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Coursework details: **Design of 10MW Wind Power Generation for a Car Battery Manufacturing Site in Ilorin, Nigeria**
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Renewable Energy Technologies
EEEE3019

Introduction and Background

- Nigeria has the largest population and economy in sub-Saharan Africa but suffers from limitations in the power sector which constrains the country's economic growth. Nigeria is endowed with large oil, gas, hydro, and solar resources, and has the potential to generate 13,014.40MW of electric power from existing plants. On most days, however, it is only able to dispatch around 4,000MW, which is insufficient for a country of over 200 million people [2][3][4].
- Wind energy involves the conversion of kinetic energy in the wind to mechanical power by rotating the rotor, connected to the shaft of a generator to produce electrical power [5] and the generated power is proportional to the magnitude of wind speed and the aerodynamic properties of the wind turbine blade.
- The growing demand for sustainable energy has propelled the development and deployment of wind turbines as a significant source of renewable power [6][7]. Modern wind turbines are divided into two basic groups; the horizontal-axis variety (HAWT), like the traditional farm windmills used for pumping water, and the vertical-axis design (VAWT), most large modern wind turbines are horizontal-axis turbines [6][7]. This design is based on HAWT for the Ilorin site.

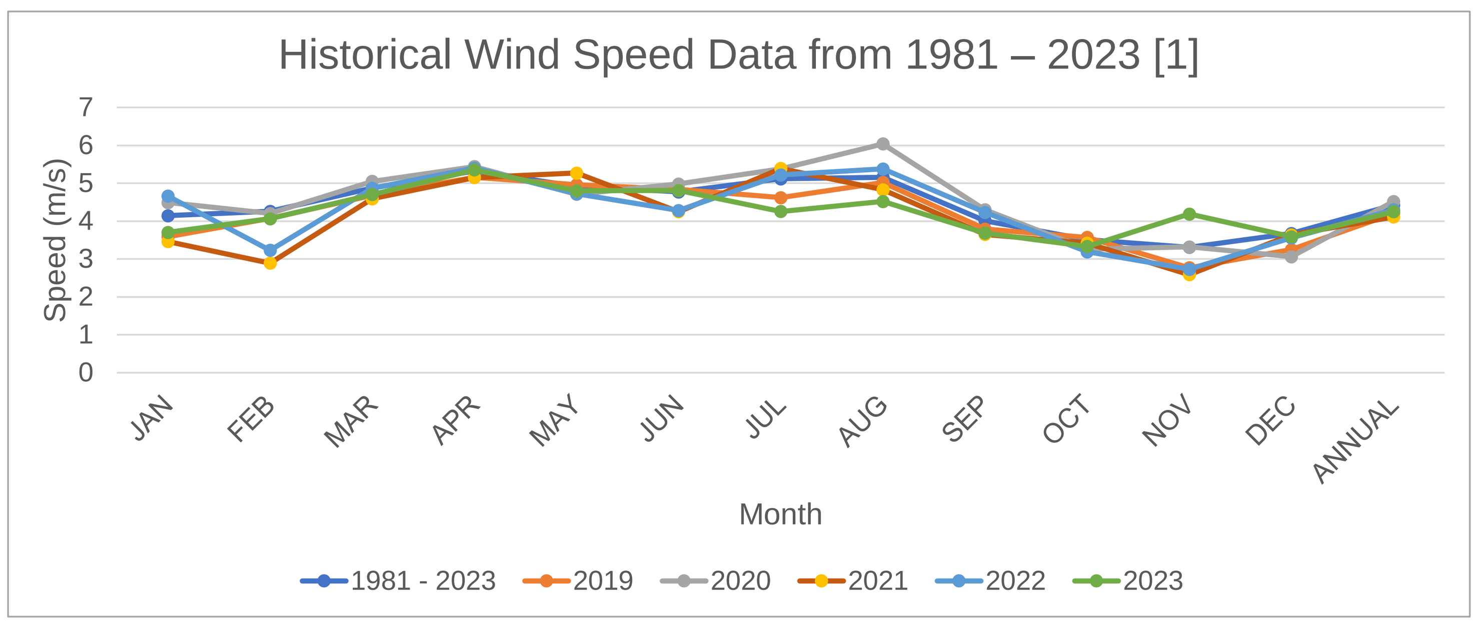

Fig. 1 – Ilorin Historical Wind Data at 50m Height [1]

Why Wind Farm in Ilorin?

