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Power Quality Improvements in Grid Connected PV System using Novel Optimization Technique

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Abstract: ***In the last few years, several concepts have been developed in the field of Power Quality (PQ) improvements. Features of PQ plays a significant part in power system based applications. Nowadays, technologies in Renewable Energy Source (RES) have got more opportunities for promoting Photo-Voltaic (PV) for generating electric power. It may affect the reliability and stability of entire power system, also produces the switching frequency with irregular manner and variation within the certain region. Also, Incremental-Conductance (IC) method miserably fails to recognize Global Maximum Power Point (MPP) and gets trapped in one of the Local MPP. Since the conventional MPPT (Maximum Power Point Tracking) might not separate the maximum power of the P-V characteristic curve, a novel tracking system needs to be established. In this research work, Kinetic Gas Molecular Optimization (KGMO) is implemented with IC for improving the PQ by providing the adequate switching pulse to inverter for enhancing the system performance. The proposed method reduced the Total Harmonic Distortion (THD) up to 4.67 %, and the efficiency is observed by evaluation over the traditional Radial Basis Function Neural Network (RBFNN) and IC-MPPT techniques. The proposed method is implemented in the MATLAB/Simulink software to analyze the performance of PQ issues.***

Index Terms: ***Renewable Energy Source, Power Quality, Total Harmonic Distortion, Photo-Voltaic, Kinetic Gas Molecular Optimization***

I. INTRODUCTION

In recent trends, the concern of power electronic devices becomes more, because of the exploitation in real time applications. Generally, various types of controllers are utilized for mitigating the various kinds of PQ issues [1]. The intense consolidation of PV is mostly build upon technological development of global radiation and PQ [2]. The inverter coupled with distribution system which is used for power conversion from DC to AC. Most of the voltage and current distortion affects the performance when the system connected with grid. Similarly, highly volatile devices are connected with increasing need of non-linear loads and RES influence the performance of system and power network regarding PQ [3]. The unusual functions of PQ affect the consumer and utility equipment. The PQ of the system may improve by integrating the renewable energy sources within the grid [4]. Here the adverse effects on system's PQ is improved based on the connected RES and nonlinear loads. The connected nonlinear loads in the grid specifies the injected harmonics and the amount of reactive power on the line is caused by the renewable energy source [5]. In the past few years, many kinds of RES based technologies have been developed. Some of that sources are increasing rapidly inexpensive and some are broadly identified as low cost option for grid related applications [6].

Similarly, the conventional methods used for improving the PQ is given as follows: The active power of RES is injected by using the Multifunctional Grid-Tied Inverter (MFGTI) for compensating the distortions and reactive power and also it balances the micro-grid currents. Due to the unbalanced load and voltage conditions, a simple control strategy is developed for a MFGTI [7]. The fundamental control and power balance control strategy are developed for PQ problems. The PQ problems of multi inverter based micro grid is resolved by the aforesaid two strategies. Besides, the harmonic suppression control strategy is used for minimizing the harmonic components [8]. The PQ is improved by adding the improved Dynamic Voltage Restorer (DVR) and RLC link filter among the injection transformers with voltage source inverter. The DVR performance is improved by using the 7-level H-bridge connected inverter. Then the switching harmonics are removed by the RLC filter [9]. In three-phase medium-voltage network, PQ and Low Voltage Ride Through (LVRT) capability of the hybrid PV-Wind is improved by using the DVR control [10].

To overcome the above-discussed issues, novel optimization is required, so here, by introducing a hybrid methodology based PV system which is connected with the grid to enhance the PQ features. The proposed MPPT method delivers extraordinary performances during constant weather conditions and unexpected dissimilarity of irradiance too. KGMO algorithm is used to validate the IC method. In other confrontations, the proposed system is utilized for monitoring the Global MPP (GMPP) of the PV. KGMO based IC technique is presented for attaining the supreme global point which exploiting the power withdrawal in the PV arrangements.

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II. RELATED WORKS

Numerous methods are proposed by researchers in power electronic devices related to PQ. In this section, a brief review of some important contributions to the existing literature is presented.

