MPPT Using Fuzzy Logic Control Strategy For A Wind Energy Conversion System

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Abstract- *An innovative fuzzy logic control strategy to get the most power out of a Wind Energy Conversion System (WECS) based on a Permanent Magnet Synchronous Generator (PMSG) is provided in this research. A wind turbine, a PMSG, and a DC/DC converter coupled to a DC load make up the WECS. The output DC voltage and power across the load are the factors taken into account for analysing the MPPT controller's efficiency. The steady state voltage and the system's dynamic reaction to various wind speeds are taken into account to support the controllers' overall effectiveness. In MATLAB/SIMULINK software, the system is created and set up, and the outcomes are validated.*

Keywords- Maximum Power Point, Wind Energy Conversion System, Fuzzy Logic Control, PMSG.

I. INTRODUCTION

Due to the rising demand for electricity and the depletion of fossil fuels like coal used in the production of electricity, the usage of renewable energy resources has expanded during the past few years. In addition, the worry over climate change has led to numerous restrictions being proposed to cut carbon dioxide (C02) emissions (Krishna et al., 2015). Due to their widespread availability and abundance, solar and wind energy are among the renewable sources that are most frequently used. Due to considerable reductions in electricity costs and technological advancements, interest is growing in wind energy. In order to get dependable, affordable, and high-quality power from the wind, more efficient control systems are being investigated.Permanent Magnet Synchronous Generators (PMSGs) are the most popular wind generators, according to Errami et al. (2015), because of their dependability and size for standalone wind energy conversion systems.

By maintaining the ideal stable voltage across the load, MPPT control algorithms can be used to maximise the power from available wind. In earlier research, a number of MPPT techniques, including the Hill Climbing Search (HCS) algorithm, the Incremental and Conductance method (INC), the Perturb and Observe (P&O) method, the Fuzzy Logic Controller (FLC), and numerous Evolutionary Algorithms, were used for the Wind Energy Conversion System (WECS).P&O method is a well-known MPPT approach because of its efficiency and simplicity. However, the P&O technique is unable to follow the highest power point due to the strong nonlinearity of wind speed, which creates huge fluctuations and results in a poor power output (Dailii et al., 2015). The PI control method is another commonly utilised control approach. Implementing PI control is pretty straightforward. Due to its uncontrolled parameter selection, PI control falls short in system efficiency. FLC is used to maximise the power from the wind in order to solve this issue. FLC is able to track the system's non-linearity and provides the highest output for the available wind.The DC voltage and current across the load serve as the FLC's input, while the DC/DC Converter's output is the duty cycle.

Here, the wind generator is connected to the DC load via a buck converter. The output of the PMSG is AC, which is then converted to DC using a diode-controlled rectifier to remove any ripple present in the AC component and a smoothing capacitor to reduce any ripple brought on by non-linearity across the rectifier. The FLC tracks the output voltage and current as the wind power varies to produce an effective duty cycle for the converter operation. Therefore, based on the available wind speed, the most power is generated.

The maximum power point tracking control strategy for standalone WECS is examined in this study. The effectiveness of the traditional PI controller, the P&O controller, and the FLC is assessed when the wind speed varies. The proposed control approach has a better chance of harnessing the full potential of the wind. The output power of the converter is used to compare the controllers' efficiency.

II. SYSTEM DESCRIPTION

2.1 Wind Energy Conversion System:

Power produced by a wind turbine is given by[2]:

$$P = \frac{1}{2}\rho\pi R^2 Cp(\lambda, \beta)V^3$$

where ρ is the air density (kg/m3),
R is the radius of turbine blade (m),
V is the wind speed (m/s),

Cp is the turbine power coefficient which is a measure of turbine power conversion efficiency and is a function of tip speed ratio (λ) and blade pitch angle (β).

