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ANFIS-Based MPPT Control Algorithm For DC-DC Converter With Flower Pollination Optimization Using IoT

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***Abstract*— Solar energy is considered to be a clean energy source which is growing in popularity in today's distribution networks. The output power of photovoltaic modules is not linearly correlated with ambient variables and it is unable to give maximum power to grid due to its inconsistent surroundings. Therefore, using Maximum Power Point Tracking (MPPT) for systems using Photovoltaic (PV) cell becomes crucial. The suggested work designs and implements a unique MPPT optimized algorithm with IoT features. In order to optimize solar photovoltaic system (SPVS), this work proposes an Adaptive Neuro Fuzzy Inference System (ANFIS) based MPPT, in which the parameters of ANFIS is optimized using Flower Pollination Algorithm (FPA). Modified Luo (M-Luo) converter is employed in this work that has a superior output waveform, high power density and improved voltage gain transfer, also tracks maximum ideal power from PV modules. For the purposes of remote monitoring and control, the proposed network system uses the Internet of Things (IoT) to send vital data to the cloud. It is possible to remotely monitor the system to IoT platforms. Both simulation and hardware implementation are performed in MATLAB/SIMULINK environment and laboratory setup, respectively, for evaluating the proposed system.**

Keywords*— *Internet of Things, Adaptive Neuro Fuzzy inference system, Flower Pollination Algorithm, Maximum Power Point Tracking, Photovoltaic system, Modified Luo converter.

I. INTRODUCTION

Consumption for renewable energy sources is growing as conventional energy sources run out day by day. Due to its availability, affordability and environmental friendliness, solar energy sources are feasible sources of clean energy for both developed and developing countries [1]. The alternative effectiveness of modern PV systems is minimal. As a result MPPT are a crucial component for obtaining best power tracking from PV modules [2]. Solar energy, a form of natural energy, has been employed extensively in response to the rising environmental deterioration because of its limitless supply and favorable effects on environment [3]. However, power extracted from panel is decreased due to receiving uneven irradiance and temperature when panel of a PV system is entirely or partially shielded by tall trees, nearby buildings, and passing clouds. Consequently, MPPT technologies have been used to increase PV system's conversion efficiency [4, 5].

The voltage from input is amplified to higher and lower voltage levels in output by using common single switch step-down/step-up converters like Boost [6], Buck-boost converter [7], Cuk [8], Single Ended Primary Inductance Converter (SEPIC) [9] and Luo converter [10]. Modified Luo converter is proposed in this work that operates with high duty cycle, better voltage gain and efficiency. Artificial Bee Colony (ABC) algorithm-based Fuzzy MPPT approach presented in [11] with a zeta converter, where PI controllers and sensors frequently impacted by environmental factors. Grey Wolf Optimizer (GWO) based MPPT technique is suggested in [12, 13], which facilitates smooth beginning of a brushless DC (BLDC) motor to regulate M-LUO converter, but its convergence speed is low. The work presented in [14] utilized Particle Swarm Optimization (PSO) technique and describes a MPPT approach for PV system based on Lagrange Interpolation Formula. In this paper, FPA is proposed for optimizing ANFIS parameters for MPPT approach. By utilizing an LC filter [15] harmonics of system is minimized and improves stability of proposed system.

The problems with conventional converters are; converters cannot be operated at high duty ratios to generate a greater gain since the output current is pulsing, requiring a large output capacitor to reduce ripple voltage and there are more number of iteration in their algorithms. A novel FPA optimized ANFIS based MPPT controller is proposed in this work which aids in improving ANFIS parameters for better working of converter which in turn produces optimal power supply to grid. The benefaction made in this work is listed in the following,

- Installing solar PV systems, which are abundant, profitable, and good for the environment, as primary power sources.

- Extracting optimal energy from a PV cell, a M-Luo converter is employed, that maintains output with minimized switching losses and operates at high duty cycle.
- ANFIS controller with FPA-tuned settings is utilized to sustain steady-state voltage at modified Luo converter's output.

Overall system is executed in both software and hardware approach and corresponding outcomes are attained.

