ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 3, Issue 12, December 2017

Intelligent Energy Control Center for Distributed Generators Using Multi-Agent System

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Abstract:-- **This paper presents the modeling of intelligent energy control center (ECC) controlling distributed generators (DGs) using multi- agent system. Multi-agent system has been proposed to provide intelligent energy control and management in grids because of their benefits of extensibility, autonomy, reduced maintenance, etc. The multi -agent system constituting the smart grid and agents such as user agent, control agent, database agent, distributed energy resources (DER) agent work in collaboration to perform assigned tasks. The wind power generator connected with local load, the solar power connected with local load and the ECC controlled by fuzzy logic controller (FLC) are simulated in MATLAB/SIMULINK. The DER model is created in client and ECC is created in server. Communication between the server and the client is established using transmission control protocol/internet protocol (TCP/IP). The results indicate that the controlling of DER agent can be achieved both from server and client.**

Keywords: Distributed energy resources (DER) and trans-mission control protocol/internet protocol (TCP/IP), distributed generators (DGs), energy control center (ECC), fuzzy logic con-troller (FLC).

I. INTRODUCTION

An economical and efficient electric power system is a vital component of a nation's economy. The demand for electrical energy is ever increasing. Today over 21% of the total electrical energy generated in India is lost in transmission (4%–6%) and distribution (15%–18%). It is possible to bring down the distribution losses with the help of newer technolo-gies in the electrical power sector, which will enable better monitoring and control. Distribution losses can be reduced, if the DER is connected near the load end.

The smooth operation of a power system requires a control ar-chitecture that consists of hardware and software protocols for exchanging system status and control signals. This is accom-plished by supervisory control and data acquisition (SCADA) systems [1], [21]. A smart grid is an intelligent grid that inte-grates advanced sensing technologies, controls and communi-cates with current electricity grid at transmission and distribu-tion levels [2], [15].

Later, multi-agent system is utilized as an application development tool that enables system integrators to create sophisticated supervisory and control applications for a variety of technological domains, mainly in the power industry [1], [12], [16]. Multi-agent system offers various advantages over the SCADA system by the implementation of an intelligent grid [4], [9], [22]. Modeling the power distribution management process focusing on outage management has been elaborated by Hammer in [10]. Planning for distributed generation and securing SCADA system is described by Roger in [11]. In-telligent Distributed Autonomous Power System is given in [17]. Interaction between distributed generation and the distri-bution network operation aspect is explained in [18]. Proposal of a local DC distribution network with distributed energy resources is given in [19]. Esmaili and Das elaborated a novel power conversion system for distributed energy resources [20]. SCADA system provides communication architecture capable of controlling and maintaining power system hardware using certain signaling protocols.

The energy control center (ECC) has traditionally been the decision center for the power generation and transmission of in-terconnected system. It consists of Energy Management System (EMS) software. The Energy control center functions for power system is mentioned in [3] by Ankaliki. Most utility compa-nies purchase their EMS from one or more EMS vendors. These EMS vendors are companies that specialize in design, develop-ment, installation and maintenance of EMS within ECCs [13]. The main objective of this work is to develop and implement an intelligent ECC using multi-agent system that would enable real-time management of DER with smart grid.

II. DESCRIPTION OF ENERGY CONTROL CENTER AND MULTI-AGENT SYSTEM

This work is an attempt made to implement a system similar to an industrial SCADA system. A multi-agent system which stands a few steps ahead of a SCADA system is used to manage the grid. The component of multi-agent system and their func-tionality are given in [15] and [21]. The block diagram is shown in Fig. 1.

The server has a wireless connection with the client as shown in Fig. 1. This is done using socket programming, which forms a part of the application program. This

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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communication enables a DER agent (from the client side) to manage the power that is to be distributed to the necessary loads. DER agent, solar and wind power generator are connected to ECC through the In-ternet. This data is stored in database agent in ECC. The control action is taken by FLC present in ECC, based on the data from DER. This is done by control agent. In this work, the Internet is used for communication.

