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Comparison of Solar P&O and FLC-based MPPT Controllers & Analysis under Dynamic Conditions

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Abstract

Increase in electricity generation is caused due to population increase, which leads to the depletion of fossil fuels, and increased pollution. This leads to focusing on alternate renewable energy, mainly solar photovoltaic generation, due to theabundant availability. The maximum power generated by a PV module depends on the temperature and irradiance because theP-V and V-I natures are non-linear. Various DC-DC boost converters are used along with the MPPT techniques because the conversion efficiency of the PV system is low [1][2]. In this paper, comparative analysis between Perturb and Observe (P&O) and Fuzzy Logic-based Maximum Power Point Tracking (MPPT) systems along with modified SEPIC are done using MATLAB/SIMULINK software. Simulations are done at different irradiations to observe its tracking speed towards MPP. From the obtained output (simulation), it is observed that the Fuzzy Logic Converter (FLC)-based MPPT controllers have good dynamicperformance, reduced oscillation, high tracking speed, maximum power, etc...[3].

Keywords: Solar PV, MPPT, P&O, FLC, Simulink

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1. Introduction

Energy consumption by humans is increased due to increased loads and most of the energy is generated from conventional resources like fossil fuels, which results in heavy environmental pollution. Alternative energyresources like wind, solar, biomass, hydropower generation, and geothermal are considered to meet the energy demands. Among all the alternate sources, PV power generation is popular due to the abundant availability of solar power.

Solar power generation reached 179 TWh in 2022 and made a 22 % increase in power generation compared to the previous year. But it has a few limitations, low conversion efficiency and unstable output powerdue to weather conditions like changes in temperature and irradiance in a day and it also depends on the connectedload. An MPPT is used to recognize the efficient utilization of solar cells because P-V and V-I curves are nonlinear, which results in non-linear power production [4].

Many MPPT techniques have evolved from the conventional MPPT algorithms like hill climbing, Perturb& Observe, IC, etc., and other advanced soft computing-based algorithms like Artificial Neural Networks (ANN), Fuzzy Logic Controller (FLC), Particle Swarm Optimization (PSO), and hybrid algorithms are also available [5][6]. This paper focuses on the comparison of conventional P&O and soft computing based FLC algorithms based on the results.