Zheng Zeng et al [11] presented a Multi objective control strategy developed for MFGCI to improve the PQ to a certain extent. This technique provides few advantage in PQ features since it customizes the available margin of capacity and requirement which demanded by consumers. But considering the PQ level, afore and afterward the compensation is quite complex to evaluate.

Mishra, N et al. [12] demonstrated A single phase grid connected systems utilizing the incremental conductance (INC) based MPPT algorithm. The appropriate voltage balancing is obtained in the neutral point by using the Carrier Based Pulse Width Modulation (CBPWM) technique. The grid current harmonics are reduced by injecting the PV power to the grid. Due to benefits of CBPWM technique such as low harmonic outputs and lesser switching losses, it is taken as suitable technique for this grid system. The PV array current is decreased simultaneously, when the insolation is changed.

Deepak C. Bhonsle, Ramesh B. Kelkar et al [13] proposed a new concept for improving the PQ at Point of Common Coupling (PCC) with the support of composite filter. This technique eliminate the random flickering compared with other type of filters. Depends upon the flickering level, some parameters will be evaluated. But sources having high flickering level, it creates more PQ issues.

Sudheer Kasa et al [14] presented Adaptive Neuro Fuzzy Inference System (ANFIS) based dynamic Active Power Filter (APF) for to mitigate the PQ issues and also enhance the THD of the power system. This method provides the continuity of supply while reducing the THD to the considerable level. But it cannot manage the huge quantity of power because it operates only in the moderate frequencies.

Madishetti, S et al. [15] demonstrated the PQ of system which is improved by using a Scott-transformer-based Power Factor Correction (PFC) rectifier for 3-level neutral point-clamped (NPC) inverter-fed induction motor drive (IMD). Moreover, the current feed forward control is used for handling the Scott-transformer-based PFC rectifier. The stator current ripple and stator voltage are decreased by using the three-level NPC Voltage Source Inverter (VSI). Also the better dynamic performance is accomplished by adding the dc bus reference current to the torque component of stator current reference. The sudden fall or increase of the motor drive's load variation affects the DC link voltage.

Sujatha, B. G., and G. S. Anitha [16] presented a hybrid method based on PQ improvement in grid integrated PV system. The joined performance of both the RBFNN and PI controller is established in this paper. The main purpose of this technique is to forecast the gain parameters for both the regular and irregular situation in micro grid. However, in contrast with other renewable technologies, PV systems still come across most important difficulties and may create some difficult effects to the system.

Prabaharan, N et al [17] proposed an incorporation of DC supply with compact switch MLI configuration for grid integrated PV system to attain better output. This topology needs few quantity of power electronic devices while related to existing MLI topologies for producing sophisticated output voltage with less THD. A possible disadvantage of every topologies is large number of autonomous fluctuating DC sources which makes their real-world usage somewhat problematic.

III. OBJECTIVES

The aim of this proposed research work is to design an effective methodology for the power electronic device with the consideration of PQ improvement. The objectives of this research are listed below,

- To satisfy the load demand of the grid, an efficient control strategy should be developed with PV source. Optimization algorithm is utilized for providing the adequate switching pulse to the multi-level inverter to provide essential power to micro grid.
- The PQ of the device is improved to create an effective power electronic device for the end users. By providing the adequate power to the grid side, there is certainly no probability of PQ problems.
- To maintain the constant voltage magnitude under system disturbances, the control strategy is used in the desired system to avoid PQ problems.
- The reactive power should be compensated at all times to enhance the entire system power factor. Meanwhile, minimizing the THD will improve the PQ of system.

IV. MODELLING OF PV SYSTEM

The PV cell's output power and efficiency are expressed in the Eqs. (1) and (2).

$$P_{pv} = AG\eta_{pv} \tag{1}$$

$$\eta_{pv} = \eta_{STC}\left[1+\alpha\left(T_c-25\right)\right] \tag{2}$$

Where, the output power is $P_{pv;}$ panel surface area is A A which is in m^2; the solar irradiation is G; the normal and standard test conditions efficiency are η_{pv} and η_{STC} respectively; the temperature coefficient is α which is denoted as $\%/^{o}C$ and the cell temperature is T_c.

