DYNAMIC MODELLING OF ISOLATED HYBRID WIND/PV/FUEL CELL POWER GENERATION SYSTEM

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ABSTRACT
The findings of dynamic modelling and simulation of a renewable energy-based hybrid power system are presented in this paper. The paper focuses on power generation using a mix of a solar cell (SC), wind turbine (WT), fuel cell (FC), and ultra-capacitor (UC) devices. Because the output power of a wind turbine changes with wind speed and the output power of solar cells fluctuates with ambient temperature and radiation, an FC system with a UC bank can be combined to ensure that the system functions under all conditions. When available, excess wind and solar energy is converted to hydrogen in an electrolyzer for subsequent use in the fuel cell. This isolated system's numerous components are dynamically modelled. The system's transient responses to step changes in the environment

1. INTRODUCTION

In comparison to nuclear and thermal energy, renewable energy is endless and pollution-free. Solar energy, wind energy, hydraulic energy, and tide energy are all natural resources that can be used to generate electricity. To lessen the pollution we have caused on the planet, wide spread and widespread use of renewable energy is highly popular. Because it is a natural, unlimited resource of sunshine to generate power, wind and solar energy are welcome substitutes for many other energy resources [1]. The biggest downside of wind turbines is that they produce voltage and power fluctuation issues at the load side due to naturally fluctuating wind speed. The use of proper power converters and control mechanisms can solve this problem.

Another major issue is storing the energy generated by wind turbines for future use when there is no wind but there is a demand [1].

The solar cell is affected by weather conditions, particularly irradiation and cell temperature. As a result, in this paper, weather variables such as irradiance and temperature are used to estimate the maximum power. Proton exchange membrane fuel cell technology has finally reached the test and demonstration phase after several technological advancements. The recent commercial availability of small PEMFC units has opened up a slew of new possibilities for developing hybrid energy systems for distant applications that use hydrogen as a type of energy storage [2].

Hydrogen conversion, which uses an electrolyzer, enables for the storage and transmission of enormous amounts of energy at much greater energy densities [2]. Furthermore, employing natural energy to combine a wind turbine, a solar cell, fuel cells, and electrolyzers is effective in reducing pollution.

A thorough dynamic model and simulation of a solar cell/wind turbine/fuel cell hybrid power system is constructed in this article, utilising a new topology to complement each other and mitigate the effects of environmental changes. To validate the efficiency of the proposed system, modelling and simulations are carried out using the MATLAB/Simulink [3] software packages.

The results reveal that the suggested hybrid power system can withstand rapid changes in natural conditions while keeping the voltage variations within an acceptable range.

2. SOLAR CELL (PHOTOVOLTAIC CELL)

Each photovoltaic system is built around a solar cell module. It's made up of a lot of solar cells that are all joined together. A number of solar cell models have been created, however for cell or module analysis, the single diode electrical equivalent circuit is typically utilised. A diode, a current source, a series resistance, and a parallel resistance make up this circuit. The photo-current is generated by the current source and is dependent on the incident solar cell radiation and temperature [4], [5]. The p-n junction of a solar cell is represented by the diode. The modelling includes the temperature dependency of the diode saturation current and a constant diode ideality factor. A voltage loss is noticed on the approach to the external connections in real solar cells. A Series resistance is used to represent this voltage loss (R_s). A parallel resistance is also used to characterise leakage currents (R_{sh}). The series resistance, on the other hand, is very low, while the parallel resistance is very high [6]. As a result, we can disregard R_s and R_{sh}

The solar cell current equation is

$$I_{pv}(t) = I_{sc}\{1 - C_1[exp(V_{mp}|C_2V_{oc}) - 1]\} + (E_{tt}(t)|E_{st})[\propto (T_a(t) + 0.002E_{tt}(t) + 1)] - I_{mp}$$

The solar cell voltage equation is

$$V_{pv}(t) = V_{mp}[1 + 0.0539log(E_{tt}(t)|E_{st})] + \beta(T_a(t) + 0.02E_{tt}(t))$$

$$C_{1=}\left(1 - \frac{I_{mp}}{I_{sc}}\right)exp\left[\frac{-V_{mp}}{C_2V_{oc}}\right]$$

$$C_2 = \frac{\frac{V_{mp}}{V_{oc}} - 1}{ln\left(1 - \frac{I_{mp}}{I_{sc}}\right)}$$

