Scilab case study project on

Integrated Analysis of Wind Power Opportunity Costs and Turbine Performance

Harikrishnan Nair

(Department of Electrical and Electronics Engineering | St. Xavier's Catholic College of Engineering, Chunkankadai)

Renewable Energy Economics, Turbine Performance and Optimization Cost Strategies

April 04, 2024

1. Abstract:

The comprehensive case study helps in understanding and analysing the power generation systems, particularly focusing on wind-generated electricity. It usually starts with a smart model optimized specifically for wind-generated electricity. This model adjusts the power output in real-time, considering factors like how much extra power is available (spinning reserve adequacy) and how it affects the environment. Its primary aim is to minimize costs while ensuring optimal system performance. Various parameters, including system efficiency, load factor, and capacity factor, are carefully assessed. Subsequently, a detailed Optimal Power Flow (OPF) analysis is conducted using a specialized mathematical approach known as a gradient descent algorithm. This analysis fine-tunes power generation across a multi-bus system to maintain equilibrium effectively. The Wind Turbine Performance Calculator is another essential tool used to study things like air thickness, wind speed, and turbine lifespan. It provides crucial information such as the amount of power generated from the wind and the reduction in carbon emissions using wind power. Additionally, an analysis of Economic Load Dispatch is conducted, taking into account both the presence and absence of losses, to determine the optimal power generation schedule for a large multi-unit system. All the results are carefully written down in CSV files. These files help us plan future work on power systems. This detailed case study also helps us figure out the best way to arrange wind turbines to make the most energy while causing the least impact on the environment.

2. Introduction:

The proposed case study aims to comprehensively analyse wind power generation probability metrics and costs, optimizing turbine performance and economic load dispatch strategies. With renewable energy gaining prominence, wind energy offers a promising avenue for sustainable power generation. Maximizing its potential requires investigating factors influencing turbine performance and integrating economic load dispatch methods for efficient grid power distribution.

A computational framework is developed by analysing user inputs including planned power output, spinning reserve adequacy coefficients, and environmental impact factors, the framework calculates metrics such as expected power output, probabilities of shortage and surplus, and opportunity costs. Additionally, it computes efficiency-related metrics, visualizes data trends, and facilitates optimal power flow analysis. This approach provides valuable insights for maximizing wind energy utilization and promoting sustainable energy management practices.

The study commences with a detailed analysis of wind turbine performance factors, examining critical variables like air density, turbine height, rotor diameter, and wind speed variability to gauge their influence on power generation. Using mathematical models, it computes metrics such as total available wind power, turbine-extracted power, and electrical power generated. Additionally, it investigates factors affecting turbine efficiency, including interference factor and power coefficient, yielding discernments for optimizing wind energy extraction.

Moving forward, the study shifts its focus to economic load dispatch optimization, a crucial facet of power system management. It develops mathematical models by factoring in cost coefficients, power constraints, and total demand to ascertain the optimal power generation schedule for multiple units across the grid. Exploring scenarios both with and without losses, it evaluates transmission losses and incremental losses to devise strategies for effective power distribution, aiming to minimize economic costs.

The methodology employs SCILAB for mathematical modelling, simulation, and data analysis, leveraging its optimization algorithms, data visualization, and CSV file handling features. It iteratively refines models with real-world data to ensure practical applicability. Anticipated outcomes include actionable insights to enhance wind turbine performance and propose economic load dispatch strategies, aiming to minimize costs and transmission losses. Overall, the case study aims to advance wind energy technologies and power system optimization for a greener energy landscape. In summary, SCILAB facilitates rigorous analysis and optimization, fostering sustainable energy solutions.

3. Problem Statement:

Problem Statement:

The global shift towards renewable energy underscores the importance of optimizing wind power generation and integrating it into existing grid systems. This case study addresses the complexities involved by focusing on wind turbine performance and economic load dispatch strategies.

Background Context:

Renewable energy, especially wind power, offers significant environmental benefits but faces challenges due to its variability. This variability affects grid stability and necessitates efficient management strategies to ensure reliable electricity supply while minimizing costs.

Challenges Overview:

Wind power, although environmentally beneficial, poses challenges due to its inherent variability, impacting grid stability and requiring effective management strategies for reliable electricity supply at minimal costs.

Solution Approach:

To tackle these challenges, a computational infrastructure will analyse factors like planned power output and environmental impact to optimize wind turbine performance and economic load dispatch. By calculating key metrics, the study aims to provide insights for maximizing wind energy utilization sustainably.

Improvement Strategies:

Enhancing the solution involves advanced modelling techniques, leveraging tools like SCILAB for efficient analysis, and continuous adaptation to technological advancements and regulatory changes. Refinement with real-world data ensures practical applicability.

Methodology:

The methodology integrates mathematical modelling, simulation, and data analysis, utilizing SCILAB for optimization and visualization. Iterative refinement with real-world data ensures actionable insights for stakeholders, promoting operational efficiency and a cleaner energy landscape. The iterative refinement process also ensures robust, adaptable solutions that enhance decision-making in renewable energy.

4. Basic Concepts Related to the Topic:

I. Sophisticated Concepts and Terminologies in Wind Energy Optimization:

Wind energy, a renewable energy source, derives from the kinetic energy of moving air masses. It is harnessed through wind turbines to generate electricity, contributing to sustainable power production. Understanding these factors is imperative for optimizing power generation efficiency to its fullest potential.

a) Wind Farm Layout Optimization: Wind farm layout optimization involves determining the optimal arrangement of wind turbines within a given area to maximize energy production while minimizing wake effects and land usage.

b) Spinning Reserve Adequacy: Spinning reserve adequacy refers to the capability of power systems to maintain a sufficient level of reserve power generation capacity to compensate for sudden fluctuations in demand or unexpected generator outages.

c) Optimal Power Flow Analysis: Optimal power flow analysis is a mathematical optimization technique used to determine the most economical operation of power systems while satisfying operational constraints such as voltage limits, power balance, and equipment limits.

d) Optimization Algorithms: Optimization algorithms are computational methods used to find the best solution to a problem within a defined set of constraints. These algorithms play a crucial role in optimizing power generation schedules and minimizing costs in energy systems.

e) Cost Analysis: Cost analysis involves evaluating the economic implications of various decisions or scenarios. In wind power generation, cost analysis helps in assessing the overall cost-effectiveness of different strategies and optimizing resource allocation.

f) Probability Metrics: Probability metrics assess the likelihood of specific events occurring within a system. In the context of wind power generation, probability metrics such as the probability of shortage or surplus help in understanding and managing power fluctuations.

g) Power Coefficient: Power coefficient quantifies the efficiency of a wind turbine in converting the kinetic energy of wind into electrical power. It is influenced by factors such as blade design, rotor diameter, and wind speed, and plays a crucial role in turbine performance optimization.

h) Economic Load Dispatch: Economic load dispatch refers to the process of allocating power generation among different generating units within a power system to meet demand at minimum cost while satisfying operational constraints.