The ouput power of the PV cell is given in Eq. (3), which is written by combining the Eqs. (1) and (2).

$$P_{pv} = P_{STC}\, f_{dr}\left\{\frac{G}{1000}\left[1+\alpha\left(T_c-25\right)\right]\right\} \tag{3}$$

Where, the f_{dr} specifies the de-rating factor and this factor considers the causes behind the dust and icing of the panels. The following Eq. (4) defines the cell temperature of the PV panel.

$$T_c = T_a + \left[\frac{NOCT - 20}{800}\right] \qquad (4)$$

Where, the ambient temperature is T_a and the cell's nominal operating temperature is $NOCT$ that is typically in the range of $45^{\circ} C\, to\, 47^{\circ} C$. The specification table for PV system is shown in below table

Table I. Specification table for PV array

Parameters	Value
Maximum power	305.226 W
Open circuit voltage (Voc)	64.2 V
Voltage at MPP (Vmp)	54.7 V
Temperature coefficient of (Voc)	-0.27269 (%/deg.C)
Cells per module	96 Ncell
Short-circuit current Isc	5.96 A
Current at MPP (Isc)	5.58 A
Temperature coefficient of Isc	0.061745 (%/deg.C)
Light generated current IL	6.0092 A
Diode saturation current	6.3014 e-12 A
Diode ideality factor	0.94504
Shunt resistance	269.5934 ohms
Series resistance	0.37152 ohms

V. PROPOSED METHODOLOGY

The block diagram for the proposed methodology is shown in below Fig. 1. The power from the PV arrays are provided to the DC-DC converter respectively. Then the power from the converters are flexibly fed into the multi-level inverter. The multi-level inverter converts the DC into AC and it is transferred to the grid (i.e., load). The basic principle behind the multi-level inverter is provided more amount of power in output. Besides, the staircase voltage waveform from the inverter accomplishes power conversion by using the semiconductor switches. This inverter enables the utilization of RES and also it gives higher power rating in the desired system. Generally, the multi-level inverter uses numerous dc voltage sources in the input to create the essential ac output level. Here, the waveform (e.g. sinusoidal) is generated as output by using more number of dc voltage sources in the input side. The increment in dc voltage source maximizes the PQ of output waveform and it decreases the lower order harmonics.

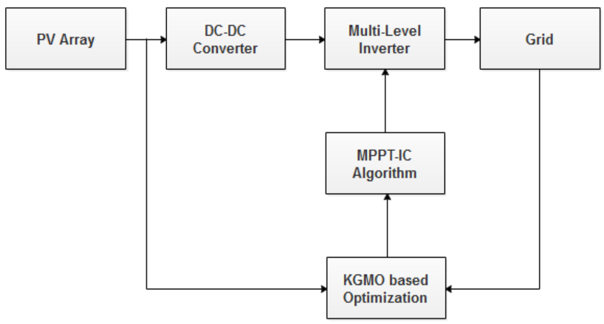

Fig. 1. Block diagram of the proposed methodology

A. KGMO Algorithm

KGMO is a swarm-based algorithm for solving nonlinear problems, which works based on gas molecule theory [18]. The gas molecules are the agents in the search space and kinetic energy is used as the basis of performance measurement and control [19], [20]. In this research, the KGMO algorithm is utilized to regulate the MLI. The PV power and load demands are the input to the KGMO. According to the input, the KGMO will generate a modulation index to regulate the switching pulses of inverter. The duty cycle for the DC-DC converter can be determined in same way that the instantaneous power can be maximized. The position of the gas molecules is determined as the duty cycle and generated power is chosen as the fitness function.