II. Proposed System Decription

The schematic diagram for FPA optimized ANFIS controller for PV tied grid system proposed for IoT monitoring application is illustrated in Fig. 1.

In this work, solar panel is employed for tracking energy from sun. Due to its erratic nature, converters are used to step up or down the power generated by solar panels. Modified Luo converter is utilized because of its high voltage gain transfer and extracts optimum power from panel constantly. To generate appropriate pulse for working of modified Luo converter's power switch, ANFIS-FPA MPPT controller unit is triggered, which in turn PWM generator produce gate signals. With an interface between inverter circuit and PV system, this converter offers a better power/density ratio with an affordable implementation. The fixed DC voltage obtained is fed into 1ϕ VSI, which assist in DC-AC conversion. The converted Ac signal is given to LC filter which eliminates harmonics like noise from signal and finally harmonics less supply is fed into grid. The output from solar panel and converter is controlled and monitored using IoT application.

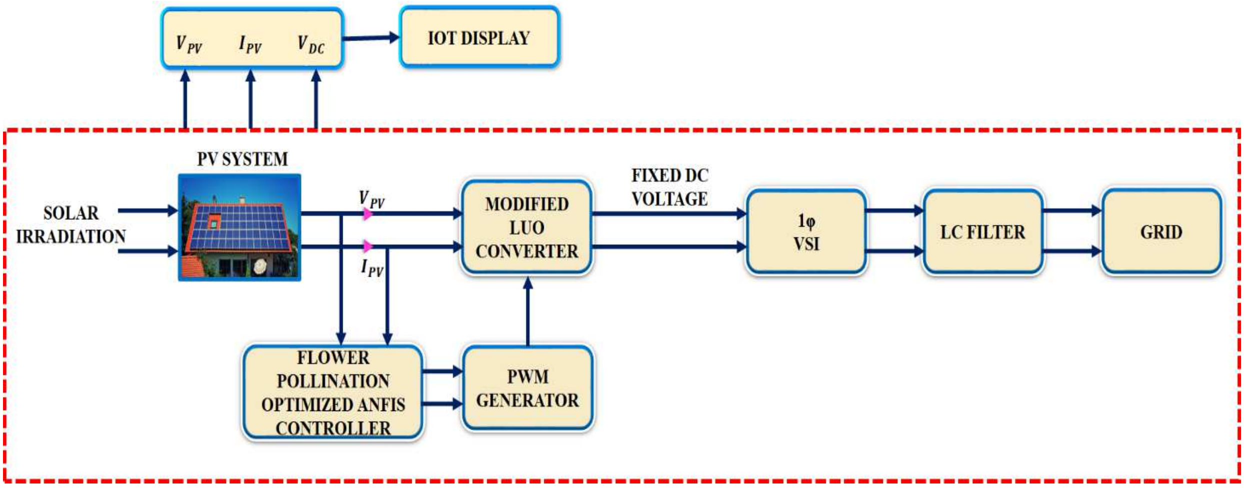

Fig. 1. Block Diagram for Proposed System

III. Proposed System Modelling

A. Modelling of PV array

Solar radiation, dirt, shadows, temperature are some of the elements that significantly affects output of PV cells. Electrical models for PV cells that are extremely popular are single diode and double diode variants. Single diode models are more efficient and simpler to build than double diode models.

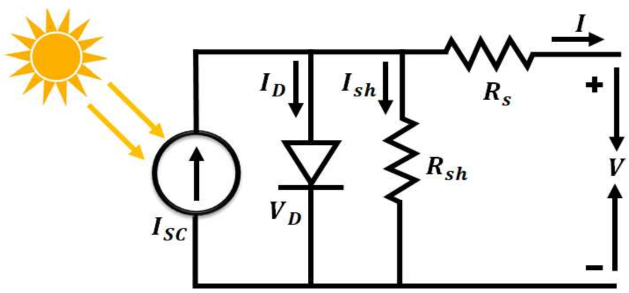

Fig. 2. Single diode solar cell

It also has series resistance with low value and optimal diode factor, which improve its performance of PV cells. Therefore, in this study, PV model with single diode is employed. Fig. 2 depicts a reduced equivalent single diode electrical model of solar cells. Equation (1) depicts the relationship between I-V curve.

