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Mathematical Modeling and Simulation of Fuel Cell based Electrical Power Generation System

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ABSTRACT: As in the coming future the fossil fuel based electrical power generation plant will not sustain due to depletion of the fossil fuels. The fossil fuels are not sustainable in nature and will be exhausted in future rapidly due to high energy consumption practices and demands worldwide. Therefore it is mandatory to have some alternative energy sources required for electricity generation to cope up the ever increasing power demand globally. Many countries including India have started working on setting up power plant based on renewable energy sources. In this paper various renewable energy sources with their potential are discussed. Special attention is given on fuel cell based power generation system. As per high theoretical efficiency and very less pollution emitting technology of fuel cell power generation plant, so it is regarded as a potential alternative standstill and moving power source. The work in this paper presents mathematical model of the fuel cell. The model of fuel cell plant is designed in MATLAB/simulink environment. The results are obtained for output voltage, current and efficiency of fuel cell based power plant. Results verify the validity of the fuel cell based power generation model. The purpose of this paper is to make people more about the renewable energy based power generation system and to encourage researchers, government and private organizations to take on projects for installation and harvesting energy from alternative energy sources.

KEYWORDS: Fuel Cell, Modelling and simulation, Renewable Energy Sources, Solar PV, Wind Energy

I. INTRODUCTION

Present need is to make more prominent mindfulness towards the utilization of elective energy assets because of the quick consumption of regular energy assets. Each action of present day man requires energy. This energy in the current worldview of energy utilizes is gotten from fossil fuel based products however the load of these non-renewable energy sources is not limitless. Other than this the creation of energy utilizing petroleum products is the agonizing acknowledgment that the side-effect of this energy utilization are green house gasses which are prompting heating up of the earth and environmental change, endangering the actual presence of earth assurance of the climate and environment and their safeguarding for the age to come, along these lines, is a requesting logical and financial assignment. The undeniable choices are just two: either radically decreases energy needs and utilization or go for sustainable and renewable energy sources (RES) [1]-[2]. However we have adequate hotspots for creation of sustainable power in our nation like sun oriented energy, wind energy, hydro energy, bio gas and so forth, yet tapping these occasionally turns out to be totally different because of normal impediments like overcast days which forestalls daylight, clean days hindering breeze blows or more all dry seasons lessening water accessibility and the hesitance of even rustic individuals in developing home grown creatures like cows, bison and so on once in a while different need formative plans like urbanization and the substantial culture additionally contribute a ton in subsidizing the energy advancement plans.

II. MATERIAL AND METHODS

Extensive literature survey collected and studied in the field of renewable energy sources. Research papers related to RES integration [12], [13] to the grid are analyzed. The work presented in this paper chose methodology to identify suitable mathematical equations, explaining working process of the fuel cell based plant and to design simulink model of the fuel cell plant with the help of MATLAB simulink tool. This method is best suited as the control of the system

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components is very easy, precise and interactive, as the waveforms obtained as simulation results well explain the objective of the work. A very concise literature survey is carried out in the specific field of RES and fuel cell. In [1] the solectrogen house near san Francisco was conceived, designed and built by Solar Depot as an off-grid renewable energy house. It is powered by a solectrogen hybrid power system consisting of a 3 kw PV array, two 1 kw wind powered generators, a 50 kwh storage battery bank. In [2] solar tracking array grid connected is discussed. Paper [3], [4], [5], discussed about design and control strategies of solar power plant. In [6], design and control of combined wind/PV/fuel cell plant. Papers [7] – [11] explain design, control, mathematical modeling and simulation of fuel cell based power plant. In [12] and [13] gave review of RES based plants, challenges and opportunity is discussed.

III. ALTERNATIVE ENERGY SOURCES

A. *Solar PV Power Generation System:*

A photovoltaic framework, changes over the light got from the sun into electric energy. In this framework, semi conductive materials are utilized in the development of sun oriented cells, which change the independent energy of photons into power, when they are presented to daylight. Block diagram in figure 1 represents the basic process of PV to electricity generation plant [3], [4], [5]. The cells are set in an exhibit that is either fixed or moving to continue to follow the sun to create the greatest force. These frameworks are natural amicable with no sort of emanation, simple to use, with basic plans and it doesn't need some other fuel than sun based light. Then again, they need huge spaces and the underlying expense is high. PV frameworks create DC voltage then, at that point moved to AC with the guide of inverters.

