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Distributed Generation Grid Infrastructure using Smart Meters Modeled with Renewable Energy Sources and Power Trading

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Abstract

The paper deals with the implementation of Smart Meters for small scale domestic electricity generation and utilization between houses connected in a Distributed Generation Grid Infrastructure (DGGI). This is a communication strategy to design the smart meters that are intelligent enough to monitor & control the flow of electricity through the entire provincial electricity system; measures the instantaneous power, being delivered to the homes connected in micro grid; records generation & consumption data on an hourly/weekly/monthly basis; and also detects the power outages. This system helps to encounter the problem of power shortages to the most profitable way since the energy crises are in the peak in recent days. Moreover the project implements the smart meters for distributed generation in a network. A lot of research works in Advanced Metering Infrastructure (AMI) is going on with the aim of giving integrated service switches, time based rates and remote meter programming. This project is further more evolution from AMI with the implementation of smart meters to monitor and control the transmission and reception of self generated power of every individual home connected in DGGI. The cost calculation for power trading between houses in grid also has been done.

Keywords: Smart Meter, Distributed Generation Grid Infrastructure (DGGI), Advance Metering Infrastructure (AMI), Remote Monitoring Unit (RMU), Power transmission, Power reception.

Introduction

Its time India makes meaningful contribution towards exploring new frontiers of energy generation. In the wake of power starvation across Tamil Nadu, a recent study that quantifies the renewable energy potential across the state flags the pitfalls in over-reliance on conventional sources of power. The Tamil Nadu Energy Development Agency, confederation of Indian industry gives the report of demand curtailment for 2011-12 financial years. It says that the gross energy consumption was 77,218 million units (MU) of which State owned generating stations contributed 27,941 MU and 42,277 MU was purchased from central, wind, open market and exchanges. The lack of long term energy security prevails. The World Institute of Sustainable Energy says that the renewable energy potential of Tamil Nadu is 720,000 MW. Alternative sources of energy like solar (TN has 78,505 MW potential from solar power technologies), windmill, bagasse based co-generation (1,073 MW power potential based on crushed sugarcane), bloom-box (bloom energy server that uses solid oxide fuel cells to generate affordable power) are present which are remaining un-exploited. All these study says that the renewable energies are not yet attained its potential because of the insufficient infrastructure for transmission and evacuation of power. Every individual consumer is responsible for self generation to meet the existing power demand crises. The paper thus proposes a communication strategy employing smart meters in DGGI (Distributed Generation Grid Infrastructure). This will be a future intelligent energy network that is based on grid integrated near real-time communications between various self-generating individual houses in generation, transmission, distribution and loads.

Smart meters are being introduced in many power systems world-wide to provide real time power consumption and price information to consumers [1]. Smart Meters are electronic measurement devices used by utilities to communicate information for billing customers and operating their electric systems. The combination of the electronic meters with two-way communications technology for information, monitor, and control is commonly referred to as Advanced Metering infrastructure (AMI). Previous systems, which utilized one-way communications to collect meter data were referred to as AMR (Automated Meter Reading) Systems. AMI has developed over time, from its roots as a metering reading substitute (AMR) to today's two-way communication and data system[2]. This paper proposes the use of smart meters in distributed generation which is still more advanced than the existing methods providing efficient transmission and evacuation of power.

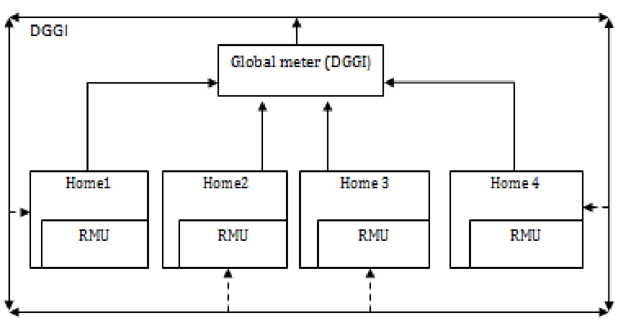
System Description

The system is a Distributed Generation Grid Infrastructure in which four houses are interconnected. It consists of two main components. They are
1) Residential Monitoring Unit
2) Global Meter
Their description is given in the table –I

TABLE I
Main Components

Component	Location	Description
Residential monitoring Unit	Individual home	It monitors the home energy generation & consumption and communicates with the Global Meter
Global Meter	DGGI	It is the Master meter that monitor & controls the energy flow throughout the Micro grid and the houses connected to it.