II. Advanced Mathematical Formulations in WPG Optimization and Economic Analysis:

Advanced mathematical formulations are essential for optimizing wind power generation and economic analysis. These complex algorithms and models are tailored to address dynamic challenges in harnessing wind energy while ensuring economic viability and grid stability.

a) Wind Power Output Calculation:

- $P = (1/2) \cdot \rho \cdot A \cdot v^3 \cdot C_p$ …. (1)

Where P is the power generated, ρ is air density, A is the swept area of the turbine blades, v is the wind speed, and Cp is the power coefficient.

b) Economic Load Dispatch Formulation:

- Minimize $\sum$ $i = 1$ *to* n $(C_i \cdot P_i)$ …. (2)
- Subject to constraints: $P_{min} \leq P_i \leq P_{max}$ *for* $i=1,2,...,n$

Where C_i is the cost of generating power at unit i, and P_i is the power output of unit i.

c) Gradient Descent Optimization:

- $x_{n+1} = x_n - \alpha \cdot \nabla f(x_n)$ …. (3)

Where x_n is the current solution, α is the learning rate, and $\nabla f(x_n)$ is the gradient of the objective function $f(x)$ with respect to x.

d) Probability Metrics Formulation:

- ***P_r (Shortage) = (Number of shortage occurrences) / (Total number of occurrences)*** …. (4)
- ***P_r (Surplus) = (Number of surplus occurrences) / (Total number of occurrences)*** …. (5)

e) Marginal Cost Formulation:

- $MC_i = (\Delta C) / (\Delta P_i)$

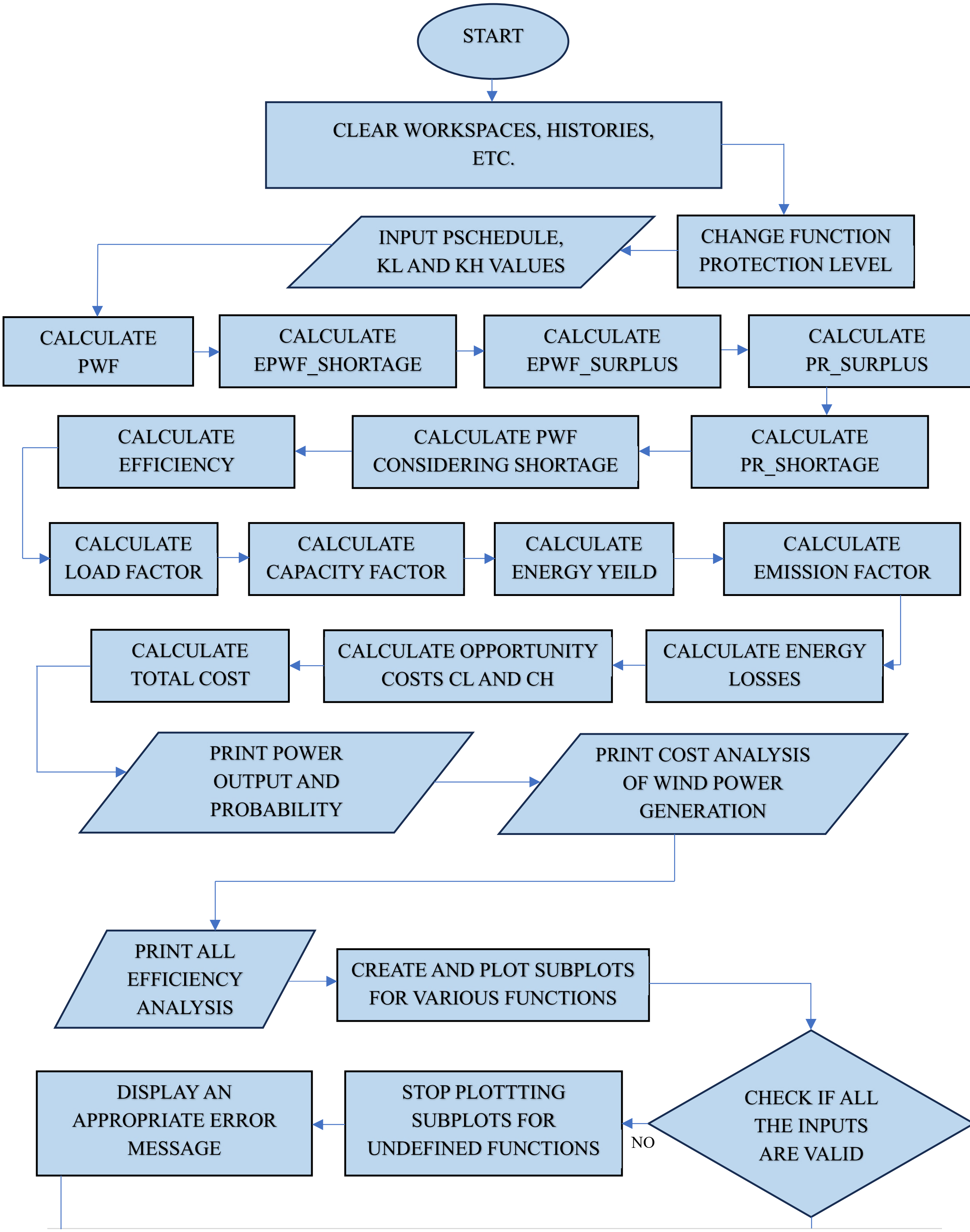
Where MC_i is the marginal cost of producing an additional unit of power at unit i, and ΔC and ΔP_i represent small changes in cost and power output, respectively.