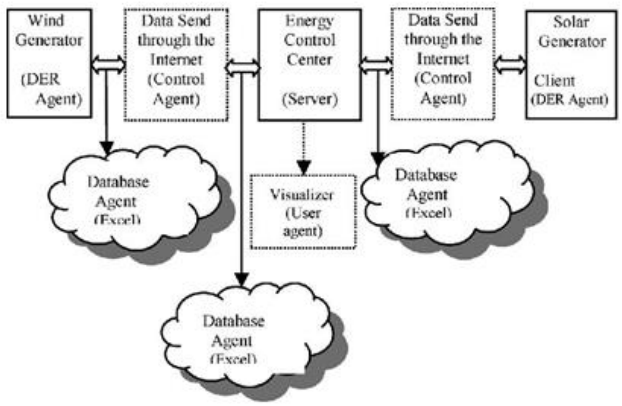

Fig. 1. Block diagram of ECC.

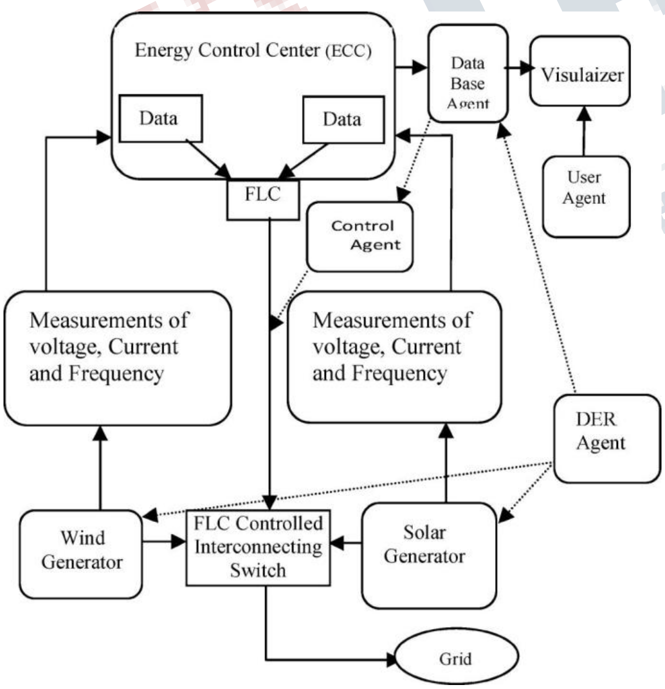

Fig. 2. Operation of multi-agent.

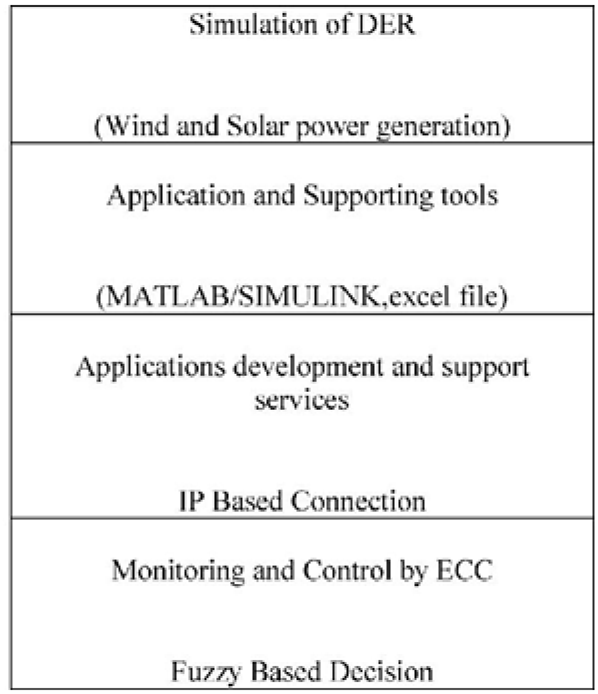

Fig. 3. Applications used.

The multi-agent system operations are shown in Fig. 2. User agent, control agent and DER agent communicate with the data-base agent. This database is sent to the server through a Remote Terminal Unit (RTU) like a conventional SCADA system. RTUs are special purpose computers which contain analog to dig-ital converters (ADC) and digital to analog converters (DAC). These converters' digital inputs are used to get the status and outputs are used to control. They can be connected to any hard-ware device to acquire the analog data from any other device.

The visualizer receives copies of all messages exchanged within the multi-agent system and is responsible for displaying these messages to the users [21] with user agents. The various applications used in the system are shown in Fig. 3.