A. Distributed Generation Grid Infrastructure



Note: DGGI- Distributed Generation Grid Infrastructure; RMU- Residential Monitoring Unit.

Fig- 1 Schematic representation of DGGI and RMU

The layout of Distributed Generation Grid Infrastructure in which the four numbers of homes each incorporated with a Residential Monitoring Unit (RMU) and a Smart Meter named Global Meter are interconnected is shown in the figure-1. In this paper it is assumed that there are no external connections. All the four homes are self generating by means of renewable energies like domestic-wind mill and solar panel arrangement. Each home is provided with a RMU. The RMU communicates with the Global meter by means of Zigbee. It monitors all the connected loads in home. A Global Meter is placed in center of DGGI which monitors and controls the power, distributed among the connected homes by communicating with each RMU. The intelligent network enables both to control the system remotely and manage consumption more efficiently with advanced data analysis.

B. Residential Monitoring Unit

The Residential Monitoring Unit refers to the Smart Meter placed is each of the individual homes. We are considering for four homes in DGGI. The Residential Monitoring Unit performs the functions like monitoring the instantaneous power generation, monitors the connected load pattern, alert the consumer about the existing generated power and the consumption of power through loads ,communicates with the Global Meter to transmit and reception of power in the conditions of power excess and shortages respectively. Through home area network and Zigbee the RMU monitor the generation and consumption of power instantaneously and communicates with the Global Meter. It also maintains the report for power generation and consumption in hourly/weekly/daily basis. The consumers can turn on/off any of the loads inside their home that communicates directly to the RMU. They can also send other commands, both control and data/status request. The functions of RMU are given in the table II.

Table ii
Functions of rmu

Functions of Residential Monitoring Unit (Home)	Description
Instantaneous power generation	Monitors the instantaneous power generation continuously
Alert the consumer	Give prior information to the consumer about the prediction of power generation for the day
Load pattern	Monitors the load pattern ie., connection of loads and estimates the consumption of power

Total Excess Power	Calculates the available power (generation-consumption)
Send request to the global controller	Request seeks for transmit / receive power to / from the grid
Update the report	Store the values and update for report daily/weekly/monthly basis respectively.

There are mainly three conditions when RMU is communicating with the Global Meter. They are analyzed as three cases.

Step 1: Read the instantaneous power generation (Pg).
Step 2: Read the instantaneous power consumption (Pc).
Case (i): Generation greater than consumption:
Step 3: Pg > Pc.
Step 4: Send request to the Global Meter to receive the excess power.
Step 5: Power is transmitted to the nearest home in DGGI
Case (ii): Generation less than Consumption:
Step 6: Pg < Pc.
Step 7: Send request to the Global Meter to transmit power to meet the power shortage.
Step 8: Receives power from nearby home in DGGI
Case (iii): Generation equals Consumption
Step 9: Pg = Pc.
Step 10: Send report to the Global Meter.
Step 11: Updates the report of instantaneous generation and consumption of power