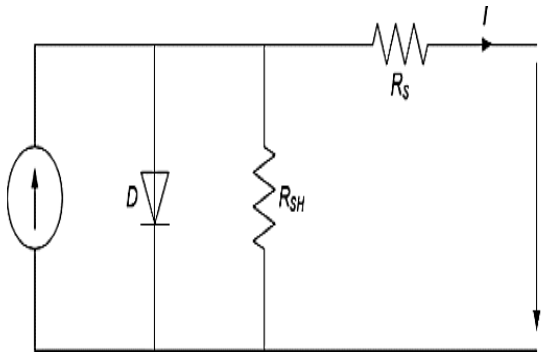

Figure 1. PV cell's equivalent circuit

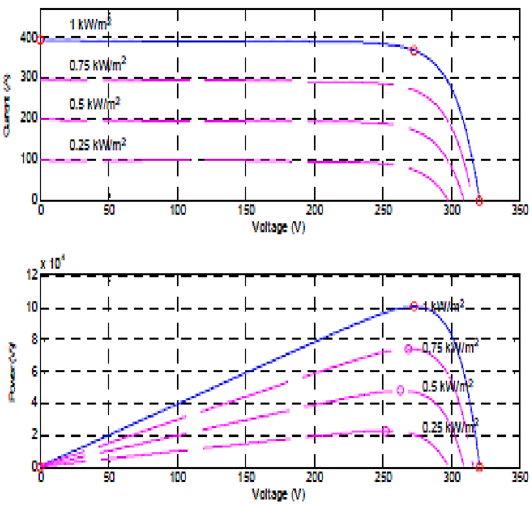

Figure 2. P-V & V-I curve of the solar panel at STC

2. Proposed Model:

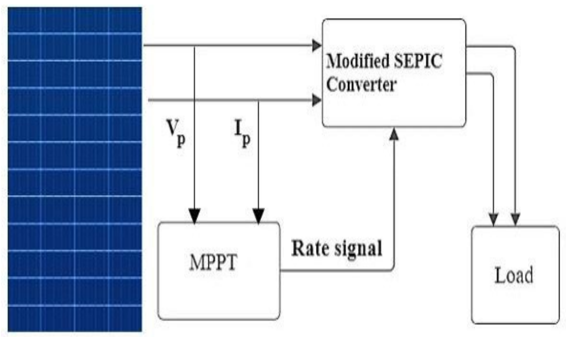

Figure 3. Schematic Diagram of the proposed work

The MPPT controller senses the voltage and current at that instant time and calculates the power. Thepresent power value and previous power value is compared [7]. If power is equal to the previous power value, then there is no change in the duty cycle. But if there is a difference in power, the MPPT controller adjusts the duty cycle of the modified SEPIC controller so that the converter is extracting the maximum power output of the PV system [8][9].

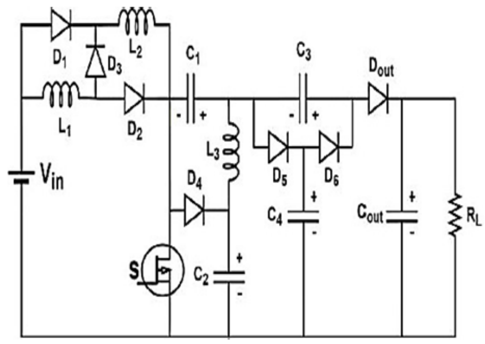

Figure 4. Modified SEPIC Converter

The proposed modified SEPIC converter is a combination of a conventional SEPIC converter with twocircuits. The split inductor circuit is the first part, and the second part has 2 diodes and 2 capacitors [10][11]. The SEPIC converter allows either buck operation or boost operation, allowing output voltages that are greater or less thanthe input voltage and that have identical polarity. With this modified SEPIC converter, the gain can be raised to 7.5 and the duty cycle is decreased to 0.5 [12]. This circuit reduces the ripple of output current and voltage, also thelimited input ripple leads to reduced switch stress [13][14].

2.1 Perturb and Observe Controller:

This MPPT algorithm will often change the switching cycle in a modified SEPIC converter by analyzing the voltage and power of current values with previously measured values [15].

Duty cycle changes:

1. The duty cycle will be increased to reach MPP if the current sensed voltage and power are higher than theprevious value.
2. The duty cycle will be lowered to reach MPP if the current sensed voltage and power are less than the precedingvalue.
3. The duty cycle will be boosted if the voltage is less than the preceding value and the current sensed power ishigher.
4. The duty cycle will be decreased if the voltage is greater than the previous value and the current sensed poweris lower [16][17].

2.2 Fuzzy Logic-based MPPT Controller:

The FLC-based MPPT controller is widely used nowadays because it effectively handles ambiguity andcan handle linear and non-linear variation in the parameter with multiple rule-based systems [18]. Fuzzification, a rule-based inference system, and defuzzification are its three main components. The inference system, where the outputis turned, has 25 if-else-based rules and has five membership functions: Negative big (NB), Negative small (NS), Zero (Z), Positive small (PS), and Positive big (PB). It also has a defuzzification module, transforming linguisticvariables into real ones [19][20].