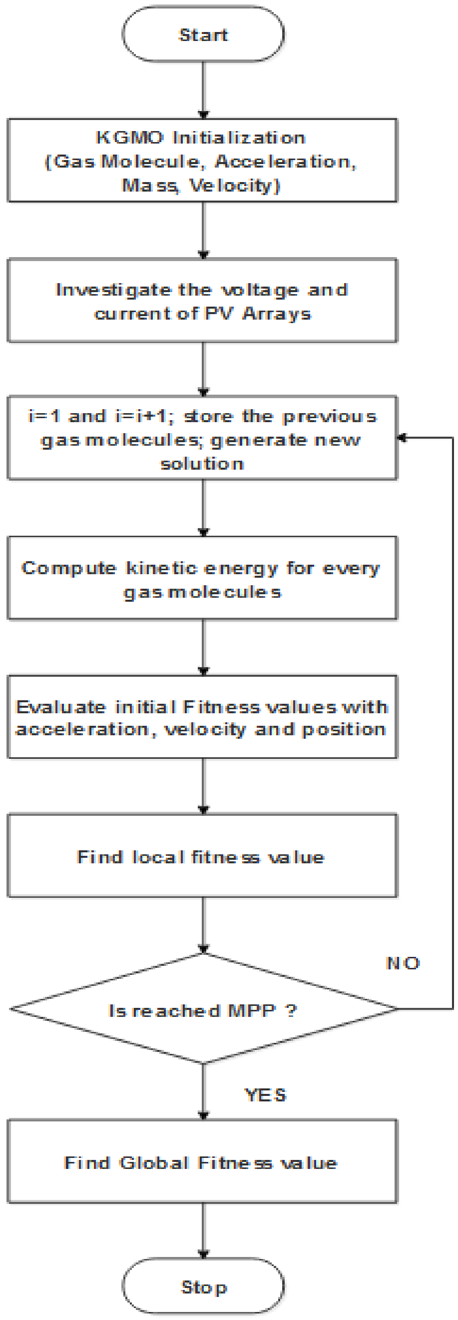

Fig. 2. Flow chart of KGMO

The process initializes with the arbitrary initialization of molecules in a search space and random initial velocities are taken. The gas molecules are initialized in the series of minimum and maximum duty cycle. Duty cycle varies in the limit of 0.1 to 0.9. The initial and final duty cycles are set as local best position and local worst position respectively. The maximum/minimum fitness values after the final iteration are assigned as global best and global worst position respectively. The new position of the gas molecules may become very far from the previous position because of the indefinite nature of KGMO. In such a case, the sudden change in position (duty cycle) will result in large voltage stress on the transistor switch. To reduce this stress, the duty cycle is sorted according to the last obtained value and the nearest duty cycle is outputted. Iteration process continues in the similar manner until the counter reaches the maximum set value and output the best solution when the maximum number of iteration count is attained. Otherwise, it increases the iteration counter and the fitness value is re-evaluated.

The number of gas molecule is a more significant factor in KGMO design. When utilizing every duty cycle, it's necessary to pause the transient condition to resolve; the higher resultant number of molecules will increase the tracking time of the MPP. In this research, 25 gas molecules are considered for finding search space. Another significant factor is a convergence of molecule since the duty cycle does not receive some value which is not within the interval [0, 1]. The gas molecules should converge in this particular duration; else, the arrangement can't discover the MPP. The flow chart of KGMO is specified in Fig. 2.

B. IC algorithm

In a PV system, an algorithm for MPPT is necessary to achieve the maximum power available from the solar modules. In the literature, the perturb-and-observe (P&O) method is the most frequently used MPPT algorithm. But in this work, IC is applied for MPPT, which is expected to give better results than the P&O method. The incremental conductance algorithm was developed based on P-V characteristic curve. It controls the duty cycle of boost converter to modify the functional idea of the PV module. It was developed to overcome the drawbacks of P&O algorithm. In this method, MPP was obtained using the relationship between $\frac{\partial I}{\partial V}$ *and* $-\frac{I}{V}$, which is expressed in Eq. (5).

$$P = VI \tag{5}$$

By taking derivative on both sides the Eq. 5, it represented in Eqs. (6), (7) and (8).

