SOLAR & WIND ENERGY ESTIMATION AND FORECASTING APPLICATION

(SWEEFA)

HELP-FILE

By

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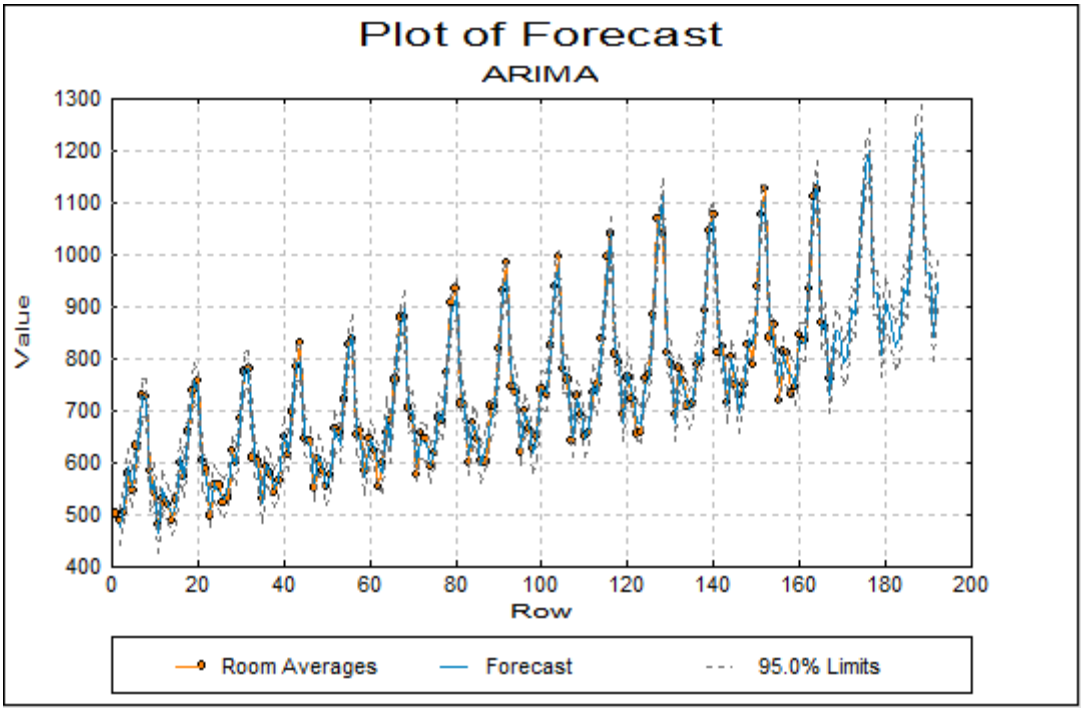
INTRODUCTION

The problem of solar and wind energy forecasting is difficult due to the stochastic nature of the weather variables (Irradiance, Temperature, Wind Speed etc.) which are the drivers of these energy systems. However, there is a vast literature on energy estimation models for both solar and wind energy systems, , it shows that, if we know the weather variables we can find the theoretical energy output of these power plants which match the real energy output to a great extent of accuracy. So, we can consider energy output from solar and wind power plants to be deterministic, if we have the accurate weather variables as input to these energy estimation models.

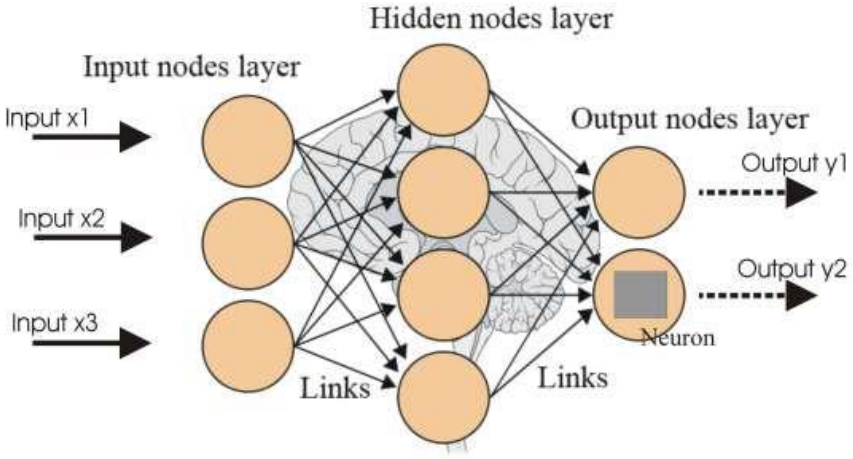
Now the problem of stochastic behaviour can be abstracted to the level of weather variables; and now we have to create accurate forecasts for the weather, rest will be taken care by the energy estimation model. Study of the literature on weather forecasting shows us three major techniques which are tested for high accuracy.

The first being the classical method of time series modelling propagated by the statisticians Box and Jenkins in the 70's, and still used today. Their models of ARMA (Autoregressive Moving Averages, for stationary time series) and ARIMA (Autoregressive Integrated Moving Averages, for non-stationary time series) provide building blocks for creating the most basic statistical forecasts based on the time series' mean and variance values.



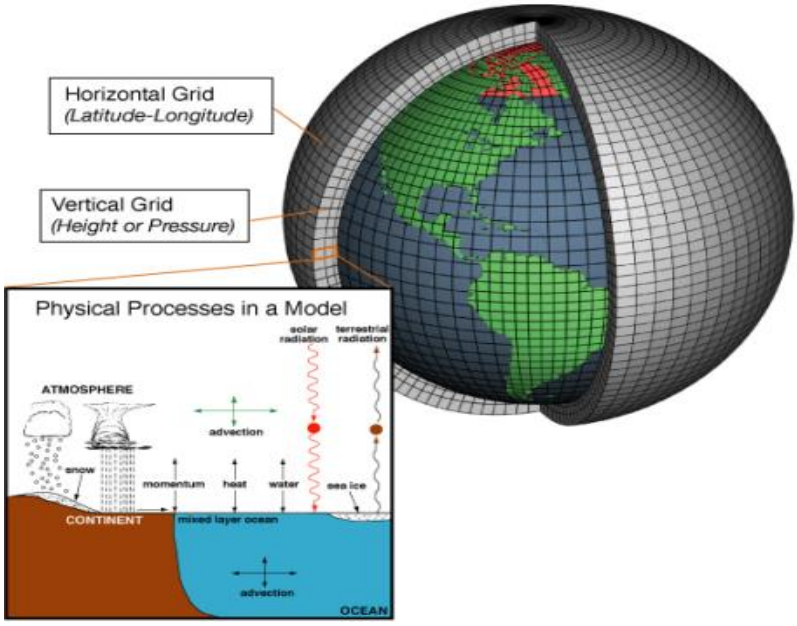
ARIMA Model Forecast

The second is the modern technique of Artificial Neural Networks, which are inspired from biological neural networks. They work on the principle of interconnected neurons forming a network between inputs and outputs; the neurons consists of a mathematical function, biases and weights. This network of neurons is made to learn the data during training phase using appropriate learning methods. ANN's can be trained to do a variety of jobs; namely Clustering, Classification and Regression. For weather variable forecasting we need to develop a neural network for solving a regression problem. ANN's are more effective than Time Series Models as they are not linear models, and are able to learn highly non-linear relationships between input and output; the only constraint being a good data set of training purposes.



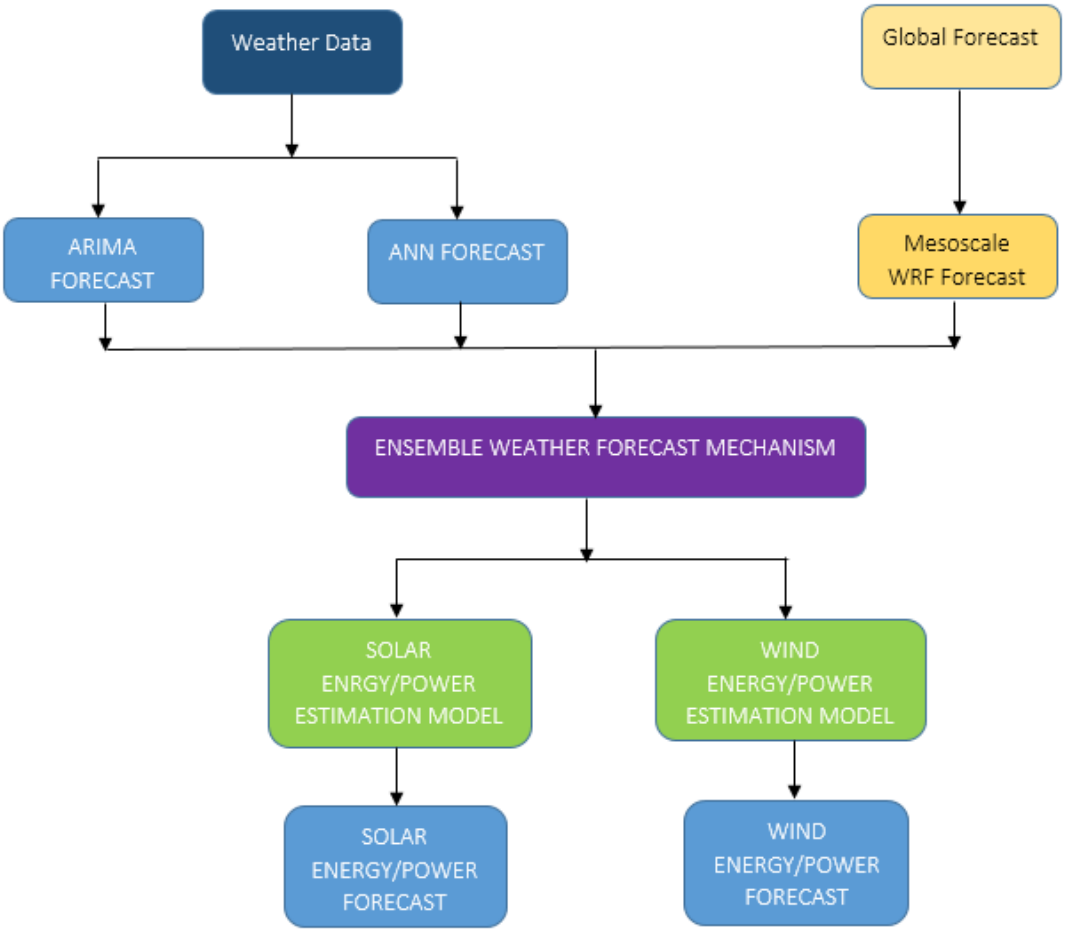
Artificial Neural Network

Finally we have the Numerical Weather Prediction Models (NWP's) like ECMWF and WRF they produce good weather forecasts up to 1km spatial and about 3min temporal resolution. NWP's are quite different from the first two forecasting techniques as they depend on accurate physical descriptions of the atmospheric processes and tend to give highly accurate forecasts. But, the problem here is these softwares require supercomputers to run them as they require a lot of computing power and memory.



Numerical Weather Prediction System

With the guidance of **Dr.Sagarkumar Agravat** (Scientist In-Charge Solar R&D Projects, Gujarat Energy Research and Management Institute [GERMI]) and help form a fellow intern (**Mr. Saurabh Gavali**) we have been able to create energy estimation applications for Solar and Wind energy. Also, applications have been created for forecasting weather variables using ANN and ARIMA methods. The applications have been created in MATLAB Software and have a graphical user interface. To deal with bad data, a data preprocessing system for weather variables has been created to give statistically correct data sets. Also, a system consisting of four raspberry pi's (micro-computer running linux) working as a cluster of computer running WRF (Weather Research and Forecast System) has been developed.

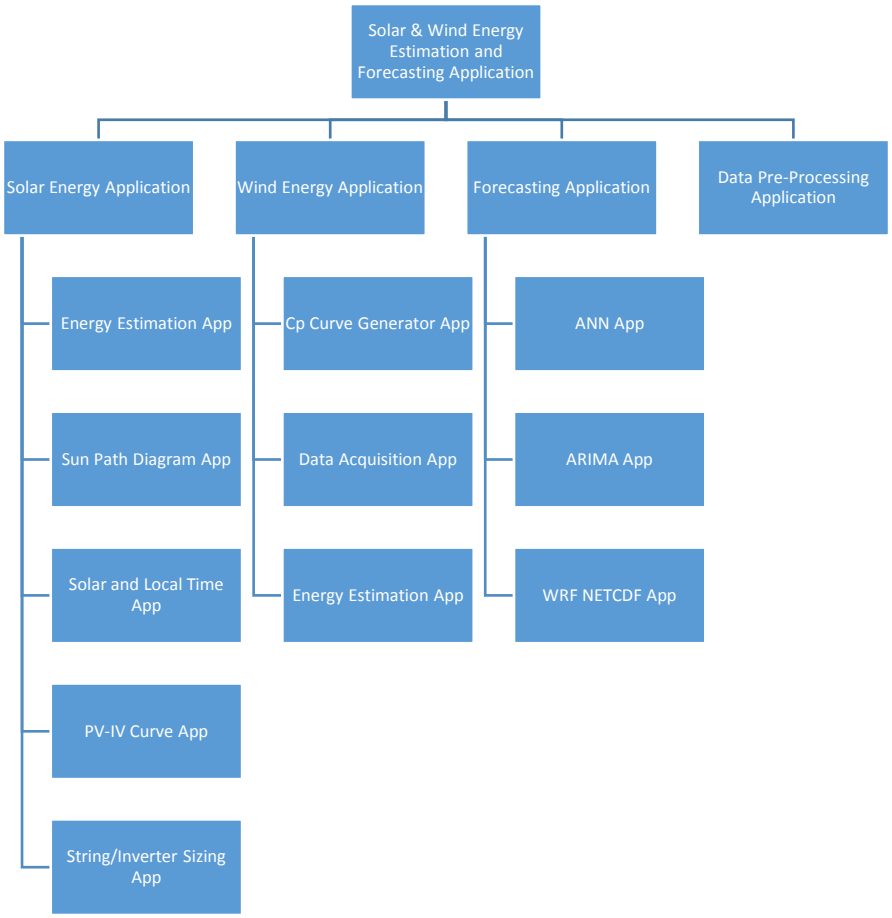


Block Diagram – Ensemble Solar/Wind Power Forecasting

The above block diagram summarizes the entire Energy Estimation and Forecasting Application System which we have developed (only the Ensemble Weather Forecast Mechanism, needs to be developed based on a rigorous analysis of huge amount of forecasted data generated from the previous methods).

This report deals with description of each component of the application and the correct way of using it along with the necessary mathematical theory wherever required.

APPLICATION STRUCTURE



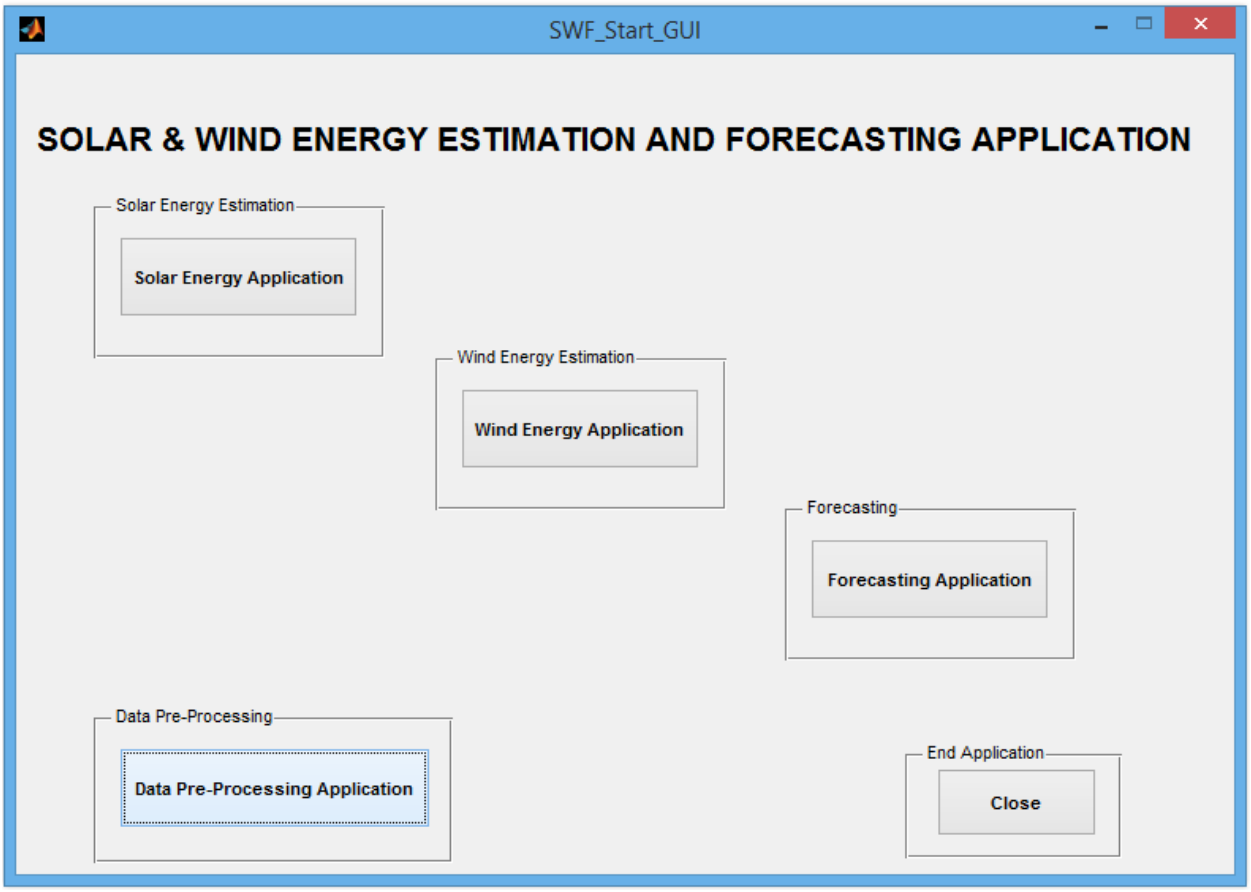
Organization of Application

The above block diagram shows the organizational structure of the entire application. The complete application i.e. Solar & Wind Energy Estimation and Forecasting Applications is composed of following four sub-applications:

- Solar Energy Application
- Wind Energy Application
- Forecasting Application
- Data Pre-Processing Application

Let us have look at the start-up GUI's of the entire application

Solar & Wind Energy Estimation and Forecasting Application – Start-up GUI



Solar & Wind Energy and Forecasting Application Start GUI

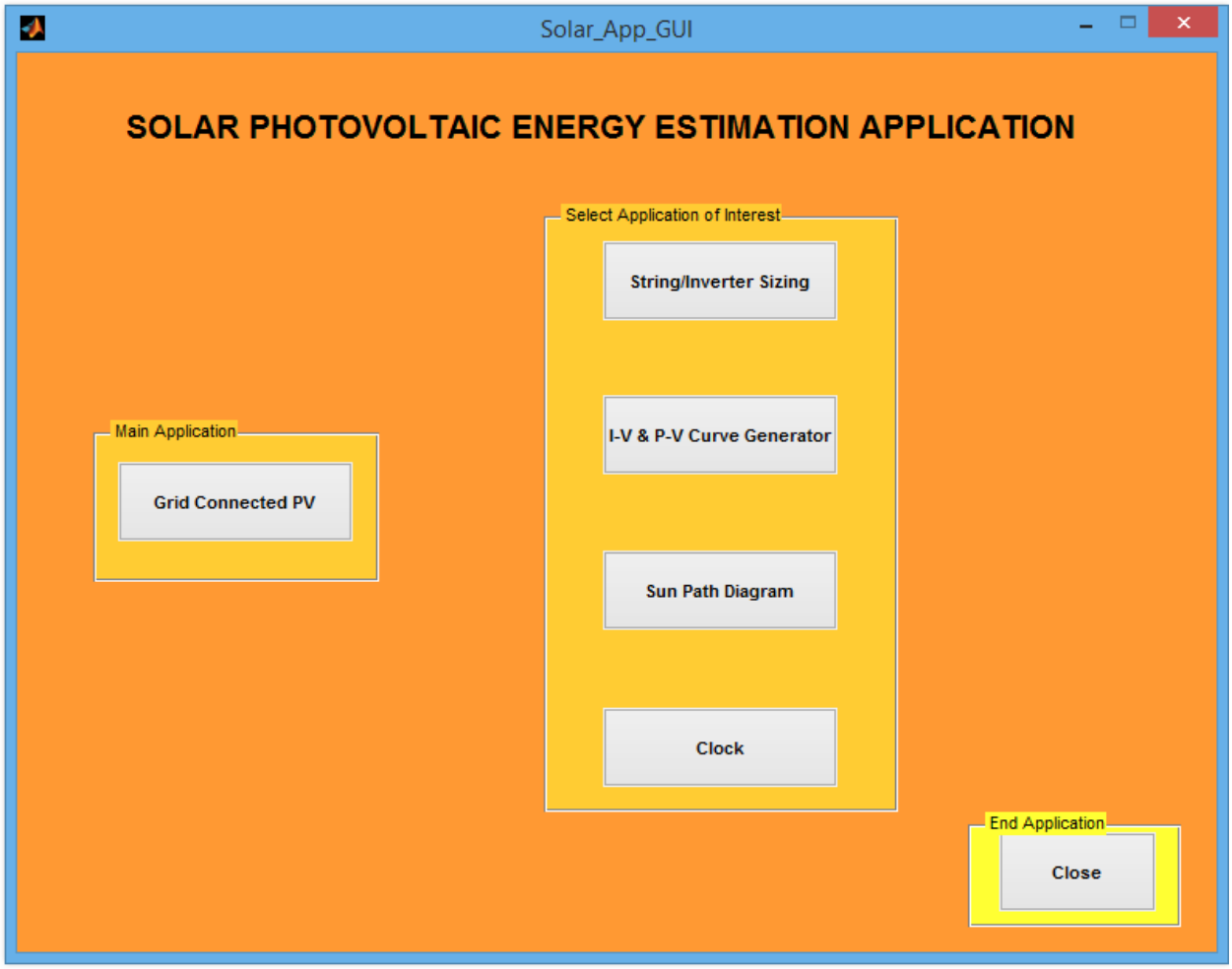
Description:

This GUI is the front face of the entire application. It provides with push buttons for starting the sub-applications.

Push Buttons:

- **Solar Energy Application:** It opens the Solar Energy Application Start-up GUI.
- **Wind Energy Application:** It opens the Wind Energy Application Start-up GUI.
- **Forecasting Application:** It opens the Forecasting Application Start-up GUI.
- **Data Pre-Processing System Application:** It opens the Data Pre-Processing System Application Start-up GUI.
- **Close:** It closes the GUI.