2.1 WIND TURBINE

The power output of a wind turbine is proportional to the wind speed. For the wind turbine rotor, both the first order moment of inertia (J) and a friction-based dynamic model, as well as a first order model for the permanent magnet generator, are used. By modelling the wind turbine response as a second order slightly under-damped system [4], the dynamics of the wind turbine related to its rotor inertia and generator are incorporated. Small wind turbine dynamics are represented as follows using this simple approach:

$$P_g(s)/P_{wt}(s) = 0.25/(s^2 + 0.707s + 0.25)$$

2.2 FUEL CELL

The PEM fuel cell is one of the most promising, if not the most well-known, of the fuel cell types that meet the aforementioned criteria. In transportation applications, it is frequently discussed as a possible alternative for the internal combustion engine. Porous carbon electrodes are linked to a very thin sulphonated polymer membrane in the PEM fuel cell. A Nernst equation in expanded form is used to define the thermodynamic potential E.

$$E = 1.229 - 0.85 \times 10^{-3}(T - 2.98.15) + 4.3085 \times 10^{-5}.T.\left(lnP_{H_2} + 0.5lnP_{O_2}\right)$$

The empirically determined parametric equation for over-voltage owing to activation and internal resistance is as follows:

$$P_{H_2} = 0.5P_{H20^{sat}}\left[exp\left(\frac{-1.635J}{T_{cell^{1.334}}}\right)\left(\frac{P_a}{P_{H2O^{sat}}}\right) - 1\right]$$

$$P_{O_2} = P_{H20^{sat}}$$

The output voltage of the cell is determined by the combined effects of thermodynamics, mass transport, kinetics, and Ohmic resistance, as defined by

$$V_{cell} = E - V_{act} - V_{ohm} - V_{conc}$$

A stack of N comparable fuel cells is linked in series to form the fuel cell system. As a result, the total stack voltage is equal to

$$V_{stack} = nV_{cell}$$

2.3 ELECTROLYZER

By sending an electric current between two electrodes separated by an aqueous electrolyte, water can be broken down into its constituent parts [7]. Water electrolysis has an electrochemical reaction that is given by

$$H_2O(l) + electrical\ energy \Rightarrow H_2(g) + 1/2O_2(g)$$

The rate of hydrogen synthesis in an electrolyzer cell is directly proportional to the electrical current in the equivalent electrolyzer circuit, according to Faraday's law.

$$n_{H2} = \left(\frac{n_F n_c i_e}{2F}\right)$$

Where the electrolyzer current is i.e., the number of electrolyzer cells in series is n_c, and the Faraday efficiency is F. 603 Faraday efficiency is the ratio between the actual and theoretical maximum amount of hydrogen produced in the electrolyzer. If the electrolyzer's working temperature is 40 °C, Faraday efficiency is expressed as

$$n_F = 96.5e^{\left(\frac{0.09}{i_e} - \frac{75.5}{i_e^2}\right)}$$

As a result, Simulink is used to create a rudimentary electrolyzer model. This model takes into account both storage and consumption.

2.4 ULTRA – CAPACITOR MODEL

Ultra-capacitors are utilised in power applications that require high peak power for a short period of time. An ultra-capacitor is a type of energy storage device that resembles a battery in construction. In this part, we provide the UC bank's model for load sharing with the FC system when both the wind turbine and the solar cell are operational at the same time. Fuel cells have a good power supply capability during steady-state operation, but their reaction during immediate and short-term peak power demand times is weak. During these times, the UC bank can aid the FC system in achieving good performance while minimising the FC system's cost and size.

$$\frac{V_{UC}}{V_{FC}} = \frac{R_c Cs + 1}{(R_s + R_C)Cs + 1}$$

Where,

Capacitance, $C = 108.75\mu F$, Series resistance$R_C = 16m\Omega$ and

Stray Resistance $R_s = 0.01\Omega$

3. SYSTEM DESCRIPTION

Figure 1 depicts the Simulink model of a hybrid power system based on renewable energy. A 75-watt solar cell, a 400-watt wind turbine, a 500-watt proton exchange membrane fuel cell, ultra-capacitors, an electrolyzer, and a power conditioner make up the system. A boost circuit and an SPWM inverter are included in the power conditioner. It is used to invert ultra- capacitor voltage to 120Vrms, 60Hz AC and step up ultra-capacitor voltage to DC 200V. Southwest Wind power Air 403 is the wind turbine used. The wind turbine produces the maximum power of 400W when the wind speed is 12.5m/s. The solar cell used is the SIEMENS SP75, which has a maximum power of 75W. The main sources for meeting load demand are wind turbines and solar cells. A fuel cell module is part of the fuel cell model.

As well as a fuel controller, the hydrogen and oxygen fluxes are limited by two PID controllers in the fuel controller. In this arrangement, the fuel cell is an additional generator that provides insufficient power.

Balanced supply and demand has to be maintained. When the supply exceeds the demand, the electrolyzer model electrolyzes water to produce hydrogen, which is then stored for later use. As a result, the system can circulate supply load demand without wasting energy.