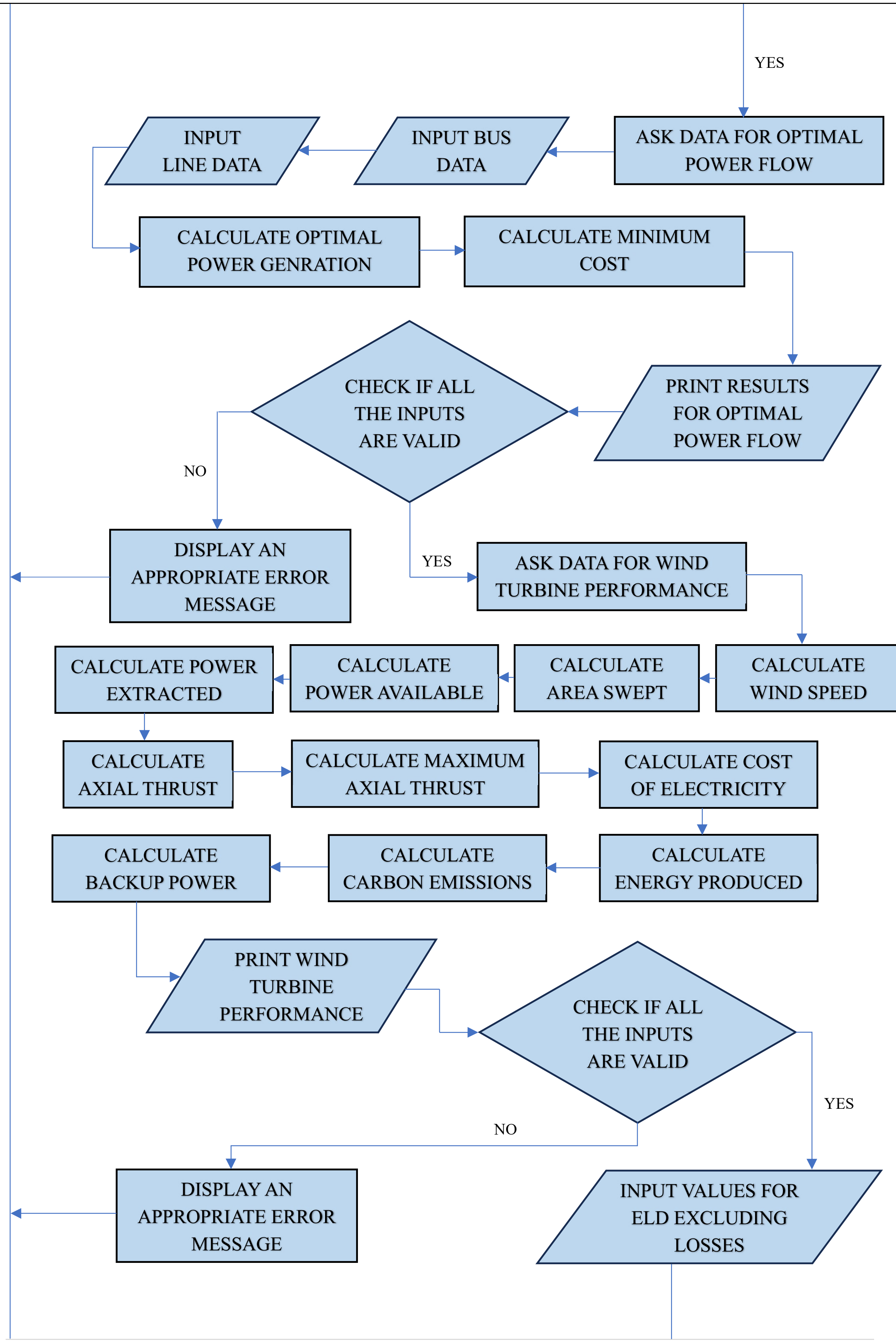
f) Capacity Factor (CF):

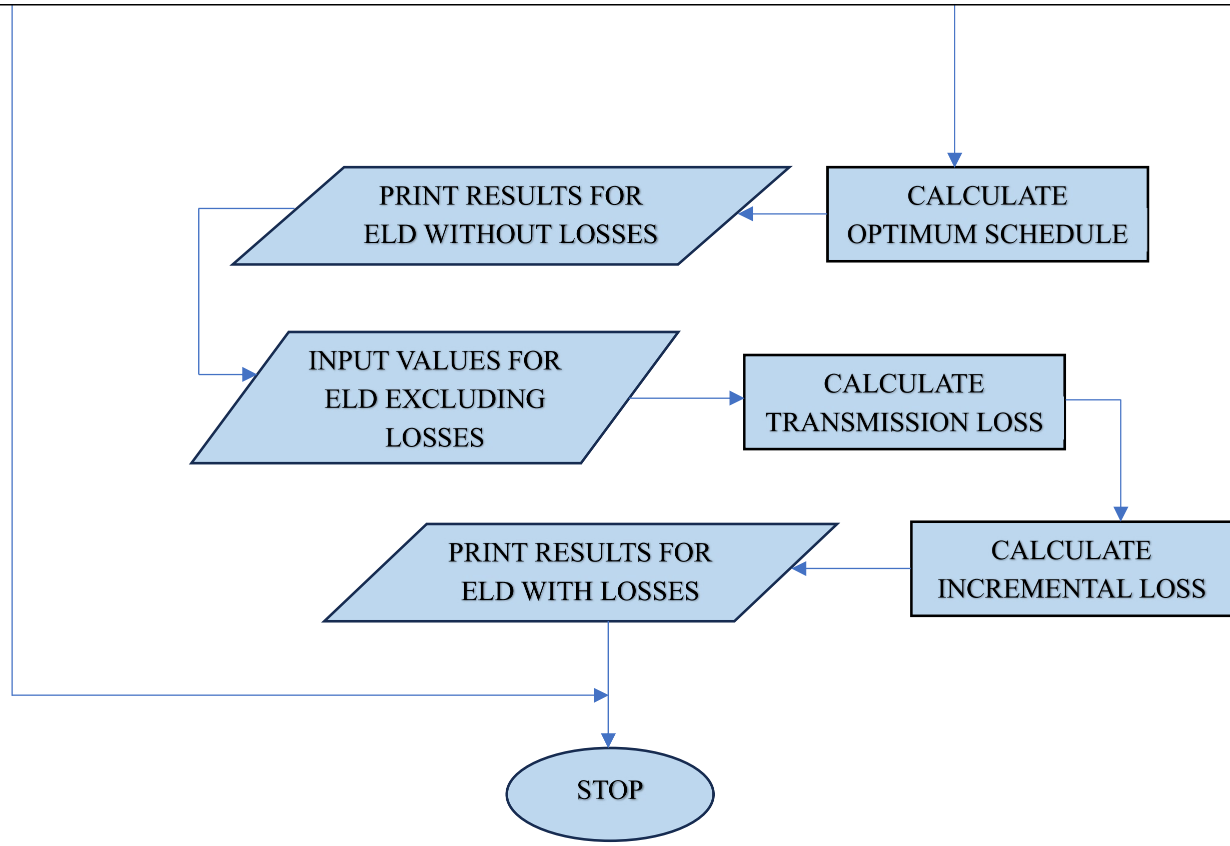
- ***CF = (Actual power generated) / (Maximum possible power generation) × 100%*** …. (6)