Solar Energy Application – Start-up GUI



Solar Energy Application Start GUI

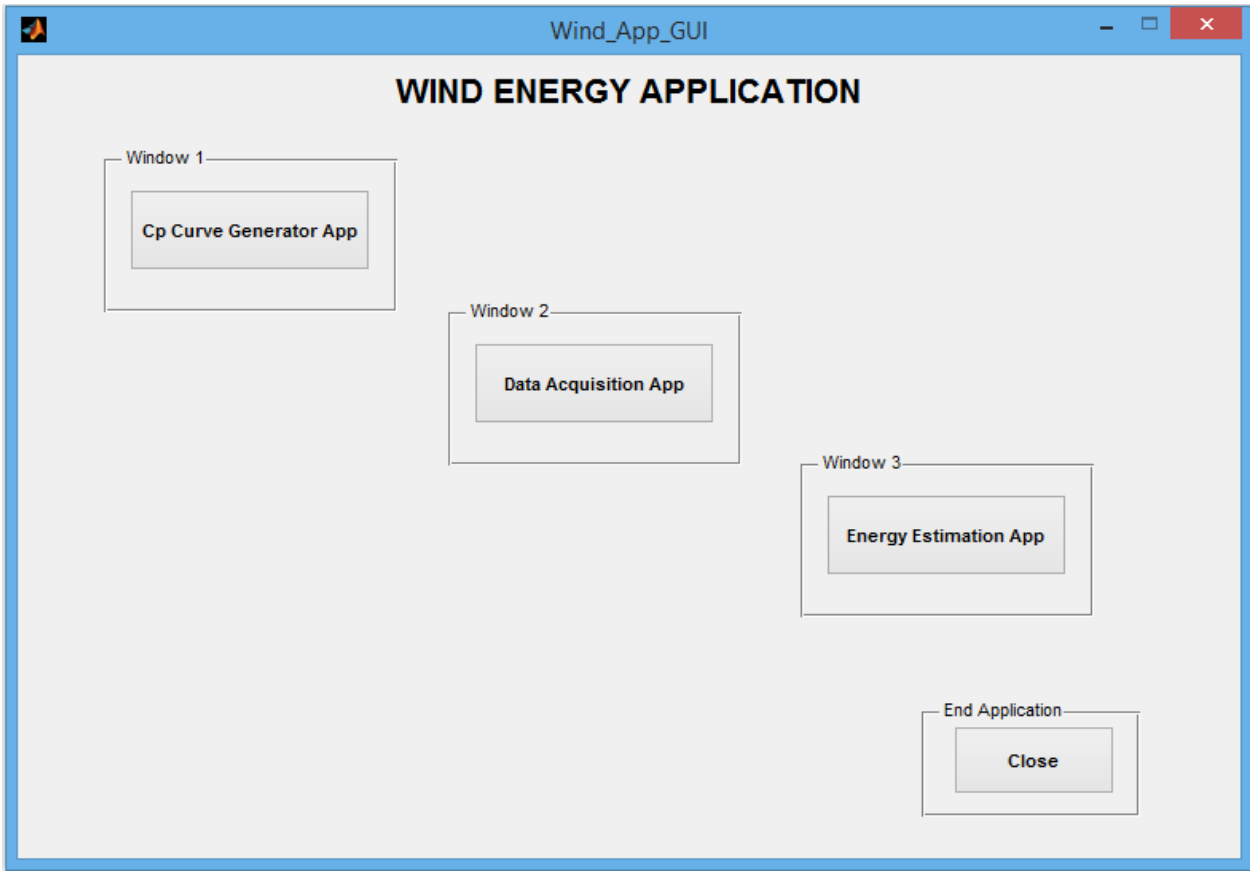
Description:

This GUI is the front face of the Solar Energy Application. It provides with push buttons for starting the sub-applications of the Solar Energy Application.

Push Buttons:

- **Grid Connected PV:** It opens the Energy Estimation App.
- **String/Inverter Sizing:** It opens the Sting/Inverter Sizing App.
- **I-V & P-V Curve Generator:** It opens the PV-IV Curve App.
- **Sun Path Diagram:** It opens the Sun Path Diagram App.
- **Clock:** It opens the Solar and Local Time App.
- **Close:** It closes the GUI.

Wind Energy Application – Start-up GUI



Wind Energy Application Start GUI

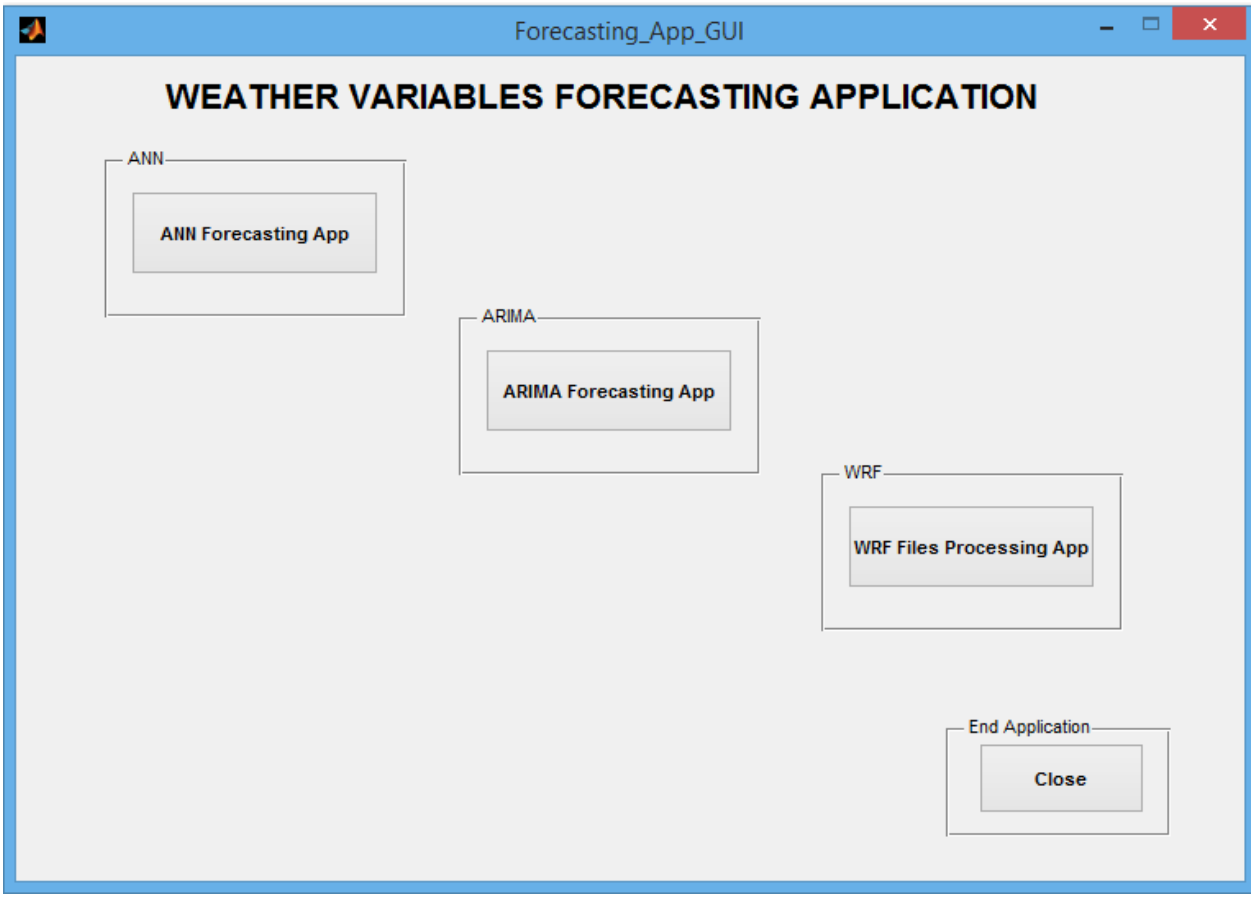
Description:

This GUI is the front face of the Wind Energy Application. It provides with push buttons for starting the sub-applications of the Wind Energy Application.

Push Buttons:

- **Cp Curve Generator App:** It opens the Cp Curve Generator App.
- **Data Acquisition App:** It opens the Data Acquisition App.
- **Energy Estimation App:** It opens the Energy Estimation App.
- **Close:** It closes the GUI.

Forecasting Application – Start-up GUI



Forecasting Application Start GUI

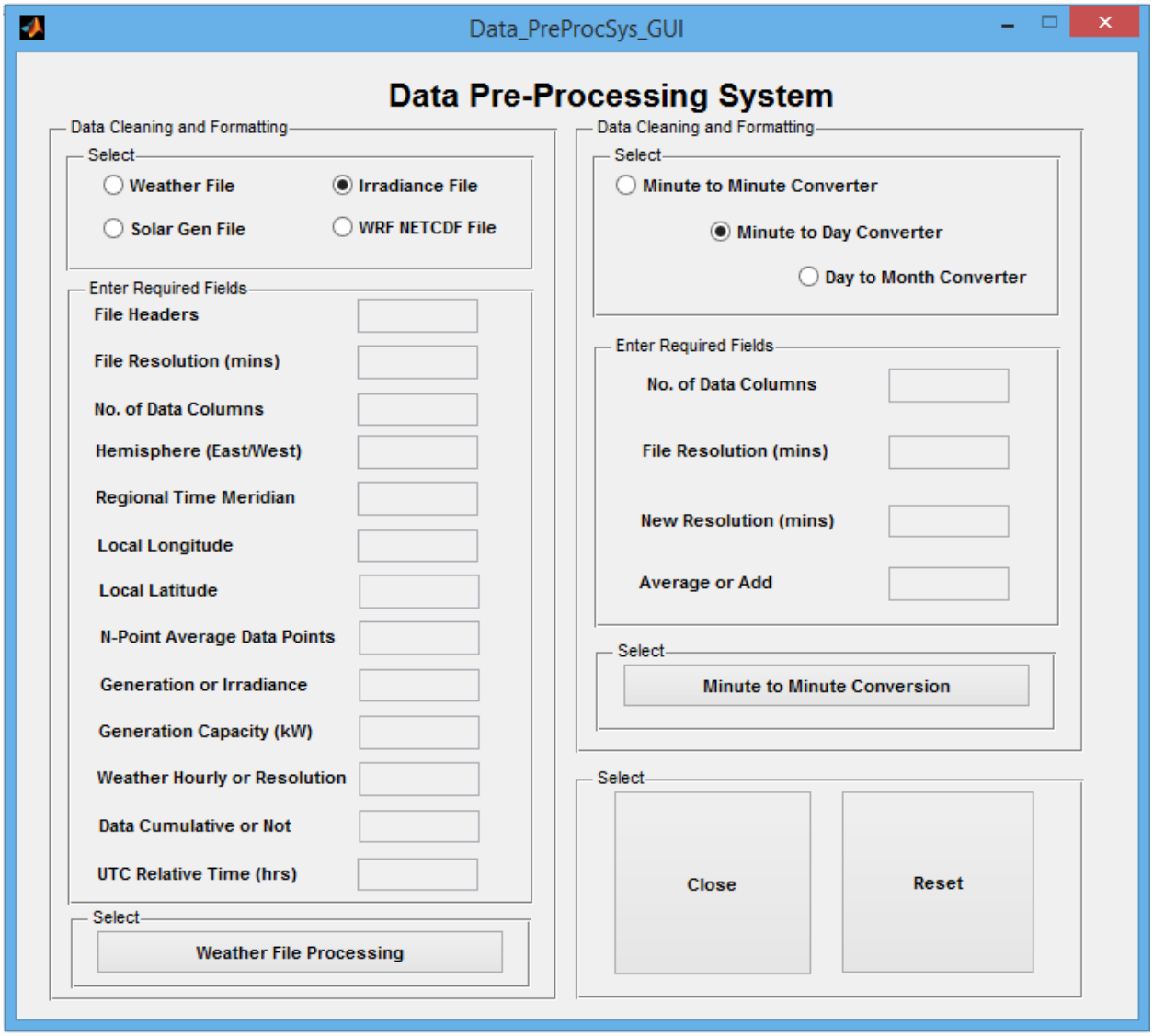
Description:

This GUI is the front face of the Forecasting Application. It provides with push buttons for starting the sub-applications of the Foreasting Application.

Push Buttons:

- **ANN App:** It opens the ANN App.
- **ARIMA App:** It opens the ARIMA App.
- **WRF NETCDF App:** It opens the WRF NETCDF App.
- **Close:** It closes the GUI.

Data Pre-Processing System Application



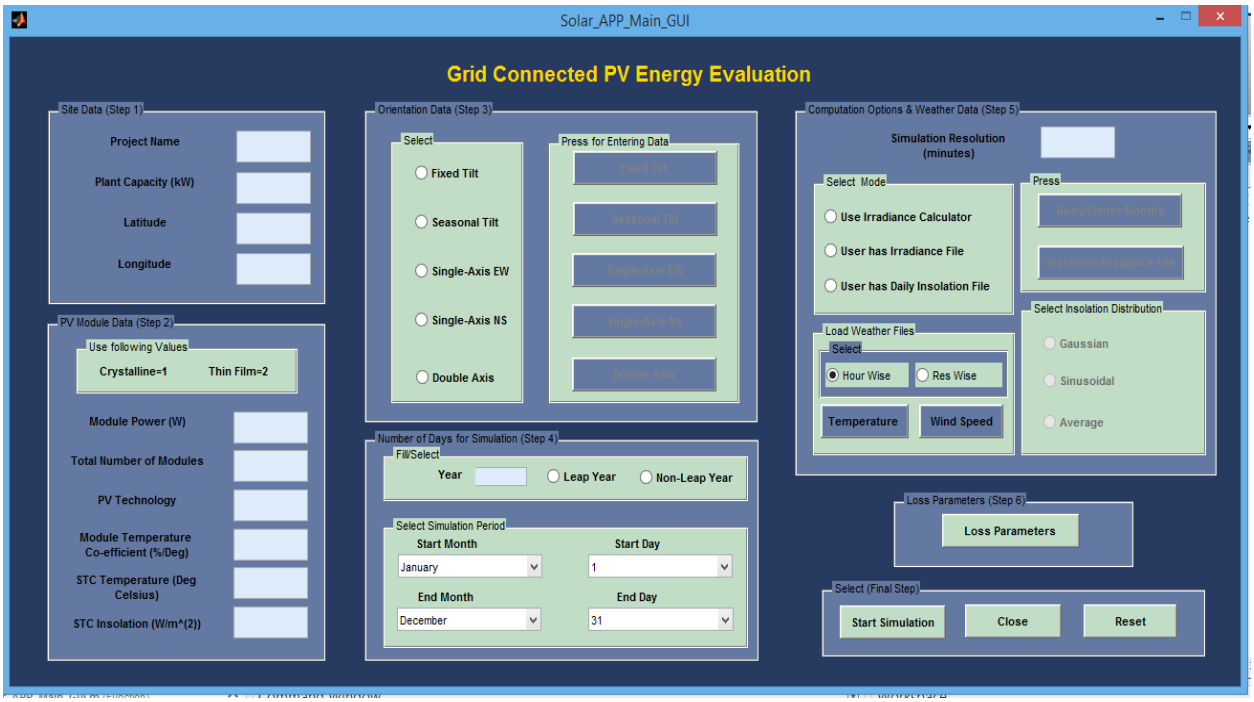
Data Pre-Processing System GUI

Description:

This GUI is the complete Data Pre-Processing System Application. Its working will be discussed in detail in the Forecasting Application Chapter.

SOLAR ENERGY APPLICATION

Energy Estimation Application



Solar Energy Estimation Application

Description:

This GUI takes in all the information regarding the site, PV modules, orientation of modules, simulation period, weather data and loss parameters to give the energy production of the described Solar PV Plant.

Step 1: Site Data

Edit Boxes:

- **Project Name:** Enter the Project Name.
- **Plant Capacity (kW):** Enter the Solar PV Plant's capacity in kW.
- **Latitude:** Enter the location latitude of the plant in decimal degrees.
- **Longitude:** Enter the location longitude of the plant in decimal degrees.

Step 2: PV Module Data

Edit Boxes:

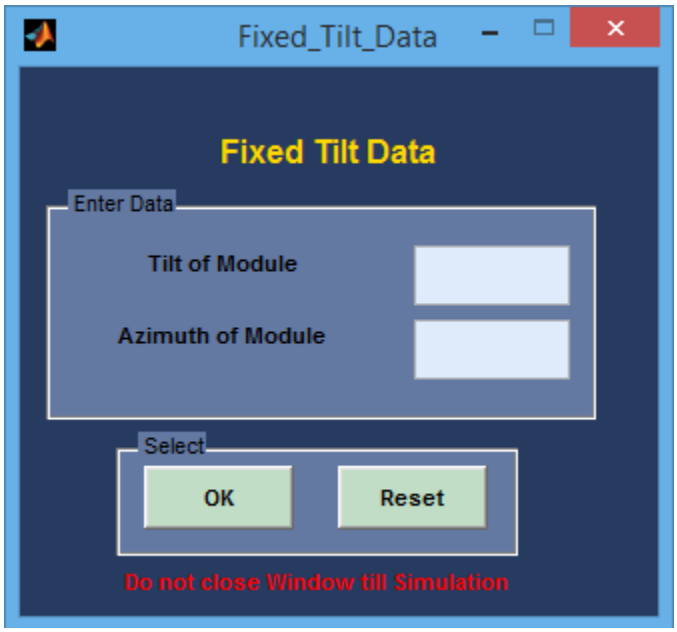
- **Module Power (W):** Enter the rated PV Module Power in W. If there are a more than one type of PV Modules then values can be entered as a comma separated list.
- **Total Number of Modules:** Enter the total number of PV Modules present in the plant. If there are a more than one type of PV Modules then values can be entered as a comma separated list.
- **PV Technology:** Enter 1 if module is of Crystalline type, and 2 if the module is of Thin Film type. If there are a more than one type of PV Modules then values can be entered as a comma separated list.
- **Module Temperature Co-efficient (%/Deg):** Enter the temperature co-efficient of power of the PV Module in %/Deg. If there are a more than one type of PV Modules then values can be entered as a comma separated list.
- **STC Temperature (Deg Celsius):** Enter STC temperature in degree Celsius. It is 25.
- **STC insolation (W/M^(2)):** Enter the STC insolation in W/m^(2). It is 1000.

Step 3: PV Module Orientation Data

Radio Buttons:

- **Fixed Tilt:** It fixes the orientation of the PV modules to fixed tilt. It enables the Fixed Tilt push button.
- **Seasonal Tilt:** It fixes the orientation of the PV modules to seasonal tilt. It enables the Seasonal Tilt push button.
- **Single-Axis EW:** It fixes the orientation of the PV modules to single axis east-west tracking system. It enables the Single-Axis EW push button.
- **Single-Axis NS:** It fixes the orientation of the PV modules as single axis north-south tracking system. It enables the Single-Axis NS push button.
- **Double Axis:** It fixes the orientation of the PV modules as double axis tracking system. It enables the Double Axis push button.

Fixed Tilt Data GUI



Fixed Tilt Orientation Data GUI

Description:
This GUI provides interface for entering orientation parameters for PV modules using fixed tilt mechanism.

Edit Boxes:

- **Tilt of Module:** Enter the fixed tilt of the PV modules in decimal degrees.
- **Azimuth of Module:** Enter the azimuth angle of the PV modules in decimal degrees.

Push Buttons:

- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Seasonal Tilt Data GUI

Seasonal Tilt Orientation Data GUI

Description:
This GUI provides interface for entering orientation parameters for PV modules using seasonal tilt mechanism.

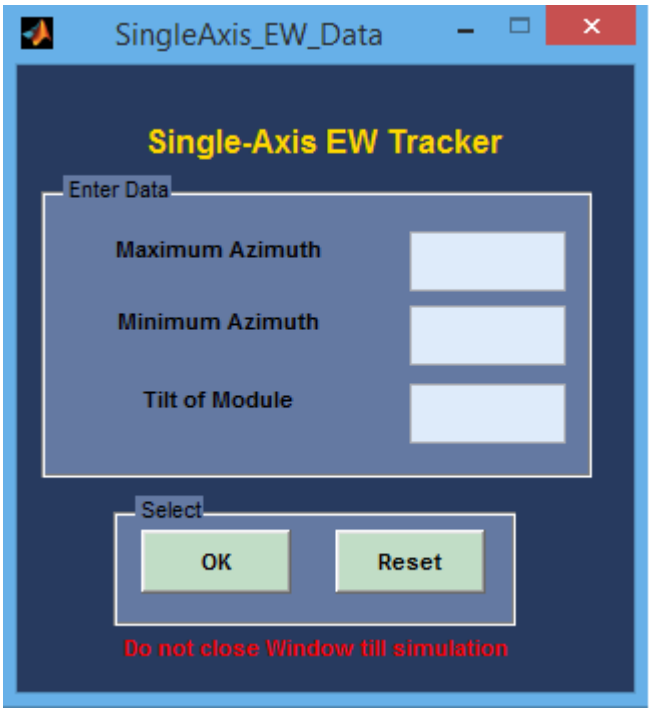
Edit Boxes:

- **Tilt of Module in Summer:** Enter the summer season tilt angle of the PV modules in decimal degrees.
- **Tilt of Module:** Enter the normal fixed tilt angle of the PV modules in decimal degrees.
- **Tilt of Module in Winter:** Enter the winter season tilt angle of the PV modules in decimal degrees.
- **Azimuth of Module:** Enter the azimuth angle of the PV modules in decimal degrees.

Push Buttons:

- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Single-Axis EW Tracker GUI



Single Axis-EW Tracker Data GUI

Description:
This GUI provides interface for entering orientation parameters for PV modules with single axis east-west tracker system.

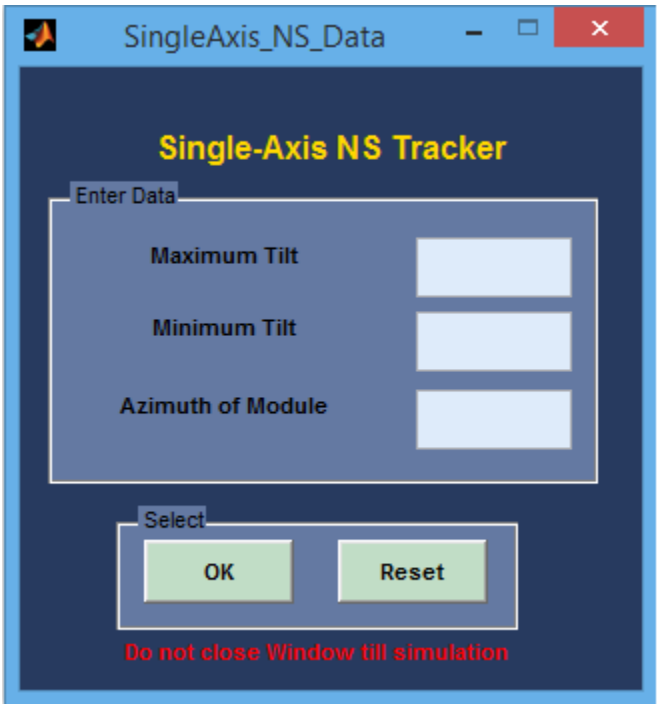
Edit Boxes:

- **Maximum Azimuth:** Enter the maximum azimuth angle allowed by the single axis tracker system employed in decimal degrees.
- **Minimum Azimuth:** Enter the minimum azimuth angle allowed by the single axis tracker system employed in decimal degrees.
- **Tilt of Module:** Enter the fixed tilt angle of the PV modules in decimal degrees.

Push Buttons:

- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Single-Axis NS Tracker GUI



Single Axis-NS Tracker Data GUI

Description:
This GUI provides interface for entering orientation parameters for PV modules with single axis north-south tracker system.

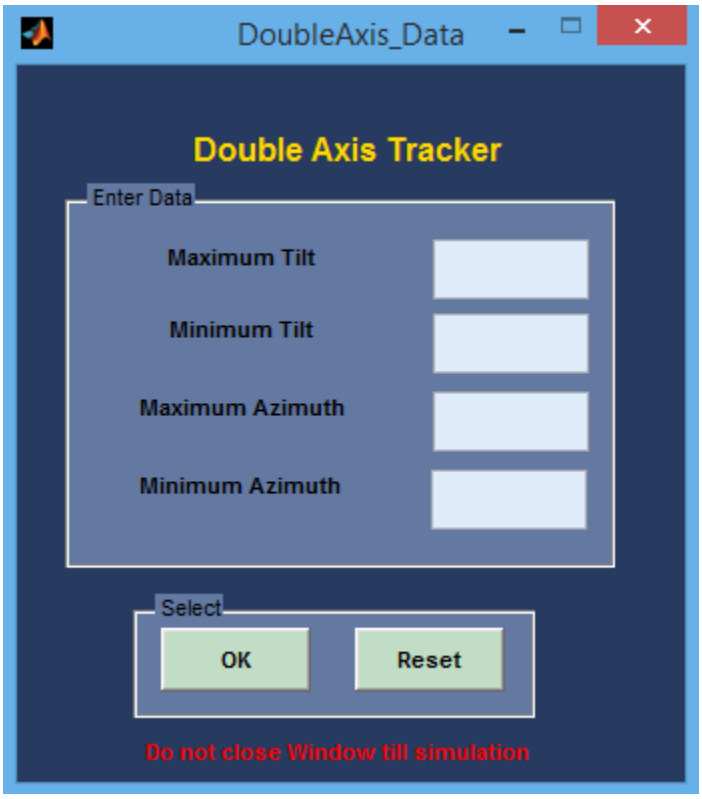
Edit Boxes:

- **Maximum Tilt:** Enter the maximum tilt angle allowed by the single axis tracker system employed in decimal degrees.
- **Minimum Tilt:** Enter the minimum tilt angle allowed by the single axis tracker system employed in decimal degrees.
- **Azimuth of Module:** Enter the azimuth angle of the PV modules in decimal degrees.

