National University of Sciences and Technology (NUST)
School of Electrical Engineering and Computer Science

ME-109:Engineering Drawing

FINAL PROJECT

GROUP NAME: WIND XPERTZ

GROUP NO: 6

Class Section: BEE-17-A

Sr.No.	Members	CMS ID
1.	Muhammad Hamza Ibrahim	541610
2.	Muhammad Yasin	574887
3.	Abdul Rehman	547498
4.	Shumaila Khalid Chaudhary	560177
5.	Fatima Munawar Lodhi	566895
6.	Sidra Rehman	543999
7.	Fizza Rafi	575479

"Onmyhonor,as a studentofNational University of Science and Technology,Ihaveneithergiven nor received unauthorized assistance on this academic work."

Submitted to:

Sir Hamza Saeed

December 15th, 2025

DEPARTMENT OF ELECTRICAL ENGINEERING,
NUST, ISLAMABAD

Table of Contents

WIND FARM LAYOUT

Drawing Reference: Annex page: ________

Introduction

Required output capacity: 1MW

Required windmills: 5kW turbine (200×)

Windmill type: Onshore Domestic purpose 5kW Wind Turbine

Required area: 25.2 Hectares or 62.3 Acres or 252,126m^2

Average Windmill center to center distance: 73.50m (row wise) and 45.90m (Column wise)

Location: Pishukan, located along the Makran Coast in Balochistan, Pakistan, experiences favorable wind conditions, making it a potential site for wind energy projects.

Location Details:

Coordinates: Pishukan is situated near 25.1° N, 62.3° E.

Region: Makran Coast, Balochistan, Pakistan.

Wind Conditions in Pishukan:

Average Wind Speed: Approximately 13.4 mph (21.5 km/h), with gusts up to 13.4 mph (21.5 km/h).

Prevailing Wind Direction: From the southeast, which is typical for coastal regions influenced by sea breezes.

Why Pishukan?

Makran coastline (Pishukan) has been studied for wind resource: site measurement campaigns (PMD / Wind Resource Mapping) were conducted there and show a seasonal pattern — moderate winds and a peak season (spring). That makes it a candidate locale when combined with coastal access and low land cost.

Components of wind farm:

Transformer: A device used to transfer electrical energy at different current and voltage levels.

Amount: 40

Type: Step up, 0.4kV-11kV, Power = 25-30kVA

Dimension Footprints: Typical small pad-mount (oil-immersed)

- Tank: ≈ 2.5 m (L) × 1.4 m (W) × 1.2 m (H)
- Fenced pad area (for safety, oil drip pit, and clearance): **≈ 3 m × 2.5 m = 7.5 m²**

Feeders: Carry Power to substation:

Amount: 8

Dimension Footprints: For 11 kV collection circuits and LV turbine cables:

Type	Typical trench width	Typical depth
LV (400 V, 5 × Turbines to Tx)	0.3–0.4 m	0.8 m
MV (11 kV feeders)	0.45–0.6 m	1.0 m

Note: Trenches are narrow; they don't consume much *land area* permanently, since they're buried and the surface (grass or road) is restored.
For the **whole 1 MW farm trenches are:** 8 feeders × 200m each = ~1600m of trench

Substation: Collects and exports power to grid. Steps up from 11kV to 33kV

A compact 33/11 kV or 11/0.4 kV substation for ~1 MW includes:

- 1 main power transformer (≈ 1.25 MVA)
- 11 kV RMUs/switchgear
- Control room, SCADA, metering
- Earthing grid and access road

Typical layout:

- Total Dimensions: 40m x 36m

Roads:
1 Spine Road: Width = 10m
1 Main Horizontal road Width = 10m
4 Smaller Horizontal Roads: Width = 5m

Cluster formation:

5 turbines per transformer

Your layout (40 transformers for 200 turbines) implies clusters of 5 turbines per transformer. This is commonly used when turbines are small and located close together:

Advantages: minimizes the length of low-voltage (LV) collection cabling (turbine → local transformer), keeps transformer ratings matched to cluster generation (25 kW for 5×5 kW), simplifies protection/coordinated isolation (transformer per cluster), and reduces the number of MV step-up points.

The choice of 5 is a sensible balance for small turbines: reduces the number of distribution step-up units while keeping LV cable runs short. No changes needed electrically, but consider redundancy or parallel feeders to each transformer if availability is important.

Cable types:

Below is list realistic, standard cable choices for the three collection segments you requested:

A. Windmill → Cluster transformer (LV collection)

4-core copper, XLPE-insulated, armored where buried — 4 × 16 mm² Cu, PVC/LSZH outer sheath for burial.