The Capacity Factor (CF) is dimensionless and is expressed as a percentage.

5. Flowchart:


START
CLEAR WORKSPACES, HISTORIES, ETC.
CHANGE FUNCTION PROTECTION LEVEL
INPUT PSCHEDULE, KL AND KH VALUES
CALCULATE PWF
CALCULATE EPWF_SHORTAGE
CALCULATE EPWF_SURPLUS
CALCULATE PR_SURPLUS
CALCULATE PR_SHORTAGE
CALCULATE PWF CONSIDERING SHORTAGE
CALCULATE EFFICIENCY
CALCULATE LOAD FACTOR
CALCULATE CAPACITY FACTOR
CALCULATE ENERGY YEILD
CALCULATE EMISSION FACTOR
CALCULATE ENERGY LOSSES
CALCULATE OPPORTUNITY COSTS CL AND CH
CALCULATE TOTAL COST
PRINT POWER OUTPUT AND PROBABILITY
PRINT COST ANALYSIS OF WIND POWER GENERATION
PRINT ALL EFFICIENCY ANALYSIS
CREATE AND PLOT SUBPLOTS FOR VARIOUS FUNCTIONS
CHECK IF ALL THE INPUTS ARE VALID
NO
STOP PLOTTTING SUBPLOTS FOR UNDEFINED FUNCTIONS
DISPLAY AN APPROPRIATE ERROR MESSAGE


YES
ASK DATA FOR OPTIMAL POWER FLOW
INPUT BUS DATA
INPUT LINE DATA
CALCULATE OPTIMAL POWER GENRATION
CALCULATE MINIMUM COST
PRINT RESULTS FOR OPTIMAL POWER FLOW
CHECK IF ALL THE INPUTS ARE VALID
NO
DISPLAY AN APPROPRIATE ERROR MESSAGE
YES
ASK DATA FOR WIND TURBINE PERFORMANCE
CALCULATE WIND SPEED
CALCULATE AREA SWEPT
CALCULATE POWER AVAILABLE
CALCULATE POWER EXTRACTED
CALCULATE AXIAL THRUST
CALCULATE MAXIMUM AXIAL THRUST
CALCULATE COST OF ELECTRICITY
CALCULATE ENERGY PRODUCED
CALCULATE CARBON EMISSIONS
CALCULATE BACKUP POWER
PRINT WIND TURBINE PERFORMANCE
CHECK IF ALL THE INPUTS ARE VALID
YES
NO
DISPLAY AN APPROPRIATE ERROR MESSAGE
INPUT VALUES FOR ELD EXCLUDING LOSSES



6. Software/Hardware Used:

a) Operating System: Windows 11 Pro

b) Scilab Version: 2024.0.0

c) Toolbox: N/A (No specific toolbox used for this case study.)

d) Hardware: N/A (The case study doesn't involve specific hardware requirements.)

e) Programming Language: Scilab (Version 2024.0.0)

f) Integrated Development Environment (IDE): Scilab Console

7. Procedure of Execution:

STEP 1: Launch Scilab on your Computer.

STEP 2: Right - Click on the Scilab Project and open it using Scilab.

STEP 3: Click on the 'Execute' menu and select the 'Save and Execute' option to save your script.

STEP 4: Save your script with a desired name and make sure to save it in .sce extension.

STEP 5: Run your script and switch to the Scilab Console Tab.

STEP 6: Enter the planned power output in the specified range.

STEP 7: Enter the coefficient reflecting spinning reserve adequacy in the specified range.

STEP 7: Enter the coefficient reflecting environmental impact in the specified range.

STEP 8: View the results for Power Metrics, Cost and Efficiency Analysis with its plotting.

STEP 9: Check whether the previous data are valid. If yes goto Step10, else goto Step 46.

STEP 10: Enter the number of buses in the system.

STEP 11: Enter the bus type. 1 for generator bus and 0 for load bus.

STEP 12: Enter the real power demand.

STEP 13: Enter the reactive power demand.

STEP 14: Enter the voltage in p.u. values.

STEP 15: Check whether the number of buses is greater than 1.

STEP 16: If yes, repeat Step 12 to Step 15. Else goto Step 46.

STEP 17: Enter the number of lines in the system.

STEP 18: Enter the value for from bus.

STEP 19: Enter the value for to bus.

STEP 20: Enter the resistance, reactance and line capacity of the system.

STEP 21: Check whether the number of lines is greater than 1.

STEP 22: If yes, repeat Step 17 to Step 21. Else goto Step 46.

STEP 23: Enter the Air Density Value within the specified range.

STEP 24: Enter the Alpha value within the specified range.