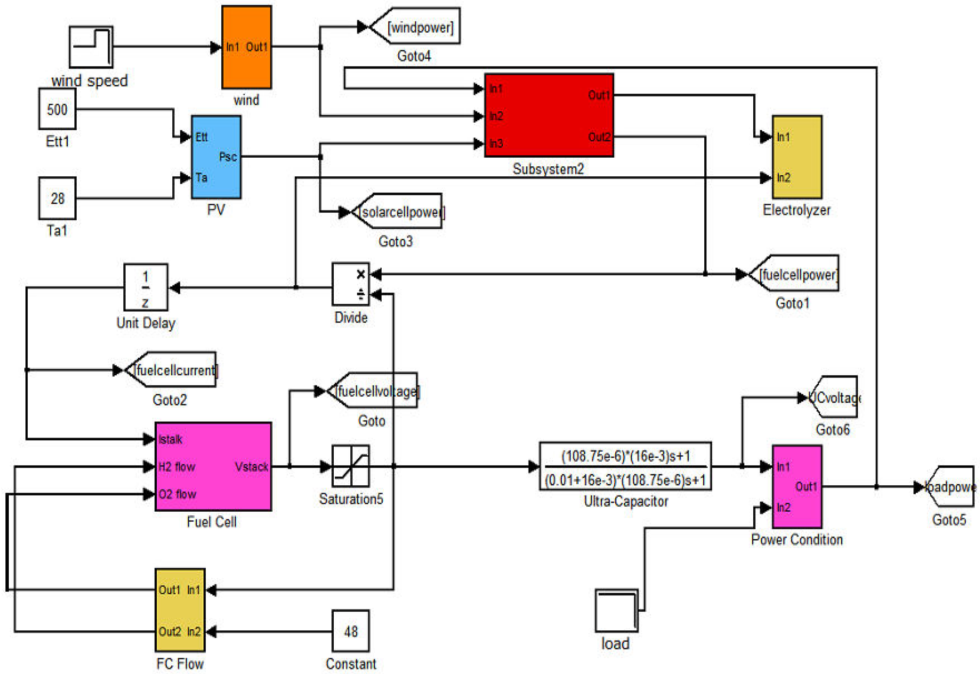

Fig 1. Renewable energy based hybrid power system model in Simulink.

4. SIMULATION RESULTS

Figures 2-5 demonstrate the simulation results with step changes in load demand, wind speed, radiation, and ambient temperature. The wind speed is initially 10 m/s. Wind speed increases from 10 to 12 m/s at t=10s and then drops to 8 m/s at t=16s. The solar cell generates power at a temperature of 25° and a radiation of 400W/m2. At 15s, the radiation reaches 600W/m2 and the temperature reaches 28°. At 10s, the load demand drops from 375W to 225W. Changes in available power and load consumption are caused by these step inputs. Figure 2 depicts the hybrid topology's power tracking performance in response to load demand changes and environmental fluctuations.

Variations in associated parameters in solar cells, wind turbines, fuel cells, ultra-capacitors, power converter output, and system performance are investigated. The power requirement changes from 375W to 225W in 10s when the load changes, as shown in Fig. 2. Because the output powers of the wind turbine and solar cell are insufficient to fulfil load needs at t=0s to 10s, the fuel cell provides power for load requirements. However, as the wind speed rises, the collected power rises and the fuel cell's contribution falls.

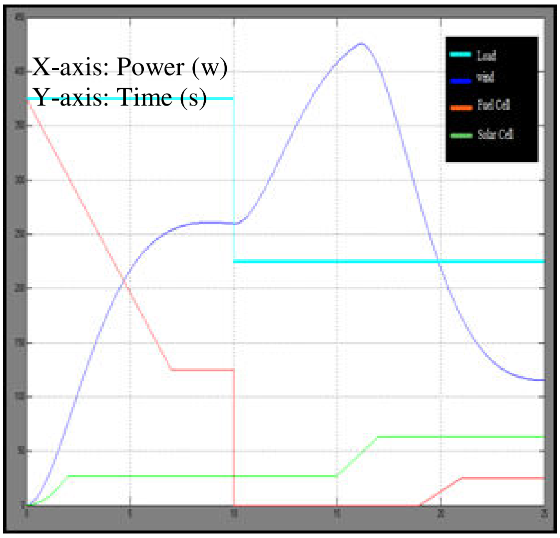

Fig. 2: The hybrid topology's power tracking performance in response to load demand changes and environmental fluctuations

During this time, any excess electricity is directed to the electrolyzer. Similarly, the contribution of the fuel cell begins at t=19.1s with a dramatic decrease in wind speed. The solar cell current and fuel cell current vary with variations in load and environmental circumstances, as shown in Fig. 3. The performance of the fuel cell system reflects these modifications. Because the solar cell and wind turbine contributions are restricted and fixed, the stack current variance from t=0s to t=10s is attributable to start-up transients and load demand. Because load demand is reduced and the wind turbine output power is increased, the fuel cell current drops to zero between t=10s and t=16s.