Why: each turbine generates ≈7.6 A; 4 × 10 mm² copper provides ample ampacity and keeps voltage drop low for typical intra-cluster distances (tens to a few hundred metres). Copper LV cables are standard for reliable low-voltage collection. Use armoured cable where mechanical protection is required (road crossings).

B. Transformer → Feeder (step-up MV connection)

Two deployment options:

Underground MV cable: 3-core Cu 35 mm² XLPE

Why: MV connections are normally installed as ACSR overhead for cost savings; if underground is required for environmental/visual reasons, use 3-core XLPE armored cable. Choose cross-section to meet mechanical strength & fault withstand rather than thermal rating only.

C. Feeder → Central substation (MV collection)

For a buried collection to the substation, we used 11 kV 3-core XLPE with 70–95 mm² conductor. Overhead will be lower cost and simpler for the coastal site.

Prices — per-item estimate:

Wind Turbine (5kW): PKR 600,000 per turbine

Transformer (25-30kW): PKR 150,000 per turbine

LV Cables (4 × 16 mm² Cu): 130,000 per 100m

MV Cables (: 3-core Cu 35 mm²): 150,000 per 100m

Total LV wire: 180m per cluster

Total MV wire: 2724m throughout the wind farm

Final total Cost of Wind farm including everything: PKR 3,000,000,000

COMPLETE DESIGN AND JUSTIFICATION OF A 25 kW, 3-PHASE, OIL-IMMERSED TRANSFORMER (400 V / 11 kV)

1. PURPOSE OF THE TRANSFORMER (WHY IT EXISTS)

Your system consists of **5 windmills × 5 kW = 25 kW total power**. Each wind turbine generates electrical power at **low voltage (400 V, 3-phase)**. Transmitting 25 kW at low voltage would require **very high current**, leading to:

- Excessive copper losses (I^2R losses)
- Thick, expensive cables
- Voltage drops

Therefore, the transformer **steps up voltage from 400 V to 11 kV**, reducing current by a factor of **27.5**, making power transmission efficient and economical.
This transformer is the **electrical heart** that connects mechanical wind energy to the electrical grid or distribution line.

2. BASIC ELECTRICAL RATINGS (DEFINED FIRST)

Parameter	Value	Justification
Rated Power	25 kVA (≈25 kW)	Windmills deliver real power, PF ≈ 0.95
Phases	3-phase	Smooth power, less vibration, industry standard
Frequency	50 Hz	Pakistan grid standard
LV Voltage	400 V (Δ)	Standard wind generator output

Parameter	Value	Justification
HV Voltage	11 kV (Y)	Medium-voltage distribution
Cooling	ONAN	Simple, reliable, passive cooling
Insulation	Oil-paper	Proven >100 years reliability

3. CURRENT CALCULATIONS (CRITICAL FOR DESIGN)

Low Voltage Side Current

$$I_{LV} = \frac{P}{\sqrt{3} \times V} = \frac{25{,}000}{1.732 \times 400} \approx 36A$$

High Voltage Side Current

$$I_{HV} = \frac{25{,}000}{1.732 \times 11{,}000} \approx 1.31A$$

Justification:

- LV side requires thick conductors
- HV side carries small current → thin conductors

4. CORE (THE MAGNETIC BRAIN)

4.1 Core Material

Cold-Rolled Grain-Oriented (CRGO) Silicon Steel

Why this material?

- High magnetic permeability → low magnetizing current
- Grain alignment reduces hysteresis loss
- Silicon (≈3%) reduces eddy currents

Alternative rejected:

- Mild steel → huge core losses
- Ferrite → unsuitable for 50 Hz power

4.2 Core Type

Three-limb laminated core

Why?

- Compact
- Balanced flux
- Minimum leakage flux

4.3 Core Losses

- **Hysteresis loss:** minimized by grain orientation
- **Eddy current loss:** minimized by laminations (0.27 mm thick)

Estimated core loss ≈ **120 W**

4.4 Core Dimensions (Approx.)

Parameter	Value
Limb cross-section	~75 cm^2
Core height	~600 mm
Core weight	~110 kg

5. WINDINGS (WHERE VOLTAGE IS CREATED)

5.1 Conductor Material

Electrolytic Copper (99.9%)

Why copper?

