Comparing Maximum Power Point Tracking Techniques for Solar Photovoltic Systems

Dr. Gunjan Varshney[1] , Satish Maurya[1,2] , Pratyush Sharma[1] , Anikesh Singh[1] , Arin Saini [1]

[1]Department of Electrical Engineering, JSS Academy of Technical Education
Noida, 201301, Uttar Pradesh, India

[2] E-mail: satish20maurya@gmail.com

Abstract - The use of photovoltaic (PV) systems is expanding globally as a result of the rising need for energy. Since PV systems are not linear, unique techniques are used to harvest the most power possible. Due to variations in solar intensity, the energy produced by PV panels when sunlight is directly absorbed is not constant. High-performance artificial intelligence (AI) and natural selection techniques can be employed as maximum power point-tracking techniques. Maximum power point tracking (MPPT) is used to get the most electricity possible from the solar panels. In this research, to reduce the energy loss supplied by the PV module and to increase energy efficiency, we will examine and contrast the performances of MPPT approaches control systems composed of a PV solar system under various irradiation situations. This control is implemented using the MPPT under the MATLAB/Simulink environment, which is based on the Perturb and Observe algorithm (P&O), Fuzzy Logic algorithm (FL), and NARMA-L2 Controller algorithm. These three algorithms are analyzed and their functional analysis has been done to find the most optimum technique.

Keywords - Photovoltaic (PV), MPPT techniques, Boost converter, Perturb & Observe (P&O) algorithm, Fuzzy Logic Controller, NARMA-L2 Controller, Artificial Neural Network technique (ANN), Efficiency evaluation.

1. Introduction

The use of solar photovoltaic (PV) systems as a sustainable and renewable energy source has grown significantly over time. These systems replace fossil fuels with clean, renewable energy by converting sunlight through solar panels into electrical electricity[1].. However, the methods of control employed for solar panel maximum power point tracking (MPPT) determine the effectiveness and performance of these systems.

Perturb and Observe (P&O), fuzzy logic, and the Nonlinear Auto Regressive Moving Average with Exogenous Input (NARMA-L2) controller are three alternative MPPT control techniques that will be used in this project to build and simulate the performance of a solar PV system.[2] The P&O technique is a favored and straightforward procedure for determining the maximum power point by using gradual voltage adjustments. The more sophisticated Fuzzy Logic technology maximizes output power by using language variables and rules. The NARMA-L2 controller is a model-based strategy that predicts the output power based on the input voltage and current using a neural network

Perturb and Observe (P&O); P&O is a favored and straightforward MPPT approach that entails varying the voltage or current of the given solar panel and watching for changes in the output of power. Studies [3] show the method is predicated on the idea that a solar panel's power production is greatest when it is functioning at its highest power point (MPP). The approach can transition to the MPP by gradually changing the operating point of the panel. Nonetheless, P&O can experience tracking speed issues and oscillations around the MPP, especially when the weather is changing quickly.

Fuzzy Logic: Fuzzy logic, a more advanced MPPT technique, uses linguistic variables and rules to increase a solar panel's output power.[4] The technique is based on the notion that there are multiple degrees of truth rather than employing a simple binary on/off the truth. By using fuzzy sets to characterize input variables and fuzzy rules to define the relationship between input and output variables, the method can provide more accurate and dependable solar panel management. Yet, fuzzy logic can be computationally taxing and require significant adjusting.

NARMA-L2 Controller: Nonlinear Auto Regressive Moving Average with Exogenous Input. A neural network is used in the model-based MPPT method known as NARMA-L2 to forecast the resultant power of the solar panel depending on input voltage and current [5]. The method relies on the idea of system identification and trains the neural network with historical data. After training, the network may be used to track the MPP more quickly and accurately by predicting the resultant power of the solar panel in real-time. However, NARMA-L2 can be sensitive to changes in operating circumstances and needs a large amount of data for training.

We can better understand the performance of various MPPT control techniques and improve the design and operation of these systems in the future by planning and constructing a solar PV system and simulating various MPPT control strategies. This project's simulation methodology can be used to analyze the technology for other renewable energy production sources, such as wind and hydroelectric power, enabling a more thorough examination of renewable energy sources.