The flow of work of the Residential Monitoring Unit is

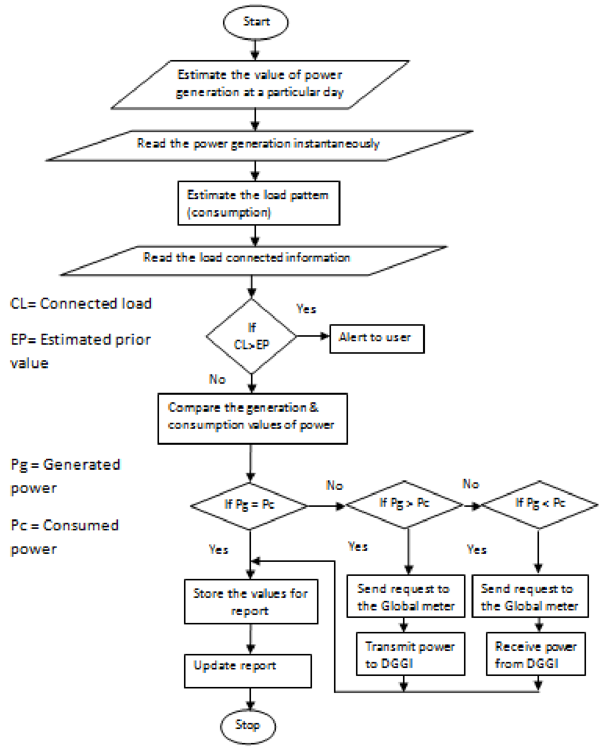


Fig- 1 Flowchart for the Residential Monitoring Unit

Figure 2 shows the flow chart of RMU in each home of DGGI. It will be having all the databases of the particular home including the details of generated power from their installed domestic-windmill or from the solar panels and instantaneous connection of loads which are highly variable. It updates for the report in hourly/weekly/monthly basis and generates the report in case of consumers' request.

C. GLOBAL METER

The Global Meter is the Master Smart Meter that monitors & controls the energy flow through the entire DGGI and processes the requests from & to the houses connected in DGGI. This is the master controller that possesses all the data bases of DGGI. The major functions of Global Meter are given in table III

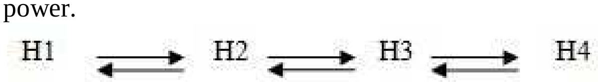
Table II
Functions of global meter

Functions of Global Meter	Description
Monitors the power status	Monitor continuously the status of power (generation & consumption) of all homes connected in DGGI
Total Excess Power(TEP)	Calculates the available power(generation - consumption)

Check the requests	Check if any requests is there from any of the homes connected in DGGI
Process the requests	Requests are processed to transmit/receive power.
Transmits the power	If total excess power is greater than the request power, then the controller gives command to transmit the power to the deficit home
Receives the power	Get power from the home having excess power
Update the report	Store the values and update for report daily/weekly/monthly basis respectively.

Comprehensive power management with optimal energy conservation is attained in DGGI by means of Global Meter. It performs the functions like continuous monitoring of the status of power prevailing in DGGI; it computes the existing power in the grid instantaneously and transmits the request power to the houses with power deficit; it process the request of power transmission from home with excess power to the DGGI. The transmission losses are minimized by transferring power to the power deficit home from the home that exists nearest. The algorithm for the functions of Global Meter is

Step 1: Read the status of existing power in DGGI and in connected homes.
Step 2: Compute the total excess power (TEP)
TEP = (EPH1)+(EPH2)+(EPH3)+(EPH4);
EPH1 = Excess power in Home1; EPH2 = Excess power in Home2; EPH2 = Excess power in Home3; EPH2 = Excess power in Home4;
Step 3: Monitor for request to transmit or receive power.
Step 4: Read the request of power if any of the connected homes sends command demanding power (RP).
Step 5: If TEP > RP
Step 6: Check for the nearest home having surplus power.



H1-Home1; H2-Home2; H3-Home3; H4-Home4.

Step 7: Send command to the respective RMU to transmit the power to the demand home through DGGI.
Step 8: Send message to the respective home as 'Request Granted'.
Step 9: If TEP < RP
Step10: Send message to the respective home as 'Request Denied'.
Step11: Update the report with instantaneous data of power transmission and distribution.