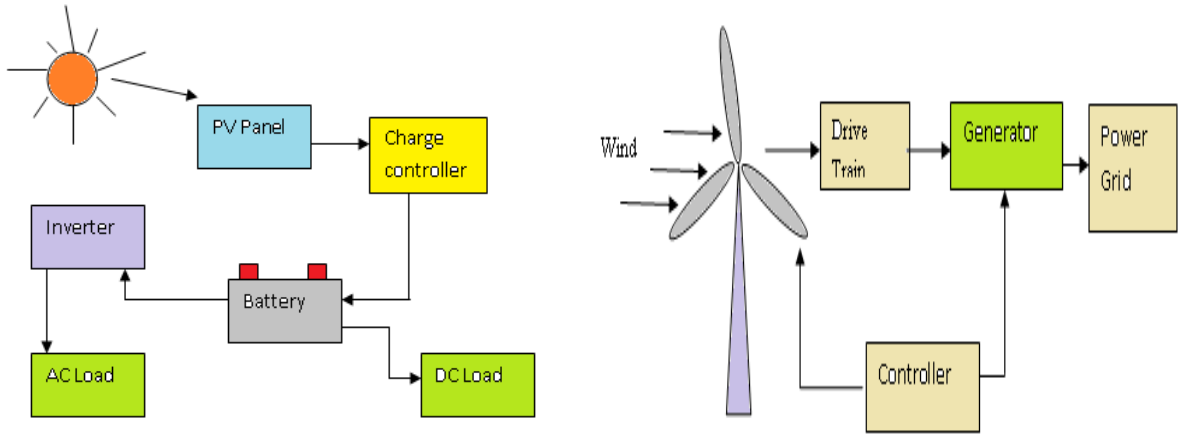

Figure 1 Solar PV and wind power generation system

B. *Wind Energy System:*

Wind turbines transform wind energy into electricity. The Principle of operation of a wind turbine is portrayed by two change steps. First the rotor extricate the dynamic energy of the breeze, transforming it into mechanical force in the shaft and in the second step the age framework changes over this force into power. For the most part in like manner framework, the generator framework gives an AC yield voltage that is subject to the breeze speed. Figure 1 represents block diagram of the process of wind power to electricity generation. As wind speed is variable, the voltage produced must be moved to DC and back again to AC with the guide of inverters. While, fixed speed wind turbines straightforwardly associate with the network.

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C. *Fuel Cell:*

Fuel cell functions like a battery that is persistently accused of a fuel gas with high hydrogen content. This is the charge of the energy unit along with air, that supplies the necessary oxygen for the compound reaction [6]. The power module uses the response of hydrogen and oxygen with the guide of a particle directing electrolyte to create an instigated DC voltage. The DC voltage is changed over into AC voltage utilizing inverters and afterward is supplied to the grid. In figure 2, working of fuel cell [7], [8] is depicted where as Figure 2 shows block diagram of for working of fuel cell plant.

