Fuzzy Logic Implementation with MATLAB for PV-Wind Hybrid System

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Abstract

The development of hybrid renewable energy sources is vital in power generation. This study focused on design of fuzzy logic control on hybrid PV/Wind system in order to improve the speed of DC motor. The fuzzy logic control based on battery management system has been designed for effective power utilization and improvement of the DC motor speed performance. In battery management system, a control was proposed to operate the charging and discharging mode of battery during non-linear power generation. While the battery would charge whenever the renewable energy power was greater than consumer load power, the battery would discharge whenever the renewable energy power was less than the consumer load power. DC motor speed control, included the simulation, implementation of fuzzy logic controller to DC motor and comparison between PID controller and Fuzzy Logic Controller. The proposed model was simulated using Matlab environment and the results was analyzed. Finally, simulation results were evaluated and validated to determine the effectiveness of the proposed controller.

Keywords: Battery Storage, Photovoltaic, Wind Turbine and Fuzzy Logic Controller

1. Introduction

Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human’s actions. Computers can provide comments only for true or false values but a human can reason the degree of truth or falseness. Fuzzy models interpret the human actions and are also called intelligent systems. In early 1930, Fuzzy logic was introduced by Janlukassiewicz [1]. While there were only two values 1 (true) and 0 (false) in operation, he introduced a logic that extended the range of truth values to all real numbers in the interval between 0 and 1. He used a number in this interval to represent the possibility that a given statement was true or false. In 1965, Lotfi A. Zadeh proposed the first fuzzy system [2]. Zadeh showed that fuzzy logic was different from the classical logic in that it could realize values between false represented by 0 and true represented by 1.

Nowadays, the hybrid power systems (HPSs) have become global issues and are widely discussed in literature in relation to the renewable energy sources (RESs) for generations of electrical power. One of the advantages of using renewable energy sources (RESs) is that the energy source is provided without involving any cost (for example, hydro, photovoltaic, wind, steam and many more) [3, 4]. This paper analyzed the operation of hybrid PV/Wind system. This study focused on design of fuzzy logic control on hybrid PV/Wind system in order to improve the speed of DC motor. The fuzzy logic control based on battery management system has been designed for effective power utilization and improvement of the DC motor speed performance. DC motor speed control included the simulation, implementation of fuzzy logic controller to DC motor and comparison between PID controller and Fuzzy Logic Controller. The proposed model was simulated using Matlab environment and the result was analyzed. Finally, simulation results were evaluated and validated to determine the effectiveness of the proposed controller.
2. Modeling Process
2.1. Structure of Fuzzy Logic

There are specific components characteristic of a fuzzy controller exist to pillar design procedures [5].

2.1.1. Preprocessing

The inputs are most often hard or crisp measurement from some measuring equipments rather than linguistic ones. A preprocessor, the first block shows the conditions of the measurements before entering the controller.

2.1.2. Fuzzification

The fuzzification is the first block which transforms each piece of input data to degrees of membership by a lookup in one or several membership functions. The input data matches the fuzzification block with the conditions of the rules to determine. There is a degree of membership for each linguistic term that applies to the variable input.

2.1.3. Rule Base

The Rule base is the collection of the rules. The rules are in “If Then” format and the formally the IF side is called the conclusion. A computer is able to execute the rule and compute a control signal depending on the measured inputs error and change in error (De). It is easy to understand and to maintain for non-specialist end user. Besides, an equivalent controller can be implemented using conventional techniques in rules based controller.

2.1.4. Defuzzification

All the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system. The levels output depend on the rules that the systems have and the positions depend on the existing non-linearity of the systems. To get the results, the control curve of the system representing the input/output relation of the systems is developed. Based on the information, the output degree of the membership function is defined with an aim to minimize the effect of the non-linearity.

2.1.5. Postprocessing

It can become an integrator and an output gain that can be tuned.

2.2. Photovoltaic System

Photovoltaic cell is made up of semiconductor materials which are capable in converting the light energy into the electrical energy by the principle of the photovoltaic effect. The photons from the sunlight provide the energy need for electrons in the semiconductor materials to cross the band gap to travel from one band to another. The movement of electrons from one band gap to travel from one band to another cause electrons flows, thus producing the current. The output voltage of a photovoltaic cell is directly dependent on the irradiance and temperature of sunlight. The simulation of PV cell is shown in Figure 1.