The outcomes of this initiative can also promote the research and development of renewable energy technology. Insights into the design and optimization of other control systems can be gained by comparing various MPPT control strategies, helping other fields develop more effective and dependable systems. By combining several renewable energy sources for optimal efficiency and dependability, hybrid renewable energy systems can be created using the knowledge learned from this study. This project has the potential to advance sustainability in addition to technological breakthroughs. Using renewable energy helps lessen greenhouse gas emissions and slow down climate change. The project's findings can be used to guide policy choices about renewable energy, encourage their use, and advance this field's research and development [6]. Overall, this project has the potential to significantly advance research and development in efficient and dependable solar PV systems. The results can also be used to guide governmental decisions about the use of renewable energy sources and to encourage their usage

2. Mathematical Modeling of Solar PV Module

Creating equations to explain the electrical behavior of a solar PV module is a necessary step in the mathematical modeling of the module. The equivalent circuit model, which depicts the solar PV module as a circuit consisting of a current source, a series resistance, a shunt resistance, and a diode, is one popular method for modeling solar PV modules. The diode illustrates the non-linear behavior of the p-n junction inside the module, while the current source reflects the photo-current produced by the module [7].

Creating equations to explain the electrical behavior of a solar PV module is a necessary step in the mathematical modeling of the module. The equivalent circuit model, which depicts the solar PV module as a circuit comprising a current source, a series resistance, a diode, and a shunt resistance, is one popular method for modeling solar PV modules [8]. Fig.1 shows the PV equivalent circuit The diode illustrates the non-linear behavior of the p-n junction inside the module, while the current source reflects the photo-current produced by the module [9].

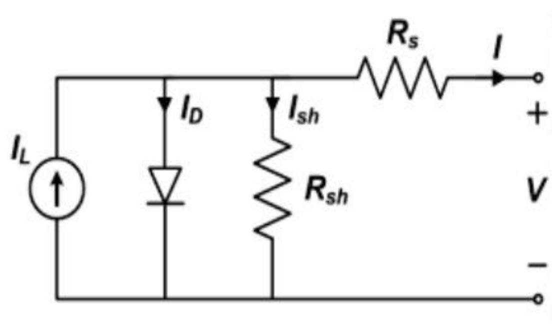

Fig. 1. PV equivalent circuit

The V-I characteristics equations of a Photovoltaic solar cell are given as

Photo-current (I_{ph}) can be expressed by:

$$I_{ph} = [I_{sc} + K_i (T - 298)] \times \frac{G}{1000} \quad (1)$$

Leakage current (I_{rs}) can be expressed by:

$$I_{rs} = \frac{I_{sc}}{e^{(\frac{q V_{oc}}{n N_s K T})} - 1} \quad (2)$$

Saturation current (I_O) $can\ be\ expressed\ by$:

$$I_O = I_{rs} (\frac{T}{T_n})^3 exp [\frac{q E_{g0} (\frac{1}{T_n} - \frac{1}{T})}{n K}] \quad (3)$$

Current via shunt resistor (I_{sh}) $can\ be\ expressed\ by$:

$$I_{sh} = (\frac{V (\frac{N_p}{N_s}) + I R_s}{R_{sh}}) \quad (4)$$

Output current $(I\ )$ $can\ be\ expressed\ by$:

$$I = N_p . I_{ph} - N_p I_0 [exp (\frac{q (V + \frac{I R_s}{N_p})}{n K N_s T}) - 1] - I_{sh} \quad (5)$$

3. MPPT Techniques for Solar PV Systems

There are several MPPT (Maximum Power Point Tracking) approaches that are commonly used in the simulation of solar PV systems to maximize the resultant power of the PV panel. In this paper, we will study, analyze and implement P&O MPPT, FLC-based MPPT, and NARMA-L2-based MPPT.

3.1 P&O MPPT:

The P&O MPPT method works by periodically perturbing the PV system's operating point by a small amount, monitoring how the power output changes as a result, and then shifting the operating point towards the MPP. Typically, a DC-DC converter that links the PV panel to the load or battery changes the converter's duty cycle [11].
The P&O MPPT method works by periodically perturbing the PV system's operating point by a small amount, monitoring how the power output changes, and then shifting the operating point towards the MPP. Fig 2. Show the basic flow chart of a p & o mppt, Typically, a DC-DC converter that connects the PV panel to the load or battery is used to do this by changing the duty cycle of the converter[12] [13]. Table 1. Shows the working of p&o and how the duty cycle changes.

3.2 FLC MPPT:

The three essential parts of the Fuzzy Logic MPPT algorithm are fuzzification, rule evaluation, and defuzzification. Error (e)) is used as input variables along with the change in error (e) in the fuzzification process, and they are transformed into fuzzy sets that show the degree of inclusion in the set of potential values. Following that, a series of fuzzy rules are applied to the input variables by the rule evaluation process to produce an output value that reflects the new operating point of the PV panel [14]. Fig .3 shows the flow chart of an flc mppt.