- High conductivity → lower I^2R losses
- Better thermal endurance
- Mechanical strength under short-circuit forces

Aluminum rejected:

- Larger size
- Poor joint reliability

5.2 LV Winding (400 V)

- Configuration: **Delta (Δ)**
- Current: 36 A
- Conductor: Rectangular copper strip
- Current density: 2.5 A/mm^2
- Cross-section ≈ 15 mm^2

Placed **closest to core** → lower insulation requirement

5.3 HV Winding (11 kV)

- Configuration: **Star (Y)**
- Phase voltage = 11kV / √3 ≈ 6.35 kV
- Current: 1.31 A
- Conductor: Round enamelled copper wire

Placed **outside LV winding** → easier insulation

5.4 Turns Ratio

$$\frac{N_{HV}}{N_{LV}} = \frac{11,000}{400} = 27.5$$

6. INSULATION SYSTEM (WHY IT DOESN'T FAIL)

Materials Used

- Kraft paper (cellulose)
- Mineral transformer oil

Why paper + oil?

- Paper provides mechanical insulation
- Oil fills voids, increases dielectric strength
- Oil removes heat

Dielectric strength of oil: **>30 kV/mm**

7. TRANSFORMER OIL

Type

Mineral insulating oil (IEC 60296)

Functions

1. Electrical insulation
2. Cooling
3. Arc suppression
4. Moisture control

Approx. oil quantity: **500-600 liters**

8. COOLING SYSTEM (ONAN)

Oil Natural – Air Natural

Heat flow path:

Copper loss → Oil → Tank walls → Air

Why ONAN?

- No pumps
- Silent
- Reliable
- Perfect for 25 kW rating

9. TANK & MECHANICAL STRUCTURE

Tank Material

- Mild steel (MS)

Why steel?

- Mechanical strength
- Weldability
- Oil compatibility

Corrugated walls increase surface area → better cooling

10. BUSHINGS

Material

- Porcelain (HV)
- Epoxy (LV)

Why porcelain?

- High dielectric strength

- Weather resistant

11. VECTOR GROUP (Δ-Y)

Why Delta on LV?

- Suppresses 3rd harmonics
- Handles unbalanced wind generation
- Circulating currents stay inside delta

Why Star on HV?

- Neutral grounding
- Lower insulation stress
- Grid compatibility

Vector group: **Dyn11**

12. LOSSES

Core Loss
≈ 120 W (constant)
Copper Loss
≈ 280 W at full load
Total Loss
≈ 400 W

13. EFFICIENCY

$$\boldsymbol{\eta = \frac{25,000}{25,400} = 98.4\%}$$

Excellent efficiency for small transformer

14. VOLTAGE REGULATION

≈ 3.5% (good for wind fluctuations)

15. PROTECTION & ACCESSORIES

- Conservator tank

- Silica gel breather
- Pressure relief valve
- Oil level indicator

16. WHY THIS DESIGN IS IDEAL FOR WIND POWER

- Handles variable load
- High efficiency at partial load
- Robust against harmonics
- Passive cooling
- Long life (>30 years)

EXTERNAL WIND TURBINE COMPONENTS

Drawing Reference: Annex page: ________

1. TOWER (SUPPORT STRUCTURE)

The tower is the structural spine of the wind turbine, crucial for ensuring operational efficiency and safety.

1.1 Function and Role

- Support: Elevates the nacelle and rotor blades to a height where wind speeds are stronger, more consistent, and less subject to ground-level turbulence.
- Safety: Ensures the rotor blades are kept safely above ground level and clear of obstacles.

1.2 Construction Details

- Typical Material: Steel tubular tower, which is the most common construction type for this size class.
- Foundation: For stability, especially in coastal or less stable soil, the tower foundation is a critical engineering component. Structural resilience against high winds and soil erosion is addressed through:
    - Pre-installation geotechnical surveys.
    - Use of deep pile foundations or geogrid-reinforced base layers.
    - Application of erosion control techniques, such as vegetation or riprap.

1.3 Typical Dimensions (for a 5 kW Domestic Turbine)

Parameter	Value	Note
Height	12 m	Places the rotor in optimal wind flow.
Diameter at Base	0.5m	Provides foundational strength.
Wall Thickness	5 mm (Steel)	Ensures sufficient structural rigidity and durability.

2. ROTOR (BLADES AND HUB)

The rotor assembly captures the wind's kinetic energy and converts it into the mechanical energy required to drive the generator.

2.1 Function and Energy Conversion

- Energy Capture: The blades use aerodynamic lift to capture the wind's kinetic energy.
- Torque Transfer: The hub serves to connect the blades and reliably transfer the rotational torque to the main shaft located inside the nacelle.