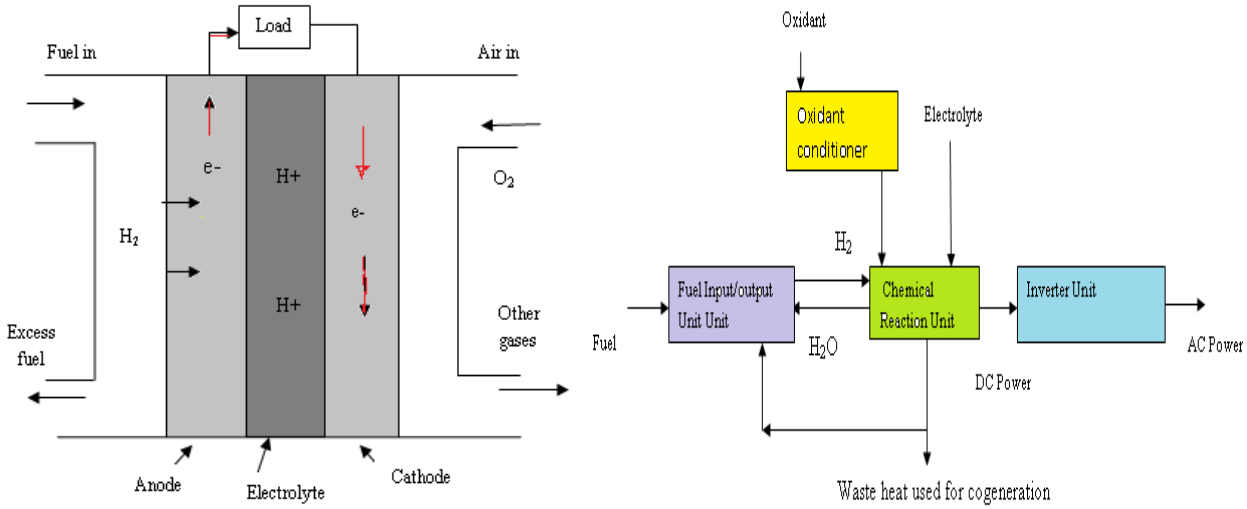

Figure 2 Fuel cell working and block diagram

Equations of mathematical modeling of fuel cell based power generation plant are presented below.
Fuel cell voltage of a single cell is given by

$$V_{fc} = E_{nernst} - V_{act} - V_{ohmic} - V_{con} \quad (1)$$

For N cells, stack output is

$$Vs = NxV_{fc} \quad (2)$$

Where N = number of fuel cells.

Thermodynamic potential is given by

$$E_{nernst} = 1.229 - 0.85x10^{10-3}(T-298.15) + 4.31x10^{10-5}x\ T\ [\ln(P_{H2}+1/2\ln(Po2)] \quad (3)$$

Here T is the cell temperature and Po2 is the partial pressure of oxygen.

Activation over potential is

$$V_{act} = -[\xi 1 + \xi 2xT + \xi 3xT\ln(CO_2) + \xi 4xT\ln(i_{fc}) \quad (4)$$

Where ξ1, ξ2, ξ3, ξ4 are constants and CO_2 is the concentration of oxygen.

Ohmic drop is given by

$$V_{ohmic} = i_{fc}(R_M + R_C) \quad (5)$$

Concentration over potential is

$$V_{con} = -B\ x\ \ln(1 - J/J_{max}) \quad (6)$$

J is the current density

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Dynamic capacitor voltage is

$$dV_d/dt = (1/C \times i_{fc}) - (1/\tau \times V_d) \quad (7)$$

Electrical time constant is given by

$$\tau = C \times Ra = C\ (R_{act} + R_{con}) \quad (8)$$

Power output will be

$$P_{fc} = i_{fc} \times V_{fc} \quad (9)$$

Efficiency will be

$$\% \eta = \mu_f \times ((V_{fc}/1.48) \times 100 \quad (10)$$

On the basis of mathematical equation, fuel cell to electricity generation model is designed in MATLAB simulink toolbox [9], [10], [11].

IV. SIMULATION RESULTS

Fuel cell based power generation model is simulated in the MATLAB environment. The waveform for generated voltage is shown in figure 3. The waveform for generated current is shown in figure 3. The waveform for generation efficiency is shown in figure 4. The data statistics for the generated voltage is shown in figue4. The data statistics for the generated current is shown in figure 5. The data statistics for the generation efficiency is shown in figure 5. RMS value of generated voltage is 45.97 volts. The RMS value of generated current is 4.558 amperes.