Tip speed ratio is defined as the ratio of the blade tip speed to the windvelocity striking the blades and can be expressed as [3]:

$$\lambda = \frac{\omega R}{V}$$

where ω is the mechanical angular speed of the turbine (rad/s)
The dynamic equation of the wind turbine is given as:

$$\frac{d\omega}{dt} = \frac{1}{J}\,[Tm - Tl - F\omega$$

where J is the system inertia,
F is the viscous friction coefficient,
Tm is the torque developed by the turbine,
TL is the torque due to load which in this case is the generator torque.

The target optimum power from a wind turbine can be written as:

$$Pmax = Kopt\omega3r\_opt$$

Where

$$Kopt = \frac{0.5\pi\rho CpmaxR^{5}}{\lambda opt^{3}}$$
$$\omega opt = \frac{\lambda opt.\,V}{R}$$

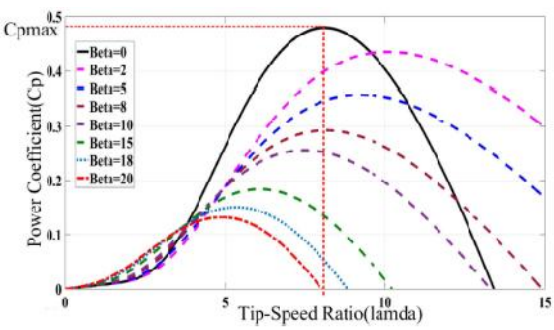

Figure 1: Turbine mechanical power as a function of rotor speed for various wind speeds

At varying wind speeds, Fig.1 displays turbine mechanical power as a function of rotor speed. At a set rotor speed, known as the optimal rotor speed opt, the power for a given wind speed is at its peak. This is the speed that corresponds to the best tip speed ratio (opt). To get the most power out of the turbine, it should always be set to opt. This is accomplished by regulating the turbine's rotational speed such that it always rotates at the optimal pace.

2.2Perturb & Observe Control

The maximum ideal spot for the specified wind speed is sought after using the P&O approach. The P&O approach does not necessitate any prior knowledge of wind turbines. It is a standalone, adaptable, and straightforward method. The P&O approach in this case determines the ideal operating point that will extract the most power by using the perturbed output voltage across the load.If the current cycle's power is higher than the previous one, the voltage is changed using the same method as before. The voltage must be changed in the other way if the power is lower than with the prior procedure. The only drawback of the P&O technique for converting wind energy is its inability to follow the rapid variation in wind speed, which slows convergence and reduces system efficiency (Dalala et al., 2013). Fig. 2 describes the P&O method's flow chaff.

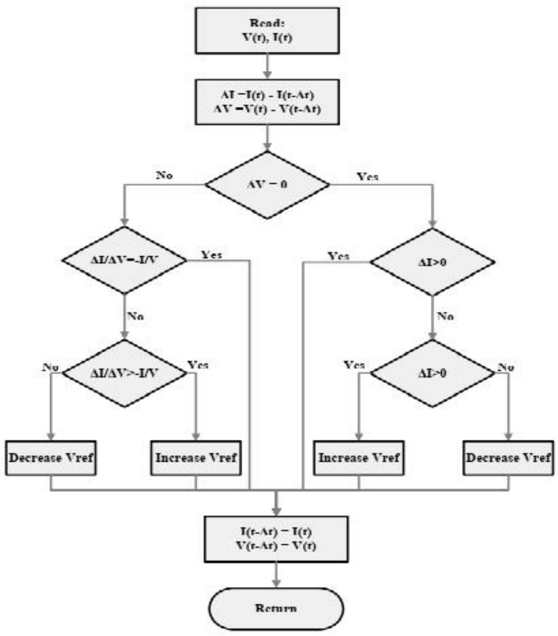

Figure 2: Flowchart of Perturb and Observe Control

III. FUZZY LOGIC CONTROL

The characteristics of the turbine and generator [16, 18,] as depicted in Fig. 3, have no bearing on the fuzzy logic controller [16]. Fuzzification I, rule-based look-up tables II, and defuzzification III are the steps of a fuzzy logic controller [19] [20]. Based on previous information, the parameter or variables will be converted to linguistic words and sent to the look-up database for the purpose of finding various errors in the original phase. The defuzzification [17] block receives this information and transforms the linguistic words into basic system input variables.