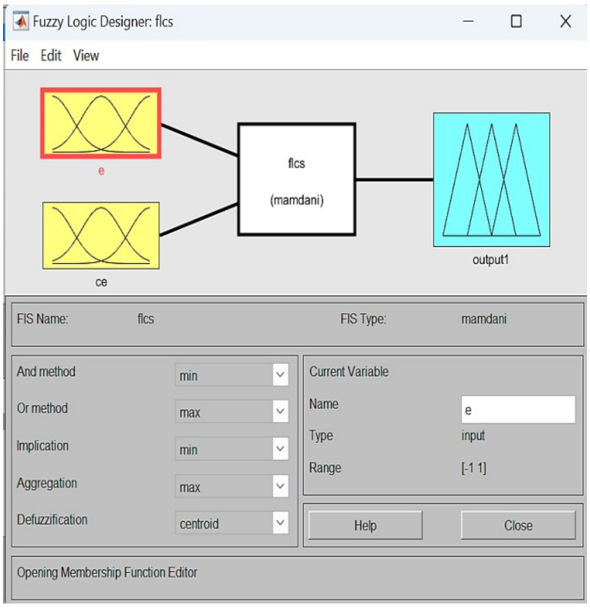

Figure 5. Fuzzy Logic Design

3. Simulink model of P&O and FLC Controller:

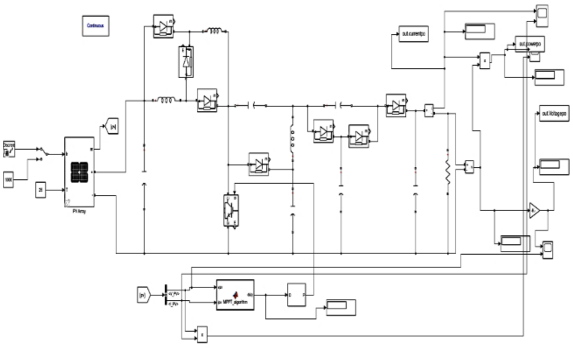

Figure 6. Matlab Simulink model of solar PV with P&O MPPT controller

Irradiance and temperature are the inputs for the solar panel in Fig.6 depicts the simulation circuit diagram of the P&O controller. The P&O controller monitors the MPP and modifies the duty cycle and voltage according to the situation [21].

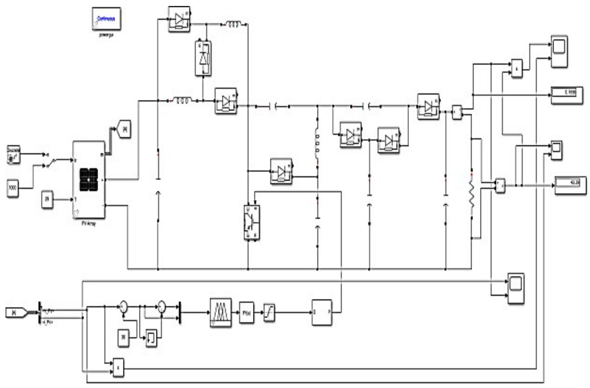

Figure 7. Simulink model of solar PV with FL MPPT controller.

The inputs for the solar panel in the above-described picture, which depicts the simulated circuit designof the FLC, are the irradiance and temperature [22]. The FLC controller maintains track of the MPP in accordance with a set of regulations. These regulations are contrasted, and the duty cycle is established based on the voltage, thereby boosting the voltage. However, it takes longer to reach the MPP using this method [23].

4. Simulation Results and Output

4.1 Output results of PERTURB & OBSERVE MPPT controller

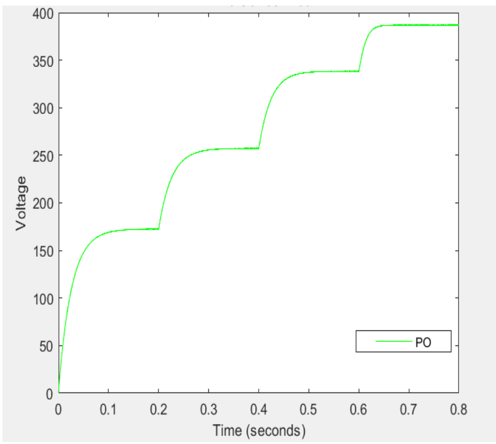

Figure 8. Solar PV simulation of P&O Controller with DC-DC modified SEPIC converter output Voltage at variable irradiance

Fig.8 depicts the Solar PV simulation with P&O Controller with DC-DC modified SEPIC converter output Voltage at variable irradiance i.e., 400, 600, 800, 1000W/$m2$. The output voltage is maximum for specified irradiance i.e., 180V, 255V, 340V, 386V.