- Wind energy is always available every hour for 24 hours a day [1] Fig. 3 as compared to Solar energy which is only available for 12 hours max
- There are two low spring rivers in Ilorin which had already been dammed for utility water, hence no potential for hydro generation. Hence giving wind power, the most preferable option
- Wind is relatively cheaper than hydro and occupies less land area as compared to solar PV panels for the same power output
- There are only onshore renewable energy resources in Ilorin hence, the land below the wind tower can be utilised for other purposes like animal grazing and farming with zero effect on the ecology
- Battery energy storage will be required when wind speed is below the cut-in speed Fig. 2 (frequency distribution graph). A hybrid PV Panel system will be incorporated because there is always sunlight during the dip in Fig. 3b.

Capacity Factor (CF)

- According to Albert Betz, the maximum coefficient of power is 59.3% [8][9][10]
- This design considered 67% of 59.3%, then Cp=0.4
- $P = \frac{1}{2}\rho A v^3 C_p$ where $\rho = 1.225 kg/m^3$
- $CF = \frac{Wind\ Energy\ per\ year}{Turbine\ Rated\ Energy\ per\ year}$
- Hence, **51% capacity factor** was chosen for this design see Table III.

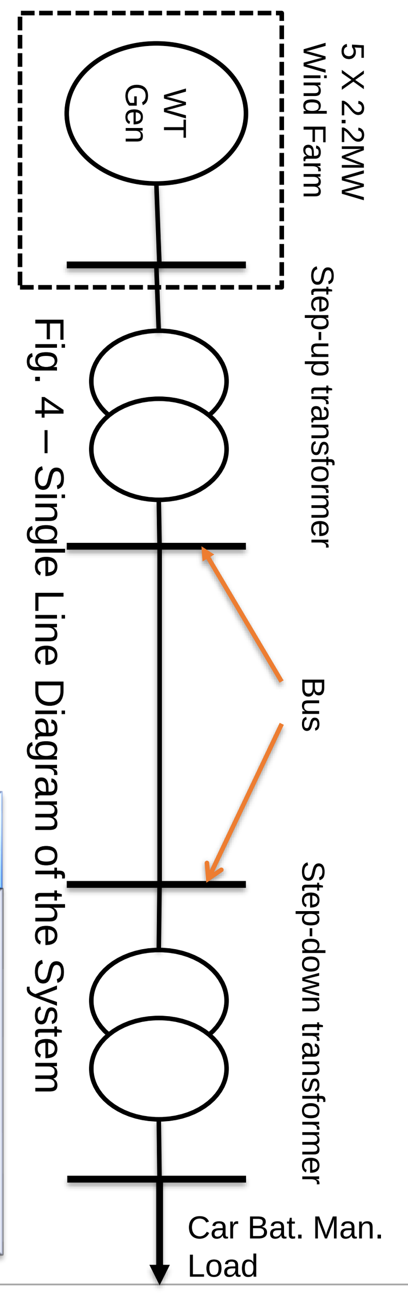

Fig. 4 – Single Line Diagram of the System

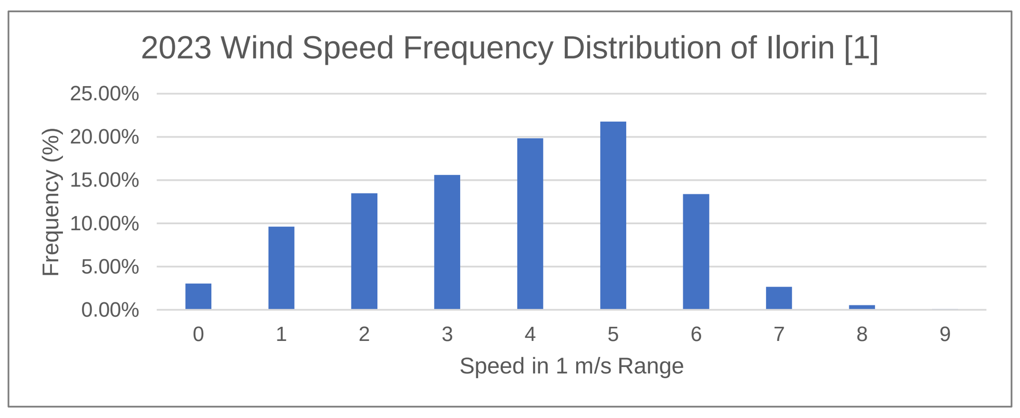

Fig. 2 – 2023 Wind Speed Freq. Distribution at 50m [1]

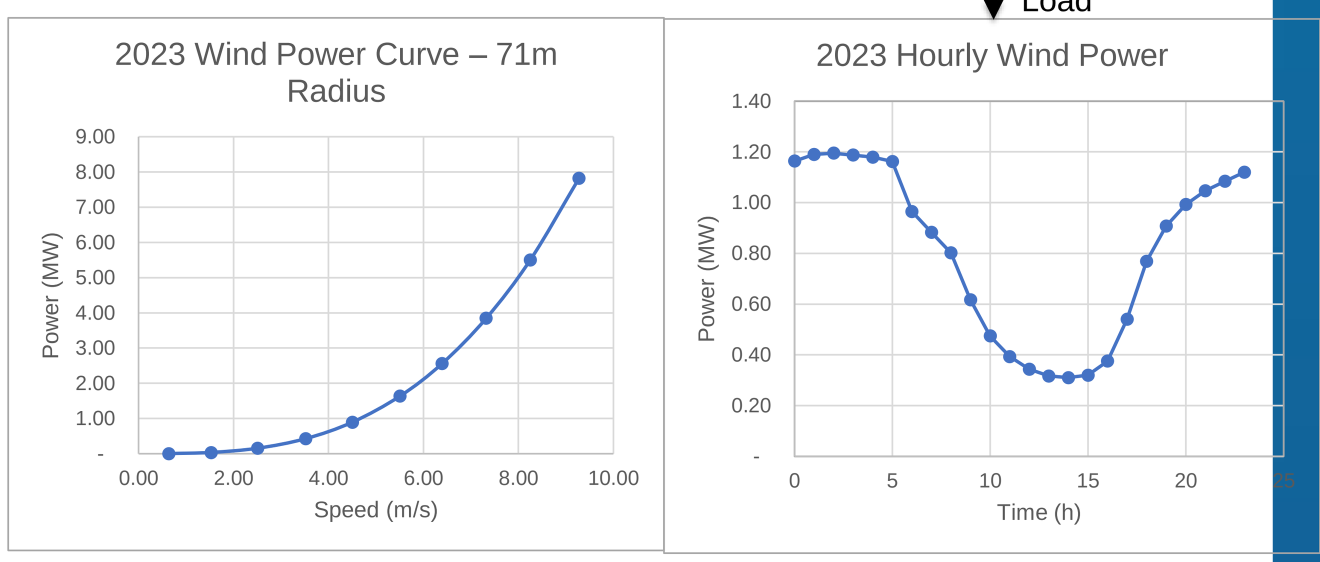

Fig. 3 – A Year Wind Power Curve [1]

Table I – Given Design Specification

Power	10MW
Wind Turbine Type	3 Blades, High-Speed Generator
City	Ilorin, Nigeria

Table II – 2023 Wind Speed Data at 50m Height [1]

Speed (m/s)	Average Speed (m/s)	Frequency (h)
0<v<1	0.64	267
1<v<2	1.53	842
2<v<3	2.51	1180
3<v<4	3.52	1366
4<v<5	4.50	1738
5<v<6	5.51	1906
6<v<7	6.39	1172
7<v<8	7.32	233
8<v<9	8.25	47
9<v<10	9.28	9