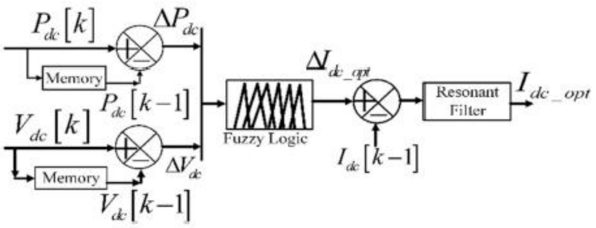

Figure 3: Fuzzy logic controller block diagram

The FLC algorithm is suggested as a solution for the P&O method's shortcomings. Fast convergence, erroneous input, and nonlinearity handling are benefits of FLC. Fuzzification, Rule base lookup tables, and Defuzzification are the three steps that make up FLC. The Rules are created based on prior understanding of the system (Simoes et al., 1997). An artificial closed-loop decision-making controller is known as an FLC. Error signal and change in error signal are the inputs for fuzzy controllers. Once the signals have been calculated and the linguistic variables have been retrieved, the duty cycle for the boost converter is produced by FLC utilising the rules. Table. 1, represents the set of rules used for modelling FLC Where, E represents the error signal and CE represents the Change m error. The Riles are framed in five level namely Negative Big(NB), Negative Small(NS), Zero(ZE), Positive Small(PS) and Positive Big(PB).

Table 1: Fuzzy Logic set of rules

E/CE	NB	NS	ZE	PS	PB
NB	ZE	PB	ZE	NB	NS
NS	PS	ZE	ZE	NB	NS
ZE	ZE	ZE	ZE	ZE	ZE
PS	PS	PB	ZE	ZE	NS
PB	PS	PB	ZE	NB	ZE

The fundamental definition of the inference process comes from the FLC membership functions, which assess the applicability of the criteria in Table 1. The input and output membership function of the FLC controller is depicted in Figures 4, 5, and 6. The surface aspect of the rule set is depicted in Figure 7. The terms Minimum (min) and Maximum (max) specify the implication and aggregation methods, respectively.The Defuzzification method uses centroid for processing.