STEP 25: Enter the height at which the wind speed is given in the specified range.

STEP 26: Enter the diameter of rotor within the specified range.

STEP 27: Enter the efficiency of the generator within the specified range.

STEP 28: Enter the reduction of speed within the specified range.

STEP 29: Enter the cost per kWh of electricity within the specified range.

STEP 30: Enter the Lifetime of the Turbine within the specified range.

STEP 31: Enter the amount of CO_2 saved per kWh in the specified range.

STEP 32: Enter the cost of backup power per kWh in the specified range.

STEP 33: Enter the Downtime of the Turbine within the specified range.

STEP 34: Enter the wind speed variability in the specified range.

STEP 35: View the results for the calculated wind turbine performance parameters.

STEP 36: Enter the number of units in the system for the ELD neglecting losses.

STEP 37: Enter the cost coefficient in matrix form.

STEP 38: Enter the minimum and maximum values of power for all units.

STEP 39: Enter the Total demand within the specified range.

STEP 40: View the results for the optimal schedule in the Scilab Console.

STEP 41: Enter the number of units in the system for the ELD considering losses.

STEP 42: Enter the loss Coefficient in matrix form.

STEP 43: Enter the power of the units in per unit values.

STEP 44: Enter the base value within the specified range.

STEP 45: View the results for the transmission and incremental losses in Scilab Console.

STEP 46: End Execution.

8. Result:

The user ran the program and meticulously calculated various metrics to provide actionable insights. From power output probabilities to economic load dispatch, the analysis offered a comprehensive view of energy dynamics.

Let us see the results obtained one by one.

1. **Planned Power Output:** The planned power output was set to 300 MW, within the specified range of 1 to 1500 MW.
2. **Coefficient Reflecting Spinning Reserve Adequacy:** The coefficient reflecting spinning reserve adequacy was determined to be 0.2, falling within the acceptable range of 0.05 to 0.25.
3. **Coefficient Reflecting Environmental Impact:** The coefficient reflecting environmental impact was estimated at 0.1 per MWh, aligning with the acceptable range of 0.05 to 0.25 per MWh.
4. **Power Output and Probability Metrics:** The real-time power output was measured at 278.73 MW, with a probability of shortage at 65.35% and surplus at 34.65%. The expected output during shortage and surplus were calculated as 193.65 MW and 495.73 MW respectively.
5. **Cost Analysis of Wind Power Generation:** The opportunity cost of wind power shortage stood at $13.90 USD, while wind power surplus incurred $6.78 USD. The overall cost of wind-generated electricity was calculated at $20.68 USD.

6. **Basic Efficiency Analysis:** The efficiency of power generation was computed at 92.91%, with a power factor of 0.90, a load factor of 92.91% and an energy loss of 21.28 kWh.

7. **Special Efficiency Analysis:** The capacity factor was estimated to be 3.87%, with an energy yield of 6689.50 kWh and an emission factor of 0.11 kg/MWh.

8. **Optimal Power Flow Analysis:** The optimal power flow analysis revealed bus voltages at 1.05 and 1.025 per unit values, with a calculated minimum cost of $2.36 USD.

9. **Wind Turbine Performance Calculator:** The wind turbine performance assessment revealed insightful metrics crucial for evaluating efficiency and viability. These were the key findings:

- Total power available in the wind: 6,467,916.855540 Watts
- Power extracted by the turbine: 2,404,202.310206 Watts
- Electrical power generated: 2,043,571.963675 Watts
- Axial thrust on the turbine: 154,867.602571 Newton
- Maximum axial thrust on the turbine: 366,637.316692 Newton
- Cost of electricity generated: $204.357196 per hour
- Energy produced in a day: 49,045.727128 kWh
- Energy produced in a day (adjusted for downtime): 38,827.867310 kWh
- Power extracted by the turbine (adjusted for wind speed variability): 2,404,202.310206 Watts
- Total energy produced over the lifetime of the turbine: 212,582,573.521342 kWh
- Total carbon emissions saved over the lifetime of the turbine: 106,291,286.760671 kg
- Total cost of backup power over the lifetime of the turbine: $159,436,930.141007

10. **Economic Load Dispatch Excluding Losses:** The economic load dispatch, excluding losses, optimized power generation across units to meet demand efficiently. Here's the optimum schedule:

- Unit 1: 130.538462 MW
- Unit 2: 41.384615 MW
- Unit 3: 103.076923 MW

11. **Economic Load Dispatch Including Losses:** The economic load dispatch, considering losses, further refined power distribution by accounting for transmission and incremental losses. The results included the following:

- Transmission loss: 0.003675 p.u.
- Incremental losses:
- Unit 1: 0.004300 p.u.
- Unit 2: 0.001350 p.u.
- Unit 3: 0.005600 p.u.

Scilab 2024.0.0 Console

File Edit Control Applications ?

Scilab 2024.0.0 Console

```
[<--- Give the value in the range (1 - 1500 MW) --->]
Enter the Planned Power Output: 300

[<--- Give the value in the range (0.05 - 0.25) --->]
Enter the Coefficient Reflecting Spinning Reserve Adequacy: 0.2

[<--- Give the value in the range (0.75 - 0.2 per MWh) --->]
Enter the Coefficient Reflecting Environmental Impact: 0.1


----- POWER OUTPUT AND PROBABILITY METRICS -----
Real-time Power Output (PWF): 278.729327
Probability of Shortage (Pr_shortage): 0.653518
Probability of Surplus (Pr_surplus): 0.346482
Expected Output during Shortage (EPWF_shortage): 193.646633
Expected Output during Surplus (EPWF_surplus): 495.733166

----- COST ANALYSIS OF WIND POWER GENERATION -----
Opportunity Cost of Wind Power Shortage (CL) in $ (USD): 13.900767
Opportunity Cost of Wind Power Surplus (CH) in $ (USD): 6.781803
Overall Cost of Wind-Generated Electricity (Ctotal) in $ (USD): 20.682570

----- BASIC EFFICIENCY ANALYSIS -----
Efficiency of Power Generation: 92.909776%
Power Factor: 0.900000
Load Factor: 0.929098
Energy Loss: 21.270673

----- SPECIAL EFFICIENCY ANALYSIS -----
Capacity Factor: 0.038712
Energy Yield: 6689.503840 kWh
Emission Factor: 0.110000 kg/MWh

----- OPTIMAL POWER FLOW ANALYSIS -----
Enter the number of buses in the system: 2


----- BUS 1 -----

DISCLAIMER !!!!
Choose a Valid Bus Type...
```

Scilab 2024.0.0 Console

File Edit Control Applications ?