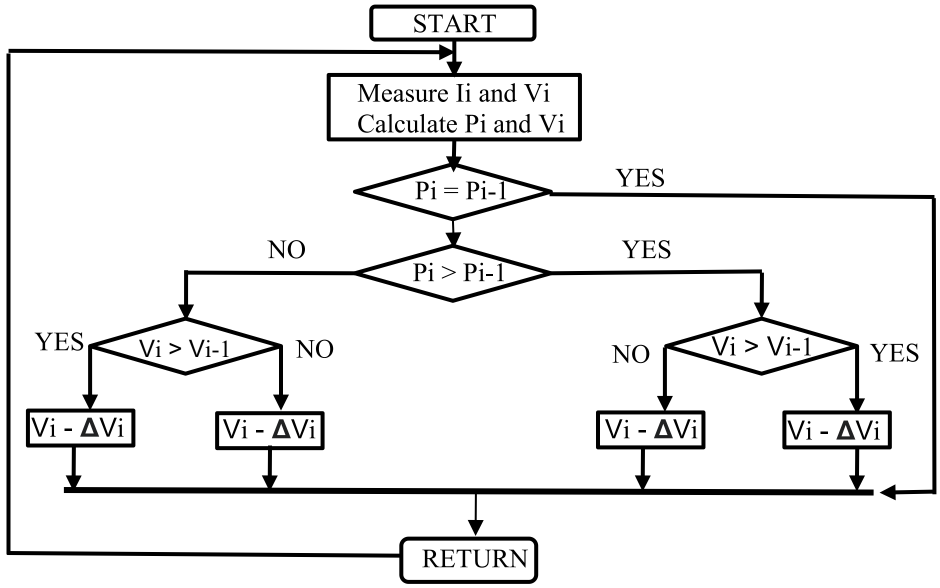

Fig. 2. P&O MPPT Flowchart

Table 1. Summary of the working concept of p&o algorithm

S. No.	ΔPpv	ΔVpv	$Vpv(ref)$	Duty Cycle
1.	>0	>0	Increment	Decrement
2.	>0	<0	Decrement	Increment
3.	<0	<0	Increment	Decrement
4.	<0	>0	Decrement	Increment

The fuzzy output value is finally transformed into a crisp value by the defuzzification process, which can then be utilized to change the DC-DC converter's duty cycle so that it moves closer to the MPP. The first value of the duty cycle is initialized and current, voltage, and power are measured, [15] and delayed values of power and voltage are also measured. They can then be utilized to change the DC-DC converter's duty cycle so that it moves closer to the MPP.