Table III – CF Determination

Turbine Rating (MW)	Cp	Swept Area (m2)	Wind Speed (m/s)	CF
10	0.4	52000	9.28	11%
5	0.4	26000	9.28	22%
3.7	0.4	19000	9.28	30%
2.2	0.4	11000	9.28	51%

Install Capacity

- Due to the low mean wind speed of **4.25m/s** for 2023, a **2.2MW** capacity is selected as a single unit with higher CF, Table III
- **5 X 2.2MW** wind farm with **11MW** total installed capacity for the Ilorin manufacturing site.

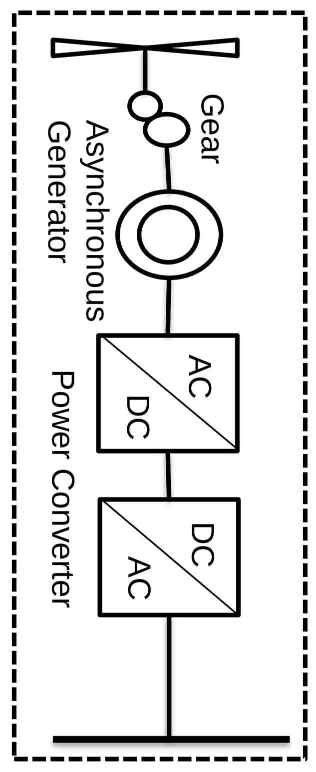

Fig. 5 – Double Fed Induction Generator

Wind Turbine Design Outline for a 2.2MW System

- The maximum wind speed at 50m is 9.28m/s, with an 11000m^2 swept area, the **hub height is 90m**
- **Blade Diameter:** $D = \sqrt{\frac{4A}{\pi}} = 118.34m$
- Wind Sheer equation [10]: $Rated\ Speed = v_2 = v_1 \left(\frac{h_2}{h_1}\right)^{\alpha}$, $\therefore v_2 = 11m/s$ where $\alpha = 0.3$ selected for Ilorin because the city is mostly flat with an average of 8m height building
- **Tip Speed Ratio:** TSR for three blades WT at maximum power is $\frac{4\pi}{3} = 4.2$
- **Blade Speed:** $\omega = \frac{v\lambda}{r} = \frac{11\times4.2}{59.17} = 0.7808 rad/s \Rightarrow N_r = 7.5029 rpm$
- **Cut-in Speed: 3m/s**

Generator Design Outline

- A Double-Fed Induction Generator (DFIG) is selected for this design because of its variable speed ability
- **Drive:** High-Speed type (gear drive)
- **Speed (Ns):** $N_s = 1{,}500\ rpm$ and frequency of 50Hz. $\omega_s = \frac{2\pi\times1500}{60} = 157.08\ rad/s$
- **Number of Poles:** $p = \frac{120f}{N_s} = 4\ poles$
- **Gear Ratio:** $GR = \frac{N_s}{N_r} = \frac{1500}{7.5029} \cong 1{:}200$, three stages
- **Three phase, 660V phase to phase**
- **Magnetic loading (B):** 0.7T
- **Electrical loading (A):** 20,000 AT
- Efficiency = 95%, $P_{out} = 0.95 \times 2.2MW = 2.09MW$
- **Shaft Torque:**
- **Bore Volume (V):** $T = 2VBA \Longrightarrow V = \frac{T}{2BA} = \frac{14005.63}{2\times0.7\times20000} = 0.5002m^3$
- **Aspect ratio (λ):** $\lambda = 0.8333$ [10][11][12] $\lambda = \frac{D}{L} \Longrightarrow L = \frac{6D}{5}$
- **Bore Diameter (D):** $V = \frac{\pi}{4}D^2L \Longrightarrow D = \sqrt[3]{\frac{20V}{6\pi}} = 809.64mm$
- **Stack Length (L):** $L = \frac{6D}{5} = 971.57mm$
- **Outer Diameter (Ds):** split ratio = 0.7 assumed, $D_s = \frac{D}{0.7} = 1{,}156.63mm$
- **Current:** $P_{out} = 3V_{ph}I_{ph}\cos\theta \Longrightarrow I_{ph} = \frac{P_{out}}{\sqrt{3}V_L\cos\theta} = \frac{2.09\times10^6}{\sqrt{3}\times660\times1} = 1{,}828.28A$