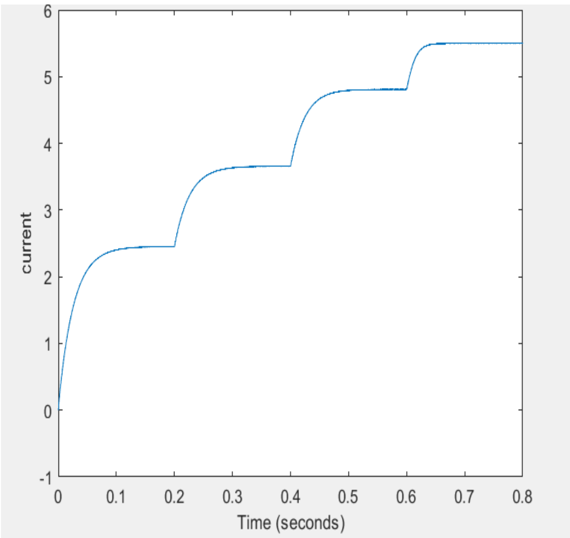

Figure 9. Solar PV simulation of P&O Controller with DC-DC modified SEPIC converter output Current at variable irradiance

Fig.9 illustrates the Solar PV simulation with P&O Controller with DC-DC modified SEPIC converter output Current at variable irradiance i.e., 400, 600, 800, 1000W/m^2. The output current is maximum for specifiedirradiance i.e., 2.5A, 3.8A, 4.7A, 5.5A.

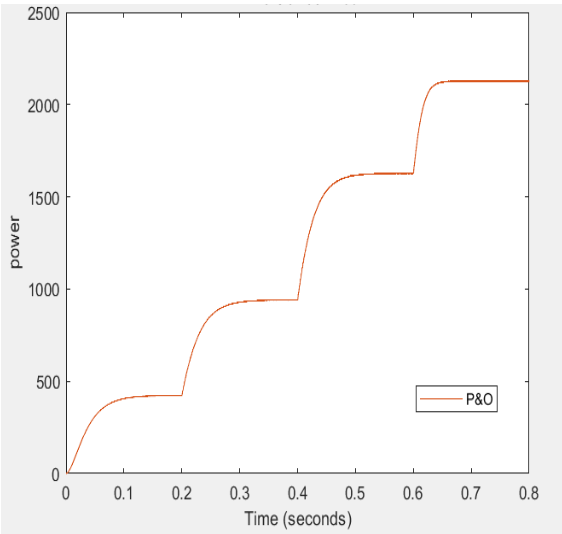

Figure 10. Solar PV simulation of P&O Controller with DC-DC modified SEPIC converter output Power at variable irradiance

Fig.10 indicates the Solar PV simulation with P&O Controller with DC-DC modified SEPIC converter output Power at variable irradiance i.e., 400,600,800,1000W/$m2$. The output power is maximum for specified irradiance i.e., 490W, 990W, 1700W, 2125W.

4.2 Output results of FUZZY LOGIC MPPT controller

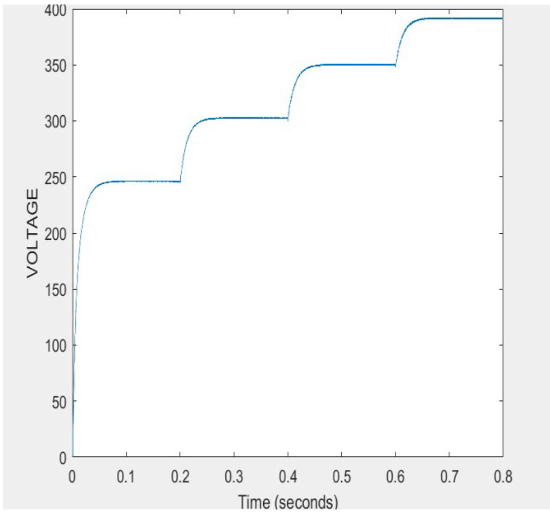

Figure 11. Solar PV of FLC with DC-DC modified SEPIC Converter output Voltage at variable irradiance

