
</table>
OVERSPEED PROTECTION SYSTEM

1st Step

Electric source is lost by mainline failures

High speed shaft
Overspeed (1) r p m

Shut Down

Blade pitch is changed from load position to no-load position

Wind direction
Blade
Load position
No-load position (Feathering) position

2nd Step

High speed shaft
Overspeed (2) r p m

Nacelle direction is changed from load position to no-load position by yaw controller

Wind direction
Nacelle
Load position

3rd Step

1st Step Shut Down

2nd Step Shut Down

Mechanical Brake on (Service Brake)

High Speed Shaft
Overspeed (3) r p m
OVER POWER PROTECTION SYSTEM

1ST STEP

OUTPUT POWER > 500 kW (BY SOFTWARE) → POWER CONTROL

2ND STEP

POWER CONTROL (1ST STEP) → AUTO STOP → RESTART UP

OVER POWER "HIGH" (BY SOFTWARE)

3RD STEP

POWER CONTROL (2ND STEP) → QUICK STOP → SHUT DOWN

OVER POWER "TOO HIGH" (BY SOFTWARE)

4TH STEP

OVER POWER "TOO HIGH" (BY HARDWARE) → QUICK SHUT DOWN

OVER POWER "TOO HIGH" (BY HARDWARE) → GEN. BREAKER OPEN

YAW CONTROL 90 DEG SIFT FROM WIND WAY
3. MWT-450 SPECIFICATIONS
   - SPECIFICATIONS AND STANDARDS

3.1 Specifications
3.1.1. Performance
Rated Output 500 kW
Wind Speed At Hub Height
(Air Density 1.225 kg/m^3, 10 minutes average)
Cut-in 4.5 m/s
Rated 12.5 m/s
Cut-out 24.0 m/s, (28.8 m/s / Instantaneous)
Reset of Cut-out 20.0 m/s
Design Maximum 59.5 m/s (Instantaneous)
* Refer to Figure 1. for the power curve

3.1.2. Noise Level
Sound Power Level less than 97dBA
The measurement tolerance is expected to be
more or less 1dBA than the above power
level.
(wind speed 6.6m/s at 10m height)
Tonal
less than 4dB
Defined within IEC

3.1.3. Rotor
Number of Blades 3
Diameter 41 m
Rotational Speed 25 rpm
Rotational Direction Clockwise (against wind direction)
Orientation Upwind
Cone Angle 0 degrees
Tilt Angle 5 degrees
-12-
3.1.4 Blade
Length
Material
Airfoil
Twist
Chord Length
   Tip
   Root
18.3 m
GFRP
NASA LS(1)-04XX
13.7 degrees
700 mm
2,000 mm

3.1.5 Gearbox
Type
   Planetary & Helical
Gear Ratio
   1 : 60
Rating (Output)
   500 kW
Rotational Speed
   High Speed Shaft
   1,500 rpm
   Low Speed Shaft
   25 rpm

3.1.6 Generator
Type
   Induction Generator
Rated Capacity
   500 kW
Power Factor
   0.95 with capacitor, at rated output
   * Refer to Attachment 2, for power factor.
Number of Poles
   4
Synchronous Speed
   1,500 rpm
Voltage
   550 V
Frequency
   50 Hz
Enclosure & Protection
   Totally-Enclosed Fan Cooled Type
Rotor Type
   Squirrel-Cage Rotor
   With Anti-Friction Bearing
Insulation
   F
Rating
   Continuance
3.1.7 Yaw Control

Type: Active

Yaw Drive: Induction Motor

Rated Power: 1.5 kW

Speed:
- High Speed Shaft: 1,450 rpm
- Low Speed Shaft: 1,100 rpm

3.1.8 Control System

Power Regulation: Full span pitch control

Yaw Orientation: Active control

3.1.9 Safety System

Automatic Shutdown: Over speed, Abnormal Vibration, Generator Overcurrent, Generator Ground Overcurrent and others.

3.1.10 Tower

Type: Taper Monopole

Hub Height: 40 m

Ground Clearance: 20 m

Top Diameter: 2.0 m

Base Diameter: 3.2 m

3.1.11 Environment Condition

Temperature: -20~+40 degrees

Elevation: 1,000 meters or lower above sea level.
3.1.12 Weight (Approximate)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Tower</td>
<td>32  ton</td>
</tr>
<tr>
<td>Tower</td>
<td>28 ton</td>
</tr>
<tr>
<td>Total</td>
<td>60 ton</td>
</tr>
</tbody>
</table>

3.2 Standards

3.2.1 Technical Standards

MWT-450 wind turbine generator and its electrical equipments will be manufactured in accordance with Japanese standards as follows.