2.2 Blade Material: Carbon Fiber Justification

- Typical Material: Carbon fiber.
- Advantages in Harsh Environments (e.g., Coastal Regions):
  - Corrosion Resistance: Highly resistant to salt corrosion and humidity.
  - Performance: Enables the use of longer, stiffer blades, allowing the turbine to handle high winds more effectively.
  - Maintenance: Reduces the overall maintenance needs in harsh operating environments.
  - Lifespan: Improves the blade's operational lifespan.

- Limitation: The material increases the risk associated with lightning strikes, necessitating advanced lightning protection systems.

2.3 Operational Specifications and Dimensions (5 kW Turbine)

Parameter	Value	Operational Note
Number of Blades	3	Standard configuration for modern turbines.
Blade Length	2.5 m	Measures the length of a single blade.
Rotor Diameter	5 m	Defines the swept area ($\sim$20–28 m^2) for energy capture.
Rated Speed	150–300 rpm	Rotational speed at which the turbine achieves maximum (rated) power output.
Start-Up Wind Speed	2.5 – 3 m/s	Minimum speed required to overcome friction and begin rotation.
Rated Wind Speed	11–12 m/s	Wind speed at which the turbine reaches its 5 kW rated power.

Parameter	Value	Operational Note
Cut-Out Wind Speed	25 m/s	Wind speed at which the turbine must shut down to prevent high-wind damage.

3. NACELLE

The nacelle is the housing unit mounted on top of the tower.

3.1 Function

- Protection: Its primary role is to enclose and protect the turbine's sensitive internal components, including the main mechanical assemblies (gearbox) and electrical generation equipment (generator).
- Integration: It provides the housing structure for critical safety systems.

3.2 Safety and Protection Systems

The structure and equipment within the nacelle must be protected against environmental dangers:

Hazard	Solution Implemented
High Winds / Gusts	Installation of automatic braking systems and pitch control to "feather" the blades (adjust the angle) and reduce load.
Lightning Strikes	Installation of a Lightning Protection System (LPS) on the turbine structure and surge arresters on the electrical systems; proper grounding and bonding is mandatory.

Hazard	Solution Implemented
Humidity / Moisture	Use of sealed enclosures and desiccant breathers. Climate control systems (dehumidifiers) may be installed inside the nacelle to prevent rust and electrical faults.

4. CONCRETE BASE/FOUNDATION

The foundation is a critical engineering component that anchors the entire turbine structure to the ground, ensuring stability against massive wind loads and operational stresses.

4.1 Function and Stability

- Anchorage: Provides the necessary mass and breadth to anchor the 12-meter tower and the 5-meter rotor assembly.
- Load Distribution: Distributes the static weight of the turbine, as well as the dynamic forces (bending moments) generated by wind push and rotor rotation, across a wide area of the soil.
- Structural Integrity: Maintaining the foundation's stability is crucial to preventing the tower from overturning or subsiding over the turbine's operational lifespan.

4.2 Construction and Engineering Solutions

The design of the concrete base depends heavily on a preliminary analysis of the ground conditions.

Engineering Aspect	Detail
Pre-Installation Requirement	Geotechnical Surveys must be conducted before installation to understand soil composition, water table depth, and load-bearing capacity.

Engineering Aspect	Detail
Foundation Type	If ground conditions are soft or unstable, deep pile foundations or geogrid-reinforced base layers are used to provide adequate support beneath the main concrete pad.
Material	Marine-grade concrete is often specified for the construction of the base, especially in coastal environments, to resist the corrosive effects of salt and moisture.

4.3 Challenges and Mitigation (Soil Erosion and Instability)

The foundation is susceptible to environmental degradation, particularly in coastal or harsh climates. The primary issue and its engineering solutions are as follows:

Issue	Solution / Mitigation Technique
Soil Erosion and Foundation Instability	Sandy or saline soil can erode over time or weaken the load-bearing capacity of the foundation.
Solution 1 (Base Reinforcement)	Use deep pile foundations or geogrid-reinforced base layers to distribute stress below the affected topsoil.
Solution 2 (Surface Protection)	Apply erosion control techniques, such as protective vegetation or heavy riprap (a layer of large stones),

Issue	Solution / Mitigation Technique
	around the base perimeter to shield the concrete and prevent soil washout.