![Simulation of PV cell](image-url)
2.3. Wind System

Wind system acts to utilize the non-conventional source of energy for generating power to meet our daily demand. The source come from wind and its kinetic energy is converted into electric energy. The system is eco-friendly and does not cause any harm to environment or to human beings [7]. It is a long term power implementation scheme and power can be generated continuously in any season and condition.

A conversion of kinetic energy of the wind into mechanical energy can be utilized to generate electrical energy. The axis may be horizontal, or vertical. The windmill type is horizontal and vertical axis. As the speed of the turbine increases, the synchronous generator rotates above the synchronous speed which acts as an induction generator which converts the mechanical energy from turbine rotation into electrical energy which is to be supplied to load. The simulation of wind system is shown in Figure 2.

![Figure 2. Simulation of Wind system [8].](image)

2.4. DC Motor Speed Controller

DC motor is used in many applications such as still rolling mills, electrictrains, electric vehicles, electric cranes and robotic manipulators which requires the speed controllers to perform their tasks. To overcome this difficulty, Fuzzy Logic Controller (FLC) can be developed. The best applications of Fuzzy Logic controller are the time-variant systems that are non-linear and ill-defined [9]. Nowadays, Fuzzy Logic Controller applications are successfully used in many fields including automatic focus cameras, household materials such as automobile and industry etc.

For the first system, the DC Motor speed was controlled by PID controller and to overcome the error the PID Controller was changed to fuzzy logic controller. To design the fuzzy logic control on the DC motor, the system was firstly modelled. Then, the familiarization of fuzzy logic took place. To design the fuzzy logic controller which has a better control to the DC motor speed, the fuzzy logic needed two input such as error (e) and different error (De). Before designing the fuzzy logic, the PID controller was used to control the speed of the DC motor [10]. The schematic representation of the DC motor is shown in Figure 3.

![Figure 3. Schematic representation of the DC motor](image)

2.4.1. PID controller

PID controller or proportional–integral–derivative controller is to correct the error between a desired set point by calculating and then outputting a corrective action and measured process variable that can adjust the process accordingly. Thus, integrating the PID controller to the DC motor was able to correct the error made by the DC motor and control the speed or the
position of the motor to the desired speed or point. This PID is a generic control loop feedback mechanism which is widely used in industrial control systems [11]. The simulation using PID controller is shown in Figure 4.

![Figure 4. Simulation using PID controller [2]](image)

2.4.2. Fuzzy Logic Controller
The simulation using Fuzzy Logic Controller is shown in Figure 5.

![Figure 5. Simulation using Fuzzy Logic Controller [2]](image)

2.5. Combined Model PV/Wind System and DC Motor
The model was simulated using the Matlab environment. The simulation model used Photovoltaic and wind power and DC motor as loads [12]. The Fuzzy Logic Controller was developed using Matlab software. The Fuzzy logic controlled the battery charging and discharging operation and the speed of DC motor. The proposed controller operated the circuit breaker of battery charging mode and battery discharging mode in battery management system. For DC motor, it controlled the speed to overcome the overshoot and error [13]. The full hybrid system is shown in Figure 6.

![Figure 6. Full Hybrid System [2]](image)

3. Result and Discussion
3.1. The Characteristic of Photovoltaic Model
The input temperature to the PV model was 25°C with an interval of 25°C, and the irradiance value set at 1000 W/m² [14].
This Photovoltaic voltage output was amplified using the rectifier. The results showed the value of the PV voltage output was 240V as shown in Figure 7. The power PV was 600W from 1kW of solar panel range (Figure 8).

3.2. The Characteristic Wind Module

The input wind speed into the wind model was randomly varied between 12 m/s, which are the typical wind speed available in Malaysia [15]. The characteristic outputs of the wind model are shown in Figure 9. The generator speed was set constant 1.2 p.u, the pitch angle was set to 0 degree and the wind speed is set to 12 m/s.
After setting the pitch angle speed and degree on wind turbine, the synchronous machine generated the current and voltage with AC output. The output from the synchronous machine was AC and was converted to DC using AC-DC rectifier [16]. Figure 10 shows the wind power from this system. The results showed that the wind power was 2200W. Figure 9 shows the wind voltage is constant at 240V. This is because, this system it used a rectifier to convert AC to DC.

3.3. DC Motor Speed Control
The DC motor speed control was performed in Matlab Simulink environment. DC motor speed was controlled by PID controller and Fuzzy Logic Controller (FLC).

3.4. Comparison between PID Controller and Fuzzy Logic Controller
The speed, armature current and torque of DC motor by using PID and Fuzzy logic controller is shown in Figure 11, 12 respectively.