On a broader perspective, a multi-agent system controls and monitors the DER for power delivery. It is used for monitoring the voltage, load management, energy management, automated meter reading and substation control [8], [22]. Many of the multi-agent systems being

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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used in today's utilities were devel-oped many years ago as SCADA systems.

III. BLOCK DIAGRAM OF THE SIMULATION MODEL

The block diagram of the multi-agent system simulation model is given in Fig. 4. Wind power generation consists of a wind mill, induction generator connected to the grid through circuit breaker and the load. Solar power generation consists of solar panel, inverter, transformer connected to the load and circuit breaker. The interconnection of wind power, solar power and grid forms the power system smart grid with DER. The voltage measured in wind power generator and solar power generator is sent to ECC through the Internet. The FLC present in ECC activates the circuit breaker according to the voltage requirement. The addition/removal of solar panels to the grid is controlled by FLC. If solar panel is removed from the grid, it will be connected to charge the battery. Since FLC is used for the control, it can be extended to control circuit breaker (CB-1) and circuit breaker (CB-2), as given in Fig. 4, depending upon the availability of DERs.

In this work, simulation model of wind power generator is created in computer-1 as shown in Fig. 5. It is considered as client. The voltage, current, frequency and power of DER can be measured. This is known as DER agent. It is converted in to excel sheet using MATLAB commands which is called data-base agent. This can be sent through the Internet to computer-2, which is a server. In this computer, solar power generation SIMULINK model is created and ECC is also developed in different file.

ECC can be developed in either computer-1 or 2. The data-base agents of wind power and solar power are converted into MATALB command and loaded in To File in SIMULINK, which is given as an input to ECC. Based on the voltage magnitude received in FLC, the decision will be taken whether solar power should be used for charging battery or connected to grid/load. The FLC decision is again converted into MATALB command and loaded in To File in SIMULINK, which is used in

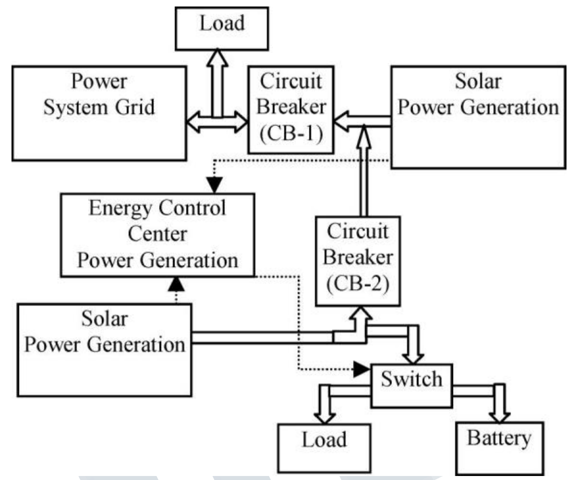

Fig. 4. Block diagram of power system interconnected with wind and solar power generation scheme.

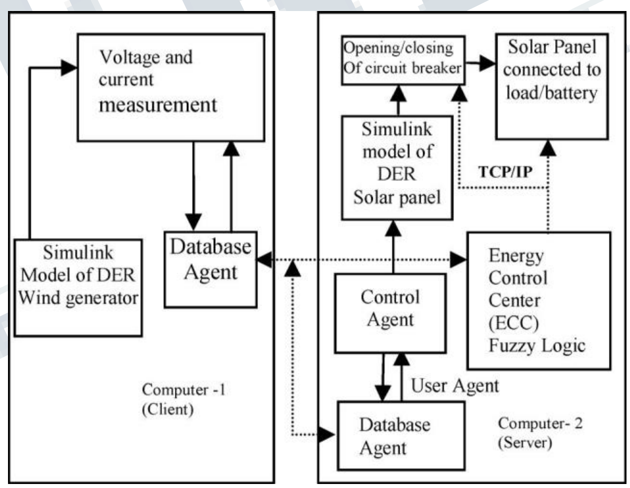

Fig. 5. Representation of multi-agent system.

solar power generation model in computer-2. The Fig. 5 shows the multi-agent system used in this work. The flexibility of the proposed method is that the ECC can be modeled in computer-1 or 2. After running the simulation, results are sent through the Internet.

The circuit breaker (CB-1) is connecting wind power gen-eration to grid. The circuit breaker (CB-2) is connecting solar power generation to grid. To utilize the maximum power from solar panel, switch is used to connect the solar power to local load or charging the battery as shown in Fig. 4.