Scilab 2024.0.0 Console

```
DISCLAIMER !!!!
Choose a Valid Bus Type...
Give the Real Power Demand (Pd) within the Range (1 - 10000 MW)...
Give the Reactive Power Demand (Qd) within the Range (1 - 10000 MVAR)...
Give the Voltage Magnitude in Per Units within the Range (0.5 - 1.2 p.u.)...
Give the Number of Lines in the system within the Range (1 - 1000)...[Recommended Value is Maximum 5, as it would keep iterating till it becomes 0]...

Choose a Bus Type (1 for Generator Bus & 0 for Load Bus): 1

Enter the Real Power Demand (Pd) in MW: 35

Enter the Reactive Power Demand (Qd) in MVAR: 45

Enter the Voltage Magnitude (V) in Per Unit Values: 1.05


----- BUS 2 -----

DISCLAIMER !!!!
Choose a Valid Bus Type...
Give the Real Power Demand (Pd) within the Range (1 - 10000 MW)...
Give the Reactive Power Demand (Qd) within the Range (1 - 10000 MVAR)...
Give the Voltage Magnitude in Per Units within the Range (0.5 - 1.2 p.u.)...
Give the Number of Lines in the system within the Range (1 - 1000)...[Recommended Value is Maximum 5, as it would keep iterating till it becomes 0]...

Choose a Bus Type (1 for Generator Bus & 0 for Load Bus): 0

Enter the Real Power Demand (Pd) in MW: 30

Enter the Reactive Power Demand (Qd) in MVAR: 40

Enter the Voltage Magnitude (V) in Per Unit Values: 1.025

Enter the number of lines in the system: 2


----- LINE 1 -----

DISCLAIMER !!!!
Give the From Bus Value within the Range (1 - 1000)...
Give the To Bus Value within the Range (1 - 1000)...
```

Scilab 2024.0.0 Console

File Edit Control Applications ?

Scilab 2024.0.0 Console

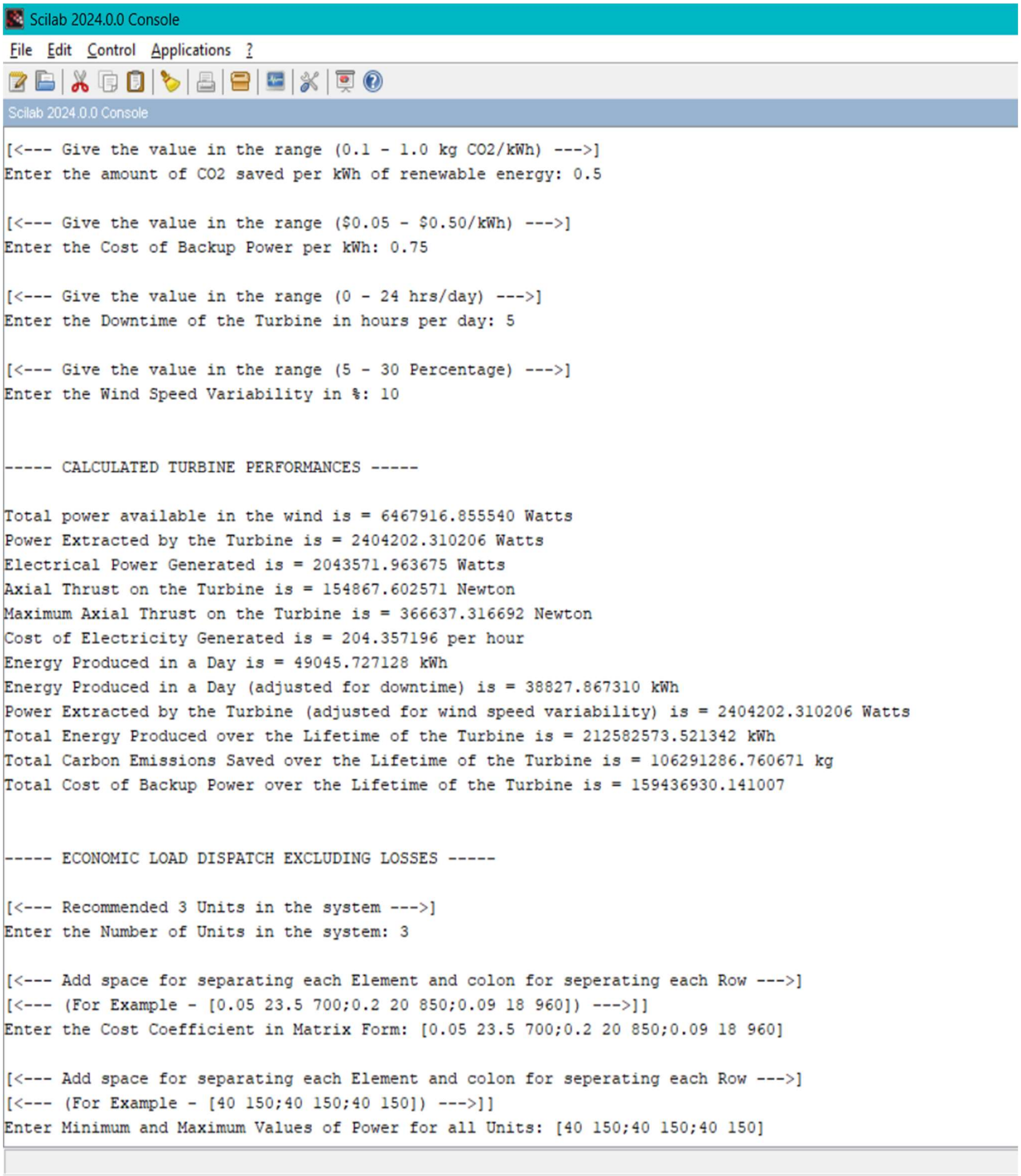
```
----- LINE 1 -----

DISCLAIMER !!!!
Give the From Bus Value within the Range (1 - 1000)...
Give the To Bus Value within the Range (1 - 1000)...
Give the value of Resistance (R - ohms) within the Range (0.001 - 10 ohms/km)...
Give the value of Reactance (X - ohms) within the Range (0.001 - 10 ohms/km)...
Give the value of Line Capacity within the Range (1 - 10000 MW)...

Enter From Bus Value in general: 1

Enter To bus Value in general: 2

Enter the value for Resistance (R) in ohms/km: 0.5

Enter the value for Reactance (X) in ohms/km: 1.0

Enter the Line Capacity of the system in MW: 20


----- LINE 2 -----

DISCLAIMER !!!!
Give the From Bus Value within the Range (1 - 1000)...
Give the To Bus Value within the Range (1 - 1000)...
Give the value of Resistance (R - ohms) within the Range (0.001 - 10 ohms/km)...
Give the value of Reactance (X - ohms) within the Range (0.001 - 10 ohms/km)...
Give the value of Line Capacity within the Range (1 - 10000 MW)...

Enter From Bus Value in general: 2

Enter To bus Value in general: 3

Enter the value for Resistance (R) in ohms/km: 1.0

Enter the value for Reactance (X) in ohms/km: 1.5

Enter the Line Capacity of the system in MW: 30


STARTING GRADIENT DESCENT ALGORITHM...
```