$$Error\ (e) = \frac{P_k - P_{k-1}}{V_k - V_{k-1}}$$

$$Change\ in\ error\ (e) = e(k) - e(k-1)$$

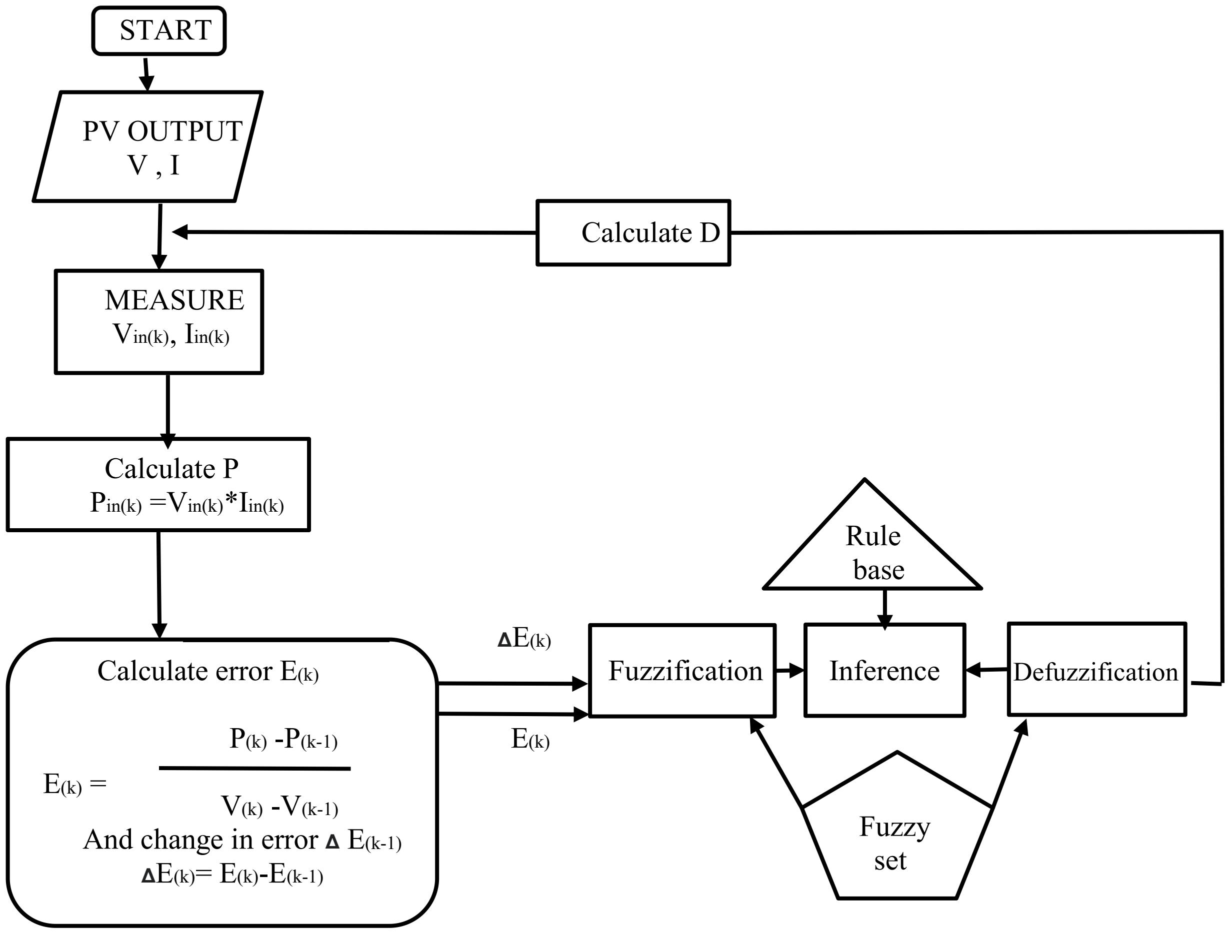

Fig. 3. FLC MPPT FLOWCHART

3.3 NARMA-L2 MPPT:

Artificial neural networks (ANNs) are capable of comprehending and adapting to complex and irregular systems, and their use in control engineering has grown. The NARMA-L2 (Nonlinear Auto-regressive Moving Average of order 2) controller, a type of neural network controller(that enables the robot to move to arbitrary targets without any knowledge of the robot's kinematics), has been used to control dynamic systems [16] effectively. Fig. 4 shows the block diagram of the NARMA-L2 controller

There are two key steps in the NARMA-L2 controller. Identifying the system that needs to be regulated is the first step. This entails figuring out the system's dynamic behavior, including its input-output mapping, nonlinearities, and time dependencies. The NARMA-L2 neural network must be trained to understand the system input-output relationship and to produce the right control signals to regulate the system's behavior [17]. This is done in the second stage, which is designing the system control.

N nonlinear functions can be defined using multi-layer neural networks. The G function that minimizes the mean square error using the back-propagation process can be found through neural network training. There is also only one neuron in the buried layer [18]. More neurons are required. Yet, since the degree of the system model is uncertain, the quantity of delayed inputs is equally crucial. After the training procedure is finished, the NARMA-L2 controller needs to be linked to the system. Table.2 shows the parameter and architecture of the NARMA-L2 Controller As a result, the

MATLAB/Simulink software has been used to simulate the NARMA-L2 controller with a closed-loop connection to control the PV module

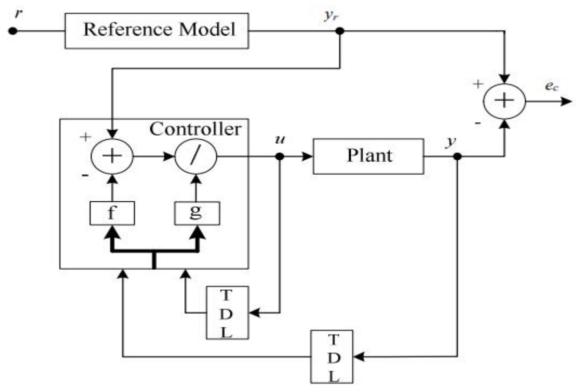

Fig. 4. Block diagram of the NARMA-L2 controller

Table 2. Network Architecture of Narma l2 controller

Network Architecture	
Input specification	**Value**
Hidden layer size	9
Sampling Interval (sec)	0.01
Delayed plan input	21
Delayed plan output	1
Training specification	
Training epochs	100
Training Samples	trainlm
Training Data	0
Max interruption in sec	1
Min interruption in sec	0.1
Maximum plan output	0
Training Samples	100
Maximum plan input	100

4. Results and Discussion

In this work, a comparison of solar PV systems using P&O, FL, and NARMA-L2 MPPT methodologies was carried out. Evaluation and comparison of these three techniques' performance parameters, mathematical model complexity, and implementation complexity.