The IEEE802.15.4g Smart Utility Network (SUN) standard is implemented in enabling interoperable communications between Residen tial Monitoring Units and Global Meter. The Residential Monitoring Unit is the controller placed in houses that will monitor and control the instantaneous power generation, consumption of power by the loads connected, interact with the Global Meter and maintains report for energy usages

The flow of work of the Global Meter is

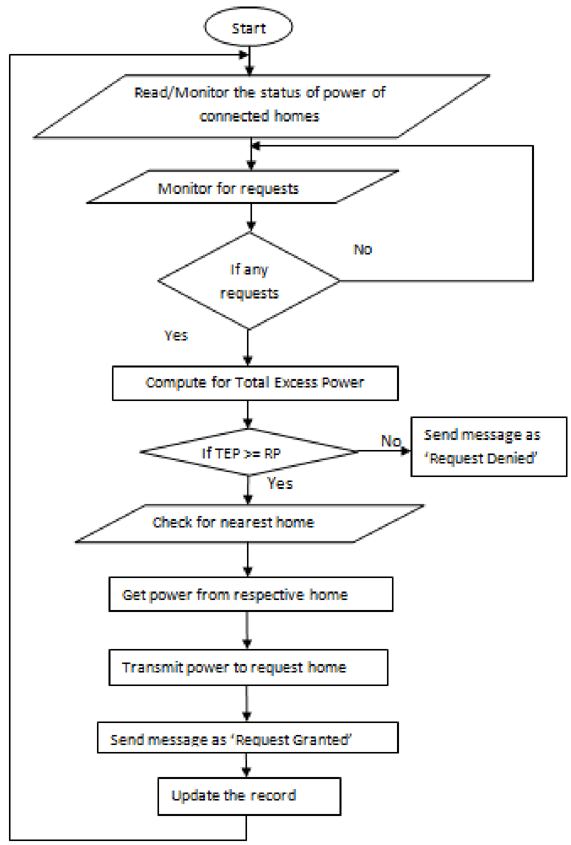


Fig-2 Flowchart for the Global Meter

Modelling and Computation

The Distributed Generation Grid Infrastructure system with Residential Monitoring Units are modeled using MATLAB GUI and Simulink simulation software. The Residential Monitoring Unit of Home1 of DGGI is shown in figure4. It will be similar to a touch screen Smart Meter model which is connected with all the loads and renewable energy installations for power generation through power line communication or Zigbee. The consumers can turn on/off any of the loads inside their home that communicates directly to the RMU. They can also send other commands for data/status request

By pressing the respected options in RMU the consumer can get the details of generated power, consumed power, additional loads, transfer and demand for power. The dynamic source model of domestic windmill is modeled using Simulink simulation software from which the RMU reads the data of generated power instantaneously. Similarly the connected loads also has been modeled.

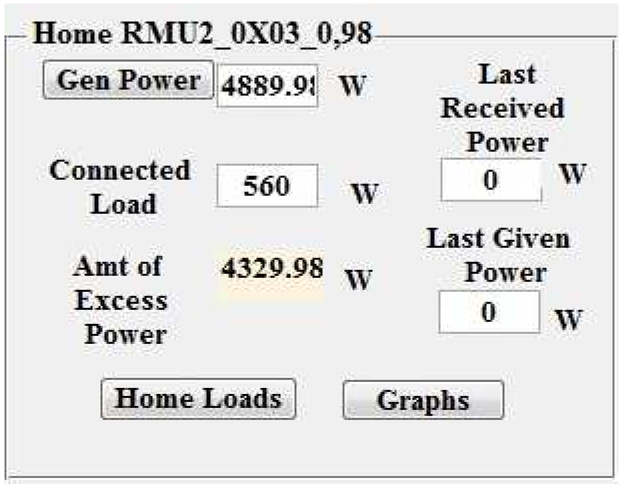


Fig-3 Residential Monitoring Unit in Home1

A. Mathematical model for generation using domestic windmill:

The wind output Pw is a function of wind velocity (Vw) such that:

Pw=Pr if Vci≤Vr≤Vco ----- (1)