$$\frac{\partial P}{\partial V} = \frac{\left[\partial(VI)\right]}{\partial V} \tag{6}$$

$$\frac{\partial p}{\partial V} = I\frac{\partial V}{\partial V} + V\frac{\partial I}{\partial V} \tag{7}$$

$$\frac{\partial P}{\partial V} = I + V\frac{\partial I}{\partial V} \tag{8}$$

At MPP, the Eq. (9) is written as

$$\frac{\partial I}{\partial V} = \frac{I}{V} \tag{9}$$

Therefore, the Eq. (10) will be expressed as

$$\frac{\partial I}{\partial V} = -\frac{I}{V} \tag{10}$$

So this is the condition used for controlling the switching features of boost converter. The MPPT controls the PWM signal until this condition is satisfied. If MPP stays on the right side of the present position, then $\frac{\partial P}{\partial V}$ will be negative and $\frac{\partial P}{\partial V} < -\frac{I}{V}$, otherwise vice versa. Therefore, to reach MPP, the PV voltage should be decreased.

VI. Results and Discussion

The PV system is executed using Matab/Simulink environment for KGMO based IC. From the figures, the distribution of the absolute power from the PV arrangement by means of proposed MPP which nearly achieves the equivalent global MPP. The ability to find the global MPP for new weather conditions is very important especially for placing PV panel with frequent weather changes. To demonstrate the tracking ability, the proposed KGMO-based IC method during transient irradiance situations are considered and evaluated. Most of the traditional researches, fails to consider PQ improvement in the power electronic devices. The implementation of the proposed technique is carried out in the MATLAB/Simulink platform. The grid-tied PV system is modeled and PQ is analyzed using KGMO optimization technique which is shown in below Fig. 3.