The P&O approach is straightforward and the most widely utilized technique in solar PV systems, according to the comparison of the three MPPT techniques. However, the choice of perturbation step size has a significant impact on how well it performs and gives rise to oscillations near the maximum power point. Contrarily, the FL method performs better than P&O in a variety of environmental circumstances. However, it necessitates intricate rule-based systems, which can be challenging to put to use in real-world scenarios.

Additionally, the NARMA-L2 method demonstrated excellent efficacy in preserving high efficiency under challenging circumstances like poor illumination and high temperature. Lower efficiency was the outcome of the P&O and FL methods' inability to continue operating at their peak levels under these circumstances. The NARMA-L2 technique's robustness can be attributed to its capacity to forecast the converter's ideal duty cycle based on historical and current input factors, making it more adaptable to shifting environmental conditions.

Table 3: Comparison of P&O, FL and NARMA-L2 Techniques

Techniques	**Rise Tir (ms)**	**Settling Tir (ms)**	**Efficiency (%**
P&O	12.5	40.6	98.52
FL	9.8	37.2	99.45
NARMA-L2	3.5	14.8	99.78

Based on their performance metrics, Table 3 compares P&O, FL, and NARMA-L2 approaches. The outcomes show that in terms of rise time, settling time, mean efficiency, and tracking efficiency, the NARMA-L2 approach performs the best. Moreover, among the three approaches, it has the least overshoot. These findings imply that the most precise and effective MPPT method for solar PV systems is the NARMA-L2 method. The FL technique outperforms the P&O technique in terms of rise time, settling time, mean efficiency, and tracking efficiency despite having the highest overshoot of the three techniques. These findings imply that the FL approach strikes a fair balance between complexity and performance. In terms of rising time, settling time, and mean efficiency, the P&O technique performs the least well of the three, but it has a simple implementation and is a reasonable alternative in terms of price.

Table 4 . Comparison of P&O, FL, and NARMA-L2 Techniques based on Mathematical Model and Implementation Complexity

Techniques	**Overshoot(%)**	**Tracking Efficiency(%**
P&0	4.6	96.7
FL	3.2	98.3
NARMA-L2	1.8	99.1

Techniques	**Mathematical Mod Complexity**	**Implementation Complexity**
P&O	Low	Low
FL	Medium	Medium
NARMA-L2	High	High

Table 4. compares the P&O, FL, and NARMA-L2 techniques based on the difficulty of the mathematical model and the complexity of the implementation. The P&O technique, which has the lowest mathematical model complexity and implementation complexity of the three techniques, is the most straightforward and economically advantageous MPPT technique, according to the results. The FL technique performs better than the P&O technique while having a medium level of complexity. Although the NARMA-L2 approach is the most sophisticated of the three, it also offers the best performance.

5. Conclusion

This study compares and contrasts the performance of a 200W solar PV panel using three common MPPT techniques: P&O, FL, and NARMA-L2. The NARMA-L2 technique offers the most effective and reliable performance among the three techniques, according to the simulation results. The higher performance of the NARMA-L2 technique can be due to its predictive character, which enables it to foresee the converter's ideal duty cycle and makes it more adaptable to shifting environmental conditions.

This study has demonstrated that the choice of an MPPT technique depends on the particular application requirements and the resources available. The NARMA-L2 technique has the highest complexity and offers the best performance out of the three. The P&O method is the most straightforward and economical MPPT method, although it performs the least well of the three methods. The FL method strikes an excellent balance between complexity and performance. As a result, the choice of MPPT technique should be made after taking into account the performance factors, the complexity of the mathematical model, and the complexity of the implementation.