$$I = I_{sc} - I_o\left[\exp\left(\frac{V+R_S I}{\frac{N_S KT}{q}a}\right) - 1\right] - \left(\frac{V+R_S I}{R_{sh}}\right) \tag{1}$$

Where I_o denotes saturation current, ideality constant of diode is indicated as a, short circuit current is defined as I_{sc}, PN junction temperature is indicated as T, N_s indicates series connected cell, $k = 1.38 \times 10^{-23} J/K$ denotes the Boltzmann constant, R_{sh} and R_s denotes shunt and series resistance of array respectively, $q = 1.6 \times 10^{-19}$ C indicates charge of an electron.

Equation (1) is expressed as (2) when rewritten, if thermal voltage of array is given as $V_t = \frac{N_S KT}{q}$,

$$I = I_{sc} - I_o\left[exp\left(\frac{V+R_S I}{V_t a}\right) - 1\right] - \left(\frac{V+R_S I}{R_{sh}}\right) \tag{2}$$

Since the output from solar panel is intermittent in nature, converter approach is required for improving solar PV array output. The converter methodology proposed in this work is explained in the following.

B. Modified Luo Converter

The elements, which include output inductorsL_2 and L_3, input inductor and capacitors L_1 and C_1 and capacitor C_2 as output dc link operate in a continuous conduction modes with minimal strain in device and its constituent parts. Fig. 3 illustrates modified Luo converter model.

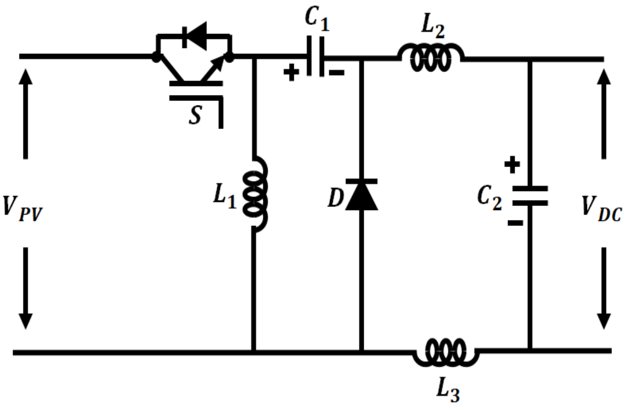

Fig. 3. Modified Luo Converter

The method of operation may change based on the duty cycle and it is expressed as,

$$\text{Duty cycle}=\frac{V_{out}}{(V_{out}+V_{solar})} \tag{3}$$

Where V_{out} Luo converter's output voltage average value. The output current is written as given in (4),

$$I_o = {}^{P_{out}}/_{V_{out}} \tag{4}$$

The maximum ripple values permitted for L_1 and C_1 is expressed as given in (5),

$$\Delta I_L = I_o \times \frac{V_o}{V_{in(min)}} \tag{5}$$

$$\text{Where } \Delta I_L = \Delta I_{l1} = \Delta I_{l2} \tag{6}$$

Modified Luo converter's inductor L_1 is expressed as given in (7) which aids in smoothen the ripple content present in input source,

$$L_1 = DV_{solar(in)}/f_{sw}\Delta I_{l1} \tag{7}$$

Where switching frequency is denotes asf_{sw}.

The inductance L_2 and L_3 of M-Luo converter are calculated using equation (8),

$$L_2 = (1-D)V_{solar(in)}/f_{sw}\Delta I_{l2}=L_3 \tag{8}$$

The change in capacitor voltage across C_1 is expressed as,

$$\Delta V_{cs} = I_o \times D/C_s f_{sw} \tag{9}$$

The capacitor C_1 in M-Luo converter is calculated as given in equation (10),

$$C_1 = I_o \times D/C_s f_{sw} \tag{10}$$

The controller approach employed for MPPT in this proposed work is explained in the following.

C. Modelling of ANFIS Controller

The system combines ANN and fuzzy logic features, in which ANN is utilized for training Sugeno fuzzy controller to determine precise membership functions for variables based on their interdependence. A comprehensive rule foundation is created by deriving the weights of each of the involved nodes. The model's inputs consist of ambient temperature, or the voltage, solar irradiance and current of the PV array. Fig. 4 depicts ANFIS's design, which has two inputs (x, y) and one output (z).