WIND TURBINE NACELLE AND ROTOR HUB ASSEMBLY REPORT (INTERNAL COMPONENTS)

Drawing Reference: Annex page: ________

Nacelle: The nacelle of a wind turbine houses all the critical mechanical and electrical components required for efficient energy conversion and turbine control. It serves as a protective enclosure, providing structural support while safeguarding the drivetrain, generator, and other systems from environmental conditions such as wind, rain, and dust. The nacelle's structural integrity and aerodynamic design are crucial to ensuring the long-term reliability and efficiency of the turbine. The specifications of the Nacelle are as follows:

- Length: 1.8 m
- Width: 0.8 m
- Height: 0.8m
- Weight: ~150–250 kg

1. **Rotor Hub Assembly**

i. **Nose Cap:**

At the forefront of the rotor assembly is the nose cap, a conical or rounded cover typically constructed from fiber-reinforced polymer (FGRP) with epoxy resin. The nose cap serves primarily an aerodynamic function, streamlining the rotor assembly to minimize drag. It also protects the internal pitch mechanisms and blade root connections from weather exposure, ensuring durability and consistent performance. The main shaft passes through the nose cap and connects directly to the rotor hub assembly.

ii. **Rotor Hub:**

The rotor hub itself connects the blades to the main shaft, transmitting aerodynamic torque from the rotor to the drivetrain while housing the pitch mechanisms. The hub is made from carbon alloy forged steel, selected for its high fatigue strength, vibration damping, and ability to withstand cyclic bending and torsion which are essential properties for handling fluctuating wind loads. Its thick-walled design, generous fillet radii, and internal corrosion-protective coating enhance structural integrity and longevity.

iii. **Pitch System**

The pitch system is a critical component that controls rotor speed, regulates power output, and provides primary aerodynamic braking during high winds. Turbine blades can rotate approximately 90°, with normal operation typically between −2° and +20° for optimal power generation. During emergency feathering, pitch speed increases to 8–12° per second to protect the turbine from extreme wind conditions. The pitch system employs AC servo motors, planetary gearboxes, and large slewing bearings at the blade roots, providing precise control and durability.

iv. **Slip Ring Assembly:**

Integral to the pitch system is the slip ring assembly, which enables continuous transmission of electrical power and sensor data between the stationary nacelle and the rotating hub. This allows the blades and hub to rotate freely while powering pitch motors and transmitting signals from sensors embedded in the blades, such as strain gauges and temperature monitors, without cable twisting. Continuous rotation support ensures the turbine operates efficiently under all conditions.

2. **Main Shaft and Gearbox**

The main (low speed) shaft operates at approximately 100 rpm at m wind speed of 11-12 m/s and experiences high torque, as well as bending loads from aerodynamic forces. Forged from 42CrMo4 steel, it provides high strength and fatigue resistance, ensuring reliability under fluctuating wind conditions..

Connected to the main shaft is the gearbox, which increases rotational speed from 100 rpm to approximately 1500 rpm to match generator requirements. The gearbox typically consists of a four-stage gear assembly with a total ratio of 15:1, constructed from 42CrMo4 carbon alloy steel for high durability under cyclical loading.

The high-speed shaft (HSS) transmits power from the gearbox to the generator. Operating at high rotational speeds (~1500 rpm) with lower torque, it requires precision balancing, proper lubrication, and continuous vibration and temperature monitoring. The HSS is also made from

42CrMo4 steel to ensure mechanical reliability and fatigue resistance. Includes brake system (mechanical or electrical) for emergency stops.

3. **Brake and Lubrication Systems**

The turbine is equipped with a brake system for emergency stopping and safe maintenance. The hydraulic disc brake, mounted on the HSS, utilizes high-carbon steel discs and fiber-resin composite pads to provide reliable stopping power. To minimize wear and ensure smooth operation of the drivetrain, a forced oil circulation lubrication system is used, employing synthetic gear oil to maintain low friction and prevent overheating.

4. Generator

Type: Standard Alternator. A standard alternator (synchronous generator) produces AC electricity directly. It has a fixed relation between speed and frequency.

- Function: Converts mechanical rotation into electrical energy (AC output).
- Output: Typically 3-phase, AC, 400V, 50 Hertz with pole count of 4.

Control System:

- Anemometer: Measures wind speed.
- Wind vane: Measures wind direction.
- Controller: Brain of the system; decides when to start, stop, or regulate the turbine.
- Brake system: Protects turbine during over-speed or high winds (>25 m/s).
- Yaw System: Keeps the turbine facing the wind for maximum energy capture.
- Pitch Control System: Adjusts the angle (pitch) of the blades to control the rotational speed and power output.

Main functions:

- Starts turbine when wind exceeds cut-in speed (≈3 m/s).
- Stops or brakes turbine at cut-out speed (≈25 m/s).
- Controls generator load to maintain rated output (5 kW).
- Yaw and pitch regulation for safety and efficiency.