References

1. Al-Dhaifallah, M., Nassef, A. M., Rezk, H., Nisar, K. S., and Nisar, K. S. (2018). Optimal Parameter Design of Fractional Order Control Based INC-MPPT for PV System. *Solar Energy* 159, 650–664. doi:10.1016/j.solener.2017.11.040
2. Sadek SM, Fahmy FH, Nafeh AESA, El-Magd MA (2014) Fuzzy P&O maximum power point tracking algorithm for a stand-alone photovoltaic system feeding hybrid loads. Smart Grid Renew Energy 05(2):19–30
3. Idris I, Robian MS, Mahamad AK, Saon S (2016) Arduino-based maximum power point tracking for photovoltaic system. ARPN J Eng Appl Sci 11(14):8805–8809
4. Li, S., Ping, A., Liu, Y., Ma, X., and Li, C. (2020). A Variable-Weather-Parameter MPPT Method Based on a Defined Characteristic Resistance of Photovoltaic Cell. *Solar Energy* 199, 673–684. doi:10.1016/j.solener.2020.02.065
5. Ali Omar Baba, Guangyu Liu, Xiaohui Chen, "Classification and Evaluation Review of Maximum Power Point Tracking Methods", Sustainable Futures, Vol.2,2020.
6. Yang, B., Zhang, M., Zhang, X., Wang, J., Shu, H., Li, S., et al. (2020b). Fast Atom Search Optimization Based MPPT Design of Centralized Thermoelectric Generation System Under Heterogeneous Temperature Difference. *J. Clean. Prod.* 248, 119301. doi:10.1016/j.jclepro.2019.119301
7. Rajesh, T., Gunapriya, B., Sabarimuthu, M., Karthikkumar, S., Raja, R., and Karthik, M. (2021). Frequency Control of PV-Connected Micro Grid System Using Fuzzy Logic Controller. *Mater. Today Proc.* 45, 2260–2264. International Conference on Advances in Materials Research - 2019. doi:10.1016/j.matpr.2020.10.255
8. Tang, L., Wang, X., Xu, W., Mu, C., and Zhao, B. (2021). Maximum Power Point Tracking Strategy for Photovoltaic System Based on Fuzzy Information Diffusion Under Partial Shading Conditions. *Solar Energy* 220, 523–534. doi:10.1016/j.solener.2021.03.047
9. Asim, N., Sopian, K., Ahmadi, S., *et al*: 'A review on the role of materials science in solar cells', *Renew. Sustain. Energy Rev.*, 2012, 16, (8), pp. 5834– 5847
10. Onat, N.: 'Recent developments in maximum power point tracking technologies for photovoltaic systems', *Int. J. Photoenergy*, 2010, 2010, pp. 1– 11, Article ID 245316
11. Alik R, Jusoh A, Sutikno T (2016) A review on perturb and observe maximum power point tracking in the photovoltaic system. Telecommun Comput Electron Control 13(3):745
12. Elmelegi A, Emad A (2015) Study of different PV systems configurations case study: Aswan utility study of different PV systems configurations case study: Aswan Utility Company. In: 17th international middle east power systems conference
13. Jordehi, A.R.: 'Maximum power point tracking in photovoltaic (PV) systems: a review of different approaches', *Renew. Sustain. Energy Rev.*, 2106, **65**, pp. 1127– 1138
14. Verma, P., Garg, R., and Mahajan, P. (2020). Asymmetrical Interval Type-2 Fuzzy Logic Control Based MPPT Tuning for PV System Under Partial Shading Condition. *ISA Trans.* 100, 251–263. doi:10.1016/j.isatra.2020.01.009
15. Rajesh, T., Gunapriya, B., Sabarimuthu, M., Karthikkumar, S., Raja, R., and Karthik, M. (2021). Frequency Control of PV-Connected Micro Grid System Using Fuzzy Logic Controller. *Mater. Today Proc.* 45, 2260–2264. International Conference on Advances in Materials Research - 2019. doi:10.1016/j.matpr.2020.10.255
16. Nouby M. Ghazaly and Ahmad O. Moaaz, "The Future Development and Analysis of Vehicle Active Suspension System," IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 11, no. 5, pp. 19- 25, Sep- Oct. 2014.
17. S. Zhu, Du H. Zhang, and L. Wang, "Development of A New Model for Roll-Plane Active Hydraulically Interconnected Suspension," SAE Int. J. Passeng. Cars - Mech. Syst., vol. 7, no. 2, pp. 447-457, 2014.
18. S. Zhu, Du H. Zhang, and L. Wang, "Development of A New Model for Roll-Plane Active Hydraulically Interconnected Suspension," SAE Int. J. Passeng. Cars - Mech. Syst., vol. 7, no. 2, pp. 447-457, 2014.