Scilab 2024.0.0 Console

File Edit Control Applications ?

Scilab 2024.0.0 Console

```
STARTING GRADIENT DESCENT ALGORITHM...

----- RESULTS -----
OPTIMAL POWER GENERATION:
Bus Voltage 1 in Per Unit Value: 1.050000
Bus Voltage 2 in Per Unit Value: 1.025000
Calculated Minimum Cost in $ (USD): 2.364450

----- WIND TURBINE PERFORMANCE CALCULATOR -----

[<--- Give the value in the range (1.0 - 1.3 kg/m^3) --->]
Enter the Air Density in kg/m^3: 1.2

[<--- Give the value in the range (0.1 - 0.5) --->]
Enter the Alpha Value: 0.4

[<--- Give the value in the range (10 - 100 m) --->]
Enter the Height at which Wind Speed is given in m: 50

[<--- Give the value in the range (50 - 150 m) --->]
Enter the Tower Height in m: 75

[<--- Give the value in the range (3 - 25 m/s) --->]
Enter the Wind Speed at given Height in m/s: 15

[<--- Give the value in the range (30 - 150 m) --->]
Enter the Diameter of Rotor in m: 50

[<--- Give the value in the range (75 - 95 Percentage) --->]
Enter the Efficiency of the Generator in %: 85

[<--- Give the value in the range (1 - 25 Percentage) --->]
Enter the Reduction of Speed in %: 12

[<--- Give the value in the range ($0.05 - $0.50/kWh) --->]
Enter the Cost per kWh of Electricity: 0.10

[<--- Give the value in the range (0 - 30 Years) --->]
Enter the Lifetime of the Turbine in Years: 15

[<--- Give the value in the range (0.1 - 1.0 kg CO2/kWh) --->]
```



Scilab 2024.0.0 Console

File Edit Control Applications ?

Scilab 2024.0.0 Console

```
[<--- Give the value in the range (0.1 - 1.0 kg CO2/kWh) --->]
Enter the amount of CO2 saved per kWh of renewable energy: 0.5

[<--- Give the value in the range ($0.05 - $0.50/kWh) --->]
Enter the Cost of Backup Power per kWh: 0.75

[<--- Give the value in the range (0 - 24 hrs/day) --->]
Enter the Downtime of the Turbine in hours per day: 5

[<--- Give the value in the range (5 - 30 Percentage) --->]
Enter the Wind Speed Variability in %: 10


----- CALCULATED TURBINE PERFORMANCES -----

Total power available in the wind is = 6467916.855540 Watts
Power Extracted by the Turbine is = 2404202.310206 Watts
Electrical Power Generated is = 2043571.963675 Watts
Axial Thrust on the Turbine is = 154867.602571 Newton
Maximum Axial Thrust on the Turbine is = 366637.316692 Newton
Cost of Electricity Generated is = 204.357196 per hour
Energy Produced in a Day is = 49045.727128 kWh
Energy Produced in a Day (adjusted for downtime) is = 38827.867310 kWh
Power Extracted by the Turbine (adjusted for wind speed variability) is = 2404202.310206 Watts
Total Energy Produced over the Lifetime of the Turbine is = 212582573.521342 kWh
Total Carbon Emissions Saved over the Lifetime of the Turbine is = 106291286.760671 kg
Total Cost of Backup Power over the Lifetime of the Turbine is = 159436930.141007


----- ECONOMIC LOAD DISPATCH EXCLUDING LOSSES -----

[<--- Recommended 3 Units in the system --->]
Enter the Number of Units in the system: 3

[<--- Add space for separating each Element and colon for seperating each Row --->]
[<--- (For Example - [0.05 23.5 700;0.2 20 850;0.09 18 960]) --->]]
Enter the Cost Coefficient in Matrix Form: [0.05 23.5 700;0.2 20 850;0.09 18 960]

[<--- Add space for separating each Element and colon for seperating each Row --->]
[<--- (For Example - [40 150;40 150;40 150]) --->]]
Enter Minimum and Maximum Values of Power for all Units: [40 150;40 150;40 150]
```

```
Scilab 2024.0.0 Console
File  Edit  Control  Applications  ?
Scilab 2024.0.0 Console

[<--- Add space for separating each Element and colon for seperating each Row --->]
[<--- (For Example - [0.05 23.5 700;0.2 20 850;0.09 18 960]) --->]]
Enter the Cost Coefficient in Matrix Form: [0.05 23.5 700;0.2 20 850;0.09 18 960]

[<--- Add space for separating each Element and colon for seperating each Row --->]
[<--- (For Example - [40 150;40 150;40 150]) --->]]
Enter Minimum and Maximum Values of Power for all Units: [40 150;40 150;40 150]

[<--- Give the value in the range (1 - 1000 MW)  --->]
Enter Total Demand: 275

The Optimum Schedule is:
    130.538462
    41.384615
    103.076923


----- ECONOMIC LOAD DISPATCH INCLUDING LOSSSES -----

[<--- Recommended 3 Units in the system --->]
Enter the Number of Units in the system: 3

[<--- Add space for separating each Element and colon for seperating each Row --->]
[<--- (For Example - [0.01 -0.0003 -0.0002;-0.0003 0.0025 -0.0005;-0.0002 -0.0005 0.0031]) --->]]
Enter the Loss Coefficient in Matrix Form: [0.01 -0.0003 -0.0002;-0.0003 0.0025 -0.0005;-0.0002 -0.0005 0.0031]

[<--- Add space for separating each Element and colon for seperating each Row --->]
[<--- (For Example - [50/200 100/200 200/200]) --->]]
Enter the Power of the Units in Matrix Form in Per Unit Values: [50/200 100/200 200/200]

[<--- Give the value in the range (1 - 1000 MW) --->]]
Enter the Base Value: 200

The Transmission Loss in p.u. is:
    0.003675
The Incremental Loss in p.u. are:
    0.004300
    0.001350
    0.005600
```