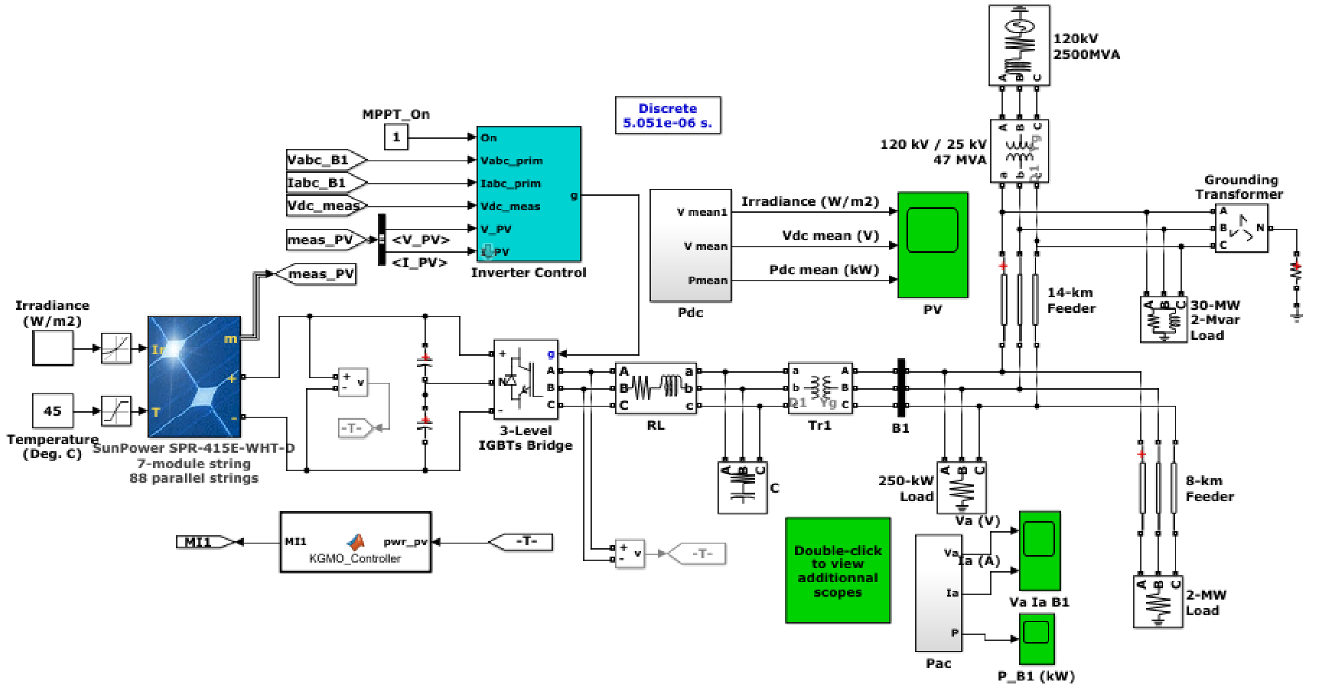

Fig. 3. Grid integrated PV system with proposed technique

In this research, the optimization algorithm with the consideration of the load demand is used for the benefits of PQ. The optimization algorithm provides the essential switching pulse at all time for various load values. To analyze the performance of simulation it's necessary to apply following modifications and the global MPP voltage and current for base case PV module is shown in Fig. 4.

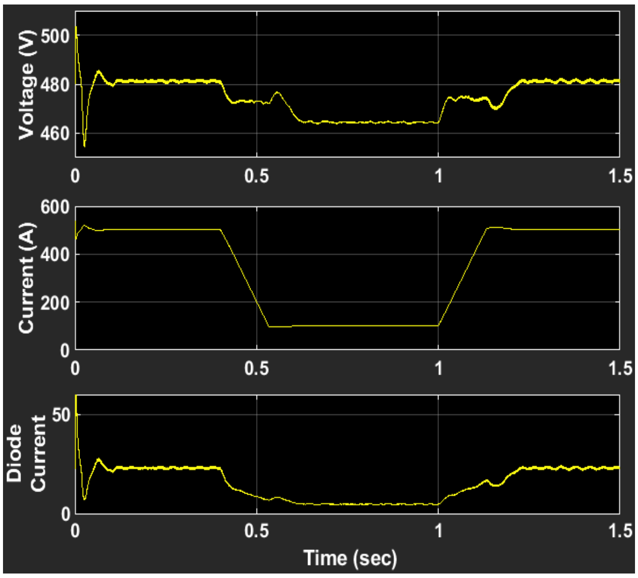

Fig. 4. Voltage and Current curve for PV

It leads to satisfy the power requirements of the system and also it improves the PQ. Similarly, the PQ is analyzed in terms of THD, voltage, current and reactive power compensation. The direct axis and quadrature axis current is shown in Fig. 5.