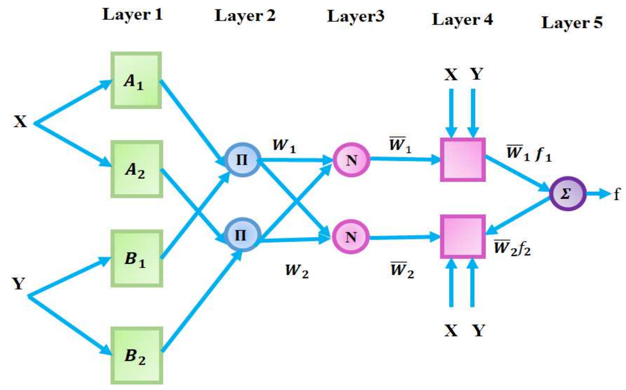

Fig. 4. ANFIS Architecture

The following are the set of fuzzy rules for a two-input (x, y) and one-output (z) FIS:

Rule 1: If x is A_1 and y isB_1 then,

$$f_1 = p_1x + q_1y + r_1 \tag{11}$$

Rule 2: If x is A_2 and y is B_2 then,

$$f_2 = p_2x + q_2y + r_2 \tag{12}$$

The output function given as follows;

$$f = \frac{w_1f_1+w_2f_2}{w_1+w_2} \tag{13}$$

The rule table and member function are readily tuned with the aid of ANN. For the purpose of improving nonlinear functions, ANFIS controller's inference system corresponds to a collection of fuzzy rulebooks with learning fitness.

In order to implement the suggested system, optimization algorithm is chosen for improving parameters of ANFIS controller and the following explains the process of optimization proposed in this work.

D. FPA-ANFIS based MPPT controller

A modern meta-heuristic optimization technique that takes guidelines from how flower pollination is processed is employed in this work. New flower species emerging as a result of this process. The FP algorithm is an incredibly simple and inexpensive method of implementing MPPT in solar panels. The software and hardware platforms are both accessible to this algorithm's adaptation. It works based on disruption occurred in PV voltage. The features of pollination process and pollinator behavior is stated up as follows in order to execute FPA:

Rule 1: Worldwide pollination process is named as cross-pollination that results when insects that pollinate, transport pollen, in a Levy flight pattern. The first rule has a specific mathematical representation as expressed in (14),

$$x_i^{t+1} = x_i^t + L(g_{best} - x_i^t) \tag{14}$$

Where g_{best} current population's best solution and x_i^t denotes pollen i or solution vector x_i at iteration$t$.

Rule 2: Local pollination process is represented by self-pollination. The following states characteristic equation for local pollination,

$$x_i^{t+1} = x_i^t + \varepsilon\left(x_j^t - x_k^t\right) \tag{15}$$

Where ε is represented by local search in distribution, $\varepsilon\, \epsilon\, [0,1]$ and x_j^t and x_k^t are different flower's pollen grain of same plant species.

Irregular optimization concerns are ideally suited for FPA algorithm. The fact that this method explores globally and utilizes locally in a single iteration makes it ideal for MPPT applications. The FPA's finest feature, in contrast to other bio-inspired algorithms, is how it infuses unpredictability through self-pollination into each cycle.