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ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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IV. DESIGN OF FLC

In this work, Sugeno or Takagi-Sugeno-Kang, method of fuzzy inference is used. It is similar to the Mamdani method in many aspects. The first two parts of the fuzzy inference process fuzzifying the inputs and applying the fuzzy operator are exactly the same. The main difference between Mamdani and Sugeno is that the output membership functions of Sugeno are either linear or constant [14] and that of Mamdani output is variable. The procedure involved to develop FLC is as follows:

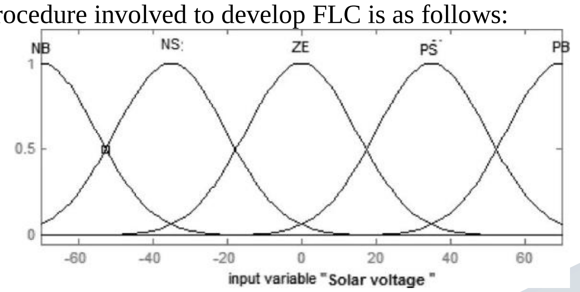

Fig. 6. Membership function for deviation in voltage (V_W).

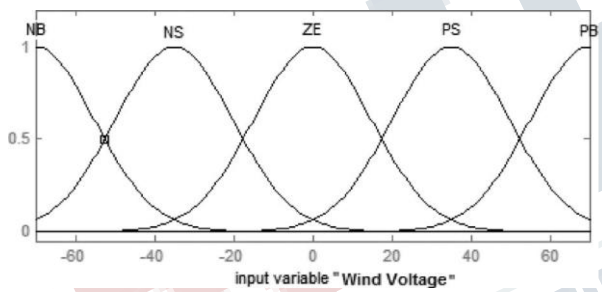

Fig. 7. Membership function for deviation in voltage (V_s).

A. Choice of Input and Output Variables

The first step is to choose the input signals to the FLC. The contents of the rule-antecedent (If-part of the rule) are selected as deviation in wind voltage (V_w) from its rated value and devi-ation in solar voltage (V_s) from its rated value. Since the system voltage should remain constant in power system, it is considered as an input. The other parameters current, real power and reac-tive power vary with respect to load and hence will not be con-sidered as inputs. The rule's-consequent (then-part of the rule) is denoted by control output (u).

B. Fuzzification

Fuzzification is the process of converting crisp value into fuzzy values. In this work, the system voltage 230 V rms is con-sidered as base voltage. Deviation in voltage V_w and V_s ranges in between [$-70V$ to $+70V$] as displayed in Figs. 6 and 7.

C. Determination of Membership Function

The linguistic variables are assigned with ranges of input and output. These variables represent the numerical values of the input to fuzzy quantities. In this work, the gauss membership function is used for simulating the FLC in input. The devia-tion in voltage V_w and V_s are classified into Negative max-imum (V_{-emax}), Negative medium (V_{-emed}), Zero (V_{ero}), Positive medium (V_{+emed}), Positive maximum (V_{+emax}) as shown in Figs. 8 and 9.

D. Rule Base

A typical rule in a Sugeno fuzzy model has the form of "If V_w is NB and V_s is NB, then Output 'u' is mf 1". Since V_w and V_s have five linguistic variables each, the output is assigned with five constant values (1, 2, 3, 4, 5) and 25 rules are formed. A typical rule in a Sugeno fuzzy model has the form