Pw=0 if 0<Vr<Vci or Vr>Vco ----- (2)

The following notations are used:

Pr: reference power, maximum power that the turbine can attain ;Vr: reference power wind speed, wind speed for which reference power is achieved. Vci: cut-in wind speed, wind speed at which the turbine starts to produce power ;Vco: upper limit of the wind speed called cutout wind speed, at which the turbine can operate.The wind speed can be found by using the formula:

$Vw= Vm(Hr/Hm)^{\gamma}$ (m/s) ---- (3)

Vm: measured wind speed at height Hm in m/s

Hr : rotor height in meters

γ : Ground surface friction coefficient (1/7)

Pr : Rated power of wind generator in kW.

Wind energy conversion system consists of wind turbine coupled with wind generators. Depending on the application, there are different types of generators and turbines available.The expression for the electromagnetic torque in the rotor reference frame is given by

$Tt= (1/2)*\rho*A*Cp(\alpha,\beta)*((R/\alpha\ opt)^3)*(\omega\ opt)^2$ ---(4)

Here ρ is the air density in (kg/m3); A is the rotor swept area in (m2); Cp is the coefficient of power; α is the tip angle; β is tip speed ratio; α opt is the optimum tip angle ratio; ω opt is the optimum angular velocity in (m/s).Electrical power generated by wind turbine is given by

$Pw= \eta t*\eta g*0.5*\rho*A*Cp*Vw^3$ ----- (5)

Vw: Wind speed at projected height in m/s .

ρ: Factor to account for air density.

Cp : Power coefficient (0.35).

A : Wind turbine rotor swept area in m2.

ηt: Turbine efficiency.

ηg : Generator efficiency.

The source model for generation is modeled using Simulink is shown in figure6.RMU is connected with the source model which reads the generation of power instantaneously. Similarly it is done for loads consumed in individual houses . RMU thus behaves as control unit to monitor and control the energy consumption and aims at energy saving.

The Global Meter in DGGI is designed in a way to control the energy flow through the entire grid infrastructure.

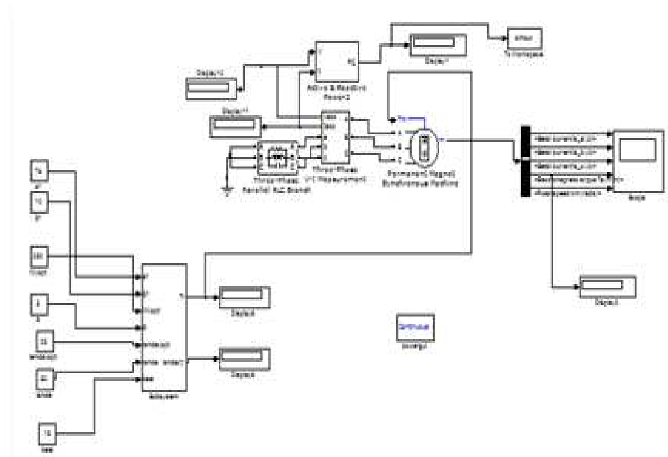


Fig-4 Generation source model

The Global Meter is responsible for the transfer of power from home that has surplus power to the home having deficit power

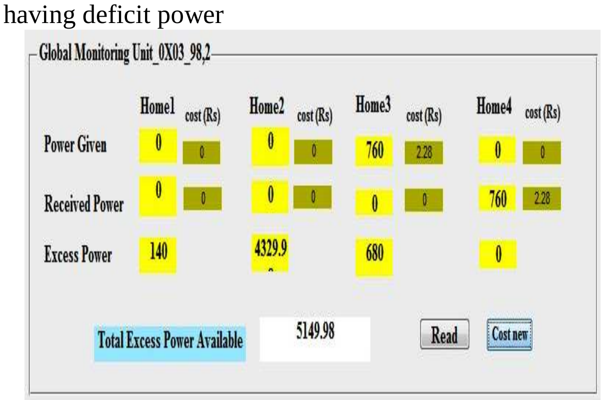


Fig-5 Global Monitoring Unit

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The IEEE802.15.4g Smart Utility Network (SUN) standard is implemented in enabling interoperable communications between Residen tial Monitoring Units and Global Meter which smart enough in data transfer.