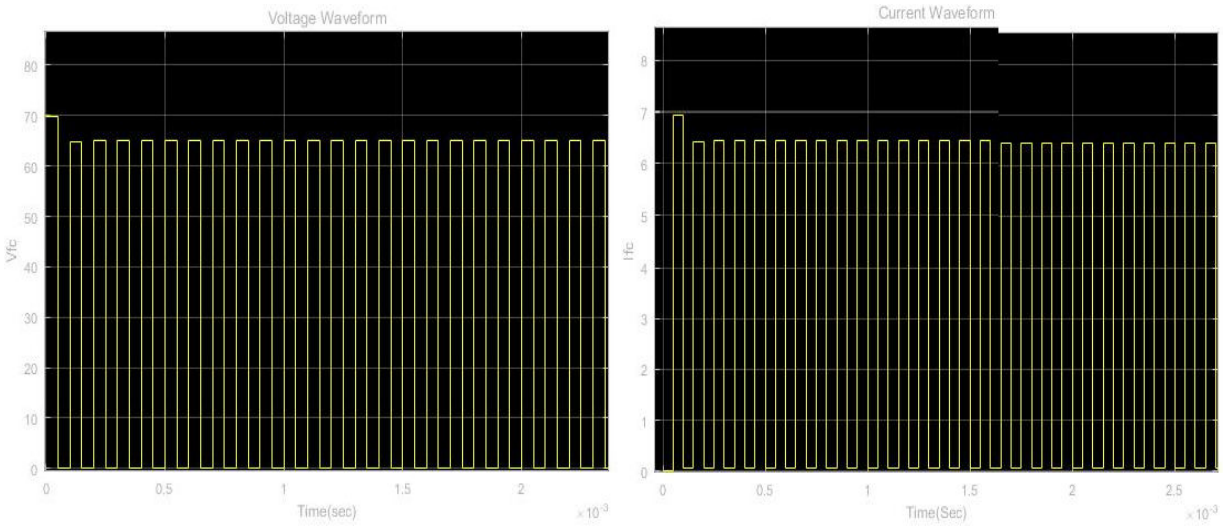

Figure 3 Waveforms of generated voltage and current

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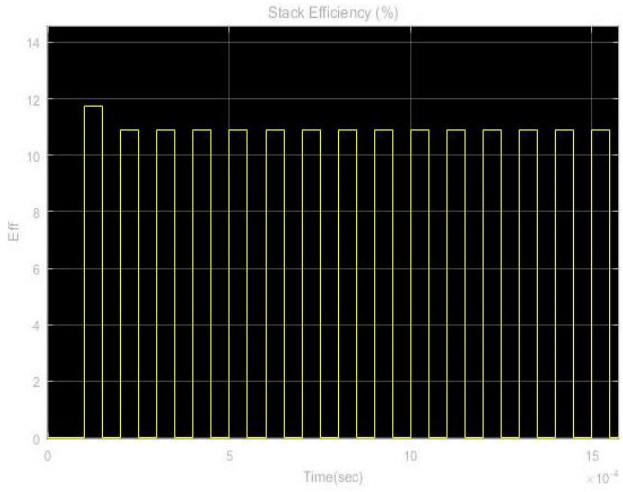

	Value	Time
Max	6.993e+01	0.000e+00
Min	0.000e+00	5.000e-05
Peak to Peak	6.993e+01	
Mean	3.248e+01	
Median	6.484e+01	
RMS	4.594e+01	

Figure 4Waveform of efficiency and statistics data of voltage

	Value	Time
Max	6.938e+00	5.000e-05
Min	0.000e+00	0.000e+00
Peak to Peak	6.938e+00	
Mean	3.248e+00	
Median	5.393e-02	
RMS	4.558e+00	

	Value	Time
Max	1.172e+01	1.000e-04
Min	0.000e+00	0.000e+00
Peak to Peak	1.172e+01	
Mean	5.456e+00	
Median	0.000e+00	
RMS	7.716e+00	

Figure 5 Statistics data of generated current and efficiency

V. DISCUSSION

Renewable energy based power generation sources are best alternatives of conventional power sources. As the ample potential of RES sources are available and these are pollution free are the best option for current and future time. The results in waveform presented in above section clearly indicate that the fuel cell based electricity generation is efficient and generate very less pollution.

VI. CONCLUSION AND FUTURE WORK

The simulation results showed that the proposed algorithm performs better with the total transmission energy metric than the maximum number of hops metric. The proposed algorithm provides energy efficient path for data transmission and maximizes the lifetime of entire network. As the performance of the proposed algorithm is analyzed between two metrics in future with some modifications in design considerations the performance of the proposed algorithm can be compared with other energy efficient algorithm. We have used very small network of 5 nodes, as number of nodes increases the complexity will increase. We can increase the number of nodes and analyze the performance.