4. **Nacelle Structure and Yaw System**

The nacelle structure and bedplate support the gearbox, generator, and shafts while maintaining precise alignment under load. The structure is made from welded structural steel, with rubber pads beneath the gearbox and generator to dampen vibrations and enhance component longevity. The yaw system aligns the nacelle with wind direction to maximize energy capture. It uses a planetary gear mechanism with a gear ratio of

1:4.8, powered by AC servo motors. The system rotates the nacelle in stepwise motions of 2–10°, pausing to correct alignment while preventing overuse. Mechanical yaw brakes lock the nacelle in position when required, reducing stress on components and avoiding damage from large misalignments. The system is designed to manage gyroscopic and fatigue loads caused by the massive nacelle structure while maintaining controlled, precise orientation.

5. Environmental Protection and Monitoring

To protect the nacelle from environmental degradation, a multi-layer coating system is applied, consisting of a zinc-rich epoxy primer, a high-build epoxy intermediate layer, and a UV-resistant polyurethane topcoat. The light-colored finish reduces heat absorption, while rounded edges prevent erosion and mechanical damage from wind-borne particles. Finally, the turbine incorporates advanced monitoring and safety systems, including SCADA (Supervisory Control and Data Acquisition) integration, temperature sensors, and vibration monitoring. These systems provide real-time operational data, enabling predictive maintenance, fault detection, and optimization of turbine performance.

Wiring of Internal Components:

1. Generator Electrical Wiring

The generator converts mechanical rotation into electrical energy.

Stator windings produce 3-phase AC power

Typical voltage output: 400–690 V A

Heavy-duty power cables carry output to:

Power converter

Transformer (if mounted in nacelle)

<u>Cables used:</u>

High-current, shielded copper cables

Heat- and vibration-resistant insulation

2. Transformer Connections (if inside nacelle)

Some turbines have a step-up transformer in the nacelle.

Input: Low-voltage AC (690 V)

Output: Medium voltage (10–35 kV)

<u>Wiring includes:</u>

High-voltage insulated cables

Grounding conductors

Temperature monitoring wires

3. Control & Signal Wiring

A large part of nacelle wiring is low-voltage control and communication cables.

Connected systems:

Yaw system (motor, brakes)

Pitch control (blade angle motors/actuators)

Hydraulic system

Cooling fans

Lubrication pumps

Cable types:

24 V DC control wiring

Fiber-optic or Ethernet communication lines

Shielded sensor cables

4. Sensors & Monitoring Wiring

Sensors provide real-time feedback to the turbine controller.

Common sensors:

Wind speed (anemometer)

Wind direction (vane)

Generator temperature

Bearing vibration

Oil pressure and temperature

Wiring characteristics:

Low-current, shielded cables

Routed separately from power cables to avoid interference

5. Slip Rings & Down-Tower Cables

Electrical power and signals must pass from the rotating nacelle to the stationary tower.

Slip rings transfer:

Power

Control signals

Data

From slip rings → vertical power cables run down the tower to:

Tower-base transformer

Grid connection panel

6. Grounding & Lightning Protection Wiring

Critical for safety and equipment protection.

Lightning rods on nacelle

Ground cables connect:

Blades

Generator

Nacelle frame

Tower
Grounding system leads to earth electrodes

GENERATOR

Drawing Reference: Annex page: ________

Definition

A Permanent Magnet Synchronous Generator (PMSG) is a synchronous generator in which the rotor magnetic field is produced by permanent magnets instead of field windings. The rotor rotates at synchronous speed, and the output frequency depends directly on rotor speed and number of poles.

Generator Specifications (Real Industrial Data)

Parameter	Value
Manufacturer	MeccAlte
Model	ECP3-1S/4C
Rated Power	6.5 kVA
Output Type	Three-phase AC
Rated Voltage	400 V
Frequency	50 Hz
Rated Speed	1500 RPM
Pole Count	4 poles
Cooling	Air-cooled
Mounting	Foot / Flange mounted
Insulation Class	Class H
Protection	IP23 (typical)
Output Power	5KW

Pole Count and Speed Relation

The synchronous speed of a generator is given by:

$Ns = 120f/p$

Where:

(Ns) = synchronous speed (RPM)

(f) = frequency (Hz)

(P) = number of poles

For this generator:

$Ns = 120(50)/4$

$Ns = 1500$

Thus, the generator has 4 poles.

Construction of PMSG

Main Parts

- Stator

- Rotor
- Shaft
- Bearings
- Cooling System
- Terminal Box
- Frame (Housing)

Construction Materials and Reasoning

Stator Core

Material: Silicon Steel Laminations

Reason:

High magnetic permeability

Low hysteresis loss

Laminated structure reduces eddy current losses

Improves efficiency at AC operation

Stator Windings

Material: Copper

Reason:

High electrical conductivity

Low resistive losses

Better thermal performance

Longer operational life compared to aluminium

Rotor

Material: Electrical Steel Core with Permanent Magnets

Magnets Used: Neodymium-Iron-Boron (NdFeB)

Why Permanent Magnets?