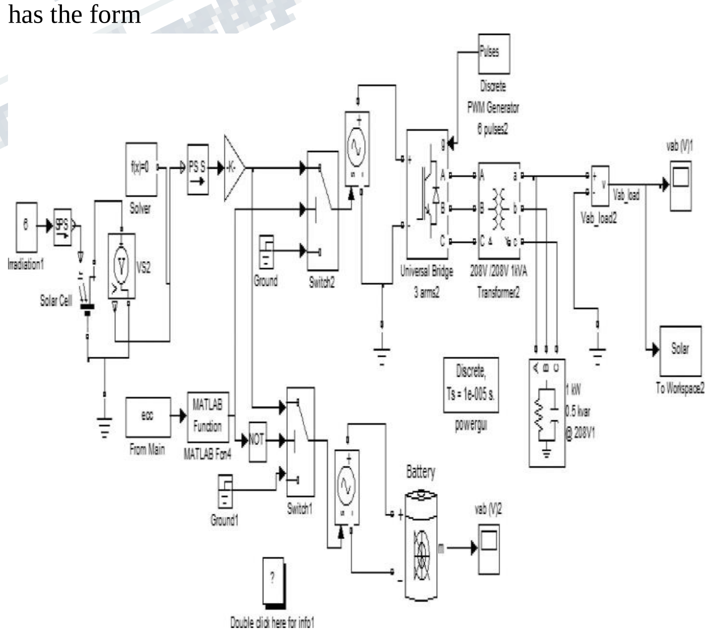

Fig. 8. Simulation diagram of solar power fed in to the battery or load based on ECC command.

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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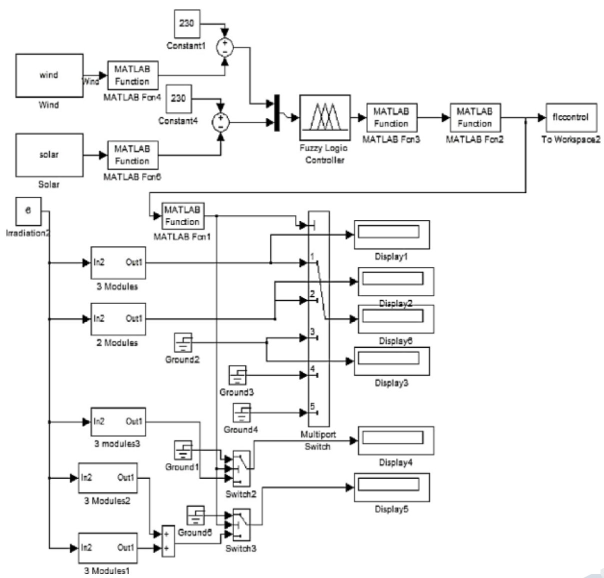

Fig. 9. Simulation diagram of FLC controlling the solar panel.

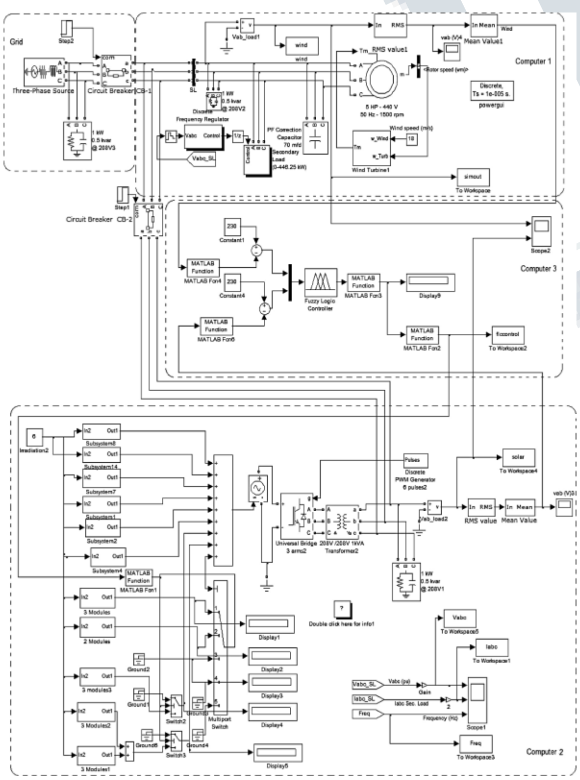

Fig. 10. Simulation diagram of power system interconnected with wind and solar power generation scheme

E. Defuzzification
This Process Used to the making. For Suge no type membership function output is singleton and there is no need for defuzzification [5].

V. SIMULATION MODEL OF THE MULTI-AGENT SYSTEM

The simulation model of the block diagram given in Fig. 5 is developed in MATLAB/SIMULINK to study the model.

A. Solar Power Generation

In a typical solar PV module, 36 cells are connected together in series. In each module, the voltages induced in the 36 cells are added together. Series combination of 36 cells will provide 21.6 V [7]. To generate 230 V ac supply with 50 Hz, approx-imately 11 modules are connected. To convert DC to AC, in-verter is used and to increase the voltage, transformer is used. Solar power generation consists of solar panel, inverter, trans-former connected to the load and circuit breaker.