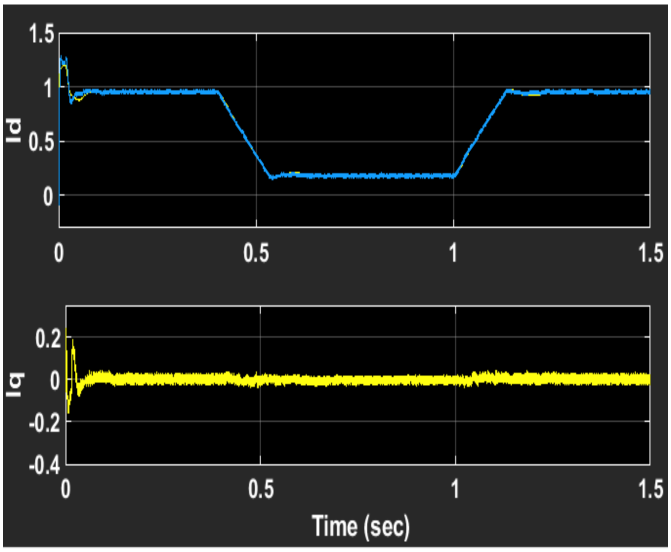

Fig. 5. Direct and Quadrature Current

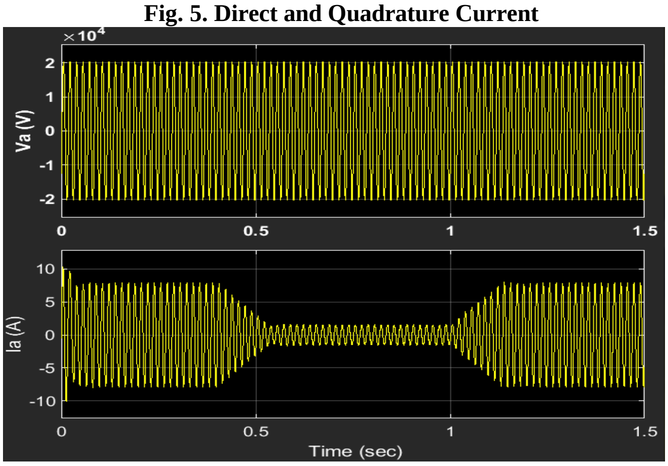

Fig. 6. Grid Voltage and Current

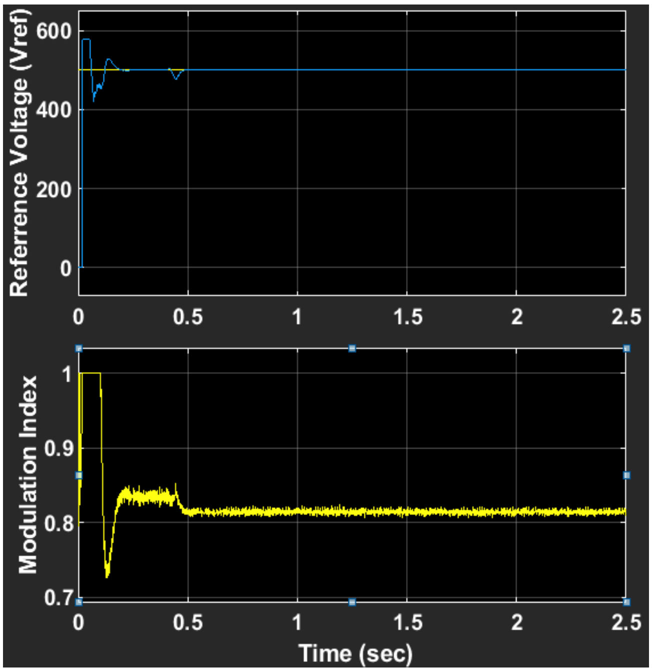

Fig. 7. Modulation Index Value

The grid parameters like voltage and current is given in Fig. 6. The proposed method gives the optimal modulation index value, which is shown in Fig. 7. The PV power, duty cycle of boost converter and grid parameters are analyzed at different conditions to check the improvement in power quality. PV power alone is illustrated in Fig 8.

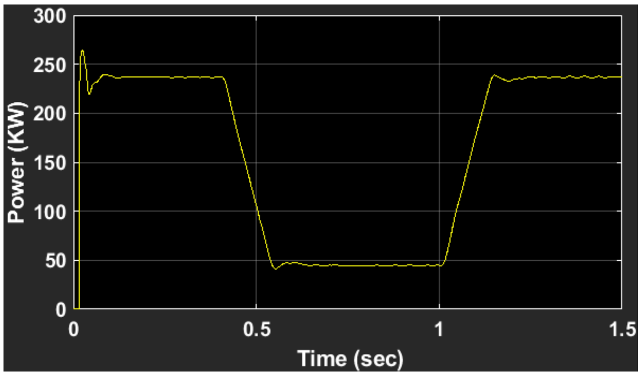

Fig. 8. Extracted PV Power

The presentation of the suggested method was evaluated by comparative examination through the proposed technique. The assessment properties represent that the projected technique could be a favorable solution for PQ enhancement of PV arrays during faults condition that is efficient over the existing methods which is mentioned in below section.

Table II. FFT computation

Solution Techniques [16]	THD (%)
Without Controller	24.97
PI Controller	12.86
ANN-PI Controller	8.44
RBFNN Controller	4.81
Proposed (KGMO) Controller	4.67

The FFT computation is shown in table 2, which clearly shows the proposed method reduced THD up to 4.67 %.