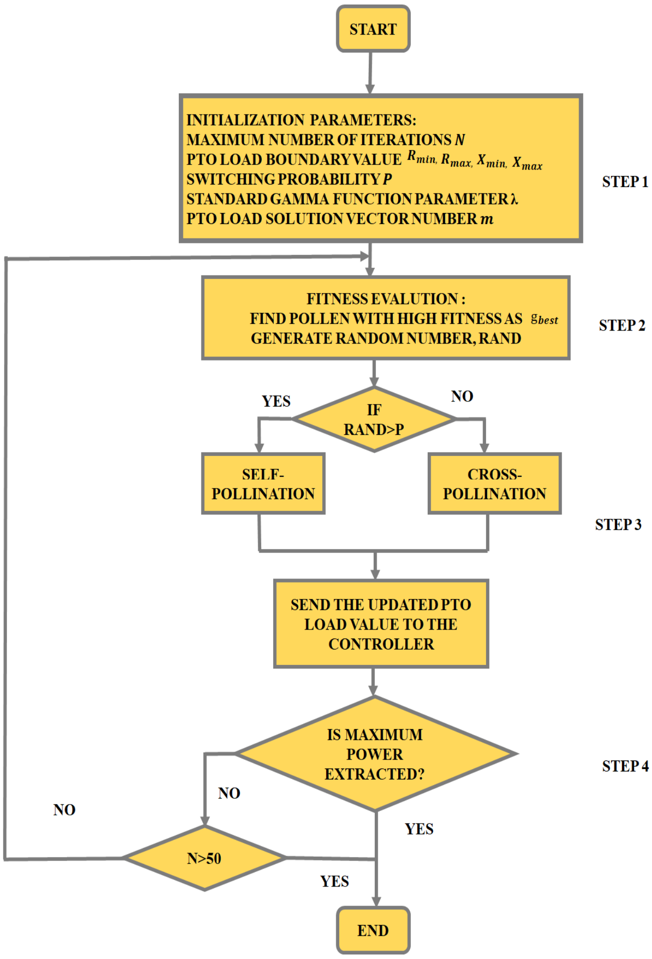

Fig. 5. Flowchart for MPPT control based FPA

The point-absorbing type WEC's maximal energy extraction is hence best suited for the FPA. Additionally, this approach is independent of irregular waves' dominating frequency characteristics and the precision of excitation force. Four steps are involved in implementing FPA-MPPT control as listed below and flowchart is illustrated in Fig. 5;

Step 1: Generate switching probability of pollination (P), maximum number of iterations (N), solution vector number of PTO load (m), standard gamma function parameter and objective function.

Step 2: Analyze state of fitness, where the fitness function serves to determine the appropriateness of pollen. After choosing pollen with highest fitness as g_{best} , a random number called $rand$ is created.

Step 3: Initiate process of pollination, which tends to choose whether cross pollination (if rand P) or self-pollination (if rand > P) is carried out. Check cross- or self-pollination took place between every pollen in the population.

Step 4: Ensure the end process, then repeatedly go from Steps 2 to 4 until most power point is collected or most iterations are displayed.

IV. Results and Discussion

In this work, FPA ANFIS based MPPT controller is employed for triggering modified Luo converter, which in turn aids in tracking optimal power from solar panel. Grid synchronization is performed using 1ϕ VSI. The overall system is executed in MATLAB and hardware implementations also performed. The waveforms are obtained correspondingly. The parameters specification of the propose system is listed in Table 1.

TABLE I. Parameters Specification

Parameters	Specification
Solar Panel	
Short circuit Current	8.3A
Battery	100Ah, 10V
Peak power	10KW, 10 panels
Series connected solar PV cell	36
Open circuit Voltage	12V
Modified Luo Converter	
Duty Cycle	80%
Switching Frequency	50kHz
Inductor (L_1)	13.46mH
Inductor (L_2)	0.005mH
Capacitor (C_1)	0.35µF
Capacitor (C_2)	97.03µF

The solar panel waveforms are illustrated in Fig. 6, in which 35 ° C of temperature is maintained constantly throughout the system as presented in Fig. 6(a).Waveform showing solar irradiance is depicted in Fig. 6(b) in which 1000 W/sq-m is attained from proposed system.