B. Wind Power Generation

Self excited wind power generation scheme is used in this work. Induction generator connected in parallel with capacitor bank provides excitation to the generator. When it is connected with grid, it injects power depending upon the speed of the gen-erator. The speed of the generator depends upon the wind speed. Wind power generation consists of a wind mill, induction gen-erator connected to the grid through circuit breaker and load.

C. ECC Model

The output voltages of the wind power generation and solar power generation are given as input to the FLC. The FLC gives the constant output values which lies between (1 and 5), that is connected to multiport switch. Based on fuzzy rule fired, this switch controls the number of solar panels connected to the load/ grid or battery.

D. Working of Simulation Model

Fig. 8 indicates the single solar cell inducing the voltage based on solar irradiation. In each subsystem, three cells

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are connected in parallel to form a panel model. In Figs. 9 and 10, only the solar panel MATLAB/SIMULINK subsystem is shown.

Fig. 9 indicates the simulation of ECC with FLC, if it is cre-ated in computer 3. The output of FLC is used to control the solar panel. Before simulation, the excel files are converted into database agent in MATLAB command window and loaded to the workspace. Based on the magnitude of voltage received in the inputs, the decision is taken by the FLC. The output of FLC is constant value (1, 2, 3, 4, and 5) and this is used to drive the multi port switch. Based on the output of FLC, the number of panels are added or removed in the model.

The wind power generation, solar power generation and grid are connected through the circuit breakers (CB-1) and (CB-2) as shown in Fig. 10. These breakers are activated based on the step pulse. In this work, these circuit breakers are controlled by ECC command. The ECC is enabled to monitor the solar voltage and wind voltage magnitude for regular intervals of time to make the decision on number of solar panels connected to the load/grid or battery based on FLC output. This is indicated in Figs. 9 and 10.

During simulation of model shown in Fig. 10, the voltage induced in solar panel and wind generators are stored in .mat file and it is converted into excel format using MATLAB com-mands. These files are sent to the ECC through the Internet.

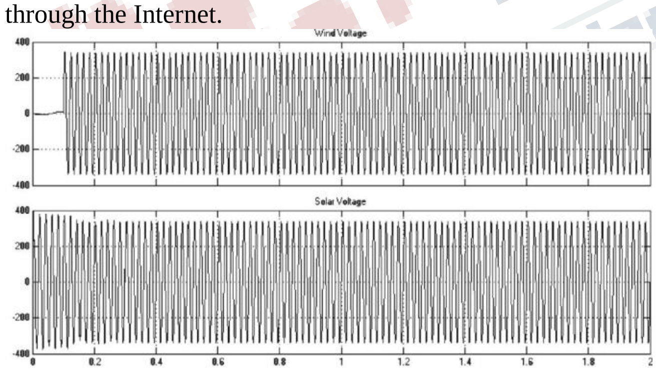


Fig. 11. Voltage waveform of wind and solar power – circuit breaker (CB-1) closed after 0.1 s and circuit breaker (CB-2) closed after 0.3 s to interconnect solar power to wind.