Push Buttons:

- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Double Axis Tracker GUI



Double Axis Tracker Data GUI

Description:
This GUI provides interface for entering orientation parameters for PV modules with double axis tracker system.

Edit Boxes:

- **Maximum Tilt:** Enter the maximum tilt angle allowed by the single axis tracker system employed in decimal degrees.
- **Minimum Tilt:** Enter the minimum tilt angle allowed by the single axis tracker system employed in decimal degrees.
- **Maximum Azimuth:** Enter the maximum azimuth angle allowed by the single axis tracker system employed in decimal degrees.
- **Minimum Azimuth:** Enter the minimum azimuth angle allowed by the single axis tracker system employed in decimal degrees.

Push Buttons:

- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Step 4: Simulation Period Data

Edit Boxes:

- **Year:** Enter the year for which simulation is going to take place. It is required to create proper date time signature on the simulation output excel files.

Radio Buttons:

- **Leap Year:** It records whether the simulation year is a leap year.
- **Non-Leap Year:** It records whether the simulation year is a non-leap year.

List Boxes:

- **Start Month:** Select the starting month for simulation.
- **Start Day:** Select the starting day of the starting month for simulation.
- **End Month:** Select the ending month for simulation.
- **End Day:** Select the ending day of the ending month for simulation.

Step 5: Computation Options and Weather Data

Edit Boxes:

- **Simulation Resolution (minutes):** Enter the resolution of simulation in minutes.

Radio Buttons:

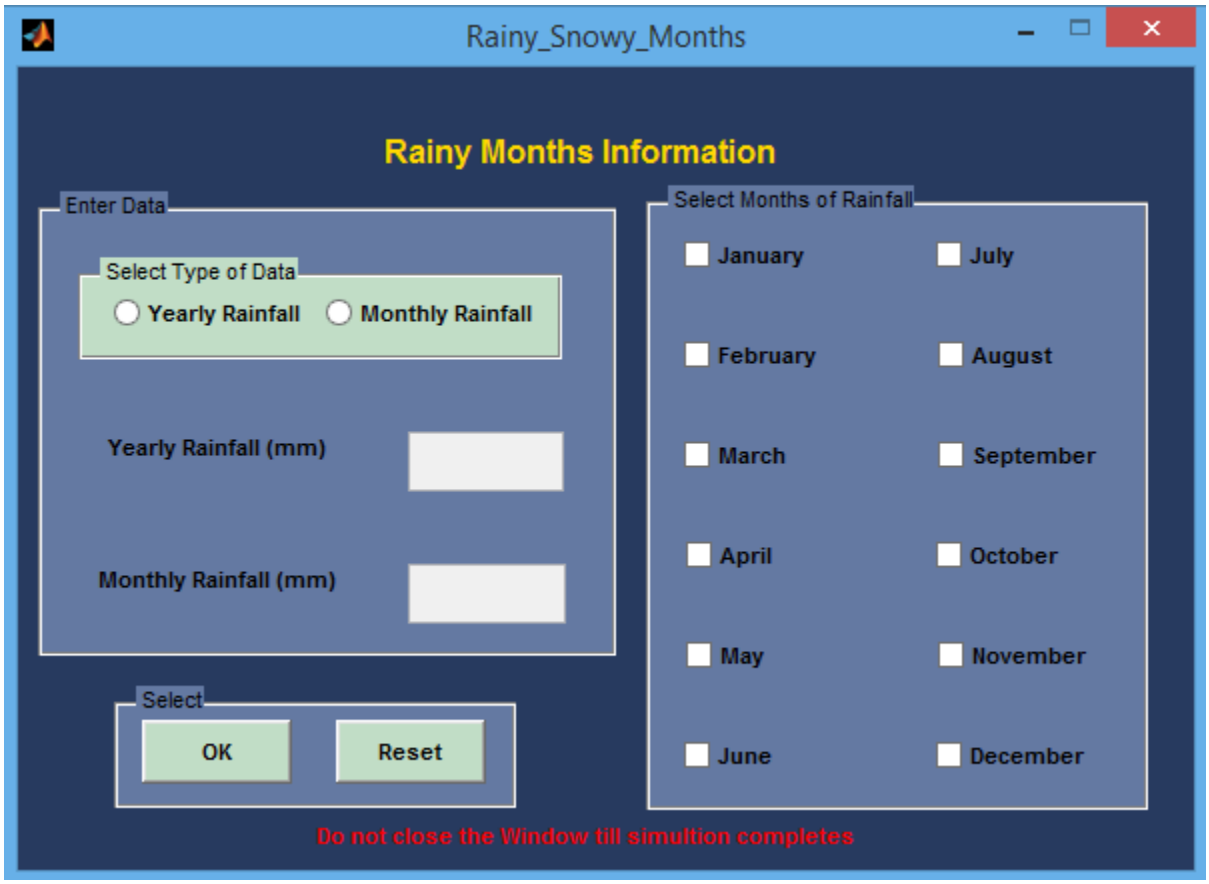
- **Use Irradiance Calculator:** It is used for selecting simulation mode. If selected, the simulation uses the clear sky model to generate synthetic irradiance values for simulation. This option should be used when the user does not have both the irradiance and daily insolation file associated with the PV plant. It enables the Rainy/Winter Months push button.
- **User has Irradiance File:** It is used for selecting simulation mode. If selected, the user has to provide the irradiance file associated with the PV plant for the duration of simulation. This option should be used when the user has the irradiance file associated with the PV plant and its resolution should match the Simulation Resolution. It enables the Insolation/Irradiance File push button.
- **User has Daily Insolation File:** It is used for selecting simulation mode. If selected, the user has to provide the daily insolation file associated with the PV plant for the duration of simulation. This option should be used when the user has the daily insolation file associated with the PV plant It enables the Insolation/Irradiance File push button. It also enables the radio buttons related to the insolation distribution type.
- **Gaussian:** It is used to select the Insolation Distribution Type. If selected, the daily insolation is distributed within the respective day as a Gaussian distribution to get irradiance values based on the Simulation Resolution.

- **Sinusoidal:** It is used to select the Insolation Distribution Type. If selected, the daily insolation is distributed within the respective day as a Sinusoidal distribution to get irradiance values based on the Simulation Resolution.
- **Average:** It is used to select the Insolation Distribution Type. If selected, the daily insolation is distributed within the respective day as an average of Gaussian and Sinusoidal distributions to get irradiance values based on the Simulation Resolution.
- **Hour Wise:** It is used to select the resolution type of weather files. If selected, the user has to provide with hourly resolution temperature (Degree Celsius) and wind speed (m/s) files associated with the PV plant for the duration of simulation.
- **Res Wise:** It is used to select the resolution type of weather files. If selected, the user has to provide with temperature (Degree Celsius) and wind speed (m/s) files associated with the PV plant for the duration of simulation and matching the Simulation Resolution.

Push Buttons:

- **Temperature:** It asks the user to provide the temperature file associated with the PV plant.
- **Wind Speed:** It asks the user to provide the wind speed file associated with the PV plant.
- **Rainy/Snow Months:** It opens the Rainy Months Information GUI.
- **Insolation/Irradiance File:** It asks the user to provide the daily insolation or irradiance file associated with the PV plant.

Rainy Months Information GUI



Rainy Months Information GUI

Description:
This GUI provides an interface for entering information about the rainy months and amount of rainfall either in yearly or monthly format. The information received is used to improve the clear sky model by using a statistical relationship between clearness index and the amount of rainfall.

Edit Boxes:

- **Yearly Rainfall (mm):** Enter the total yearly rainfall in mm at the PV plant site.
- **Monthly rainfall (mm):** Enter a list of twelve values of rainfall in mm one each for a month. If there is no rainfall in month, enter zero.

Check Boxes:

- Check the names of the month which have non-zero rainfall.

Push Buttons:

- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Step 6: System Loss Parameters Data

Solar Energy Application Loss Parameters GUI

Description:
This GUI provides an interface for entering the loss parameters associated with a Solar PV plant. The values received from this GUI helps in calculating powers and energies at each level of power/energy transfer.

Edit Boxes:

- **Soiling Loss %:** Enter the percentage of power/energy loss due to soiling. Default value is 2%. The user has the option of changing the default value.

- **Light Induce Degradation %:** Enter the percentage of power/energy loss due to light induced degradation of modules. Default value is 2%. The user has the option of changing the default value.
- **Light Soaking %:** Enter the percentage of power/energy increase due to light soaking effect of thin film PV technologies. Default value is 3%. The user has the option of changing the default value.
- **Array Mismatch %:** Enter the percentage of power/energy loss due to array mismatch phenomena. Default value is 2%. The user has the option of changing the default value.
- **Ohmic Loss %:** Enter the percentage of power/energy loss due to cable resistances. Default value is 3%. The user has the option of changing the default value.
- **Albedo Value:** Enter the albedo value of the PV plant site. Default value is 0.2. It is the value of reflectance of the ground surface where the PV modules are mounted. Its range is from 0 to 1; higher the albedo value, higher is the amount of reflected radiation on the PV modules.
- **Inverter Efficiency %:** Enter the percentage efficiency of the Inverter. Default value is 98%. The user has the option of changing the default value.
- **Transformer Loss %:** Enter the percentage of power/energy loss due to losses in Transformer. Default value is 1%. The user has the option of changing the default value.
- **Faiman's Uo Co-efficient:** It is the co-efficient of constant heat transfer in the Faiman's Model for module temperature. Default value is 25. Its range is from 23.5 to 26.5.
- **Faiman's U1 Co-eeficient:** It is the co-efficient of convective heat transfer in the Faiman's Model for module temperature. Default value is 6.84. Its range is from 6.25 to 7.68.
- **Shading Loss %:** Enter the percentage of power/energy loss due to shading effect. Default value is 1%. The user has the option of changing the default value.
- **IAM Factor (bo):** It is the constant in the Incidence Angle Modifier Model. Default value is 0.05 (for crystalline modules).

Radio Buttons:

- **Default Values:** If selected, the user cannot modify the loss parameters.
- **User-Defined:** If selected, the user can modify the loss parameters.

Push Buttons:

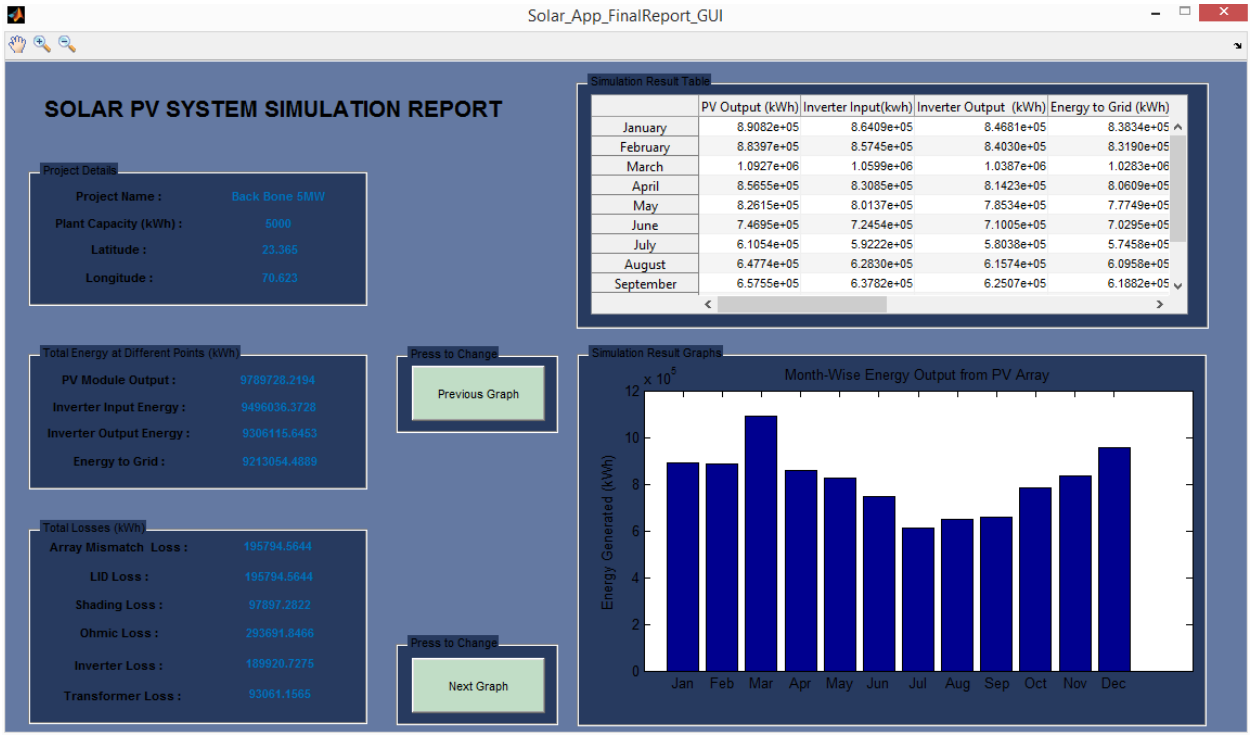
- **OK:** It sends the data entered to the application.
- **Reset:** It resets the GUI to initial condition.

Step 6: Simulation and Results

Push Buttons:

- **Start Simulation:** It starts the internal simulation engine which computes the energy produced in the PV plant during the simulation period. It creates appropriate excel files recording energy production in intra-day, daily and monthly format. It also opens the Report GUI where all the results of simulation are displayed.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

Energy Estimation Simulation Report GUI



Solar Energy Estimation Simulation Report GUI

Description:
This GUI displays the results of the energy estimation simulation of a PV Plant.

Text Boxes:

- **Project Name:** It shows the project name.
- **Plant Capacity (kW):** It shows the plant capacity in kW.
- **Latitude:** It shows the latitude of the PV plant location in decimal degrees
- **Longitude:** It shows the longitude of the PV plant location in decimal degrees.
- **PV Module Output:** It shows the annual PV module output energy in kWh.
- **Inverter Input Energy:** It shows the annual Inverter input energy in kWh.
- **Inverter Output Energy:** It shows the annual Inverter output energy in kWh.
- **Energy to Grid:** It shows the annual energy transmitted to the grid in kWh.
- **Array Mismatch Loss:** It shows the annual energy lost due to array mismatch in kWh.
- **LID Loss:** It shows the annual energy lost due to LID effect in kWh.
- **Shading Loss:** It shows the annual energy lost due to Shading effect in kWh.
- **Ohmic Loss:** It shows the annual energy lost due to cable resistance in kWh.
- **Inverter Loss:** It shows the annual energy lost due to Inverter losses in kWh.

- **Transformer Loss:** It shows the annual energy lost due to Transformer losses in kWh.

Table:

- It summarizes the monthly energy produced and lost at different levels.

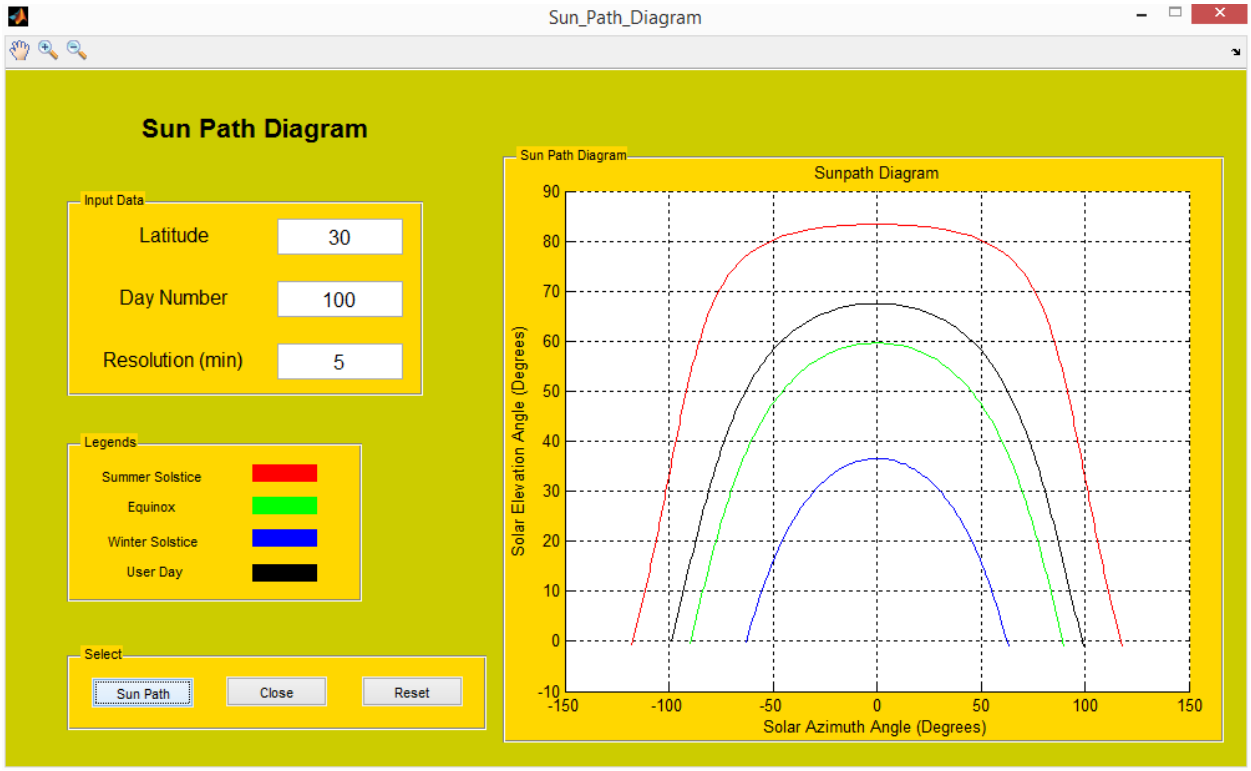
Graph:

- It displays the bar graph of monthly energy produced/lost of a particular variable.

Push Buttons:

- **Next Graph:** It changes the monthly energy bar graph of a particular variable to the bar graph of the next variable w.r.t the initial variable as placed in the table columns.
- **Previous Graph:** It changes the monthly energy bar graph of a particular variable to the bar graph of the previous variable w.r.t the initial variable as placed in the table columns.

Sun Path Diagram App



Sun Path Diagram GUI

Description:
This GUI plots the sun path diagram during summer solstice (Red curve), winter solstice (Blue curve), equinoxes (Green curve) and user-defined day (Black curve).

Edit Boxes:

- **Latitude:** Enter the latitude of the location.
- **Day Number:** Enter the Julian day number for the day you want the user-defined sun path diagram to be plotted.
- **Resolution (min):** Enter the resolution in minutes.

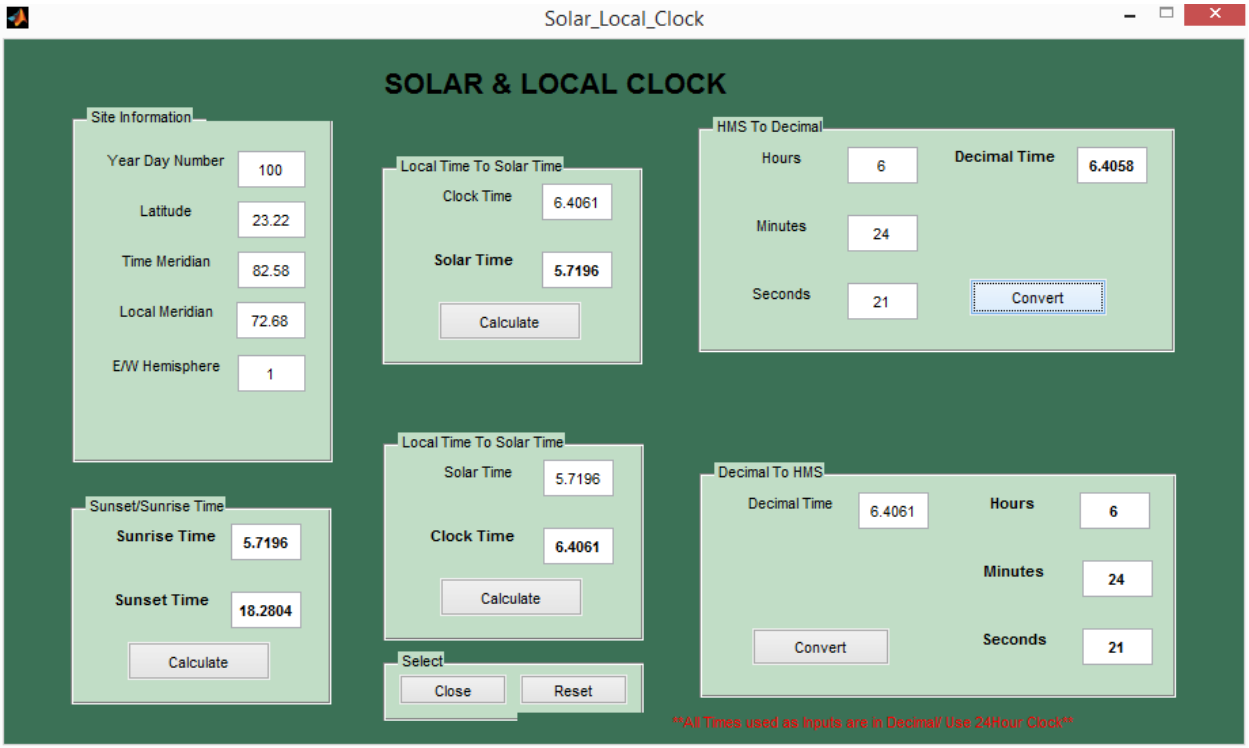
Graphs:

- The sun path diagrams are plotted on this graph.

Push Buttons:

- **Sun Path:** It computes the sun paths and displays them in the graph.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

Solar and Local Clock App



Solar and Local Clock

Description:
This GUI helps in computing the sunrise and sunset times (in solar time) for a particular location. In addition, it also computes solar time from local time and vice-versa. Moreover, it can also compute decimal time from hours, minutes, seconds and vice-versa.

Edit Boxes:

- **Year Day Number:** Enter the Julian day number.
- **Latitude:** Enter the latitude of the location in decimal degrees.
- **Time Meridian:** Enter the time longitude of the region in decimal degrees.
- **Local Meridian:** Enter the longitude of the location in decimal degrees.
- **E/W Hemisphere:** If location in eastern hemisphere, enter 1; if location in western hemisphere, enter -1.
- **Clock Time:** Enter the clock time to be converted to solar time.
- **Solar Time:** Enter the solar time to be converted to clock time.
- **Hours:** Enter the hours in 24 hour format.
- **Minutes:** Enter the minutes.
- **Seconds:** Enter the seconds.

- **Decimal Time:** Enter the time in decimal format.