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BIOGRAPHY

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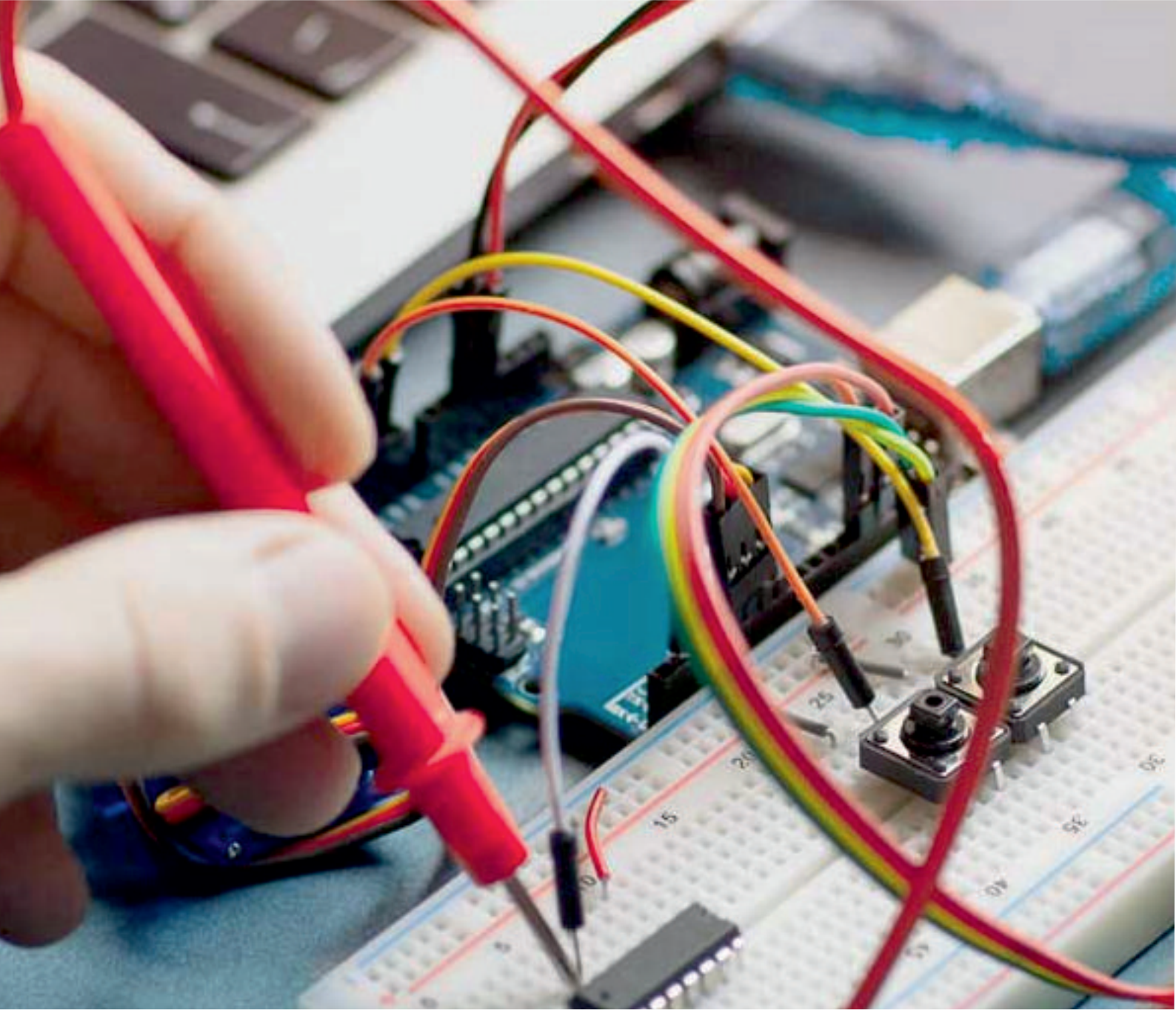

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