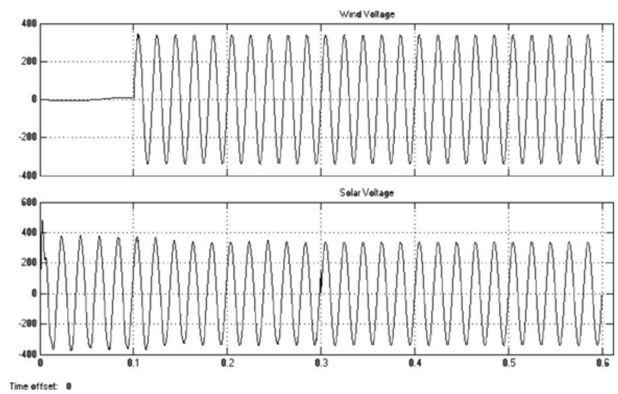
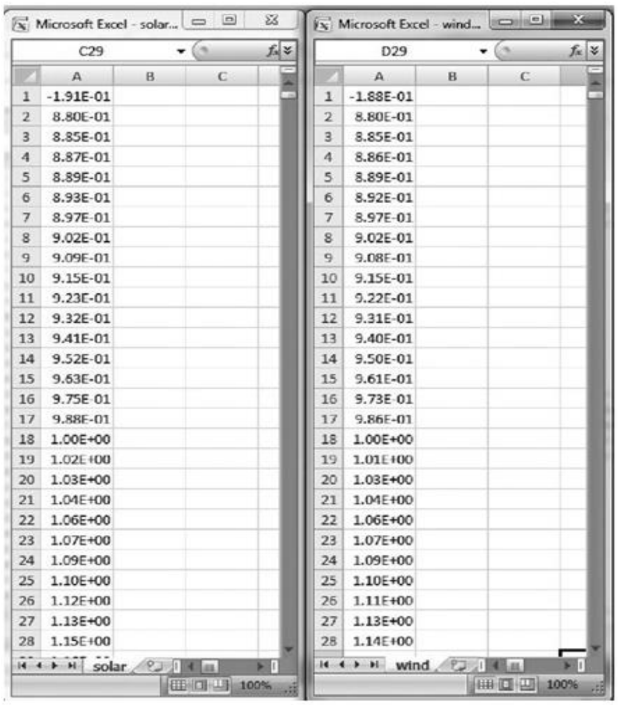


Fig. 12. Voltage waveform of wind and solar power circuit breaker (CB-1) closed after 0.1 s and circuit breaker (CB-2) closed after 0.3 s to interconnect solar power to wind observed up to 0.6 s.

VI. RESULT ANALYSIS

The simulation result of solar and wind power generation mentioned in Fig. 10 is given in Fig. 11. In this model, the ir-radiation is assumed as 600 W/m and the voltage generated is 230 V (rms) or 325.2691 V (max). The wind velocity is assumed constant (12 m/s). After the simulation, the results are stored in workspace which is converted into excel sheet using MATLAB command window in the file names "solar" and "wind". When the wind power generation given in Fig. 10 is simulated, the induction generator generates the voltage after few seconds as shown in Fig. 11. The induction generator is under self excited mode. It requires few cycles to induce the voltage because, the induction generator is not connected with the grid. To demon-strate this, circuit breaker (CB-1) is closed after 0.1 s. This can be observed in wind voltage waveform as given in Fig. 11. Solar power generator is connected to the grid through the circuit breaker (CB-2) after 0.3 s. Fig. 12 indicates the transient in solar voltage waveform at initial and after 0.3 s.

The view of database agent in excels sheets named as "solar" and "wind" is shown in Fig. 13. This sheet is generated by the simulation model of Fig. 10. This sheet is used as input to fuzzy logic controller during simulation. For the same simula-tion model, the three phase voltage and three phase current is shown in Figs. 14 and 15. The frequency waveform is shown in



	Solar A		Wind A
1	-1.91E-01	1	-1.88E-01
2	8.80E-01	2	8.80E-01
3	8.85E-01	3	8.85E-01
4	8.87E-01	4	8.86E-01
5	8.89E-01	5	8.89E-01
6	8.93E-01	6	8.92E-01
7	8.97E-01	7	8.97E-01
8	9.02E-01	8	9.02E-01
9	9.09E-01	9	9.08E-01
10	9.15E-01	10	9.15E-01
11	9.23E-01	11	9.22E-01
12	9.32E-01	12	9.31E-01
13	9.41E-01	13	9.40E-01
14	9.52E-01	14	9.50E-01
15	9.63E-01	15	9.61E-01
16	9.75E-01	16	9.73E-01
17	9.88E-01	17	9.86E-01
18	1.00E+00	18	1.00E+00
19	1.02E+00	19	1.01E+00
20	1.03E+00	20	1.03E+00
21	1.04E+00	21	1.04E+00
22	1.06E+00	22	1.06E+00
23	1.07E+00	23	1.07E+00
24	1.09E+00	24	1.09E+00
25	1.10E+00	25	1.10E+00
26	1.12E+00	26	1.11E+00
27	1.13E+00	27	1.13E+00
28	1.15E+00	28	1.14E+00

Fig. 13. Representation of database agent in Excel sheet which indicates solar voltage and wind voltage.