No external DC excitation required

Eliminates slip rings.

High power density

Improved efficiency

Reduced maintenance

Shaft

Material: High-carbon or alloy steel

Reason:

High mechanical strength

Ability to withstand torque and bending stresses

Long fatigue life

Bearings

Material: Hardened steel

Reason:

Reduces friction
Ensures smooth rotation
Supports rotor weight and axial loads

Frame (Housing)

Material: Steel
Reason:
Mechanical rigidity
Protection of internal components
Efficient heat dissipation

Working Principle

The working principle of a PMSG is based on Faraday's Law of Electromagnetic Induction.

When the rotor containing permanent magnets rotates, a rotating magnetic field is produced. This magnetic field cuts the stationary stator windings, inducing an alternating voltage across them. Since the rotor rotates at synchronous speed, the frequency of induced EMF remains constant.

Working Steps

Wind blows and rotates the wind turbine blades.
The turbine shaft transmits mechanical energy to the generator shaft.
The rotor with permanent magnets rotates at 1500 RPM.
Magnetic flux cuts stator windings.
EMF is induced in stator coils.
Three-phase AC voltage is produced at 400 V, 50 Hz.
Output power is supplied to the grid or load through control systems.

Output Characteristics

Type: Three-phase AC
Voltage: 400 V
Frequency: 50 Hz
Rated Apparent Power: 6.5 kVA
Output Power: 5KW
Waveform: Sinusoidal
Speed Dependency: Frequency depends on rotor speed

Dimensions:

Parameter	Dimension (cm)
Overall Length	43.0 cm
Overall Width	31.0 cm
Overall Height	31.0 cm
Shaft Diameter	4.0 cm
Shaft Length	59.0 cm

Approximate Weight 85 – 95 kg

Type of Wires Used in the Generator

Stator Windings

Material:

Electrolytic Grade Copper

Wire Type:

Enamelled Copper Wire (Magnet Wire)

Shape:

Mostly round enamelled wire

In some slots, rectangular copper conductors may be used for better slot fill

Insulation Class:

Class H (180 °C)

Why Enamelled Copper Wire Is Used

Reason	Explanation
High conductivity	Reduces I^2R losses
Thin insulation	More turns fit in stator slots
High thermal endurance	Withstands heating under load
Mechanical strength	Resists vibration in wind turbines
Long life	Suitable for continuous operation

Insulation Materials Used on Windings

Primary insulation: Polyurethane / Polyester enamel

Slot insulation: Nomex / DMD (Dacron-Mylar-Dacron) sheets

Impregnation: Epoxy or polyester varnish

Reason:

Improves heat dissipation, vibration resistance, and dielectric strength.

Rotor Side Wiring

Rotor Type: Permanent Magnet Rotor

Wires on Rotor: None

Since it is a Permanent Magnet Synchronous Generator, the rotor:

Does not use field windings

Does not require slip rings or brushes

This significantly reduces maintenance.

Advantages of Using PMSG in Wind Farms

High efficiency

No field excitation losses

Brushless operation

Low maintenance

Compact size

Suitable for variable wind speeds

High reliability

GEAR BOX, WIND VANE, ANEMOMETER

Drawing Reference: Annex page: ________

Gear Box

Material:

The gearbox is made from high-strength alloy steel to withstand heavy loads and continuous operation. The gears and shafts are manufactured from hardened steel to provide high strength, durability, and resistance to wear. The gearbox casing is usually made of cast iron or steel to protect internal components. Lubricating oil or grease is used inside the gearbox to reduce friction, heat, and mechanical wear.

Working:

The wind causes the turbine blades to rotate at low speed and high torque. This rotation is transferred to the gearbox through the low-speed shaft.

The gearbox contains gears with the following teeth numbers:

- $R_1 = 75$
- $R_2 = 15$
- $R_3 = 40$

First stage:
Gear R_1 (75 teeth) drives gear R_2 (15 teeth).

Speed ratio=75/15=5

So, the speed increases 5 times.

Second stage:
The second gear stage further increases the speed so that the overall gear ratio becomes 1 : 15.

This means that for every 1 rotation of the wind mill shaft, the output shaft rotates 15 times. This high-speed output is suitable for driving the generator

Output:

The gearbox plays a key role in transferring mechanical power from the wind mill blades to the generator. The blades rotate at low speed and high torque, which is not suitable for direct electricity generation.