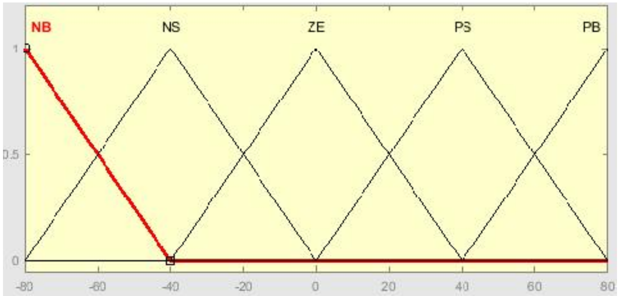

Figure 4: Membership Function for Error

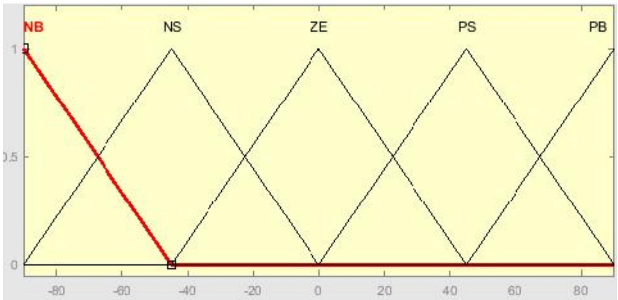

Figure 5: Membership Function for Change in Error

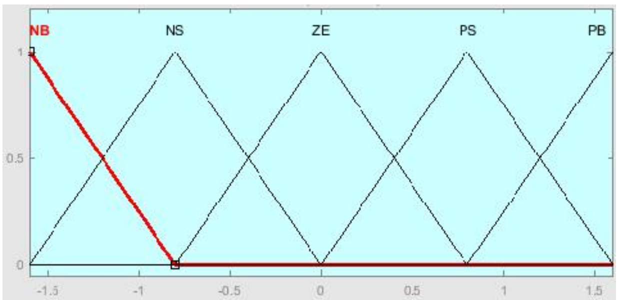

Figure 6: Membership Function for Output

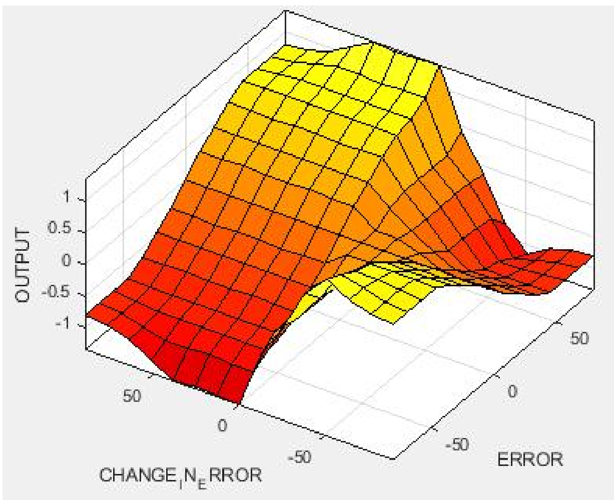

Figure 7: Surface view of the rule base

More quickly and accurately, FLC tracks the abrupt shift in wind speed. The controller determines the maximum power point using the inference system, which was previously mapped by human knowledge in the form of rules. The controller monitors changes in output voltage and current and provides an error signal that is used as input for the fuzzification process. The Mamdani method is used to transform the input data into the appropriate fuzzy linguistic sets. Then, utilising fuzzy rules, the inference system processes the fuzzy set to provide a suitable fuzzy output. The fuzzy output is then transformed into a systematic crisp value as a duty cycle in the defuzzification process. Thus, the duty cycle is used to control the switching pattern of the converter switch.

IV. SIMULATION AND RESULTS

Figure 8 illustrates the precise implementation of PMSG-based WECS in MATLAB/Simulink utilising a boost converter combined with a fuzzy logic controller. As illustrated in Fig. 11, the wind speed is varied from 0 m/s to 12 m/s to test the tracking capability of MPPT approaches. According to the investigation, the FLC based MPPT technique is more effective at tracking maximum power than the P&O based technique.

The output voltage and output power comparison of MPPT controllers are shown in Figs. 9–12. The maximum and constant voltage are provided by the FLC-based MPPT controller while the wind turbine is operating in its steady state. As shown in Figs. 9 and 12, the voltage output of both MPPT controllers is compared in order to analyse their performance.