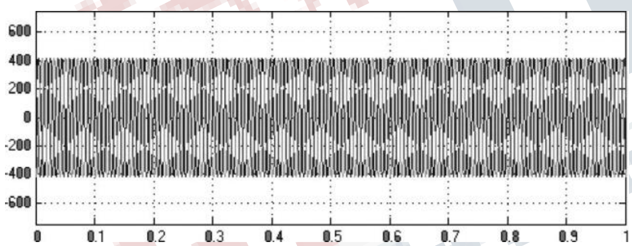


Fig. 14. Three-phase voltage waveform of the power system.

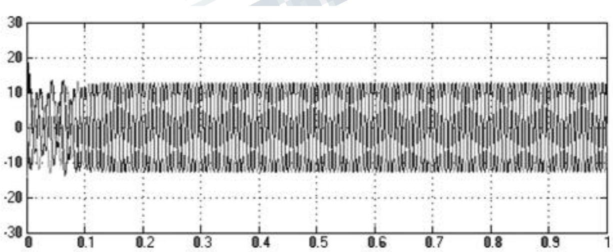


Fig. 15. Three-phase current waveform of the power system.

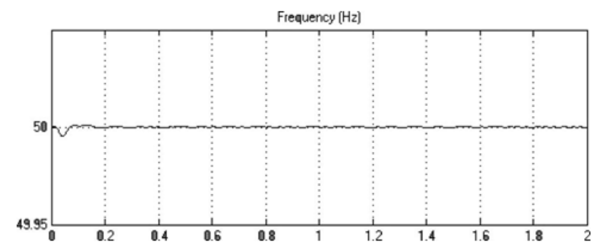
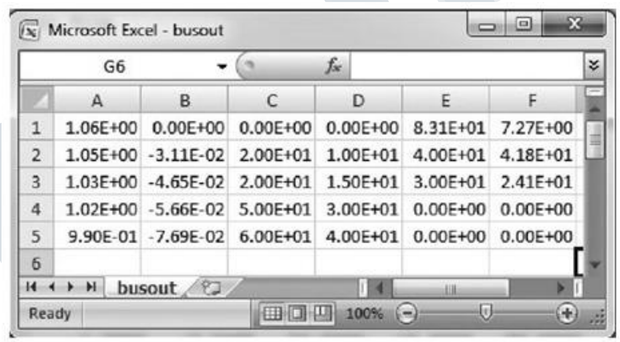


Fig. 16. System frequency waveform of the power system.



	A	B	C	D	E	F
1	1.06E+00	0.00E+00	0.00E+00	0.00E+00	8.31E+01	7.27E+00
2	1.05E+00	-3.11E-02	2.00E+01	1.00E+01	4.00E+01	4.18E+01
3	1.03E+00	-4.65E-02	2.00E+01	1.50E+01	3.00E+01	2.41E+01
4	1.02E+00	-5.66E-02	5.00E+01	3.00E+01	0.00E+00	0.00E+00
5	9.90E-01	-7.69E-02	6.00E+01	4.00E+01	0.00E+00	0.00E+00

Fig. 17. Results of load flow analysis in excel.

Fig. 16. These waveforms can be converted into excel sheet and this data can be sent to ECC.

VII. CONCLUSION

The simulation model of ECC, controlling the solar power generation and wind power generation interconnected with grid using multi-agent system is described in this paper. The voltage of wind and solar power are stored in a excel sheet as a database agent. Intelligent controller FLC controls the switch provided in the solar panel to add/remove depending upon the voltage requirements. This excel sheet acting as a monitoring tool to access the simulation results, provides the visualization of the grid. The results prove that the multi-agent component controls the Distributed Energy Resources.

VIII. FUTURE SCOPE

The results of load flow analysis voltage, angle, real power demand, reactive power demand, real power generation and re-active power generation are stored in excel sheet using proposed method as shown in Fig. 17. This load flow analysis is per-formed using Newton-Raphson method in a five-bus system. This method is applicable for any number of buses. These re-sults also can be sent to the ECC. In future, the same work can be enhanced by considering results of load flow analysis in the FLC. The FLC can decide whether DER can be added or re-moved. There is another scope to develop control logic to con-trol the voltage of solar panel and wind generator.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Dr. C. Prabhakar, Gopalan Foundation, Dr. R. Karunamoorthy, Academic ad-ministrator, Gopalan College of Engineering and Management, Bangalore, Karnataka, India for providing encouragement and facility to perform this work.

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