Fig.11 shows the Solar PV with FLC with DC-DC modified SEPIC Converter output Voltage at variable irradiance i.e., 400, 600, 800, 1000W/$m2$. The output Voltage is maximum for specified irradiance i.e., 249.3V, 299.6V, 351.1V, 392.3V

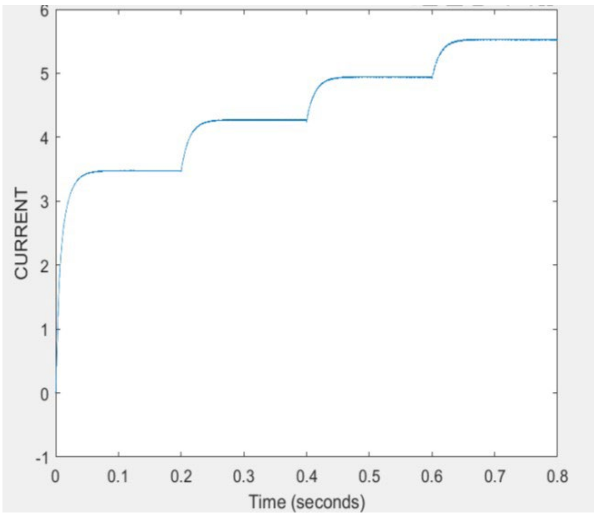

Figure 12. Solar PV of FLC with DC-DC modified SEPIC Converter output Current at variable irradiance

Fig.12 depicts Solar PV with FLC with DC-DC modified SEPIC Converter output Current at variable irradiance i.e., 400, 600, 800, 1000W/$m2$.

The output voltage is maximum for specified irradiance i.e., 3.2A, 4.4A, 4.9A, 5.5A.

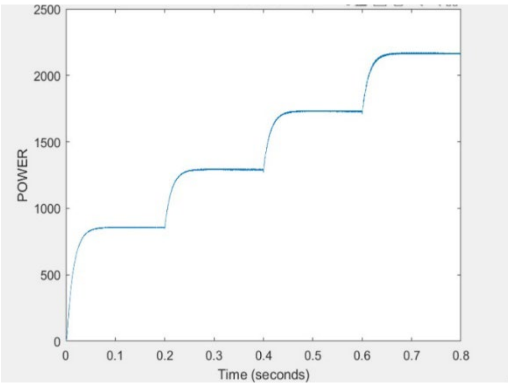

Figure 13. Solar PV of FLC with DC-DC modified SEPIC Converter output Power at variable irradiance

Fig.13 demonstrates the Solar PV with an FLC with DC-DC modified SEPIC Converter output Power at variable irradiance i.e., 400, 600, 800, 1000W/$m2$. The output Voltage is maximum for specified irradiance i.e., 822.26 W, 1324.73 W, 1746.94 W, 2183.4W

5. Comparison of Simulation Output of P&O and FLC MPPT controller:

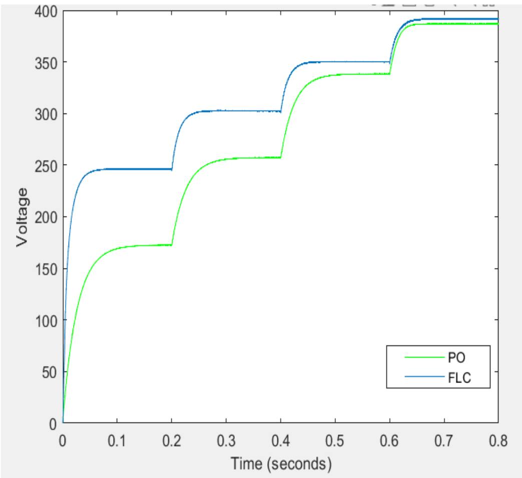

Figure 14. Comparison waveform of Solar PV with an FLC with DC-DC modified SEPIC Converter output voltage at variable irradiance