The layout of the DGGI in MATLAB GUI is shown in figure8. The infrastructure is designed in such a way to meet the energy demands, intelligent energy transmission and evacuation of power with minimized losses.

Simulation Results

The load details of the four homes were studied in detailed and daily and annual consumption of loads are taken which has been implemented in software.

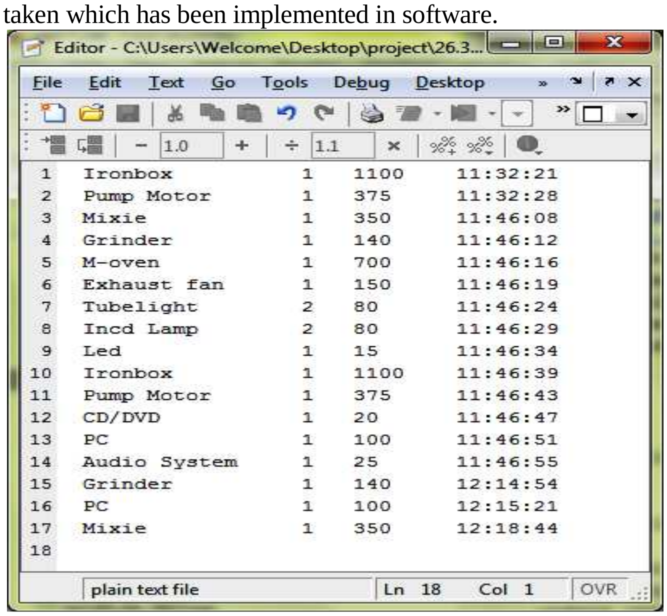

Fig-6 Simulation Result

Here it is the condition that there is power shortage in Home4 so its RMU is communicating with the Global Meter requesting power. Through DGGI the Global Meter transfers power from Home3 to Home4 considering the nearest home. The cost will be displayed by the Global Meter at a rate of 3 Rs per unit as per the normal electricity board nominations and respective home will be sent the bill by the Global Meter.

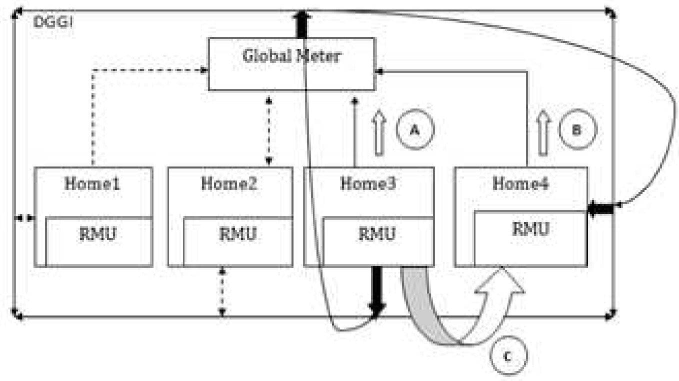

Fig-8 Transfer of power from Home3 to Home4

In figure9, A represents the request sent to the Global Meter by the RMU of Home3 to transmit the excess power to the DGGI; B represents the request sent to the Global Meter by the RMU to receive power from the DGGI due to power deficient in Home4. C represents the power is transferred from Home3 to Home4.