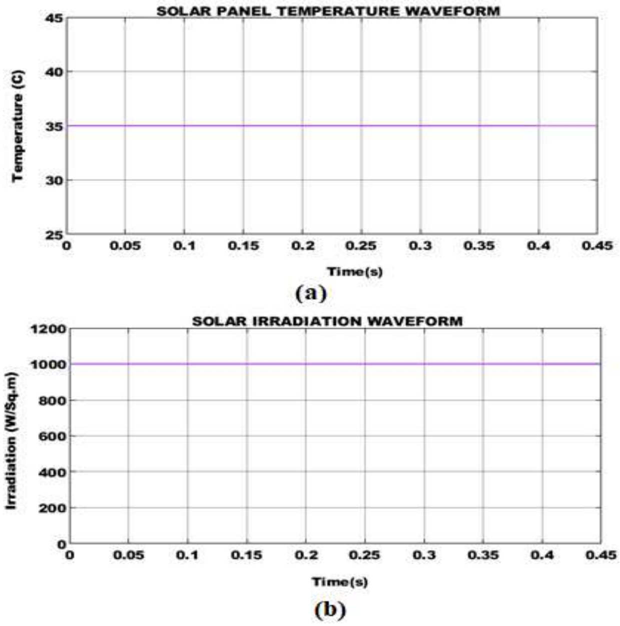

Fig. 6. Solar Panel Waveforms (a) Temperature (b) Solar Irradiation

The waveforms showing solar panel voltage and current are depicted in Fig. 7. The voltage waveform shown in Fig. 7(a) for solar panel details that 70V is steadily maintained throughout the system. Fig. 7(b) shows current waveform for solar panel in which initially it raised suddenly to 100A, then gradually decreased and maintained constantly at 35A after 0.15s.

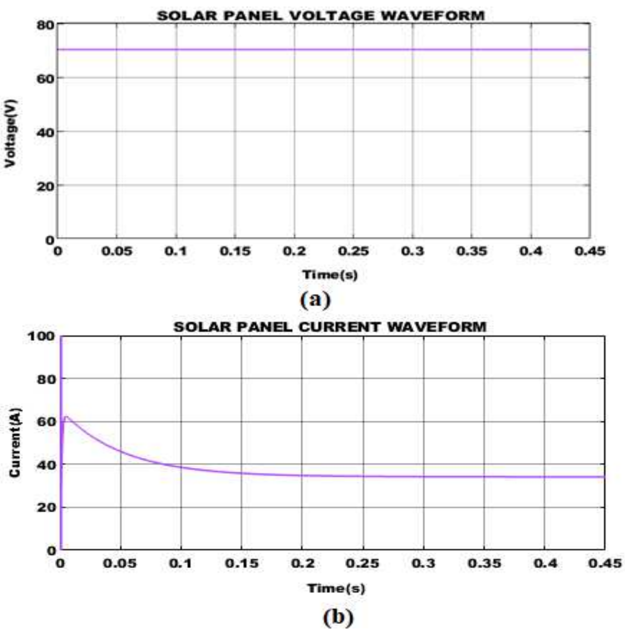

Fig. 7. Solar Panel Waveform (a) Voltage (b) Current

The waveforms for converter output is illustrated in Fig. 8. An output current waveform shown in Fig. 8(a) details that current is gradually raised above 3A and then maintained constantly at 3.3A after 0.25s. The waveform shown in Fig. 8(b) details that output voltage of converter is gradually increased above 300V and then maintained constantly at 330V after 0.25s.

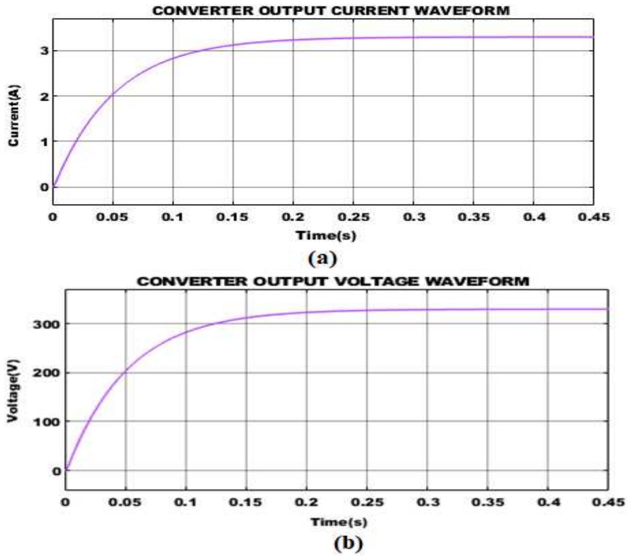

Fig. 8. Converter Waveforms (a) Current (b) Voltage

The output voltage of converter with FPA-ANFIS MPPT controller is depicted in Fig. 9, which details that 350V is maintained constantly using FPA-ANFIS MPPT controller.