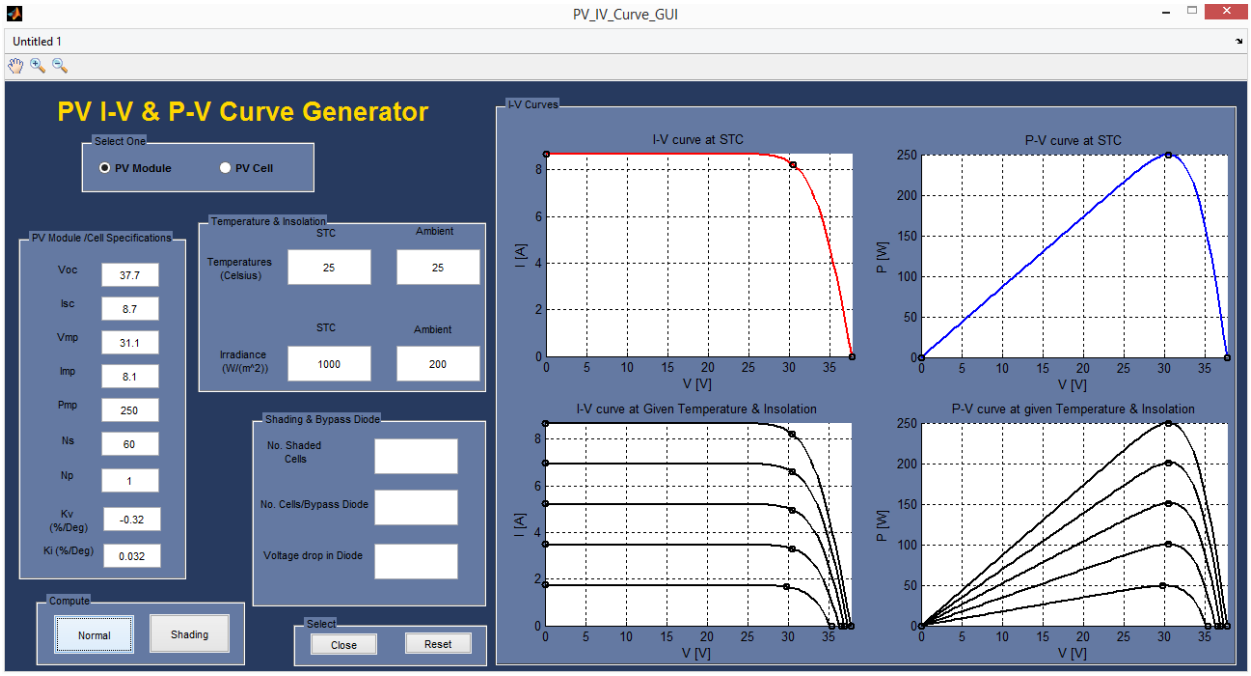
Edit Boxes:

- **Sunrise Time:** It displays the computed sunrise time in solar time.
- **Sunset Time:** It displays the computed sunset time in solar time.
- **Solar Time:** It displays the computed solar time in decimal format.
- **Clock Time:** It displays the computed clock time in decimal format.
- **Decimal Time:** It displays the computed decimal time.
- **Hours:** It displays the computed hours in 24 hour format.
- **Minutes:** It displays the computed minutes.
- **Seconds:** It displays the computed seconds.

Push Buttons:

- **Calculate:** It calculates the appropriate quantities in respective panels.
- **Convert:** It converts the given quantities to appropriate quantities in respective panels.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

PV-IV Curve Generator App



PV-IV Curve Generator GUI

Description:
This GUI plots the I-V (Current vs Voltage) and P-V (Power vs Voltage) curves of a single PV cell or of a PV module at STC and any other temperature and irradiance. It also plots I-V and P-V curves under the effect of shading and By-pass Diodes.

Edit Boxes:

- **Voc:** Enter the open circuit voltage of PV module/cell in Volts.
- **Isc:** Enter the short circuit current of PV module/cell in Amperes.
- **Vmp:** Enter the voltage at mpp of PV module/cell in Volts.
- **Imp:** Enter the open circuit voltage of PV module/cell in Amperes.
- **Pmp:** Enter the power at mpp of PV module/cell in Watts
- **Ns:** Enter the number of units in a string of PV module/cell.
- **Np:** Enter the strings of PV module/cell in parallel.
- **Kv (%/Deg):** Enter the temperature co-efficient of open circuit voltage of PV module/cell in %/Deg.
- **Ki (%/Deg):** Enter the temperature co-efficient of short circuit current of PV module/cell in %/Deg.
- **Temperature STC:** Enter the temperature at STC in Degree Celsius. It is 25.
- **Temperature Ambient:** Enter the ambient temperature in Degree Celsius.
- **Irradiance STC:** Enter the irradiance at STC in W/m^(2). It is 1000.
- **Irradiance Ambient:** Enter the open circuit voltage of PV module/cell.

- **No. Shaded Cells:** Enter the number of shaded cells in a string.
- **No. Cells/Bypass Diode:** Enter the number of cells per bypass diode.
- **Voltage drop in Diode:** Enter the voltage drop in the bypass diode in Volts.

Radio Buttons:

- **PV Module:** Select this option, if the information you are going to enter in the GUI is of a PV Module.
- **PV Cell:** Select this option, if the information you are going to enter in the GUI is of a single PV cell.

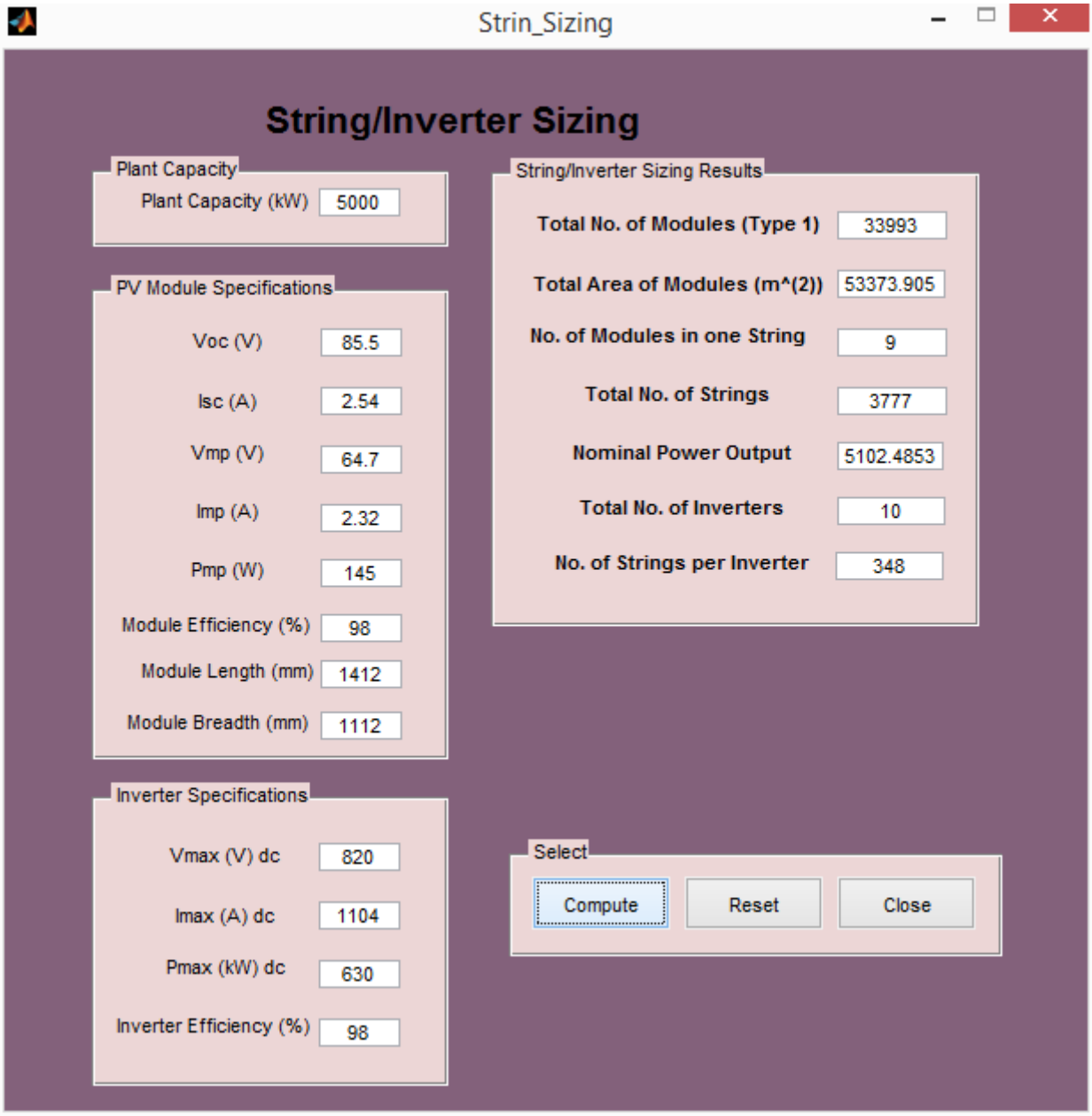
Graphs:

- **G1:** It is the upper-left graph. It plots I-V curves.
- **G2:** It is the upper-right graph. It plots P-V curves.
- **G3:** It is the lower-left graph. It plots I-V curves.
- **G4:** It is the lower-left graph. It plots P-V curves.

Push Buttons:

- **Normal:** It computes and plots the I-V and P-V curve at STC in G1 and G2. Moreover, it computes and plots the I-V and P-V curve at the ambient temperature and irradiance in G3 and G4.
- **Shading:** It computes and plots the I-V and P-V curve at ambient temperature and irradiance with shading effect in G1 and G2. Moreover, it computes and plots the I-V and P-V curve at the ambient temperature and irradiance with bypass diode in G3 and G4.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

String/Inverter Sizing App



String/Inverter Sizing GUI

Description:
This GUI computes the total number of PV modules of a particular type , the number of modules in on string, the total number of strings, total number of inverters and number of strings per inverter for a given plant capacity.

Edit Boxes:

- **Plant Capacity (kW):** Enter the plant capacity of the PV plant in kW.

- **Voc (V):** Enter the open circuit voltage of the PV module in Volts.
- **Isc (A):** Enter the short circuit current of the PV module in Amperes.
- **Vmp (V):** Enter the voltage at mpp of the PV module in Volts.
- **Imp (A):** Enter the current at mpp of the PV module in Amperes.
- **Pmp (W):** Enter the power at mpp of the PV module in Watts.
- **Module Efficiency (%):** Enter the efficiency of modules in percentage.
- **Module Length (mm):** Enter the PV module length in mm.
- **Module Breadth (mm):** Enter the PV module breadth in mm.
- **Vmax (V) dc:** Enter the maximum dc voltage as input to the inverter in Volts.
- **Imax (A) dc:** Enter the maximum dc current as input to the inverter in Amperes.
- **Pmax (W) dc:** Enter the maximum dc power as input to the inverter in Watts.
- **Inverter Efficiency (%):** Enter the efficiency of inverter in percentage.

Text Boxes:

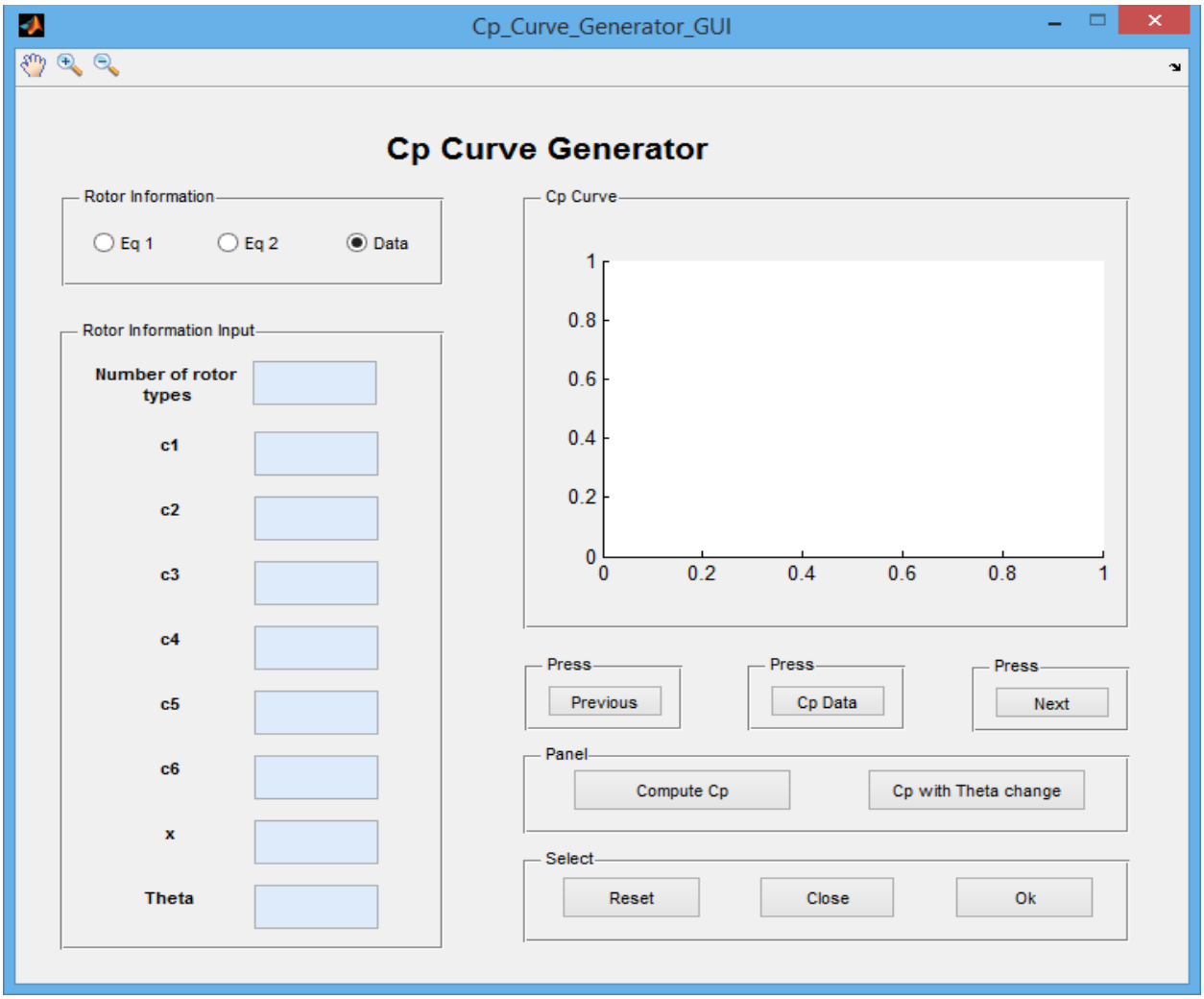
- **Total No. of Modules:** It displays the computed value of total number of PV modules in the PV plant.
- **Total Area of Modules (m^(2)):** It displays the computed value total area occupied by the PV modules in m^(2).
- **No. of Modules in one String:** It displays the computed value of number of PV modules in a single string.
- **Total No. of Strings:** It displays the computed value of total number of strings in the PV plant.
- **Nominal Power Output:** It displays the computed value of nominal power output of the PV plant in kW.
- **Total No. of Inverters:** It displays the computed value of total number of inverters required in the PV plant.
- **No. of Strings per Inverter:** It displays the computed value of number of strings of PV modules attached to a single inverter.

Push Buttons:

- **Compute:** It computes all the required quantities.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

WIND ENERGY APPLICATION

Cp Curve Generator App



Cp Curve Generator App

Description:

This GUI provides an interface to the user to generate Cp curves for the Wind Turbine Rotors using two different equations, also the user can provide Cp curve data in excel file format. The Cp curve/curves are visualized on graph and the Cp curve data is passed to the main application.

Edit Boxes:

- **Number of rotor types:** Enter the number of different turbine rotors.

- **c1:** Enter the c1 turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **c2:** Enter the c2 turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **c3:** Enter the c3 turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **c4:** Enter the c4 turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **c5:** Enter the c5 turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **c6:** Enter the c6 turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **x:** Enter the x turbine rotor constant which is dependent on the turbine design. If there a multiple values, enter the values in a comma separated format.
- **Theta:** Enter the blade pitch angle in degrees.

Radio Buttons:

- **Eq 1:** Select this option, to model Cp based on the equation given by P. M. Anderson and B. Anjan (1983). It enables Next and Previous push buttons, and disables Data push button. It enables all the edit boxes.
- **Eq 2:** Select this option, to model Cp based on the equation given by P. M. Anderson and Bose's empirical equation. It disables Next and Previous Data push buttons. It disables all the edit boxes except Theta edit box.
- **Data:** Select this option, if user has the Cp curve data in an excel file format**.** It disables Next and Previous push buttons, and enables Data push button. It enables all the edit boxes.

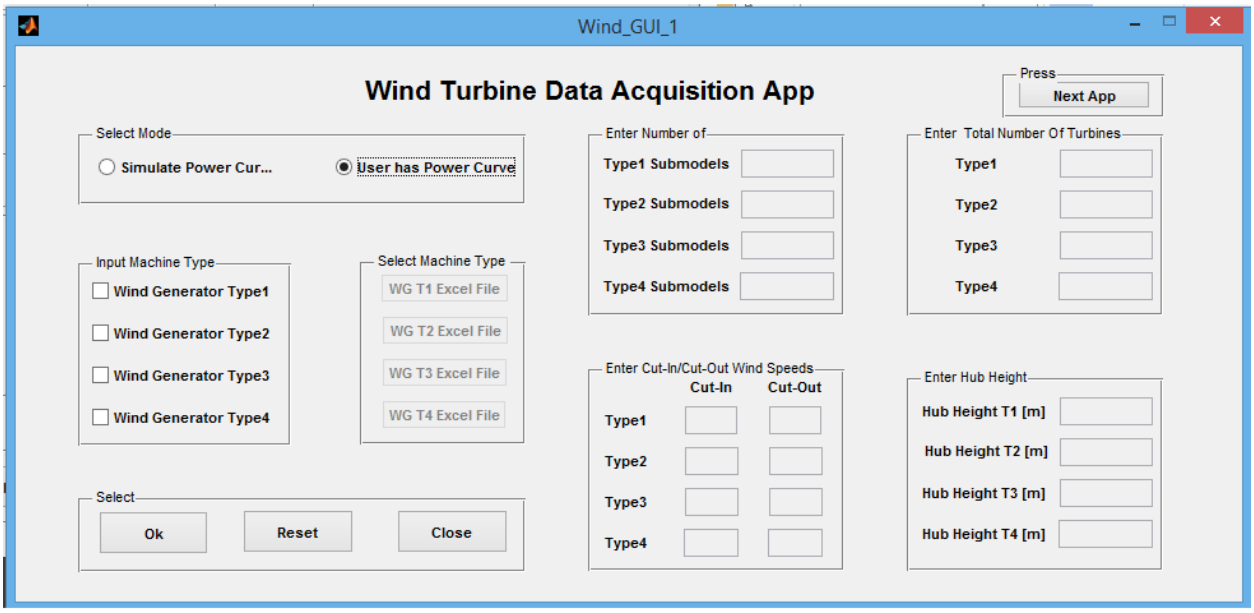
Graphs:

- **G1:** It dispalys the Cp curve.

Push Buttons:

- **Compute Cp:** It computes initial Cp curve at Theta=0 and plots it on graph G1.
- **Cp with Theta change:** It computes Cp curve at user given Theta and plots it on graph G1.
- **Cp Data:** It asks the user to provide the Cp curve ddata file in an excel file format.
- **Next:** It plots the next Cp curve on the graph G1.
- **Previous:** It plots the previous Cp curve on the graph G1.
- **Reset:** It resets the GUI to its initial state.
- **Close:** It closes the GUI.
- **OK:** It sends the entered values to the main application.
- **Next App:** It opens the Data Acquisition App.

Data Acquisition App



Data Acquisition App

Description:

This GUI provides an interface to the user to enter the wind turbine power plant information.

Edit Boxes:

- **Type1 Submodels:** Enter the number of different sub-models of Type 1 Wind Turbine.
- **Type2 Submodels:** Enter the number of different sub-models of Type 2 Wind Turbine.
- **Type3 Submodels:** Enter the number of different sub-models of Type 3 Wind Turbine.
- **Type4 Submodels:** Enter the number of different sub-models of Type 4 Wind Turbine.
- **Type1 Cut-In:** Enter the Cut-In speed of Type 1 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type2 Cut-In:** Enter the Cut-In speed of Type 2 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type3 Cut-In:** Enter the Cut-In speed of Type 3 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type4 Cut-In:** Enter the Cut-In speed of Type 4 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.

- **Type1 Cut-Out:** Enter the Cut-Out speed of Type 1 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type2 Cut- Out:** Enter the Cut- Out speed of Type 2 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type3 Cut- Out:** Enter the Cut- Out speed of Type 3 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type4 Cut- Out:** Enter the Cut- Out speed of Type 4 Wind Turbine in m/s. If there are multiple values, enter the values in a comma separated format.
- **Type1:** Enter the total number turbines installed of Type 1 Wind Turbine. If there are multiple values, enter the values in a comma separated format.
- **Type2:** Enter the total number turbines installed of Type 2 Wind Turbine. If there are multiple values, enter the values in a comma separated format.
- **Type3:** Enter the total number turbines installed of Type 3 Wind Turbine. If there are multiple values, enter the values in a comma separated format.
- **Type4:** Enter the total number turbines installed of Type 4 Wind Turbine. If there are multiple values, enter the values in a comma separated format.
- **Hub Height T1 [m]:** Enter the hub height of Type 1 Wind Turbine in m. If there are multiple values, enter the values in a comma separated format.
- **Hub Height T2 [m]:** Enter the hub height of Type 2 Wind Turbine in m. If there are multiple values, enter the values in a comma separated format.
- **Hub Height T3 [m]:** Enter the hub height of Type 3 Wind Turbine in m. If there are multiple values, enter the values in a comma separated format.
- **Hub Height T4 [m]:** Enter the hub height of Type 4 Wind Turbine in m. If there are multiple values, enter the values in a comma separated format.

Radio Buttons:

- **Simulate Power Curve:** Select this option, if user does not have the wind turbine power data in excel file format and wants to generate power curve from Simulink dynamic wind turbine model.
- **User has Power Curve:** Select this option, if user has the wind turbine power data in excel file format.

Check Boxes:

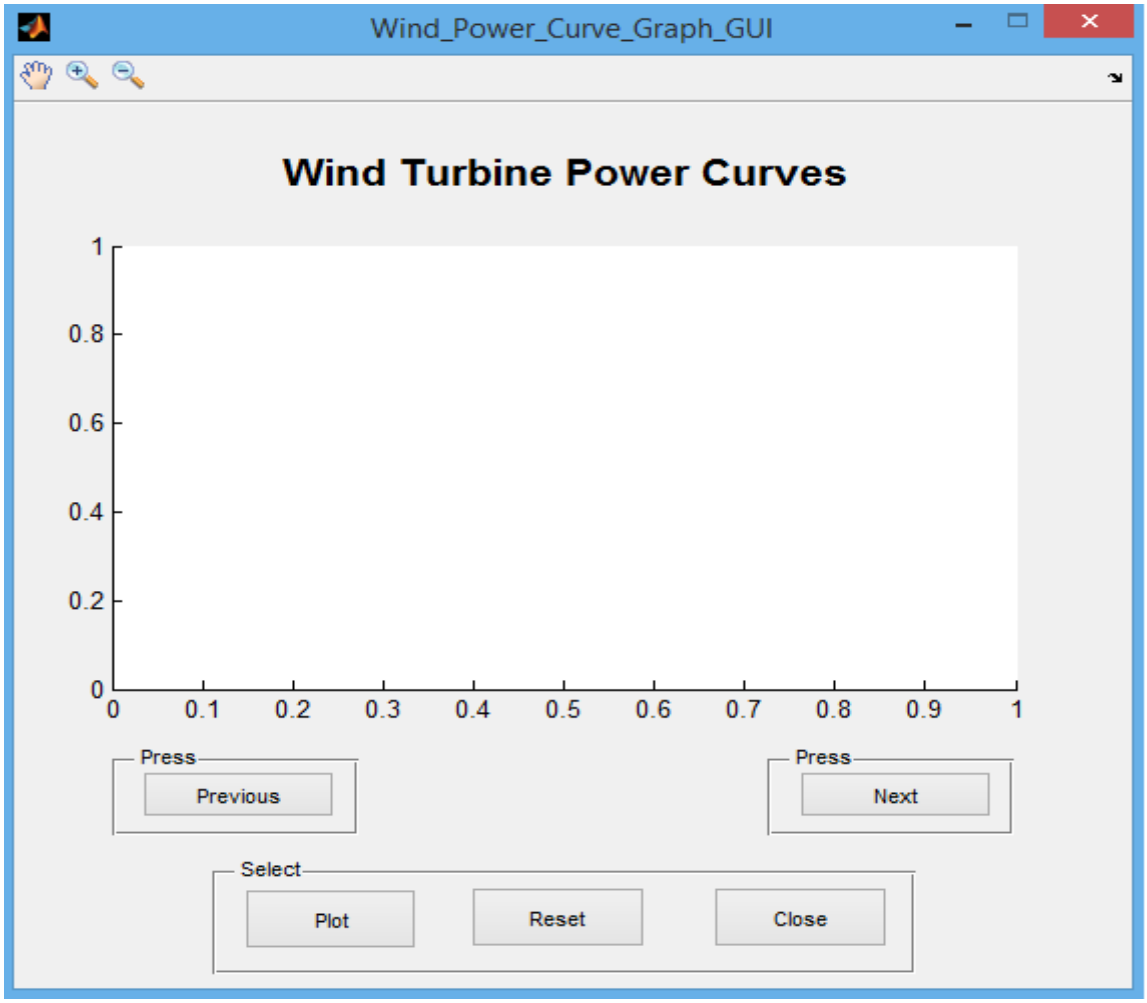
- **Wind Generator Type1:** Select this option, if the wind power plant has Type 1 Wind Turbines. It enables all the edit boxes and push buttons associated with the Type 1 Wind Turbines.
- **Wind Generator Type2:** Select this option, if the wind power plant has Type 2 Wind Turbines. It enables all the edit boxes and push buttons associated with the Type 1 Wind Turbines.
- **Wind Generator Type3:** Select this option, if the wind power plant has Type 3 Wind Turbines. It enables all the edit boxes and push buttons associated with the Type 1 Wind Turbines.