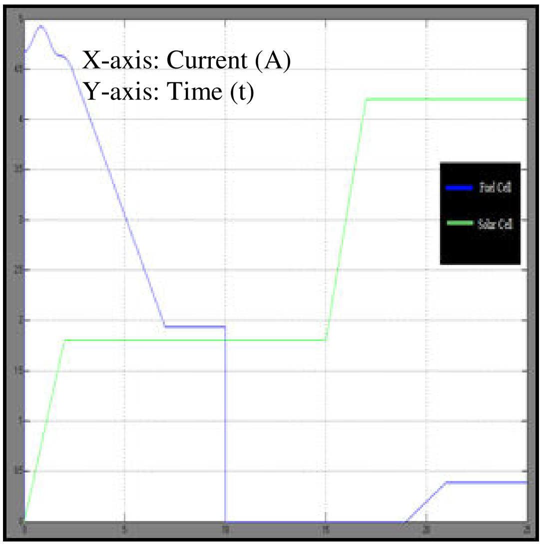

Fig. 3: Current variations

The changes across power demand from fuel cell will occur along with fluctuating wind availability, due to the above process there will be variation in fuel cell after t=16s. The stack voltage varies dramatically as a result of changes in fuel cell current. In general, a lower current level indicates a higher stack voltage, and vice versa. As illustrated in Fig. 4, using an ultra-capacitor in parallel with the fuel cell minimises the output fluctuation of the stack.

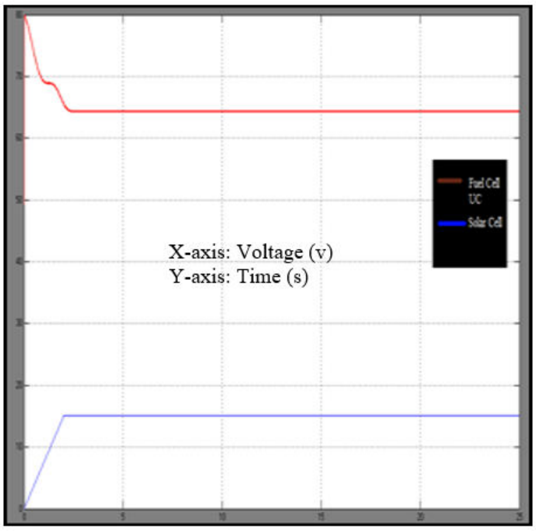

Fig. 4: Voltage variations

The power converter unit adjusts the load voltage by varying the ultra-capacitor voltage between 49 and 62 V. The boost converter's controller changes the duty ratio to maintain a constant 200V DC at the inverter's input. The inverter, on the other hand, supplies the load with 120 V_{rms}, 60 Hz AC. In the fuel cells hydrogen is used is fuel. The electrolyzer uses the system's extra electricity to electrolyze water and store hydrogen from t=10s to t=19.1s. Figure 5 depicts the fluctuation of hydrogen in a storage tank. The system can supply load demand without wasting renewable energy.

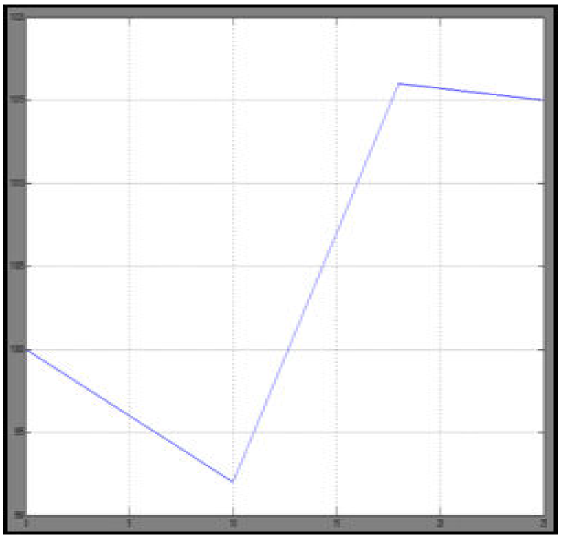

Fig 5: Variation in Hydrogen Level in Storage Tank

CONCLUSION

In this study, a novel renewable energy-based hybrid power system with appropriate power controllers is developed and modelled for a stand-alone user. Wind speed, radiation, and ambient temperature are all factors that influence the amount of electricity available from renewable energy sources. We used a unique architecture to integrate the solar cell and wind system with the FC/UC system to solve this limitation. The output voltage variation is found to be within permissible limits. A fuel cell reduces the output fluctuations of a wind turbine that varies with wind speed and a solar cell that varies with both environmental temperature and sun radiation. As a result, this system can withstand fast changes in load and climatic conditions while suppressing the effects on the equipment side voltage. Off-grid power generation in non-interconnected locations or remote isolated villages is possible with the suggested approach.

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