- JIS (Japanese Industrial Standard)
- JEM (The Standard of Japan Electrical Manufacturer Association)
- JEC (Japanese Electrotechnical Committee)
- Exclude CB Marking

3.2.2 Quality Control

The quality control of MWT-450's is in accordance with ISO-9001.
8. PERFORMANCE

8.1 Standard Power Curve

The standard power curve is shown in the Figure 1 and Table 1.

Figure 1. Standard Power Curve of MWT-450

(Air Density: 1.225 kg/m³)

These data are valid for the wind data measured at the hub height.
Losses are not included in this power curve. Refer to Section 8.
Table 1. Standard Power Curve of MWT-450

( Air Density : 1.225 kg/m³ )

<table>
<thead>
<tr>
<th>Wind Speed [m/s]</th>
<th>Power Output [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>0</td>
</tr>
<tr>
<td>5.0</td>
<td>22</td>
</tr>
<tr>
<td>5.5</td>
<td>43</td>
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<tr>
<td>6.0</td>
<td>64</td>
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<td>90</td>
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<td>7.0</td>
<td>115</td>
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<td>7.5</td>
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</tr>
<tr>
<td>9.0</td>
<td>247</td>
</tr>
<tr>
<td>9.5</td>
<td>287</td>
</tr>
<tr>
<td>10.0</td>
<td>325</td>
</tr>
<tr>
<td>10.5</td>
<td>361</td>
</tr>
<tr>
<td>11.0</td>
<td>401</td>
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<td>11.5</td>
<td>433</td>
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<td>12.0</td>
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<td>28.0</td>
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</tr>
<tr>
<td>29.0</td>
<td>0</td>
</tr>
<tr>
<td>30.0</td>
<td>0</td>
</tr>
</tbody>
</table>

These data are valid for the wind data measured at the hub height.

Losses are not included in this power curve. Refer to Section 8.2.
8.2 Expected Power Output

The expected power output at sub-station, \( P \), can be calculated from the aerodynamic power output, \( P_0 \), using the following equation. \( P_0 \) can be read on the aerodynamic performance curve.

\[
P = P_0 \times (1 - e_C) \times (1 - e_T) \times (1 - e_E) \times (1 - e_A) \times C_A
\]

Where,
- \( P \) : Power output at substation (Actual output)
- \( P_0 \) : Aerodynamic power output (Calculated output)
- \( e_C \) : Control loss factor (2%)
- \( e_T \) : Turbulence loss factor (3%)
- \( e_E \) : Electric transfer loss factor
- \( e_A \) : Array loss factor
- \( C_A \) : Correction coefficient of anemometer
Attachment 1. Outline of MWT-450
Attachment 2. Power Factor

<table>
<thead>
<tr>
<th>Load (%)</th>
<th>Power Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>77.0</td>
</tr>
<tr>
<td>50</td>
<td>91.0</td>
</tr>
<tr>
<td>75</td>
<td>95.0</td>
</tr>
<tr>
<td>100</td>
<td>95.5</td>
</tr>
</tbody>
</table>
DET NORSKE VERITAS

QUALITY SYSTEM CERTIFICATE

Certificate No. 2982

This is to certify that

THE QUALITY SYSTEM

of

MITSUBISHI HEAVY INDUSTRIES, LTD.
NAGASAKI SHIPYARD & MACHINERY WORKS

NAGASAKI SHIPYARD:
1-1, AKUNOURA-MACHI,
NAGASAKI-CITY 850-91,
JAPAN.

SAIWAI-MACHI PROD. SHOP:
6-12 SAIWAI-MACHI,
NAGASAKI,
JAPAN.

Has been found to conform to the Quality System Standard


This Certificate is valid for the following product or service ranges

DESIGN AND MANUFACTURE OF WIND TURBINE GENERATOR

Place and date

London 24th January 1997

for the Accredited Unit

Det Norske Veritas QA Ltd.

Management Representative

This certificate is valid until

22nd October 1999

Original certificate valid from: 22nd October 1993

Lead Auditor

10510

Lack of fulfillment of conditions as set out in the Appendix may render this certificate invalid.

The use of the Accreditation Mark indicates accreditation in respect of the activities covered by the accreditation number 013.