- **Wind Generator Type4:** Select this option, if the wind power plant has Type 4 Wind Turbines. It enables all the edit boxes and push buttons associated with the Type 1 Wind Turbines.

Push Buttons:

- **WG T1 Data:** It asks the user to provide wind turbine power curve data (Wind speed –m/s, Power-kW) of Type 1 Wind Turbine in excel file format.
- **WG T2 Data:** It asks the user to provide wind turbine power curve data (Wind speed –m/s, Power-kW) of Type 2 Wind Turbine in excel file format.
- **WG T3 Data:** It asks the user to provide wind turbine power curve data (Wind speed –m/s, Power-kW) of Type 3 Wind Turbine in excel file format.
- **WG T4 Data:** It asks the user to provide wind turbine power curve data (Wind speed –m/s, Power-kW) of Type 4 Wind Turbine in excel file format.
- **OK:** It sends the entered data to the main application and opens the Wind Power Curve Graph GUI.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to its initial state.
- **Next App:** It opens the Energy Estimation App.

Wind Power Curve Graph GUI



Wind Power Curve Graph GUI

Description:

This GUI plots the wind turbine power curves of the different wind turbine types provided by the user.

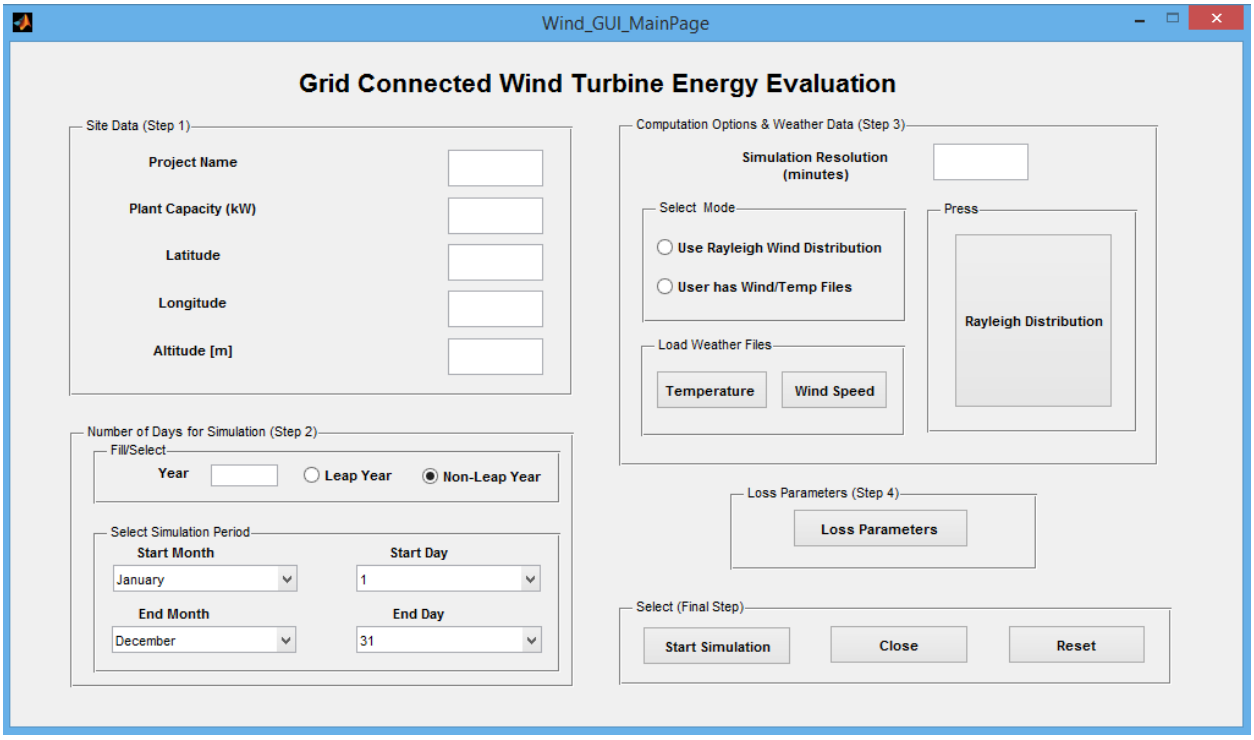
Graphs:

- **G1:** It plots the wind turbine power curves.

Push Buttons:

- **Plot:** It plots the initial wind turbine power curve.
- **Next:** It plots the next wind turbine power curve.
- **Previous:** It plots the previous wind turbine power curve.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

Energy Estimation App



Energy Estimation App GUI

Description:

This GUI takes in all the information regarding the site, simulation period, weather data and loss parameters to give the energy production of the described Wind Power Plant.

Step 1: Site Data

Edit Boxes:

- **Project Name:** Enter the Project Name.
- **Plant Capacity (kW):** Enter the Wind Turbine Plant's capacity in kW.
- **Latitude:** Enter the location latitude of the plant in decimal degrees.
- **Longitude:** Enter the location longitude of the plant in decimal degrees.
- **Altitude:** Enter the altitude of the plant in m.

Step 2: Simulation Period Data

Edit Boxes:

- **Year:** Enter the year for which simulation is going to take place. It is required to create proper date time signature on the simulation output excel files.

Radio Buttons:

- **Leap Year:** It records whether the simulation year is a leap year.
- **Non-Leap Year:** It records whether the simulation year is a non-leap year.

List Boxes:

- **Start Month:** Select the starting month for simulation.
- **Start Day:** Select the starting day of the starting month for simulation.
- **End Month:** Select the ending month for simulation.
- **End Day:** Select the ending day of the ending month for simulation.

Step 3: Computation Options and Weather Data

Edit Boxes:

- **Simulation Resolution (minutes):** Enter the resolution of simulation in minutes.

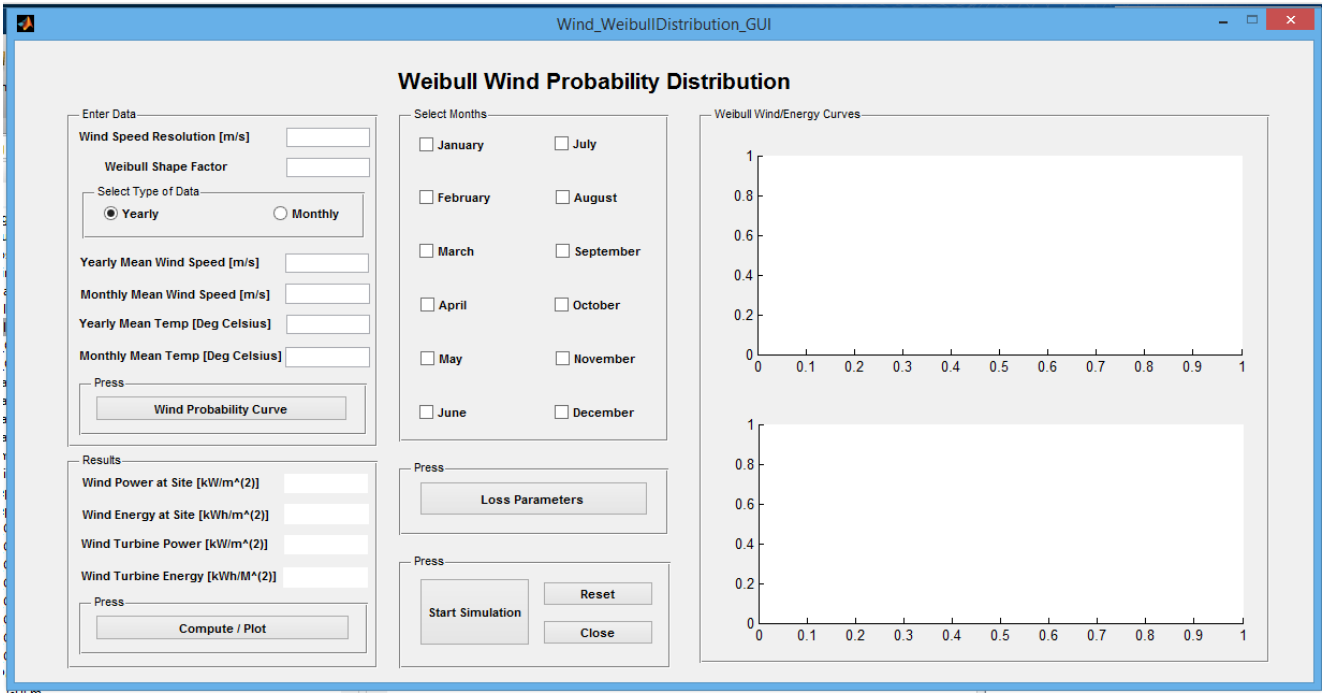
Radio Buttons:

- **Use Rayleigh Wind Distribution:**
- **User has Wind/Temp Files:**

Push Buttons:

- **Temperature:** It asks the user to provide the temperature file associated with the Wind Turbine plant.
- **Wind Speed:** It asks the user to provide the wind speed file associated with the Wind Turbine plant.
- **Rayleigh Distribution:** It opens the Rayleigh Distribution GUI.

Weibull Distribution GUI



Weibull Distribution GUI

Description:

This GUI takes in all the information regarding the wind speeds monthly/yearly and temperatures monthly/yearly. It computes the potential of the site based on the provided information using the Weibull Distribution nature of wind speeds.

Edit Boxes:

- **Wind Speed Resolution [m/s]:** Enter the wind speed resolution to be used in generation the distribution curves and energy computations in m/s.
- **Weibull Shape Factor:** Enter the Weibull shape factor which closely resembles the wind speed distribution of the site.
- **Yearly Mean Wind Speed [m/s]:** Enter the average yearly wind speed in m/s.
- **Monthly Mean Wind Speed [m/s]:** Enter the monthly average wind speed values in m/s. If there are a more than one values then the values can be entered as a comma separated list.
- **Yearly Mean Temp [Deg Celsius]:** Enter the average yearly temperature in Deg Celsius.
- **Monthly Mean Temp [Deg Celsius]:** Enter the monthly average temperature values in Deg Celsius. If there are a more than one values then the values can be entered as a comma separated list.

Text Boxes:

- **Wind Power at Site [kW/m^(2)]:** It shows the averaged wind power at the site.
- **Wind Energy at Site [kW/m^(2)]:** It shows the averaged Wind energy at the site.
- **Wind Turbine Power [kW/m^(2)]:**It shows the averaged Wind power extracted by the Wind Turbine at the site.
- **Wind Turbine Energy [kW/m^(2)]:** It shows the averaged Wind energy extracted by the Wind Turbine at the site.

Check Boxes:

- Check the names of the month for which user is providing the monthly data.

Radio Buttons:

- **Yearly:** It should be selected, when the user is going to provide yearly data It should be selected, when the user is going to provide yearly data. It enables the Yearly Mean Wind Speed and Yearly Mean Temp text boxes.
- **Monthly:** It should be selected, when the user is going to provide monthly data. It should be selected, when the user is going to provide yearly data. It enables the Monthly Mean Wind Speed and Monthly Mean Temp text boxes.

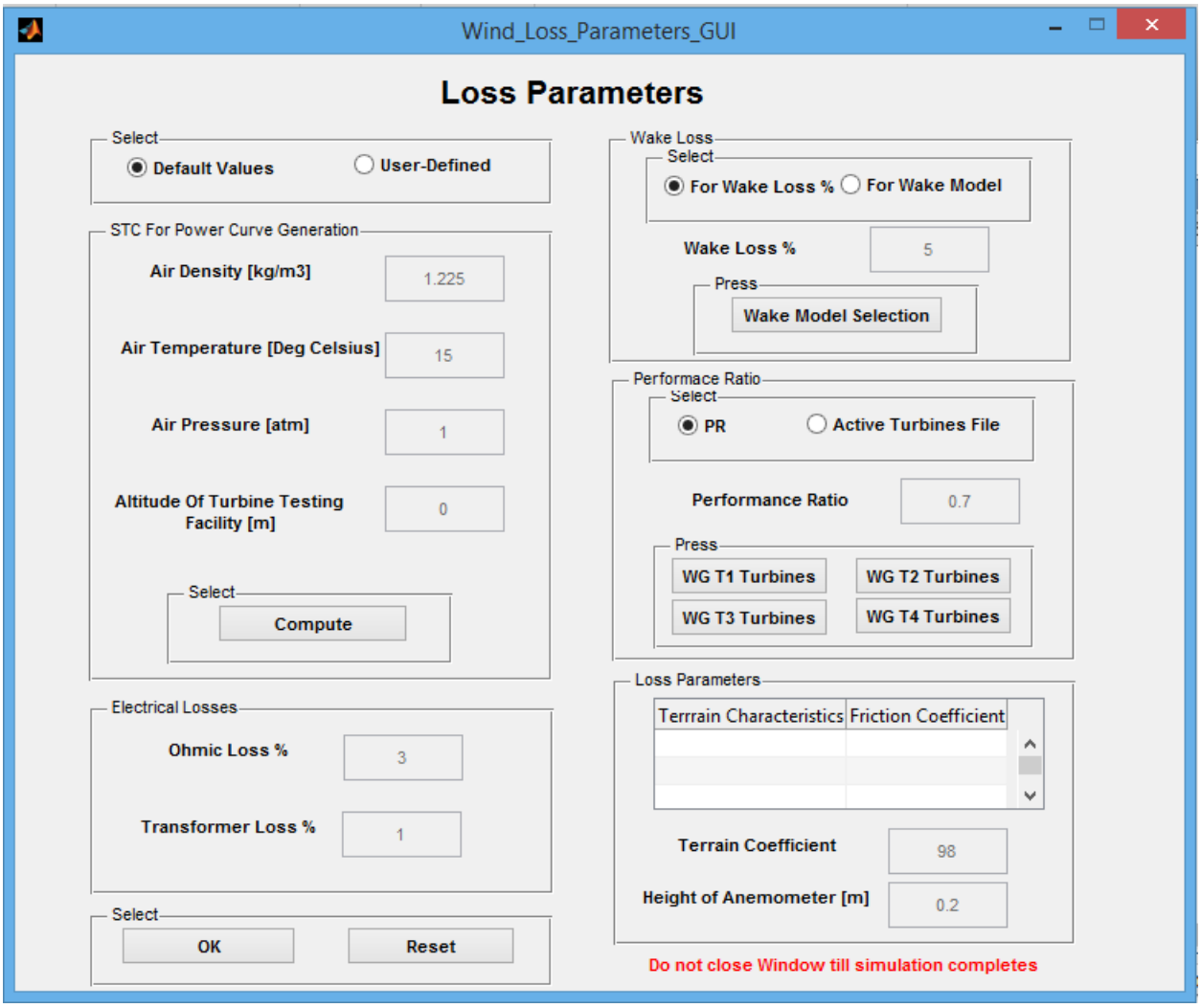
Graphs:

- **G1:** It shows the wind speed Weibull distribution.
- **G2:** It shows the energy and power distribution curves for an ideal wind turbine at the site.

Push Buttons:

- **Wind Probability Curve:** It plots the wind Weibull distribution curve on Graph 1.
- **Compute / Plot:** It plots the energy and power distribution curves for an ideal wind turbine at the site on Graph G2.
- **Loss Parameters:** It opens the Loss Parameters GUI.
- **Start Simulation:** It starts the simulation of energy estimation for the wind plant as described by the data entered by the user in the Data Acquisition and Energy Estimation Apps. Results are collected in excel files.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

Loss Parameters GUI



Loss Parameters GUI

Description:
This GUI provides an interface for entering the loss parameters associated with a Wind Power plant. The values received from this GUI helps in calculating powers and energies at each level of power/energy transfer.

Edit Boxes:

- **Air Density [kg/m3]:** Enter the density of air at turbine test facility in kg/m3. Default value is 1.225.
- **Air Temperature [Deg Celsius]:** Enter the air temperature at turbine test facility in degree celsius. Default value is 15.
- **Air Pressure [atm]:** Enter the air pressure at turbine test facility in atm. Default value is 1.

- **Altitude of Turbine Testing Facility [m]:** Enter the altitude of turbine test facility in m. Default value is 0.
- **Ohmic Loss %:** Enter the percentage of power/energy loss due to cable resistances. Default value is 3%. The user has the option of changing the default value.
- **Transformer Loss %:** Enter the percentage of power/energy loss due to Transformer loss. Default value is 1%. The user has the option of changing the default value.
- **Wake Loss %:** Enter the percentage of power/energy loss due to wake effect. Default value is 5%. The user has the option of changing the default value.
- **Performance Ratio:** Enter the performance ratio of the wind power plant based on historical generation data. Default value is 0.7.The user has the option of changing the default value.
- **Terrain Coefficient:** Enter the terrain coefficient selected appropriately from the table as per the terrain surrounding the wind power plant.
- **Height of Anemometer [m]:** Enter the height at which measurement anemometer is situated in m.

Radio Buttons:

- **Default Values:** If selected, the user cannot modify the loss parameters.
- **User-Defined:** If selected, the user can modify the loss parameters.
- **For Wake Loss %:** Select this option, to use fixed percentage of wake loss.
- **For Wake Model:** Select this option, to use wake effect models. It enables the Wake Model Selection GUI.
- **PR:** Select this option, to use fixed performance ratio which is based on historical generation of the wind power plant.
- **Active Turbines File:** Select this option, if the user has the active turbine file associated with wind power plant in excel file format.

Tables:

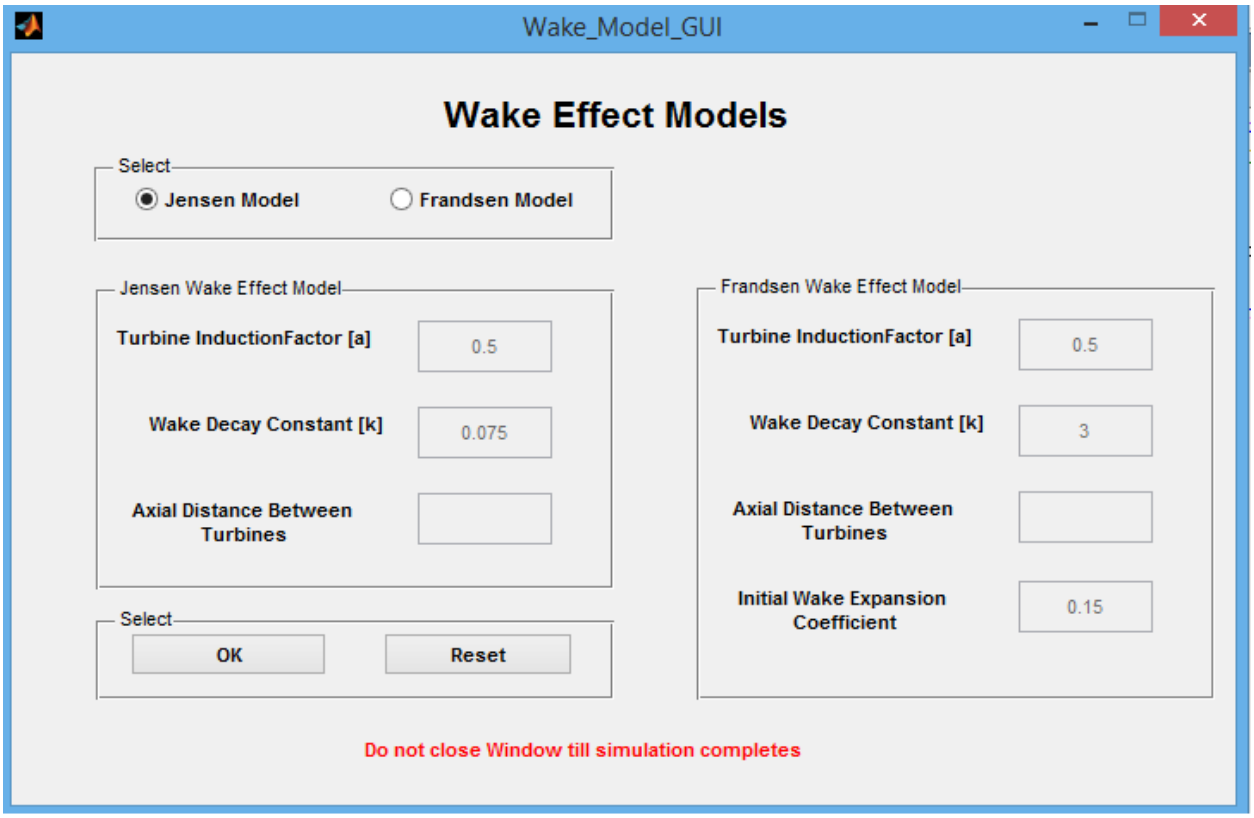
- **Terrain Characteristic-Friction Coefficient:** It stores the friction coefficients of different terrains.

Push Buttons:

- **Compute:** It computes the air pressure in atm and air density in kg/m3 for the given altitude of the wind turbine testing facility.
- **Wake Model Selection:** It opens the Wake Effect Models GUI.
- **WG T1 Turbines:** It asks the user to provide active turbines file for the Type 1 Wind Turbine in excel file format.
- **WG T2 Turbines:** It asks the user to provide active turbines file for the Type 2cWind Turbine in excel file format.
- **WG T3 Turbines:** It asks the user to provide active turbines file for the Type 3 Wind Turbine in excel file format.

- **WG T4 Turbines:** It asks the user to provide active turbines file for the Type 4 Wind Turbine in excel file format.
- **Ok:** It sends the entered values to the main application.
- **Reset:** It resets the GUI to initial condition.

Wake Effect Models GUI



Wake Model GUI

Description:

Edit Boxes:

- **Turbine Induction Factor [a]:** Enter the turbine induction factor. For Jensen Wake Model. The default value is 0.5.
- **Wake Decay Constant [k]:** Enter the wake decay constant. For Jensen Wake Model. The default value is 0.075.
- **Axial Distance Between Turbines [m]:** Enter the axial distance between turbines in m. For Jensen Wake Model.
- **Turbine Induction Factor [a]:** Enter the turbine induction factor. For Frandsen Wake Model. The default value is 0.5.
- **Wake Decay Constant [k]:** Enter the wake decay constant. For Frandsen Wake Model. The default value is 3.
- **Axial Distance Between Turbines [m]:** Enter the axial distance between turbines in m. For Frandsen Wake Model.
- **Initial Wake Expansion Coefficient:** Enter the initial wake expansion coefficient. For Frandsen Wake Model. The default value is 0.15.