Control Strategies [13]

- Active Stall Control
- Passive Stall Control
- Collective Pitch Control
- Individual Pitch Control
- Electric Pitch Controller
- Robust Pitch Controller
- Soft Computing Controller
- Conventional Controller
- Hydraulic Pitch Controller
- MPPT control strategies
- Hence, MPPT control strategies are selected for this design in conjunction with active stall control.

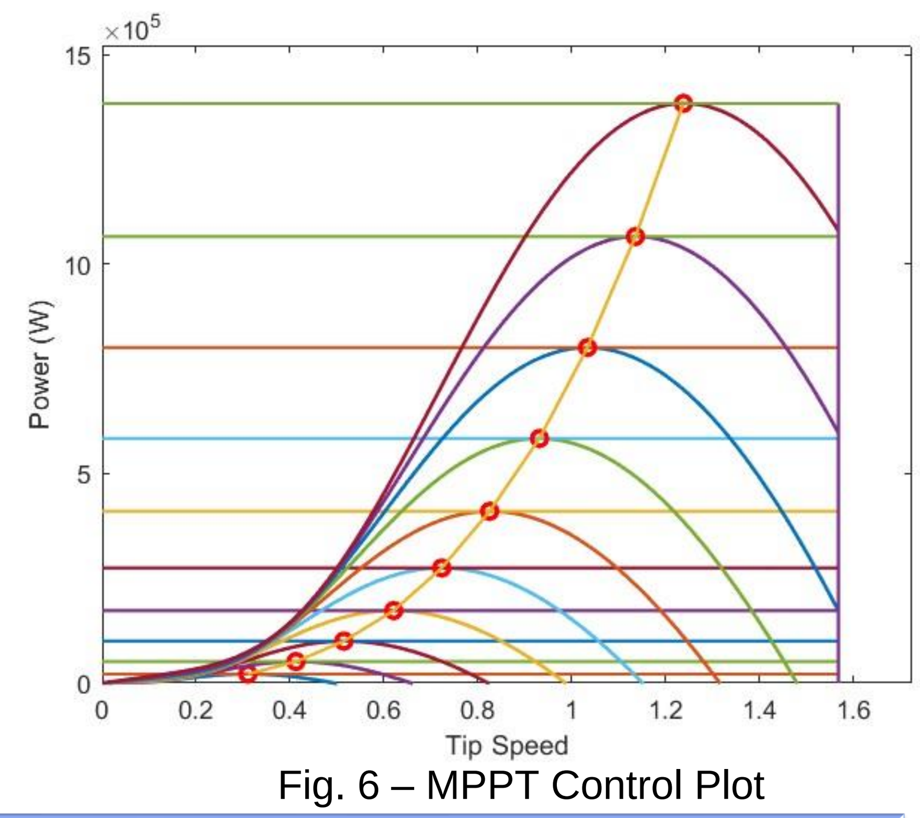

Fig. 6 – MPPT Control Plot

Production Selection

- **Model:** Vestas V120-2.2 MW™ IEC IIB/IEC S
- **Rated Power:** 2,200kW
- **Cut-in Speed:** 3m/s
- **Cut-out Speed:** 20m/s
- **Rotor Diameter:** 120m
- **Swept Area**: 11,310 m²

Production Selection

- **Frequency:** 50Hz
- **Generator Type:** 4 poles, Double Fed Generator, slip rings
- **Hub Heights:** 80 m (IEC S), 92 m (IEC S), 118 m (IEC S), 122 m (IEC S), 137 m (IEC S)
- **Gearbox**: 3 stages type
- Product Datasheet Link

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