Graphic window number 0
File Tools Edit ?
Graphic window number 0
Sinusoidal Function vs. Scheduled Power Output
Sinusoidal Function
Scheduled Power Output
Exponential Function vs. Scheduled Power Output
Exponential Function
Scheduled Power Output
Logarithmic Function vs. Scheduled Power Output
Logarithmic Function
Scheduled Power Output
Cost vs. Scheduled Power Output
Cost
CL
CH
Ctotal
Scheduled Power Output
Cumulative Cost Over Time
Cumulative Cost
Scheduled Power Output
Opportunity Cost of Shortage vs. Scheduled Power Output
Opportunity Cost of Shortage
Scheduled Power Output

9. References:

1. Optimal Power Flow Solution Incorporating Wind Power, Libao Shi, Senior Member, IEEE, Chen Wang, Liangzhong Yao, Yixin Ni, Senior Member, IEEE, and Masoud Bazargan, IEEE SYSTEMS JOURNAL, VOL. 6, NO. 2, JUNE 2012.

2. Power System Simulation - Prof – Dr. Jain B. Marshel – Scilab Code, https://www.scribd.com/document/429026663/Power-System-Simulation-Prof-Jain-B-Marshel-Scilab.

3. Power System Operation and Control, Anna University Syllabus, Regulation – 2013, M. Jeraldin Ahila, Lakshmi Publications, Chennai, Electrical and Electronics Engineering.

4. Economic Load Dispatch Using Optimization Algorithms, Aakash Kedari, Aumkar Borgaonkar, Genetic Algorithms, Power system optimization, Firefly Algorithm, VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY, NAGPUR, https://www.academia.edu/13342664/ECONOMIC_LOAD_DISPATCH_USING_OPTIMIZATION_ALGORITHMS.

5. A Comprehensive Review of Economic Load Dispatch Techniques in Power Systems, Vimal Bhatt and Pramod Kumar Rathore, RKDF College of Engineering, Bhopal, Madhya Pradesh, India, https://www.ijtrd.com/papers/IJTRD26724.pdf.

6. Wind turbine performance analysis for energy cost minimization, Yassine Charabi & Sabah Abdul-Wahab, Original Research Article, Open access, Published: 17 August 2020, https://sustainenergyres.springeropen.com/articles/10.1186/s40807-020-00062-7.

7. Principle Parameters and Environmental Impacts that Affect the Performance of Wind Turbine: An Overview, Review Article-Mechanical Engineering, Published: 18 November 2021, Volume 47, pages 7891–7909, (2022), https://link.springer.com/article/10.1007/s13369-021-06357-1

8. SYNTHESIS AND REVIEW - Environmental Impact of Wind Energy, J Mann and J Teilmann, Department of Wind Energy, Technical University of Denmark, Frederiksborgvej 399, DK - 4000 Roskilde, Denmark - Department of Bioscience, Aarhus University, Frederiksborgvej 399, DK-4000 Roskilde, Denmark.

9. Estimating the Spinning Reserve Requirements in Systems with Significant Wind Power Generation Penetration, Publisher: IEEE, Miguel A. Ortega-Vazquez; Daniel S. Kirschen, Print ISBN:978-1-4244-4241-6, Print ISSN: 1932-5517, Estimating the spinning reserve requirements

in systems with significant wind power generation penetration | IEEE Conference Publication | IEEE Xplore.

10. Quantifying Spinning Reserve in Systems With Significant Wind Power Penetration, Kevin Tomsovic, 2000, IEEE Transactions on Power Systems, Electrical And Electronic Engineering, Publication Name: IEEE Transactions on Power Systems, https://www.academia.edu/16668564/Quantifying_Spinning_Reserve_in_Systems_With_Significant_Wind_Power_Penetration.

11. Economic_Load_Dispatch, IIT Patna, Economic_Load_Dispatch.pdf (iitp.ac.in).

12. Wind Energy Formulas, https://byjus.com/wind-energy-formula/.

13. Wind Energy Formula, Power Calculations and Solved Examples, Physics Wallah (PW.LIVE), https://www.pw.live/exams/school/wind-energy-formula/.

14. A Traditional Approach to Solve Economic Load Dispatch Problem Considering the Generator Constraints, Department of Electrical and Electronics Engineering, SSTC, Bhilai, Chhattisgarh, India, Department of Electrical Engineering, Bhilai Institute of Technology, Durg, Chhattisgarh, India, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 2 Ver. III (Mar – Apr. 2015), PP 27-32, https://www.iosrjournals.org/iosr-jeee/Papers/Vol10-issue2/Version-3/E010232732.pdf.

15. Environmental Impacts of Wind Power, Published Mar 5, 2013, REPORTS & MULTIMEDIA / EXPLAINER, https://www.ucsusa.org/resources/environmental-impacts-wind-power.

----xxxx---