![Figure 11](image1.png)
Figure 11. The speed, armature current and torque of DC motor using PID controller

![Figure 12](image2.png)
Figure 12. The speed, armature current and torque of DC motor using Fuzzy logic controller
In general, the membership functions and controls rules based on trial and error and designers’ experience. In this paper, the membership function consisted of three memberships functions (two input and one output) [17]. Each membership function had seven memberships, comprising seven triangular memberships. For this cases, general two inputs and one output controller is used. Figure 13 shows the membership function for error input. The Derror and Output had the same membership function. The fuzzy rules is shown in Table 1.

For the simulation design, the DC motor used the PID and Fuzzy Logic to control the speed of the DC motor [18]. The current, voltage, power and torque respon will depend on the speed of the motor. After that, the PID controller was changed with the fuzzy logic controller. The results showed the speed, armature current and torque of DC motor using PID controller. The results showed that the outputs from this three parameter were constantly changed and not fixed. The speed took more time to stabilize and decrease. The simulation results showed that Fuzzy logic control had a clearly better performance in rise time, steady state error and percent overshoot criteria in comparison with PID controller.

### 3.5. Hybrid System With Battery Management Using Fuzzy Logic

The hybrid system, consisted of a PV system and Wind system [19]. These systems were combined to get renewable energy. The other resources to the battery storage was power load generated by power load.

The results showed the power after PV system and wind were combine (Figure 14). This power went directly to the battery management system before being controlled by the fuzzy logic. The fuzzy logic controls the battery management regardless of whether the battery charges or discharges and also controls the decision to connect with battery or load by circuit breaker. To control it, the fuzzy logic was designed using mandani [20].

For this fuzzy logic design, one input and two output were used (Figure 15). The input represented the power from the renewable energy and load (Figure 16). Output 1 was the battery control (Figure 16) and output 2 was the load control (Figure 17) [21].
Figure 14. The hybrid system power

Figure 15. Fuzzy logic design

Figure 16. The membership function for input

Figure 17. The membership function for output 1
In term of the input, the range was set from -3500 to 3500 (Figure 19). Output 1 and output 2 had the same range 0 to 1. The output had two conditions, one and zero. When the output was one the circuit went through with circuit and not with other circuit.

The results showed, the output plot on 2440 and the output 1 was 1 and output 2 is 0. Meanwhile, if the input plot was on negative, result would change that output 1 to 0 and output 2 to 1. This will produce from the sum of power of Hybrid system, the photovoltaic system and wind power system [22]. These two renewable energies were combined to get the renewable energy power. The DC motor produced the load power. These two powers went the battery storage. The fuzzy logic controlled the battery management of this system and the DC motor speed. For battery management system, the fuzzy logic controller operated the two circuit breakers, such as battery charging mode and discharging mode. The battery charging mode circuit breaker was closed and discharging mode circuit breaker was opened whenever the generation of renewable energy power was greater than load power. The battery discharging mode circuit breaker was closed and charging mode circuit breaker was opened whenever the generation of renewable energy power was less than load power.

4. Conclusion

In this study, hybrid photovoltaic and wind power systems are simulated using Matlab Simulink environment. An effective power utilization of the above hybrid system battery management technology is developed using the fuzzy logic controller and simulated in Matlab.
The fuzzy logic controller is to operate the two circuit breakers, such as battery charging mode and discharging mode. The battery charging mode circuit breaker is closed and discharging mode circuit breaker opened whenever the generation of renewable energy power is greater than consumer load. The battery discharging mode circuit breaker is closed and charging mode circuit breaker opened whenever the generation of renewable energy power is less than power load. The proposed model simulation results are evaluated and they have shown the effectiveness of the controller.

Furthermore, DC motor generates the power load. The DC motor is controlled by PID controller and Fuzzy logic controller to regulate the speed of motor. The results yield, that the Fuzzy Logic Controller is better than PID controller methods. The Fuzzy Logic Controller presents the following satisfactory performance indices. First, the overshoot may be reduced by using Fuzzy Logic Controller. Then, the rise minimum which is minimum as compared to other methods and steady state error is near to zero. Hence the proposed Fuzzy Logic Controller provides better performance characteristics and is able to improve the control of DC motor.

Acknowledgements

We wish to express our gratitude to Universiti Teknikal Malaysia Melaka (UTeM) especially to Faculty of Electrical Engineering for the grant PJP/2015/FKE(3A)/S01401 as well as moral support.

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