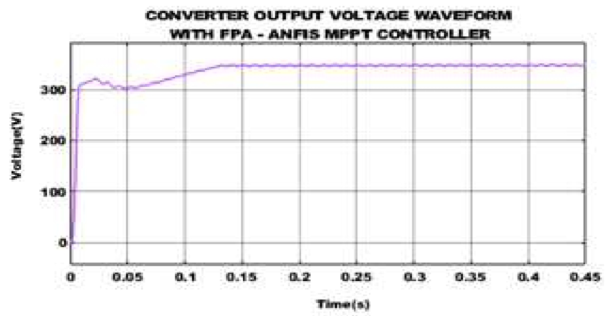

Fig. 9. Waveform for converter output with FPA-ANFIS MPPT controller

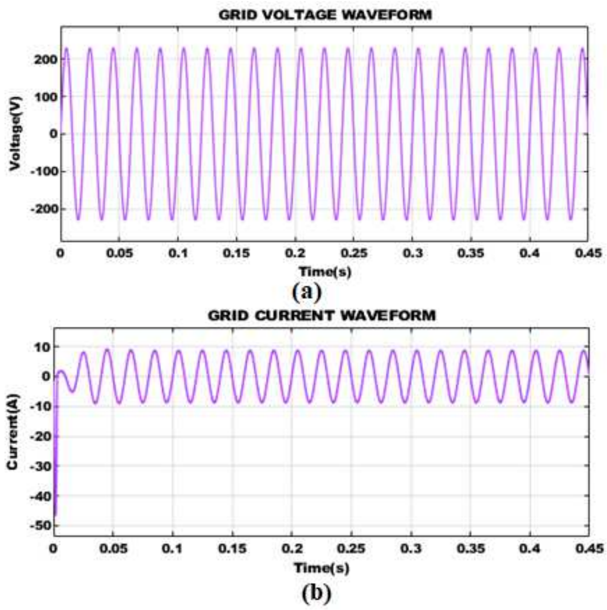

Fig. 10. Grid Waveforms (a) Voltage (b) Current

Fig. 10 shows the voltage and current waveforms of a single phase grid. Grid voltage is maintained within the range of +220V to -220V throughout the system as shown in Fig. 10(a). Initially grid current is decreased to negative value and then it is maintained constantly at 8A after 0.05s as presented in Fig. 10(b).

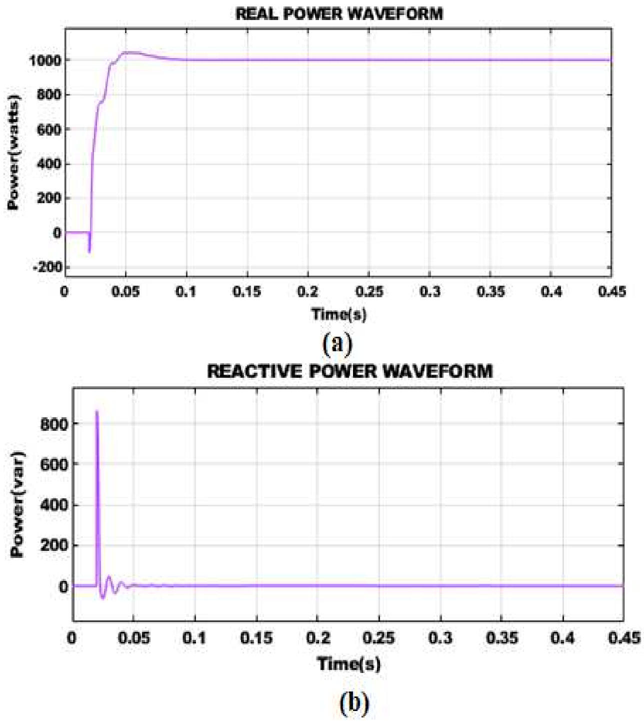

Fig. 11. Waveforms for (a) Real power (b) Reactive power

The waveforms for real and reactive power is presented in Fig. 11. Initially real power is maintained zero and then gradually increased to 1000W after 0.1s as depicted in Fig. 11(a). Reactive power waveform illustrated in Fig. 11(b) is maintained at zero throughout the system.