Radio Buttons:

- **Jensen Model:** Select this option, if Jensen Wake Model is to be used for wake effect calculation. It enables the edit boxes relevant for Jenesen wake model.
- **Frandsen Model:** Select this option, if Frandsen Wake Model is to be used for wake effect calculation. It enables the edit boxes relevant for Frandsen wake model.

Push Buttons:

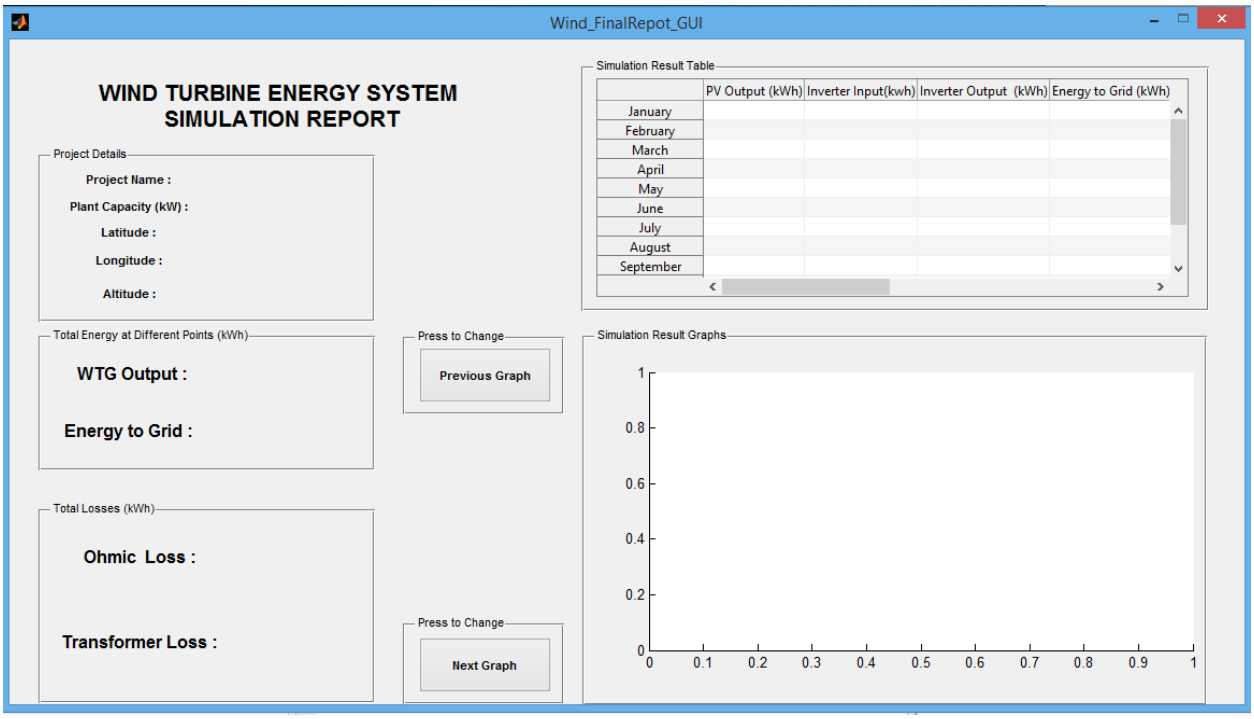
- **Ok:** It send entered data to the application.
- **Reset:** It resets the GUI to initial condition.

Step 5: Simulation and Results

Push Buttons:

- **Start Simulation:** It starts the internal simulation engine which computes the energy produced in the Wind Power plant during the simulation period. It creates appropriate excel files recording energy production in intra-day, daily and monthly format. It also opens the Report GUI where all the results of simulation are displayed.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

Energy Estimation Simulation Report GUI



Wind Energy Estimation Simulation Report GUI

Description:
This GUI displays the results of the energy estimation simulation of a Wind Turbine Plant.

Text Boxes:

- **Project Name:** It shows the project name.
- **Plant Capacity (kW):** It shows the plant capacity in kW.
- **Latitude:** It shows the latitude of the Wind Turbine plant location in decimal degrees
- **Longitude:** It shows the longitude of the Wind Turbine plant location in decimal degrees.
- **Altitude:** It shows the altitude of the Wind Turbine plant location in meters.
- **WTG Output:** It shows the annual Wind Turbine module output energy in kWh.
- **Energy to Grid:** It shows the annual energy transmitted to the grid in kWh.
- **Ohmic Loss:** It shows the annual energy lost due to cable resistance in kWh.
- **Transformer Loss:** It shows the annual energy lost due to Transformer losses in kWh.

Table:

- It summarizes the monthly energy produced and lost at different levels.

Graph:

- It displays the bar graph of monthly energy produced/lost of a particular variable.

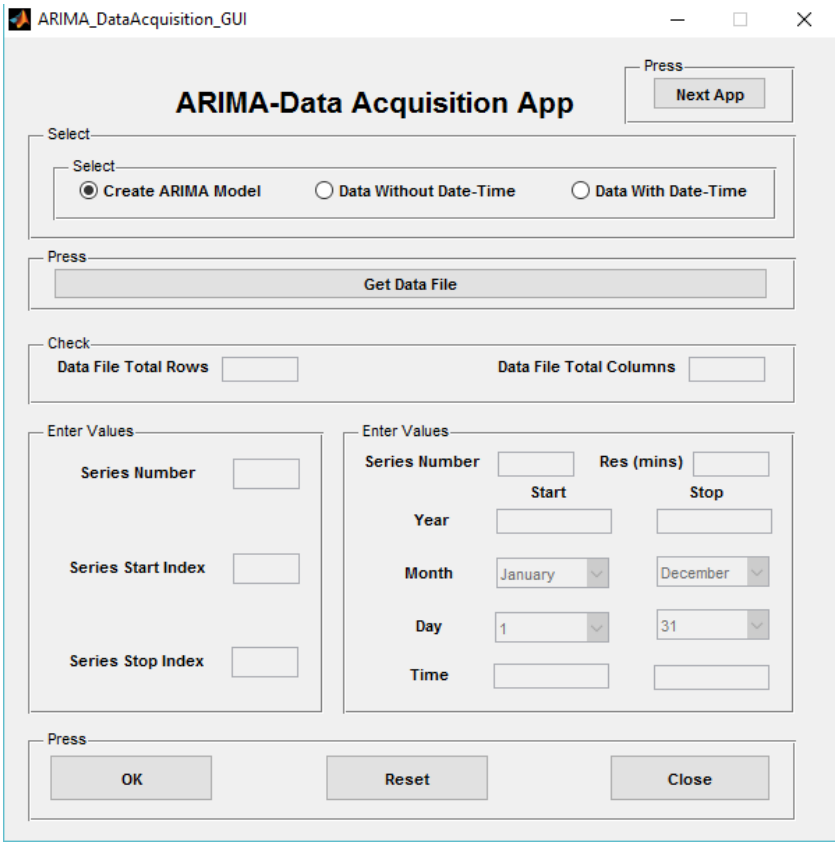
Push Buttons:

- **Next Graph:** It changes the monthly energy bar graph of a particular variable to the bar graph of the next variable w.r.t the initial variable as placed in the table columns.
- **Previous Graph:** It changes the monthly energy bar graph of a particular variable to the bar graph of the previous variable w.r.t the initial variable as placed in the table columns.

FORECASTING APPLICATION

ARIMA Forecasting APP

Data Acquisition App:



ARIMA-Data Acquisition GUI

Description:

This GUI provides an interface to input different types of univariate data series in to the ARIMA Forecasting App.

Edit Boxes: [Data Without Date-Time]

- **Series Number:** Enter the column number of the data series desired to be operated with.
- **Series Start Index:** Enter the start row number of the data series selected as per the Series Number.
- **Series Stop Index:** Enter the end row number of the data series selected as per the Series Number.

Edit Boxes: [Data Witht Date-Time]

- **Series Number:** Enter the column number of the data series desired to be operated with.
- **Res (mins):** Enter resolution of the data file in minutes.
- **Year Start:** Enter the start year for the desired data series.
- **Year End:** Enter the end year for the desired data series.
- **Time Start:** Enter the start time for the desired data series in decimal time.
- **Time End:** Enter the end time for the desired data series in decimal time.

List Boxes:

- **Start Month:** Select the starting month for the desired data series.
- **Start Day:** Select the starting day of the starting month for the desired data series.
- **End Month:** Select the ending month for the desired data series.
- End Day: Select the ending day of the ending month for the desired data series.

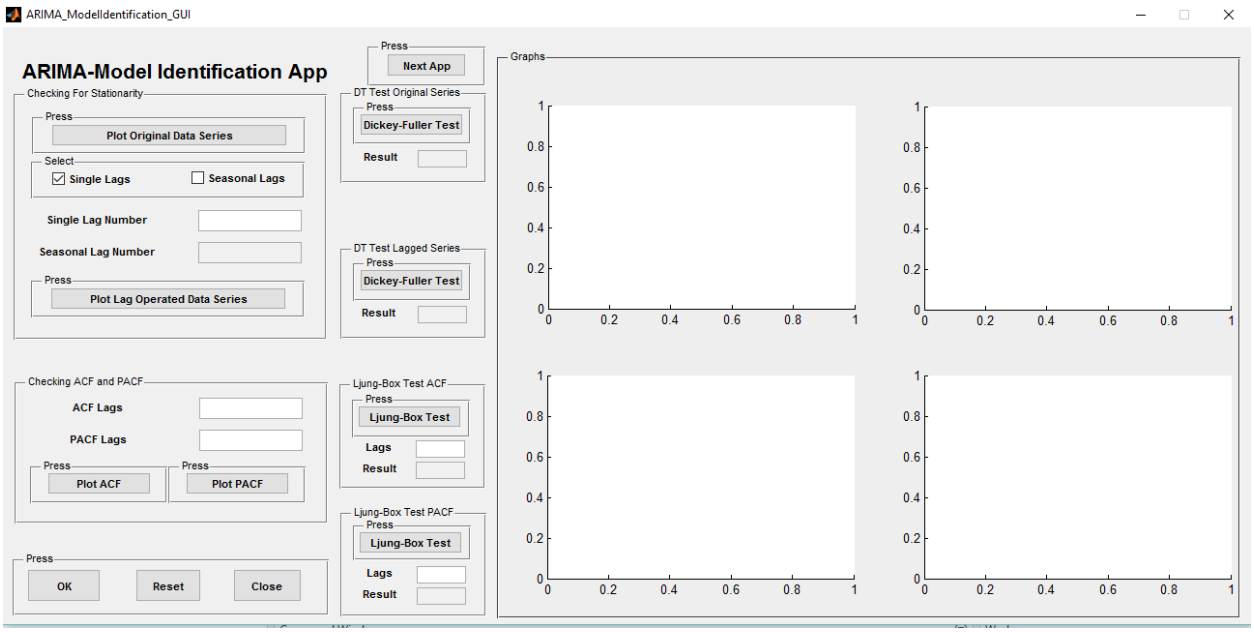
Radio Buttons:

- **Create ARIMA Model:** It should be selected when the user wants to create custom ARIMA models and not work with real data files.
- **Data Without Date-Time:** It should be selected when the user wants to use data file without date-time signature.
- **Data With Date-Time:** It should be selected when the user wants to use data file with date-time signature.

Push Buttons:

- **Get Data File:** It enables the user to select the excel file of the data
- **OK:** It selects the appropriate data series and slices it as desired according to the user, and sends the desired sliced data series to the application
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.
- **Next App:** It opens the next GUI.

Model Identification App:



ARIMA-Model Identification GUI

Description:

This GUI provides an interface to the user to identify the approximate ARIMA models which could fit the desired and sliced data series.

Edit Boxes:

- **Single Lag Number:** Enter the number of times the series should be differenced.
- **Seasonal Lag Number:** Enter the seasonality number which can be differenced.
- **ACF Lags:** Enter the number of ACF (Auto-Correlation Function) lags to be computed.
- **PACF Lags:** Enter the number of PACF (Partial Auto-Correlation Function) lags to be computed.
- **Lags:** Enter the lag numbers of the ACF and PACF plots which should be tested with Ljung-Box Test for correlation. If there are more than one lags then values can be entered as a comma separated list.

Text Boxes:

- **Result:** There are four results text boxes, two for displaying the result of the Dickey-Fuller Test for Stationarity (), and the remaining two for displaying the result of the Ljung-Box Test ().

Check Boxes:

- **Single Lags:** Select when series is to be differenced with single lags.
- **Seasonal Lags:** Select when series is to be difference for seasonality.

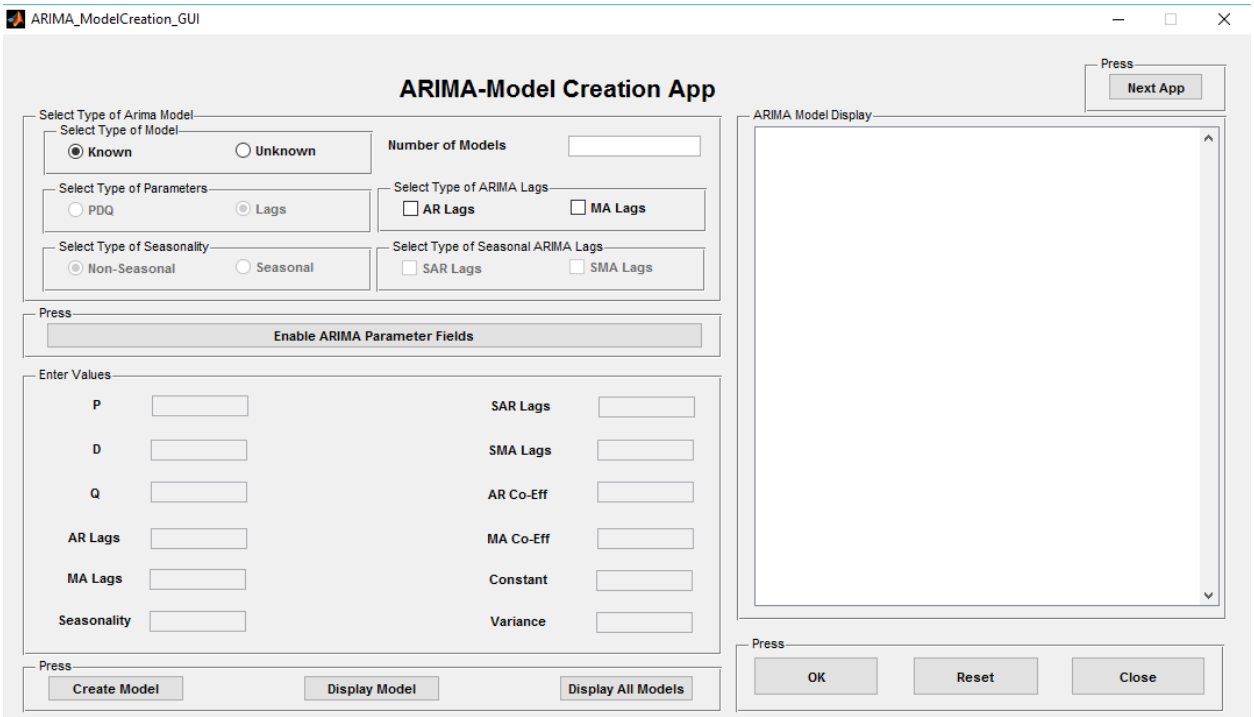
Graphs:

- **G1:** It plots the original data series.
- **G2:** It plots the differenced data series.
- **G3:** It plots the ACF of the differenced data series.
- **G4:** It plots the PACF of the differenced data series.

Push Buttons:

- **Plot Original Data Series:** It plots the original data series in Graph G1.
- **Plot Lag Operated Data Series:** It plots the differenced data series in Graph G2.
- **Plot ACF**: It plots the ACF of the differenced data series in Graph G3.
- **Plot PACF:** It plots the PACF of the differenced data series in Graph G3.
- **Dickey-Fuller Test:** There are two push buttons one each for computing the Stationarity of the original and differenced data series.
- **Ljung-Box Test:** There are two push buttons one each for computing the correlation of the given lags for the ACF and PACF of the differenced data series.
- **OK:** It opens the next GUI.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.
- **Next App:** It opens the next GUI.

Model Creation App:



ARIMA-Model Creation GUI

Description:

This GUI provides an interface to the user to create a wide variety of ARIMA family models with different options. More than one ARIA family models can be created at once.

Edit Boxes:

- **Number of Models:** Enter the total number of ARIMA family models to be created.
- **P:** Enter the AR (autoregressive) component of the ARIMA model.
- **D:** Enter the I (integrated) component of the ARIMA model.
- **Q:** Enter the MA (moving average) component of the ARIMA model.
- **AR Lags:** Enter the autoregressive lags. If there are more than one lags then the values can be entered as a comma separated list.
- **MA Lags:** Enter the moving-average lags. If there are more than one lags then the values can be entered as a comma separated list.
- **Seasonality:** Enter the seasonality of the data.
- **SAR Lags:** Enter the seasonal AR lags. If there are more than one lags then the values can be entered as a comma separated list.

- **SMA Lags:** Enter the seasonal MA lags. If there are more than one lags then the values can be entered as a comma separated list.
- **AR Co-Eff:** Enter the known AR coefficients. If there are more than one lags then the values can be entered as a comma separated list.
- **MA Co-Eff:** Enter the known MA coefficients. If there are more than one lags then the values can be entered as a comma separated list.
- **Constant:** Enter the constant for the ARIMA family model.
- **Variance:** Enter the known variance for the ARIMA family model.

Text Boxes:

- **ARIMA Model Display:** It displays the details of the created ARIMA family models according to the push buttons: Display Model and Display All Models.

Check Boxes:

- **AR Lags:** Select if user wants to enter AR lags.
- **MA Lags:** Select if user wants to enter MA lags.
- **SAR Lags:** Select if user wants to enter SAR lags.
- **SMA Lags:** Select if user wants to enter SMA lags.

Radio Buttons:

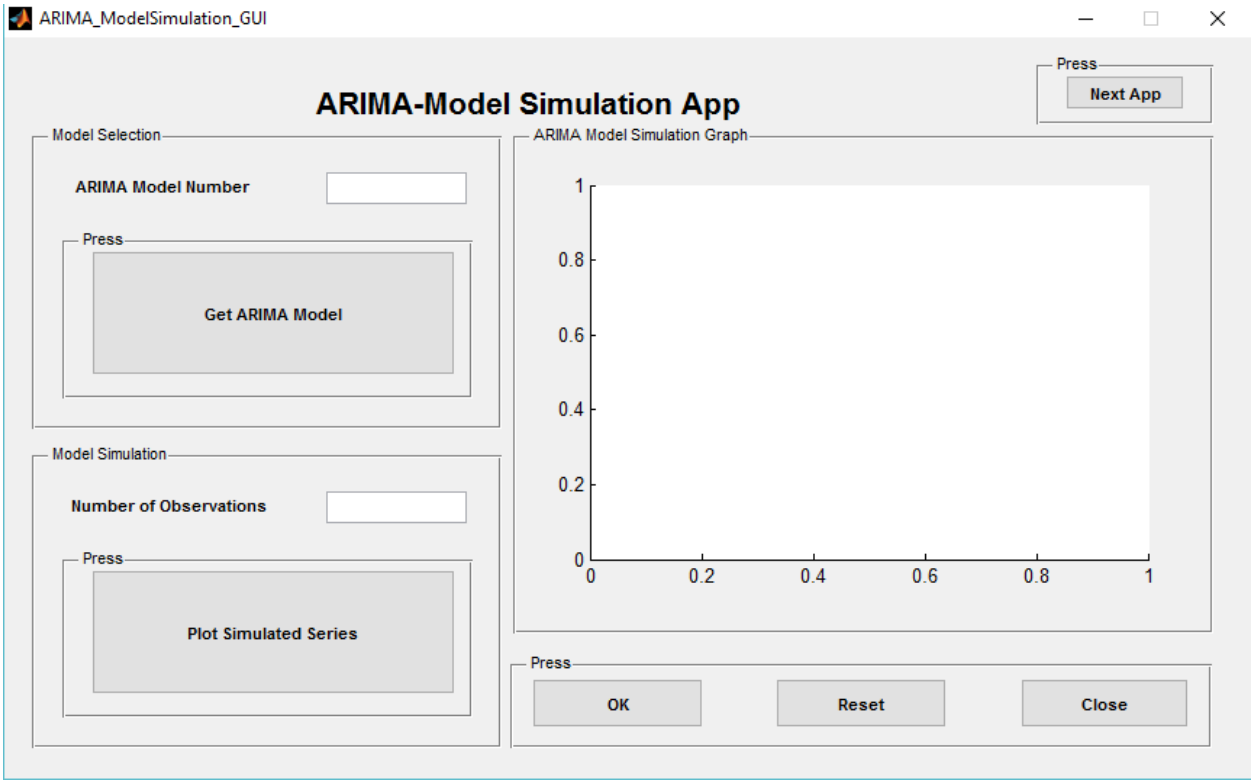
- **Known:** Select if the user is creating a Known (co-efficients are known) ARIMA Family model.
- **Unknown:** Select if the user is creating a Unknown (co-efficients are unknown) ARIMA Family model.
- **PDQ:** Select if the user wants to provide only P, D and Q values to describe the ARIMA family model.
- **Lags:** Select if the user wants to Lag values to describe the ARIMA family model.
- **Non-Seasonal:** Select if the user wants to create a non-seasonal ARIMA family model.
- **Seasonal:** Select if the user wants to create a seasonal ARIMA family model.

Push Buttons:

- **Enable ARIMA Parameter Fields:** It enables the edit boxes I accordance with the radio and check box selection of the user.
- **Create Model:** It creates the ARIMA family model in accordance with the currently enabled edit box values entered by the user.
- **Display Model:** It displays the details of the ARIMA family model currently created in the ARIMA Model Display Text Box.
- **Display All Models:** It displays all the ARIMA family models created.

- **OK:** It sends all the created ARIMA family models to the application.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.
- **Next App:** It opens the next GUI.

Model Simulation App:



ARIMA-Model Simulation GUI

Description:

This GUI provides an interface to the user to simulate known parameter ARIMA models.

Edit Boxes:

- **ARIMA Model Number:** Enter the number of the ARIMA model Created.
- **Number of Observations:** Enter the total number of observations to be simulated.

Graphs:

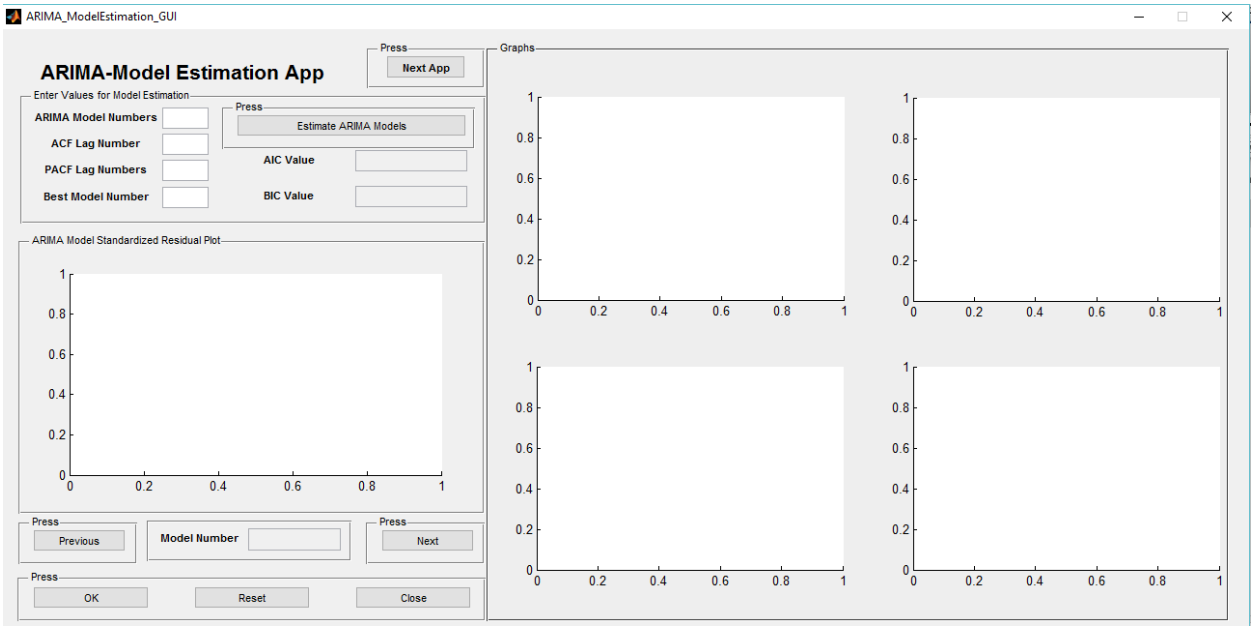
- **G1:** It plots the simulated data series.