By using a gear ratio of 1 : 15, the gearbox increases the rotational speed of the shaft 15 times before it reaches the generator. As the speed increases, the torque decreases, but the power transmitted remains almost the same, except for small losses due to friction and heat in the gears.

Since the increase in speed compensates for the reduction in torque, sufficient mechanical power is delivered to the generator. This allows the generator to rotate at its required high speed, enabling efficient conversion of mechanical energy into electrical energy.

Wind vane

Material:

The wind vane is usually made of lightweight and corrosion-resistant materials such as aluminum, stainless steel, or reinforced plastic (fiberglass). These materials ensure durability, low inertia, and resistance to harsh weather conditions like wind, rain, and dust

Working:

The wind vane is a direction-sensing device mounted on top of the wind mill, usually behind the nacelle. Its function is to detect the direction of the wind.

When the wind changes direction, the wind vane turns accordingly. This movement sends a signal to the yaw control system, which rotates the nacelle and rotor so that the blades always face directly into the wind. Proper alignment with the wind ensures maximum wind energy capture.

Output:

The wind vane does not produce power directly, but it plays a crucial role in maximizing power output. By continuously aligning the wind mill with the wind direction, it ensures that the blades receive maximum wind force.

Correct alignment reduces aerodynamic losses and improves efficiency, allowing more mechanical power to be transferred to the gearbox and generator. Thus, the wind vane indirectly helps increase the electrical power output of the wind mill.

Anemometer

Material:

The anemometer is usually made from lightweight and durable materials such as aluminum, stainless steel, or reinforced plastic. The cups or blades are designed to be light so they can rotate easily even at low wind speeds. The internal sensors and shaft are made of corrosion-resistant materials to withstand outdoor conditions.

Working:

The anemometer is mounted on top of the wind mill, near the nacelle. Its function is to measure wind speed.

When wind blows, the cups of the anemometer rotate. The speed of rotation is directly proportional to the wind speed. This rotational speed is converted into an electrical signal and sent to the wind mill's control system.

The control system uses this data to:

- Start the wind mill when wind speed is sufficient
- Adjust blade pitch for efficient operation
- Stop the turbine during very high wind speeds to prevent damage.

Output:

The anemometer does not generate power but helps optimize power production. By providing accurate wind speed data, it ensures that the wind mill operates only under suitable conditions.

At optimal wind speeds, the turbine produces maximum mechanical power, which is then transferred to the gearbox and generator. During very high winds, the anemometer helps reduce or shut down operation, protecting the generator and ensuring safe, efficient power output.

CONCLUSION

Wind farms represent a technically mature, environmentally responsible, and strategically important method of electricity generation when they are **designed around the wind resource, not forced onto it**. Windmills (modern wind turbines) convert a freely available, renewable kinetic resource into electrical energy with no fuel cost, no direct emissions, and minimal water use. However, their success is fundamentally governed by **site wind quality, layout discipline, and electrical integration**, not by turbine count alone.

From an engineering perspective, the **wind resource is the controlling variable**. Annual mean wind speed, turbulence intensity, wind directionality, and seasonal consistency directly determine capacity factor and economic viability. Even modest reductions in wind speed cause disproportionate losses in energy output due to the cubic relationship between wind speed and power. Consequently, long-term site measurement and conservative energy modeling are not optional—they are decisive.

At the layout level, **spacing and wake management** define performance. Densely packed windmills may appear to maximize installed capacity per unit land area, but excessive wake interference reduces net energy yield, increases mechanical fatigue, and shortens component life. Effective wind farms balance land utilization with aerodynamic efficiency, prioritizing optimized spacing and orientation over sheer turbine density. Clustered arrangements (such as 5 turbines per transformer) are electrically efficient and operationally practical, provided that wake effects are accounted for and maintenance access is preserved.

From a strategic and environmental standpoint, wind farms contribute to **energy security, decarbonization, and long-term cost stability**. Once installed, operating costs are low and predictable, making wind power particularly attractive in regions with rising fuel prices or constrained water resources. Coastal and semi-arid regions, when properly assessed, can leverage wind energy to support local development without the environmental burden of conventional thermal generation.

In conclusion, wind farms are highly effective infrastructure assets **only when engineering discipline aligns with natural conditions**. Successful projects are characterized by realistic wind assessment, aerodynamically sound layouts, well-structured electrical systems, and conservative assumptions. When these principles are respected, windmills collectively form a resilient, clean, and economically sound power generation system capable of delivering value for decades.