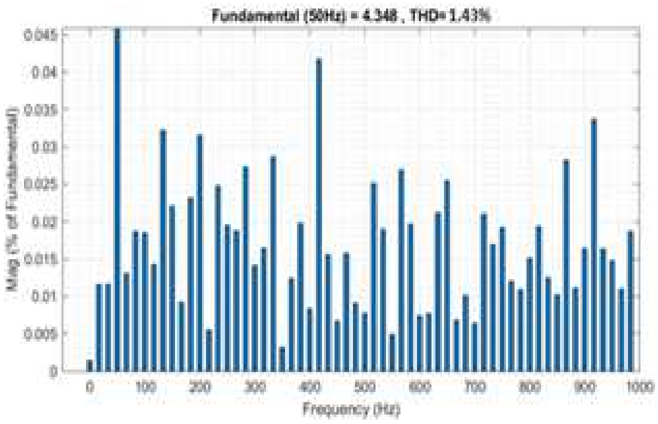

Fig. 13. THD waveform

The visual representation for THD is illustrated in Fig. 13. It is observed that 1.43% THD value is obtained for the proposed system, which indicated less harmonic distortion occurred in system.

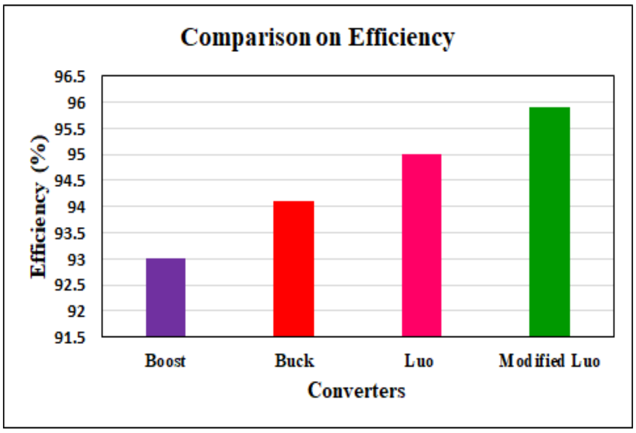

Fig. 14. Comparison Graph for Efficiency

The graph showing comparison for converter efficiency is depicted in Fig. 14, which M-Luo converter have better efficiency with 95.8% than Boost, Buck, Luo converters with 93%, 94.1% and 95% respectively.

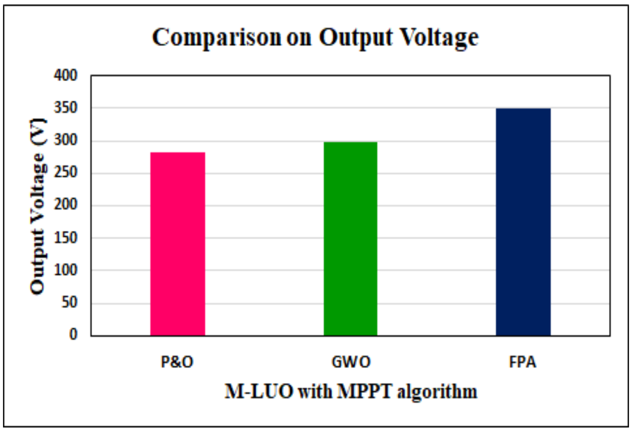

Fig. 15. Comparison Graph for Output Voltage

The output voltage comparison of several MPPT techniques is shown in Fig. 15. M-LUO converter based FPA with higher output voltage with 350V, performs better than previous approaches.

V. Conclusion

The intermittent nature of solar energy prevents a PV system from producing a balanced supply. Hence a novel M-Luo converter is employed in this work to step up and down as required, which in turn pulse signal is triggered using FPA-ANFIS based MPPT controller. Optimal power is extracted from solar panel using this converter which operates at high duty cycle, less switching loss and minimized ripples in outputs. The final system is analyze in MATLB Simulink software and THD value obtained from proposed system is 1.43% which is less than other conventional approaches and performance of the system is enhanced with efficiency about 95.8%. IoT feature is included in this system for controlling and monitoring the system remotely.

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