Push Buttons:

- **Get ARIMA Model:** It loads the correct known parameter ARIMA family model.
- **Plot Simulated Series:** It plots the simulated data series in Graph G1.
- **OK:** It opens the next GUI.
- **Close:** It closes the GUI.

- **Reset:** It resets the GUI to initial condition.
- **Next App:** It opens the next GUI

Model Estimation App:



ARIMA-Model Estimation GUI

Description:

This GUI provides an interface to user to estimate the ARIMA Family Models coefficients and check their Goodness of Fit.

Edit Boxes:

- **ARIMA Model Number:** Enter the total number of ARIMA family models created.
- **ACF Lag Numbers:** Enter the ACF Lag numbers to be computed.
- **PACF Lag Numbers:** Enter the PACF Lag numbers to be computed.
- **Best Model Number:** Enter the number of the ARIMA family model with the best fit to the data series.

Text Boxes:

- **AIC Value:** It shows the Akalike Information Criterion (Lower the value, better the fit of the model) for the current ARIMA family model.
- **BIC Value:** It shows the Bayesian Information Criterion (Lower the value, better the fit of the model) for the current ARIMA family model.
- **Model Number: It shows the current ARIMA family model under estimation number.**

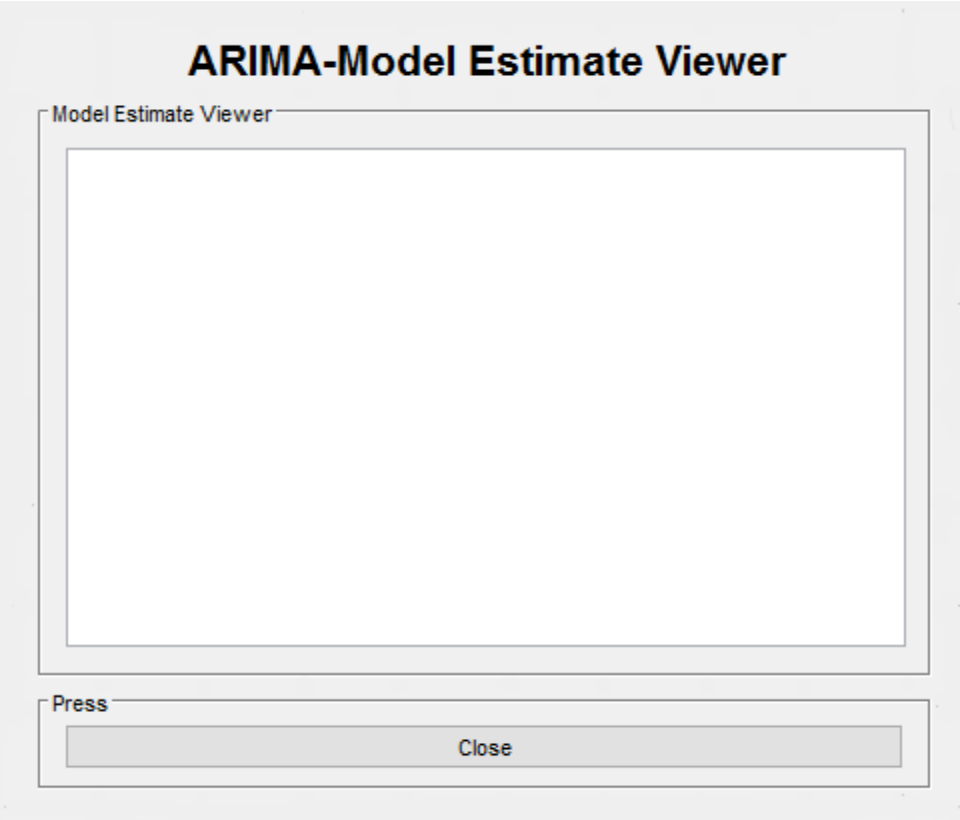
Graphs:

- **G1:** It plots the QQ Plot.
- **G2:** It plots the Standardized Residuals and Standard Normal Plots.
- **G3:** It plots the ACF of the Standardized Residuals.
- **G4:** It plots the PACF of the Standardized Residuals.
- **G5:** It plots the Standardized Residuals.

Push Buttons:

- **Estimate ARIMA Models:** It estimates all the ARIMA family models created and displays the AIC, BIC, Residual Plots, ACF/PACF of standardized residuals of the first ARIMA Family model.
- **Next:** It displays the AIC, BIC, Residual Plots, ACF/PACF of standardized residuals of the first ARIMA Family model.
- **Previous:** It displays the AIC, BIC, Residual Plots, ACF/PACF of standardized residuals of the first ARIMA Family model.
- **OK:** It sends the estimated best ARIMA family model to the application
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.
- **Next App: It opens the next GUI**

Model Estimate Viewer Window:



ARIMA-Model Estimate Viewer Window

Description:

This GUI provides an interface to user to view the estimated ARIMA Family Model details.

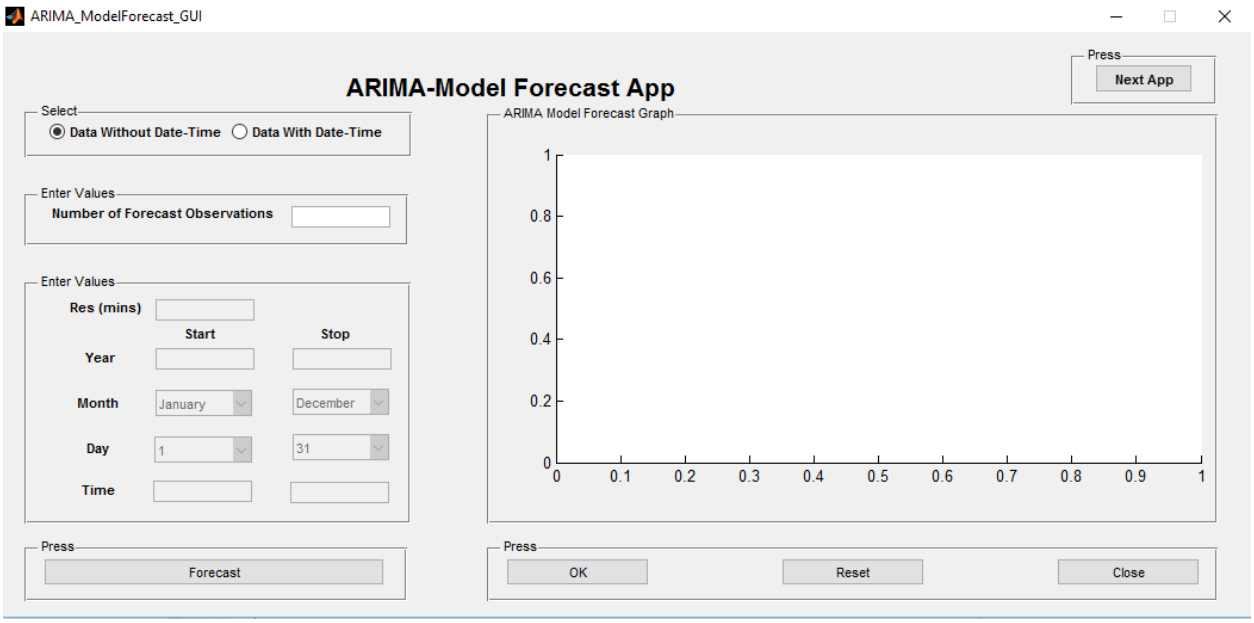
Text Boxes:

- **Model Estimate Viewer:** It shows the details of the estimated ARIMA family models.

Push Buttons:

- **Close:** It closes the GUI.

Model Forecast App:



ARIMA-Model Forecasting App

Description:

This GUI provides an interface to the user to forecast data series on the basis of the best fit ARIMA Family Model selected.

Edit Boxes: [Data Without Date-Time]

- **Number of Forecast Observations:** Enter the total number of forecasted values to be computed.

Edit Boxes: [Data Witht Date-Time]

- **Res (mins):** Enter the Data File resolution in minutes.
- **Year Start:** Enter the start year for the forecast series.
- **Year End:** Enter the end year for the forecast series.
- **Time Start:** Enter the start time for the forecast series in decimal time.
- **Time End:** Enter the end time for the forecast series in decimal time.

List Boxes:

- **Start Month:** Select the starting month for the forecast series.
- **Start Day:** Select the starting day of the starting month for the forecast series.
- **End Month:** Select the ending month for the forecast series.
- **End Day:** Select the ending day of the ending month for the forecast series.

Radio Buttons:

- **Data Without Date-Time:** Select if the user has entered a data file without date-time signature in the data acquisition app, It enables the text boxes for the Data Without Date-Time Panel.
- **Data With Date-Time:** Select if the user has entered a data file with date-time signature in the data acquisition app, It enables the text boxes and list boxes for the Data With Date-Time Panel..

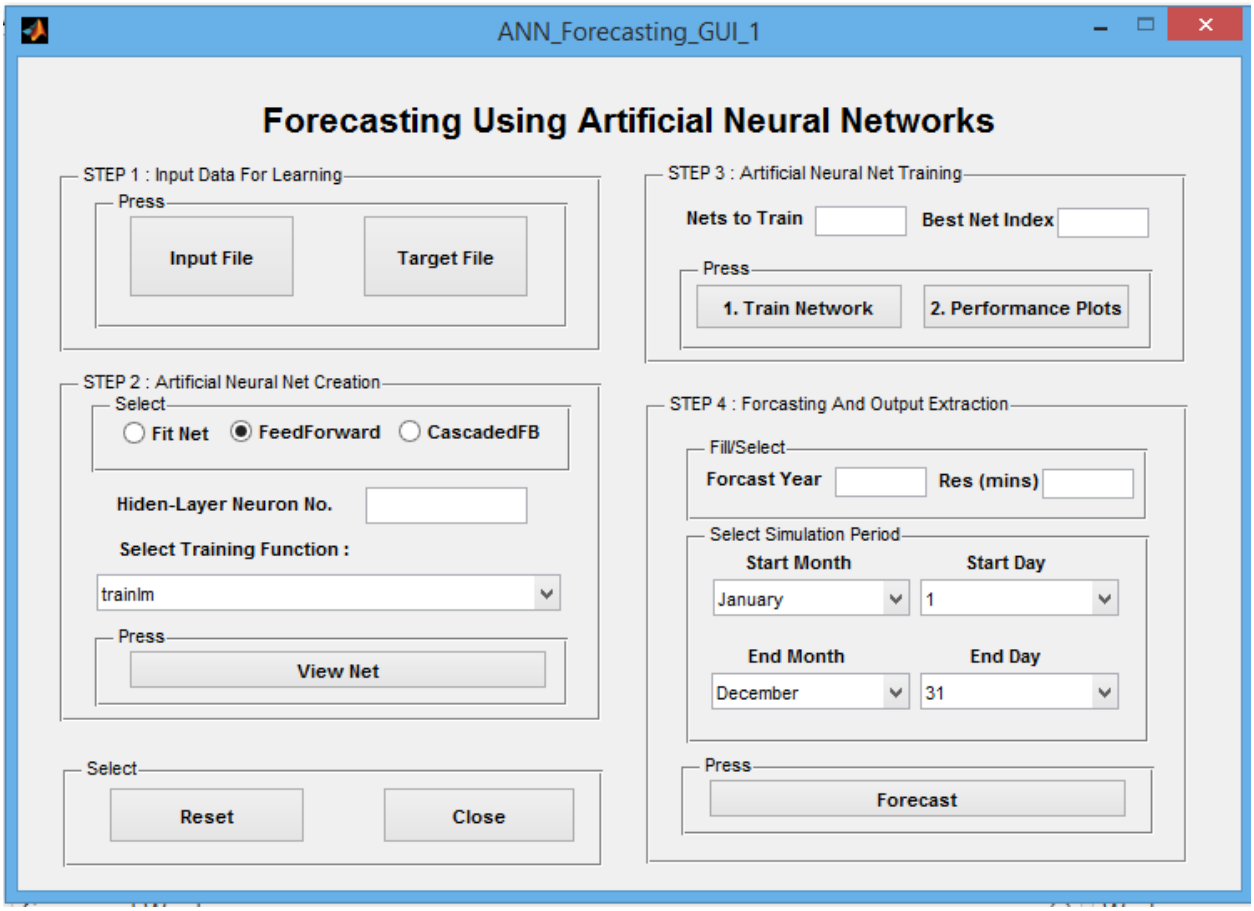
Graphs:

- **G1:** It plots the forecasted data series.

Push Buttons:

- **Forecast:** It computes the forecasted data series in accordance with the user parameters and plots it in Graph G1.
- **OK:** It creates excel files of the forecasted data series.
- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

ANN Forecasting App



ANN Forecasting App GUI

Description:

This GUI provides an interface to the user to create custom neural networks, train them with appropriate input and target files, using appropriate training function, to generate forecasts.

Step 1: Input Data for Learning

Push Buttons:

- **Input File:** It asks the user to provide the input file for neural network training in excel file format.
- **Target File:** It asks the user to provide the target file associated with the input file provided earlier in excel file format.

Step 2: Artificial Neural Net Creation

Edit Boxes:

- **Hidden-Layer Neuron No.:** Enter the number of hidden neurons. If you desire for a multi-layer neural network, enter the number of neurons in each of the hidden layer in a comma separated format.

List Boxes:

- **Selecting Training Function:** Select the most appropriate neural net training function from the list of 12 neural network training functions.

Radio Buttons:

- **Fit Net:** If selected, the neural network architecture would be the simplest one similar to a feed forward neural network.
- **FeedForward:** If selected, the neural network architecture would be a feed forward neural network.
- **CascadedF:** If selected, the neural network architecture would be a cascaded forward neural network.

Push Buttons:

- **View Net:** It graphically represents the designed neural network.

Step 3: Artificial Neural Net Training

Edit Boxes:

- **Nets to Train:** Enter the number of different nets to be trained with the input and target data. This helps in overcoming the problem of random initialization of weights and biases during the training process.
- **Best Net Index:** Enter the neural net number of the best performing neural net, once you have seen the neural network performance plots.

Push Buttons:

- **Train Network:** It trains all the neural nets of the given architecture each with a different initialization of weights and biases and the training function previously selected by the user.
- **Performance Plots:** It opens the Neural Network Performance Plots GUI .

Step 4: Forecasting and Output Extraction

Edit Boxes:

- **Forecast Year:** Enter the year for which forecasting is going to take place. It is required to create proper date time signature on the forecasting output excel files.
- **Res (min):** Enter the resolution in (minutes). It should match the resolution of the input and target files used to train the neural network.

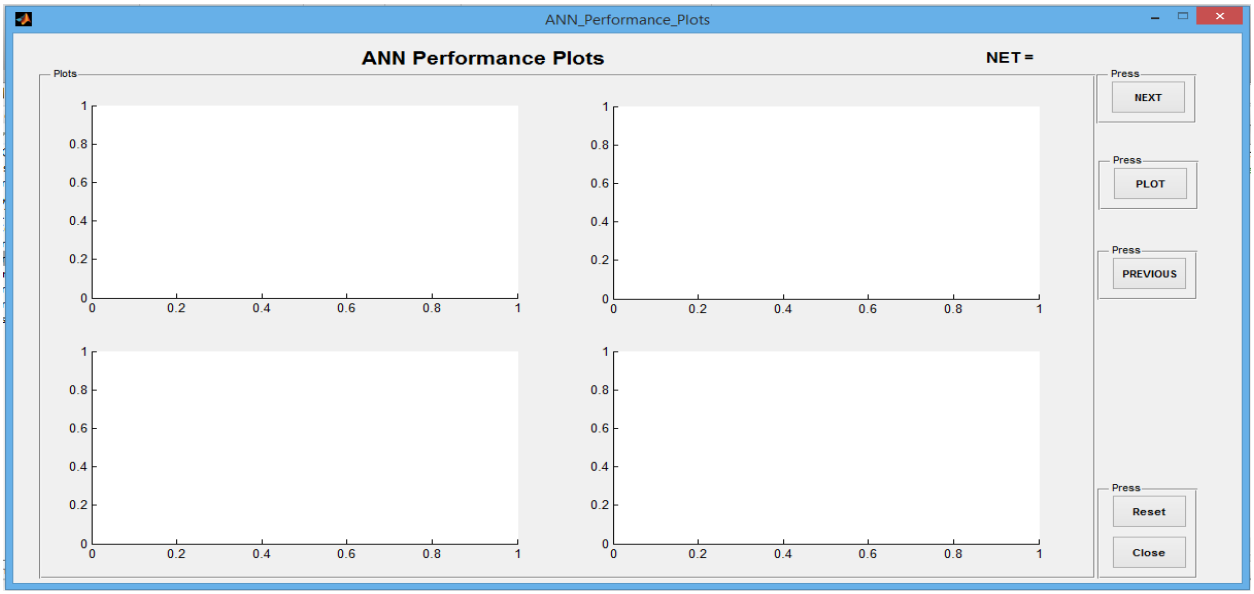
List Boxes:

- **Start Month:** Select the starting month for forecast.
- **Start Day:** Select the starting day of the starting month for forecast.
- **End Month:** Select the ending month for forecast.
- **End Day:** Select the ending day of the ending month for forecast.

Push Buttons:

- **Forecast:** It forecasts using the trained network selected by the user as the best performing neural network based on the performance plots. It outputs the forecast file in the form of excel file.

ANN Performance Plots GUI



ANN Performance Plots GUI

Description:
This GUI plots the performance mapping graphs for the trained neural network.

Text Boxes:

- **Net =:** It displays the number of the neural net whose performance mapping graphs are currently displayed on the GUI.

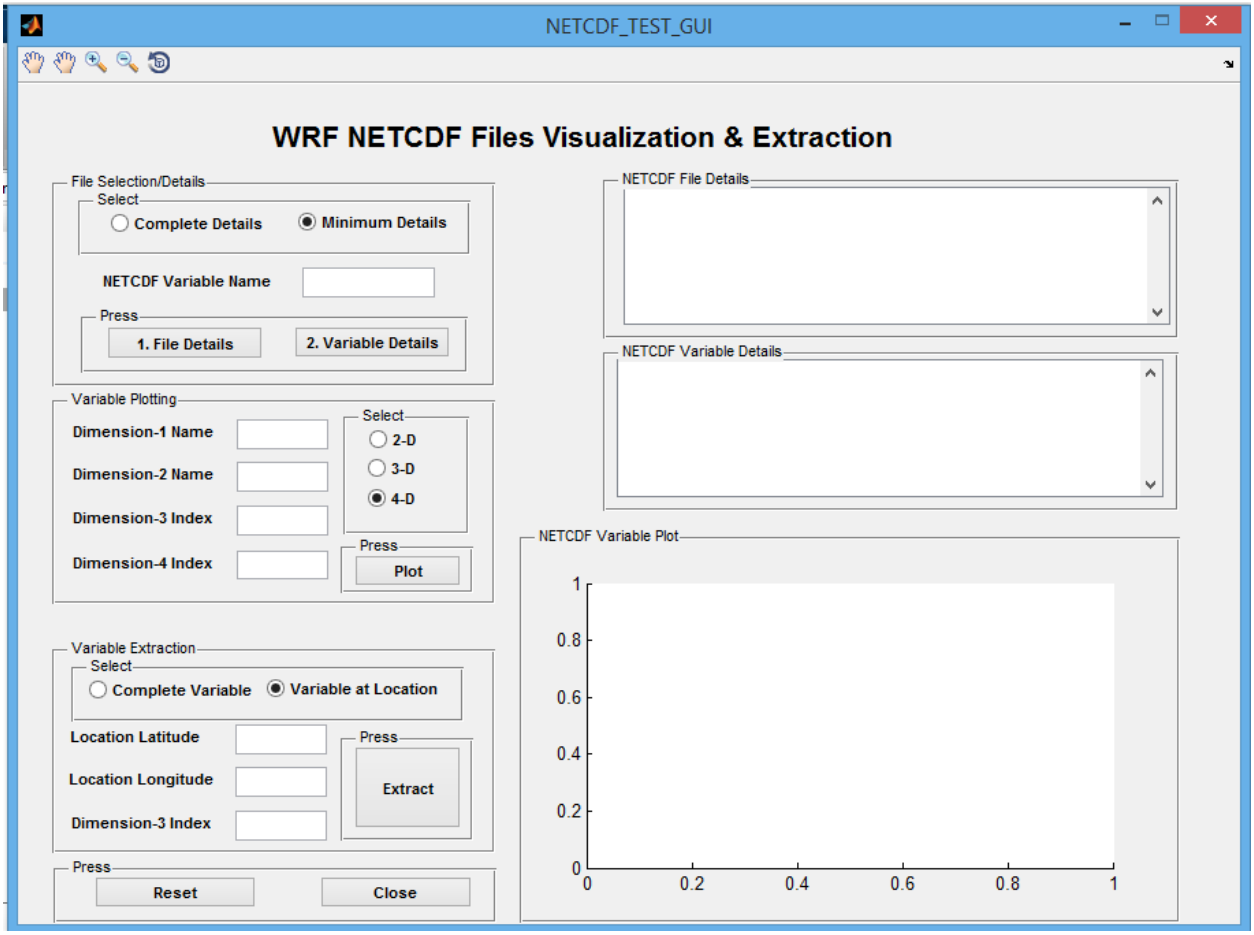
Graphs:

- **G1:** It the upper-left graph. It plots the performance graph of the current ANN.
- **G2:** It the upper-right graph. It plots the training state graph of the current ANN.
- **G3:** It the lower-left graph. It plots the regression graph of the current ANN.
- **G4:** It the upper-right graph. It plots the error histogram of the current ANN.
-

Push Buttons:

- **Plot:** It plots the four performance mapping graphs of the first trained neural network. It enables the Next and Previous push buttons
- **Next:** It plots the four performance mapping graphs of the next trained neural network.
- **Previous:** It plots the four performance mapping graphs of the previous neural network.
- **Close:** It closes the GUI.
- Reset: It resets the GUI to initial condition.

WRF NETCDF App



WRF NETCDF Files Visualization and Extraction GUI

Description:

This GUI provides an interface to the user to interact with the NETCDF output files from the WRF software. It helps in viewing the details of the NETCDF file and variables. It helps in visualizing a particular variable using a graph. It also helps in extracting variables for a particular location into an excel file format

File Selection/Details

Edit Boxes:

- **NETCDF Variable Name:** Enter the variable name after going through the entire structure of the NETCDF file. This variable will be used for visualizations and data extraction.

Text Boxes:

- **NETCDF File Details:** It displays the details of the NETCDF File selected by the user.
- **NETCDF Variable Details:** It displays the details of the variable whose name is entered by the user.

Radio Buttons:

- **Complete Details:** If selected, the full details of the NETCDF file and variables are displayed.
- **Minimum Details:** If selected, the minimum required details for understanding the NETCDF file and variables are displayed.

Push Buttons:

- **File Details:** It asks the user to provide with a NETCDF file. It displays the file details in the NETCDF File Details text box.
- **Variable Details:** It displays the file details of the variable whose name is entered by the user NETCDF Varibale Details text box.