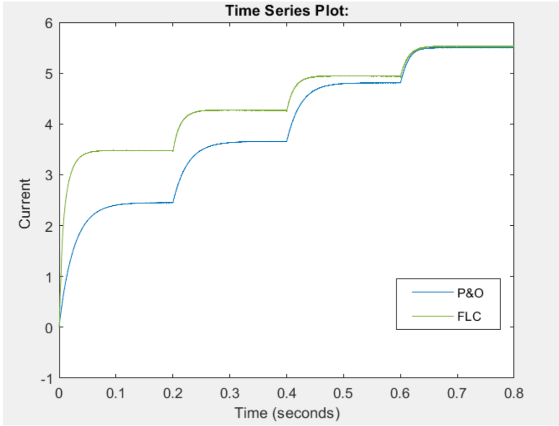

Figure 15. Comparison waveform of Solar PV with an FLC with DC-DC modified SEPIC Converter output current at variable irradiance

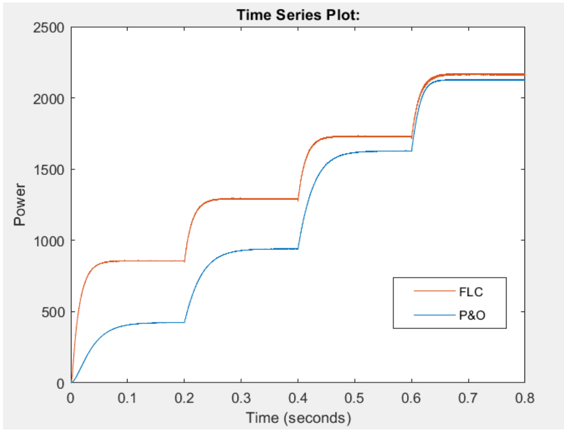

Figure 16. Comparison waveform of Solar PV with an FLC with DC-DC modified SEPIC Converter output power at variable irradiance

From the graph, power, voltage, and current values are observed and tabulated.

Table 1: Comparison output of P&O, FLC-based MPPT controller

Controller/ Irradiance W/m2	**400**	**600**	**800**	**1000**
P&O	V:189V I:2.5A P:472.5W	V:262.3V I:3.821A P:997.5W	V:341V I:4.7A P:1603W	V:386V I:5.399A P:2084W
FCL	V:249.3V I: 3.432A P:855.6W	V:299VI: 4.286AP: 1284W	V:351.1V I:4.962A P:1742W	V:392.3V I:5.412A P:2123W

From Table.1, it is observed that the Fuzzy Logic Controller has improved output at all irradiance levels of 400 W/m2, 600 W/m2, 800 W/m2, and 1000 W/m2 with power level of

855.6W, 1284 W, 1742W, 2123W, where the power level is 472.5W, 997.5W, 1603 W, 2048 W. From the comparison of outputs of P&O and FLC controllers, it is concluded that the FLC-based controller will produce the improved voltage, current and power level at all irradiance levels.

Conclusion:

In this paper, P-V and V-I characteristics of P&O, FLC-based controllers are designed with variable irradiance level using MATLAB/Simulink. Controllers work in improving the steady-state accuracy. This is done by decreasing the steady state error. With better steady-state accuracy, we acquire better stability [24]. Controllers also help with unwanted offsets produced by the system by reducing them. From the charts and result it is observed the FLC-based controllers has maximum output power, voltage and current of 2123 W, 392.3 V, and 5.412 I. A reduced oscillation, less fluctuation, and high tracking speed makes FLC controller better than the P&O controller. To improve the output power several other hybrid soft computing algorithms will be used for future enhancement [25].

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