Results and Discussions

The transmission and evacuation of power in this Distributed Generation Grid Infrastructure using Residential Monitoring unit is done efficiently unless the other existing methods. It can extended to remote monitoring with fully automated load end generation management

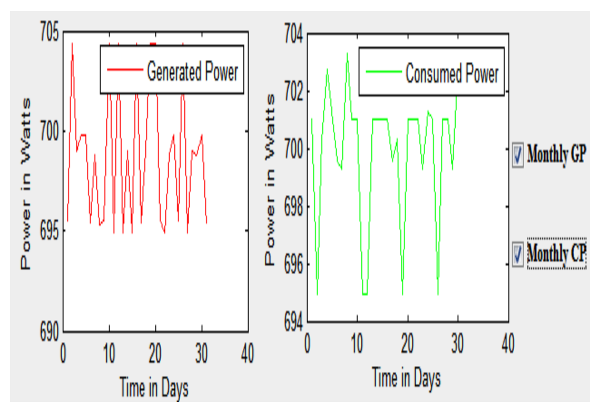

Fig-9 Graph for monthly generated and consumed power

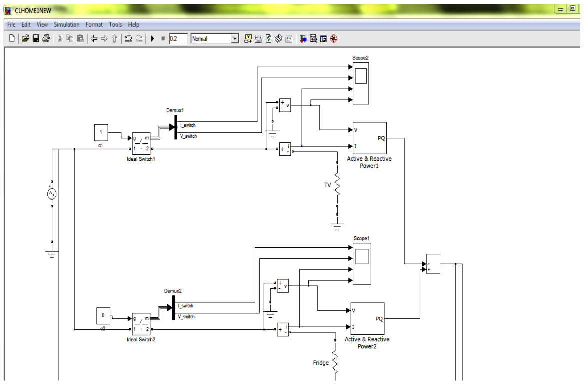

Fig-10 Home loads modeled in simulink

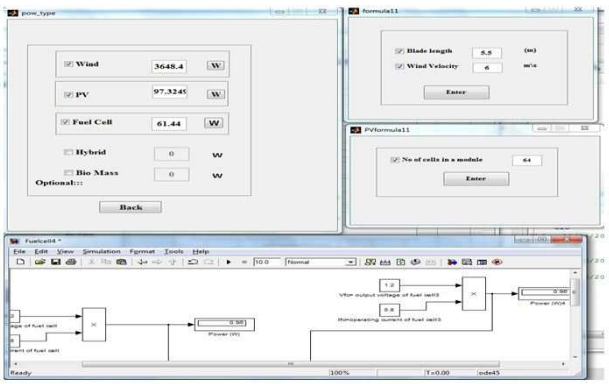

Fig-11 Source model with renewable energy sources

Fig-12 Distributed Generation Grid Infrastructure(DGGI)

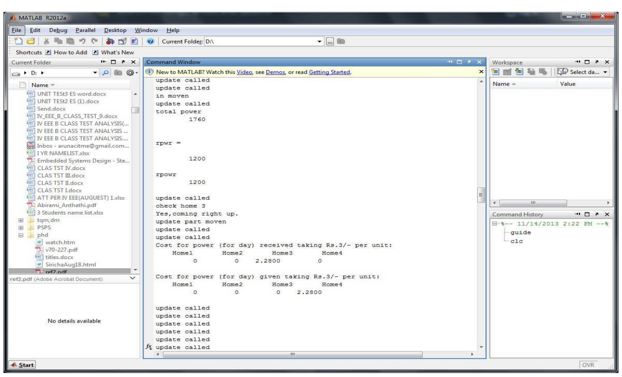

Fig-13 Cost display for Power trading

Figure 11 shows the generation model in Matlab GUI. It has been modeled with domestic wind mill with user's choice of blade length and a PV model for generating power from solar energy. The Fuel cell model is done using Simulink in Matlab.

The power from the home having surplus power will be sent to the home having deficit power through DGGI. Global Meter will monitor and control this power trading by displaying the cost and sending bill to the respective homes as shown in Figure 12 & Figure 13.

Conclusion

The DGGI with RMU and Global Meter is an advanced method of automation with self generation and utilization of power with renewable energy sources. Global meter is termed as Global Monitoring Unit which is the master controller for DGGI with request processing from RMU and power between houses in DGGI. This model aims at self satisfying power crises without connecting with national grid using renewable energy sources thus giving a new solution for energy demands prevailing in society.

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