Variable Plotting

Edit Boxes:

- **Dimension-1 Name:** Enter the name of the first dimension of the netcdf variable.
- **Dimension-2 Name:** Enter the name of the second dimension of the netcdf variable.
- **Dimension-3 Name:** Enter the name of the third dimension of the netcdf variable.
- **Dimension-4 Name:** Enter the name of the fourth dimension of the netcdf variable.

Radio Buttons:

- **2-D:** Select this option, if the variable is two dimensional. It enables Dimension-1 Name and Dimension-2 Name edit boxes only.
- **3-D:** Select this option, if the variable is three dimensional Dimension-1 Name, Dimension-2 Name and Dimension-3 Name edit boxes only.
- **4-D:** Select this option, if the variable is four dimensional Dimension-1 Name, Dimension-2 Name, Dimension-3 Name and Dimension-4 Name edit boxes only.

Graphs:

- **G1:** It plots the variable data in appropriate format.

Push Buttons:

- **Plot:** It plots the netcdf variable on the graph.

Variable Extraction

Edit Boxes:

- **Location Latitude:** Enter the latitude of the location.
- **Location Longitude:** Enter the longitude of the location.
- **Dimension-3 Index:** Enter the index of the third dimension.

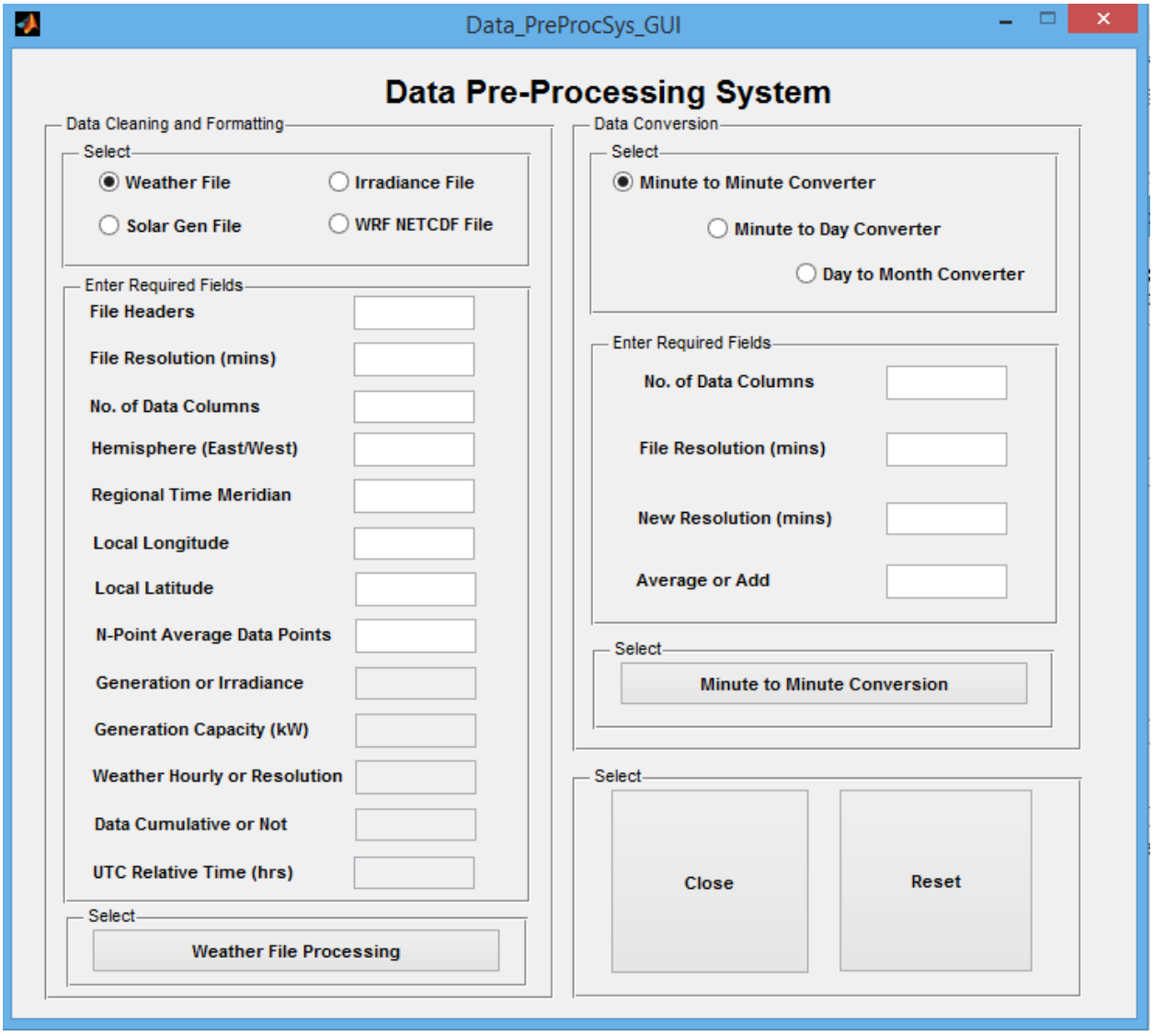
Radio Buttons:

- **Complete Variable:** Select this option, if user wants to extract the entire data stored in the variable.
- **Variable at Location:** Select this option, if the user wants to extract the values of the variable at a particular location. It enables the Location Latitude and location Longitude edit boxes. The Dimension-3 Index edit box is enabled if the 4-D radio button is selected.

Push Buttons:

- **Extract:** It extracts the appropriate data stored in the netcdf variable and outputs in excel file format.

DATA PRE-PROCESSING SYSTEM APPLICATION



Data Pre-Processing System GUI

Description:

This GUI provides an interface to clean the weather, irradiance and solar generation files. In addition, it converts cleaned files from minute-wise to hour-wise, hour-wise to day-wise and day-wise to month-wise formats.

Data Cleaning and Formatting

Edit Boxes:

- **File Headers:** If file has headers, enter 1; if file does not have headers, enter 0.
- **File Resolution (mins):** Enter the file resolution in minutes.
- **No. of Data Columns:** Enter the number of data columns in the file not counting the date-time signature columns.
- **Hemisphere (East/West):** If location is in the eastern hemisphere, enter 1; if location is in the western hemisphere, enter -1.
- **Regional Time Meridian:** Enter the regional time longitude in decimal degrees.
- **Local Longitude:** Enter the location longitude in decimal degrees.
- **Local Latitude:** Enter the location latitude in decimal degrees.
- **N-Point Average Data Points:** Enter the number of previous data points to be averaged in order to fill the next missing data value.
- **Generation or Irradiance:** If the data column is of solar generation (kWh), enter 1; if the data column is of irradiance, enter 0. Enter values for each of the data column in a comma separated format.
- **Generation Capacity (kW):** Enter the generation capacity of the PV plant section associated with the solar generation data column in kW. For multiple solar generation data columns enter the values in a comma separated format.
- **Weather Hourly or Resolution:** If weather files (wind speed and temperature) are in hourly resolution, enter 1; if the weather files are in resolution equal to that of the solar generation file to be processed, enter 0.
- **Data Cumulative or Not:** If the data in a column is cumulative stored, enter 1; if the data in a column is stored as value at that particular instant of time, enter 0. For multiple data columns enter the values in a comma separated format.
- **UTC Relative Time (hrs):** Enter the relative difference in time between the location and UTC in hours. It can have negative values.

Radio Buttons:

- **Weather File:** It enables the appropriate edit boxes and Weather File Processing push button.
- **Irradiance File:** It enables the appropriate edit boxes and Irradiance File Processing push button.
- **Solar Gen File:** It enables the appropriate edit boxes and Solar Gen File Processing push button.
- **WRF NETCDF File:** It enables the appropriate edit boxes and WRF NETCDF File Processing push button.

Push Buttons:

- **Weather File Processing:** It cleans and fills the data in the weather file and makes it of full size which can be used in the energy estimation application.
- **Irradiance File Processing:** It cleans and fills the data in the irradiance file and makes it of full size which can be used in the energy estimation application.

- **Solar Gen File Processing:** It cleans and fills the data in the solar generation file and makes it of full size which can be used in the plat performance studies.
- **WRF NETCDF File Processing:** It converts the UTC character date-time string in the WRF NETCDF files to local solar time, so that it can be used in the energy estimation application.

Data Conversion

Edit Boxes:

- **No. of Data Columns:** Enter the number of data columns in the file, not counting the columns with date-time signature.
- **File Resolution (mins):** Enter the original resolution of the data file in minutes.
- **New Resolution (mins):** Enter the new resolution to which the file should be converted in minutes.
- **Average or Add:** If the data in the column is to be added (Energy Data) when compressing, enter 1; if the data in the column is to be averaged (Irradiance, Wind Speed, Temperature etc.) when compressing, enter 0. For multiple data columns enter the values in a comma separated format.

Radio Buttons:

- **Minute to Minute Converter:** It enables the appropriate edit boxes and Minute to Minute Conversion push button.
- **Minute to Day Converter:** It enables the appropriate edit boxes and Minute to Day Conversion push button.
- **Day to Month Converter:** It enables the appropriate edit boxes and Day to Month Conversion push button.

Push Buttons:

- **Minute to Minute Conversion:** It converts a minute-wise resolution file into another file with a new minute-wise resolution.
- **Minute to Day Conversion:** It converts a minute-wise resolution file to a day-wise resolution file.
- Day to Month Conversion: It converts a day-wise resolution file to a month-wise resolution file.

Push Buttons:

- **Close:** It closes the GUI.
- **Reset:** It resets the GUI to initial condition.

RASPBERRY PI COMPUTING CLUSTER FOR RUNNING WRF

Raspberry Pi 2

Description:

It is a single-board micro-computer developed by the Raspberry Pi Foundation in the United Kingdom. Its primary purpose is to serve as a low priced tool for teaching and learning computer science. However, due its inexpensiveness and the broad spectrum of capabilities has made it a favourite of hobbyists, computer enthusiasts, students and researchers for embedded development. As it has an ARMv7 processor, it can run a full range of ARM GNU/Linux distributions.

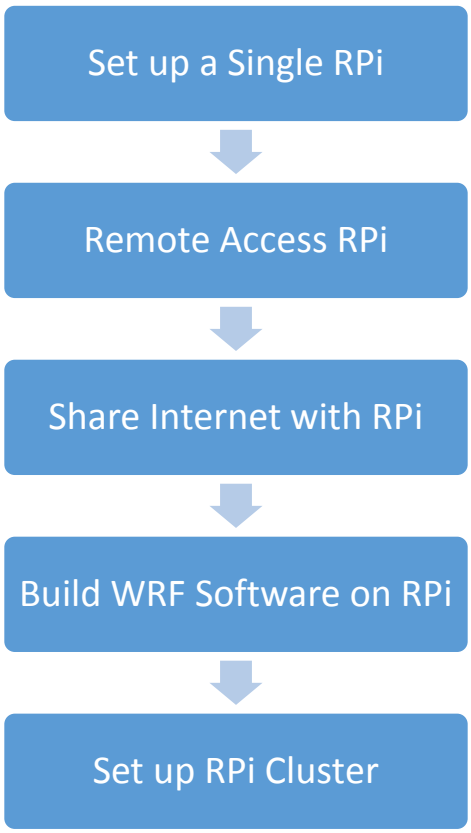
Hardware:

- A 900MHz Quad-Core ARM Cortex-A7 CPU
- 1GB RAM
- 4 USB Ports
- 40 GPIO (General Purpose Input/Output) pins
- Full HDMI Port
- Ethernet Port
- Combined 3.5mm Audio Jack and Composite Video
- Camera Interface (CSI)
- Display Interface (DSI)
- Micro SD Card slot
- VideoCore IV Graphics Core

Software (Operating Systems):

- RASPBIAN
- UBUNTU MATE
- SNAPPY UBUNTU CORE
- WINDOWS 10 IOT CORE
- OSMC
- OPENLECPINETRISC OS

Setting up Raspberry Pi Cluster for WRF:



Steps for setting up Raspberry Pi Computing Cluster

Set up a Single RPi:

- Components required are: 1 × Raspberry Pi, 1 × 32GB Micro SD Card, 1 × Card Reader, 1 × USB Power Cable, 1 × USB Power Hub, 1 × HDMI Cable, 1 × USB Mouse, 1 × USB Keyboard and 1 × HDMI compatible Display.
- Download the RASPBIAN-OS from the Raspberry Pi website (free).
- Download SD Formatter Software from internet (free).
- Download Win32DiskImager Software from the internet (free).
- Format the 32GB Micro SD Card using SD Formatter software.
- Write the downloaded RASPBIAN-OS image to the 32GB Micro SD Card using the Win32DiskImager software.
- Insert the SD card in the RPi.
- Connect the USB Power Hub to the Power source, and the USB Power Cable to the USB Power Hub.
- Attach the USB mouse and keyboard to the USB ports of the RPi.
- Connect the HDMI cable from the RPi to the display screen.
- Power up the RPi by connecting the USB Power Cable to the Micro USB Power port of the Rpi.

- The Rpi will boot; Username – pi and Password – raspberry.
- Go to the configuration menu and do the following:
    - Change the Hostname to Pi01
    - Enable SSH
    - Expand storage system
    - You may or may not overclock the RPi
- Reboot the Pi
- Shutdown the Rpi.

Remote Access RPi:

- Remote access means, able to control RPi without additional display, mouse and keyboard. We will control the RPi via our workstation (Laptop/Desktop) using SSH (Secure Shell).
- Components required are: LAN Cable
- Download Putty software from the internet (free).
- Find out the IP address of the Ethernet port of the workstation and note it down.
- Take out the SD Card from the RPi, using the SD Card Reader to read into its boot partition and add xxx.xxx.xxx.RPi::xxx.xxx.xxx.PC at the end of the cmdline.txt file. Where the first part is the IP static address of the RPi which is set to be in the network space of the workstation's IP address, and the second part after the double colons is the IP address of the workstation which was found out earlier.
- Now put the SD Card back into the RPi connect it to the workstation via a LAN cable and power it up.
- Open Putty software.
- In the Hostname field enter the Static IP address of our RPi, in the Port field enter 22, and give a name to this configuration and save with the hostname of our RPi i.e. Pi01.
- Now select the hostname of the RPi from the list, press Load and the press open.
- A terminal window will open, giving us a terminal access to our RPi.

Share Internet with RPi:

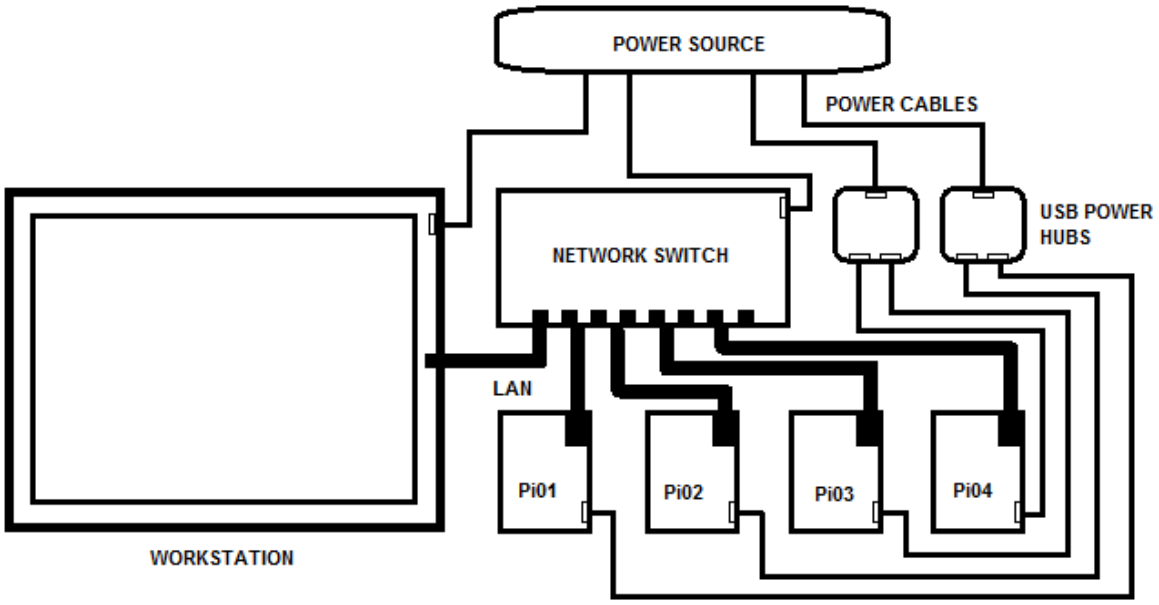
- From now on we will be using the RPi through SSH.
- We will share the internet (WiFi) of workstation with the RPi through the Ethernet port where it is connected.
- In a Windows system, this can be done by going to the *Networks and Sharing* Option of the Control Panel.
- Go to the Change Adapter Settings page.
- There Right-Click on the WiFi icon which shows internet connectivity and hit *Properties*.
- Navigate to the *Sharing* Tab and select the *Allow other users to connect through this computer's Internet connection* checkbox.

- Now Right-Click on the *LAN Adapter* and hit *Properties*. Double click the *IPV4* option and verify that some dynamic IP is populated. The IP address of the RPi should be within this IP addresses range.
- After this you can power up the RPi and connect to the workstation via the LAN cable.
- Now using Putty's terminal we can have internet access in the RPi which is shared from the workstation. (Check connectivity using ping www.google.com)

Build WRF on RPi:

- Download the TAR file of the WRF (Weather Research and Forecasting) and WPS (WRF Pre-processing System) from the WRF model site. Also download static geographic data used along with WPS and WRF from the UCAR EDU website.
- Download Filezilla Software from the internet (free).
- Run the RPi through SSH on the workstation, transfer the downloaded TAR files from the workstation to the RPi using the Filezilla software.
- Use the WRF Build Scripts developed to build and install WRF system on the RPi.
- Power off the RPi and remove the SD Card.
- Using the SD Card Reader and the Win32DiskImager; create an image of the SD Card, and store it in the workstation

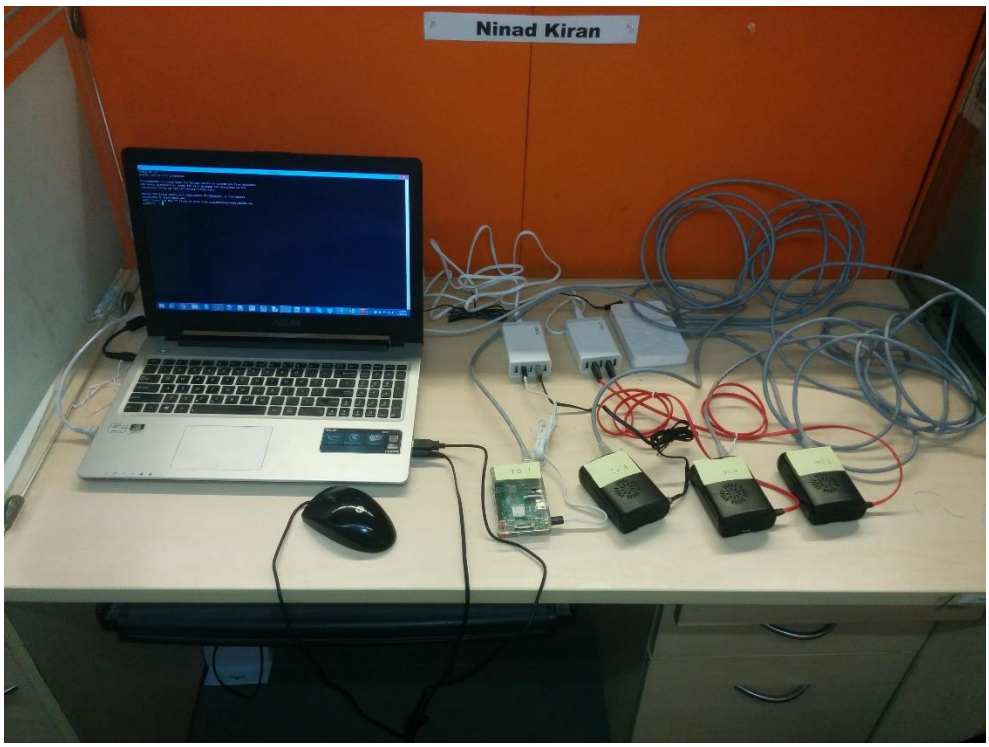
Set up RPi Cluster:

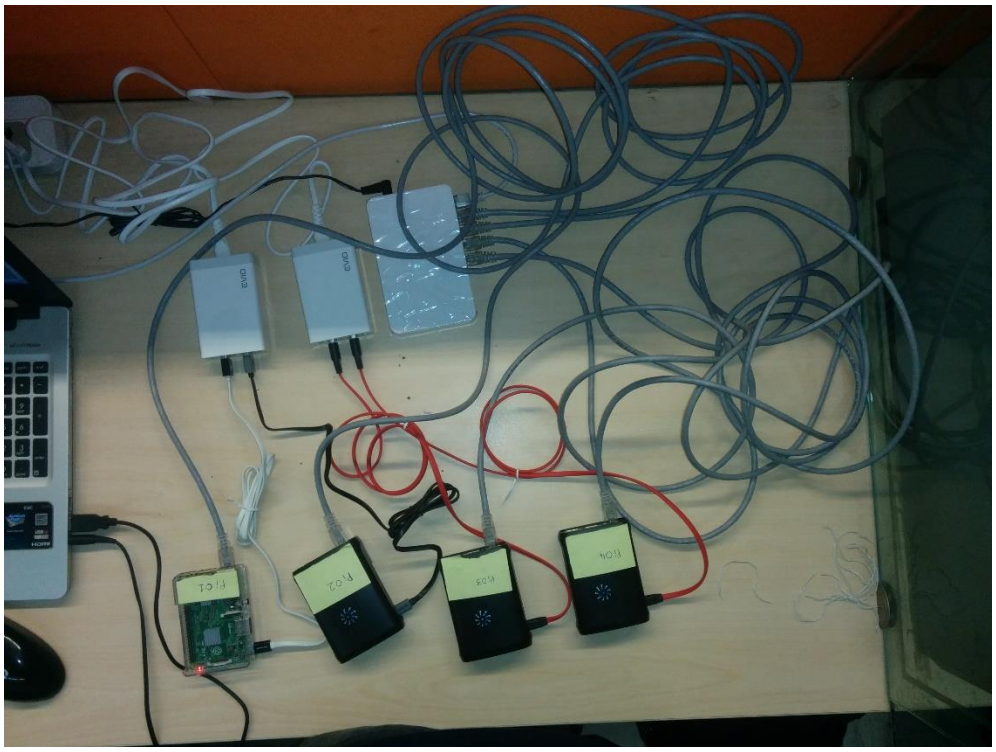


Raspberry Pi Cluster Schematic

- Components required are: 4 × Raspberry Pi, 4 × 32GB Micro SD Cards, 1 × Card Reader, 4 × USB Power Cables, 4 × LAN Cables, 2 × USB Power Hub, 1 × Extension Box.
- Using the SD Card reader and the Win32DiskImager software, burn the image which was earlier stored on the workstation (with installed WRF) onto to the rest of the SD Cards.
- Now, for each of the new SD Cards using the SD Card Reader read into its boot partition and add xxx.xxx.xxx.RPi::xxx.xxx.xxx.PC at the end of the cmdline.txt file. Where the first part is the IP static address of the RPi which is set to be in the network space of the workstation's IP address, and the second part after the double colons is the IP address of the workstation which was found out earlier. Make sure that all the IP addresses are unique.
- Put the SD Cards in the respective RPi's.
- Connect all the RPi's and the workstation to the Network Switch via LAN Cables.
- Connect all the RPi's to the Power USB Hubs using the USB Power Cables.
- Connect the workstation, the Network Switch and the Power USB Hubs to the Power Source, switch on the Power Source.
- Using Putty softare to SSH into all the RPi's create a passwordless SSH between them.
- Create a machine file in each of the RPi's home directory.
- The RPi cluster is ready to use.

Working RPi Cluster:





Rpi Cluster

YouTube TUTORIAL LINK

https://www.youtube.com/watch?v=UTBeBQLXG8U&list=PLrlB-ixA7o7IL84ifYV5PYK9qQ8AgN6r4