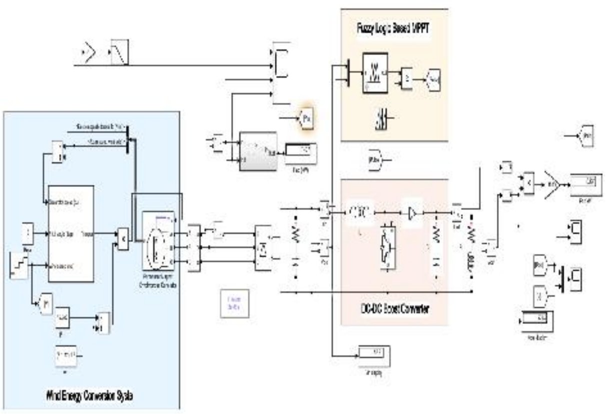

Figure 8: Simulink Model

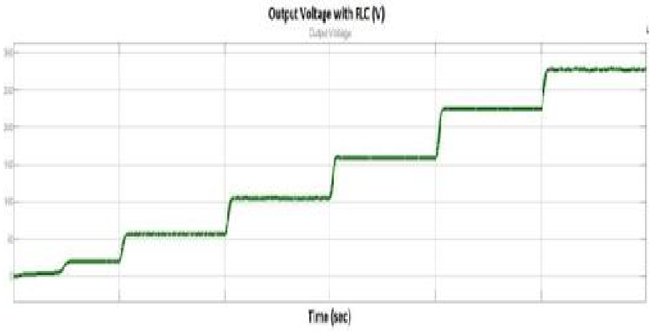

Figure 9: Output DC Voltage

MPPT controller accompanying PID found to have some oscillation in its output and failing to produce a steady DC voltage and power (clearly depicted on fig 12). On the other hand, FLC found to perform far better as seen from figure 9. Moreover, it is following the wind speed in the quickest possible time as can be seen from fig 11.

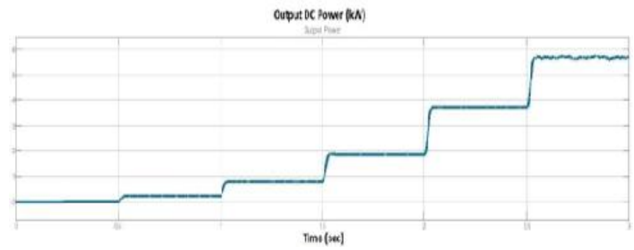

Figure 10: Output DC Power

Above Fig 10. shows the Output DC Power.the wind speed is varied from 0 m/s to 12 m/s to test the tracking capability of MPPT approaches.

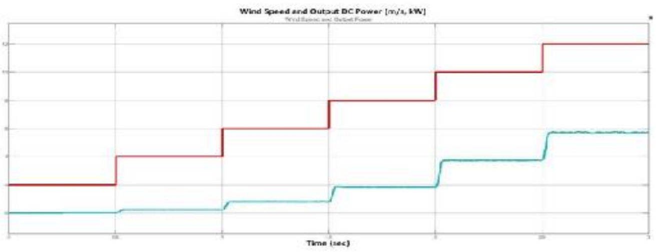

Figure 11: Output DC Power w.r.t wind speed

It is following the wind speed in the quickest possible time as can be seen from fig 11. Above Fig shows the output DC power and wind speed.

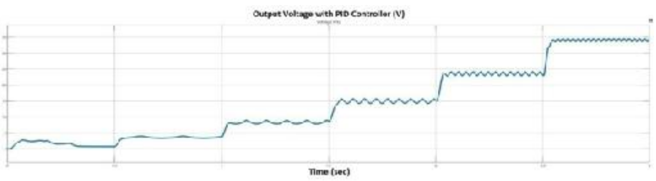

Figure 12: Output DC Voltage with PID controller

MPPTcontrolleraccompanyingPIDfoundtohavesomeoscillationinitsoutputandfailingto produce a steady DC voltage and power (clearly depicted on fig 12).

Table2:ResultSummary

WindSpeed	OutputVoltage	OutputPower
2m/s	20V	0.1kW
4m/s	55V	0.4kW
6m/s	105V	0.8kW
8m/s	160V	1.8kW
9m/s	230V	3.8kW
12m/s	275V	5.8kW

V. CONCLUSION

In this study, a fuzzy logic-based MPPT controller is modelled, and the output for wind energy is compared under conditions of varying wind speed. Analysis of the controller's performance demonstrates that the FLC-based controller is more effective and dependable than the PID-based P&O controller. The PID controller produces insufficient output power by failing to track the nonlinearity of the wind speed. This method works best in situations where the system is stable or has little volatility.Due to the strong nonlinearity of wind speed, the P&O algorithm oscillates around the ideal position, making it challenging to follow the next point. The FLC approach allows for quick tracking. FLC is a quick and effective method for finding the WECS maximum power point. Regarding stability, quicker monitoring capability, and fluctuations, FLC's findings are more effective and superior to those of the P&O technique. The FLC based MPPT approach is therefore determined to be the optimum choice for standalone WECS.

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