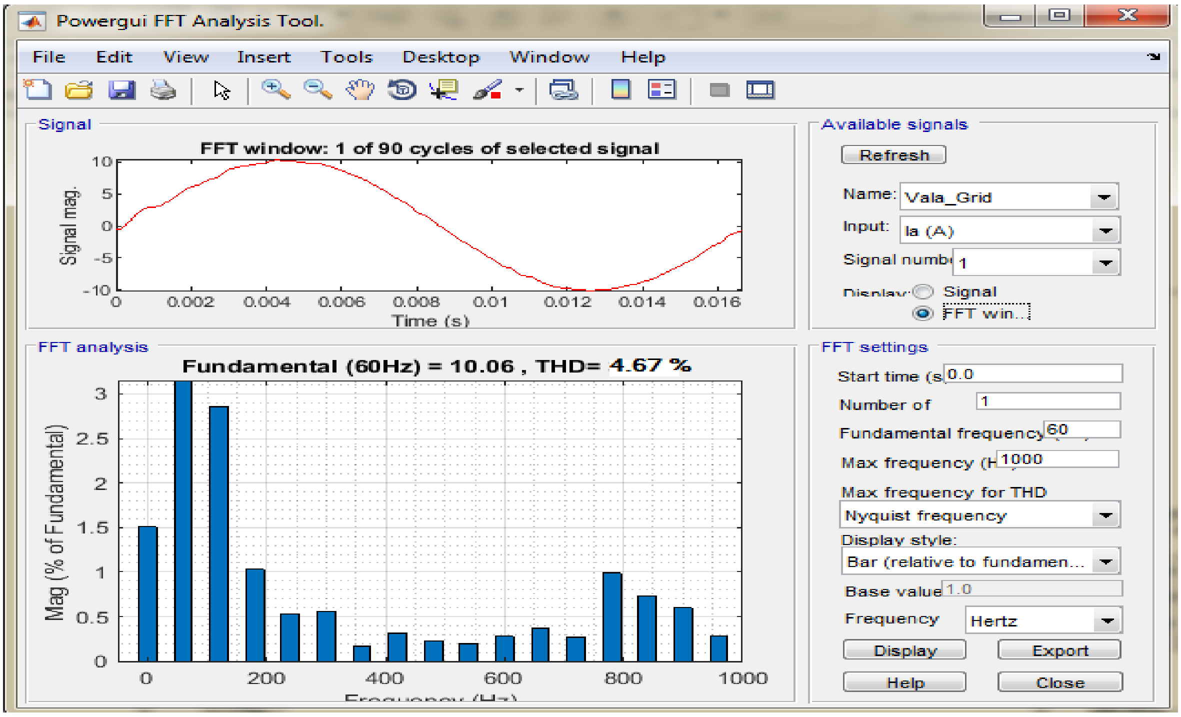

Fig. 9. THD calculation of Proposed Method

The THD calculation of load side current is done at different conditions and its measurement is given in Fig. 9. In the earlier studies, PQ of PV system output was improved using PI controller and ANN-PI controller. The PI controller reduced the THD only up to 11% in grid current and results from ANN-PI also had 7% THD.

The above results concluded that KGMO based optimization technique is very effective in dynamic weather conditions and gives lesser harmonics compared to other techniques.

Table III. FFT computation

Solution Techniques [17]	THD (%)
Improved IC-MPPT algorithm	17.95
Proposed (KGMO) Controller	4.67

From the table 2 and 3, it clearly shows that the THD of proposed controller is much superior over the existing techniques [16] and [17]. It can determine that the projected technique effectively enhances the PQ of the grid-connected PV system when related to the existing techniques.

VII. Conclusion

This paper evaluates and compares the proposed method with the conventional P&O algorithm based MPPT. The existing MPPTs are incompetent to identify the MPP during quickly varying insolation circumstances. Hence these procedures cannot be utilized in PV system to attain maximum obtainable power. In this research, proposed method will be integrated with PV for eliminating the harmonics, compensate the reactive power and maintain the voltage of dc link as constant. Furthermore, it will improve the efficiency of power conversion and PV is used as a source for providing the power to the loads. The PQ problems are occurred, when the source cannot send the essential power to the grid. So, the proposed method is exploited to provide the proper switching pulse to the multi-level converter. The switching pulse from the optimization algorithm is mainly based on the load demand of the grid. Then the multi-level converter provides the required power to the grid for eliminating the PQ problems. From the simulation results, the proposed KGMO achieves better THD values as 4.67 % which is much better than other existing techniques. In future, this research can be extended by modifying topology of inverter or by means of latest novel optimization technique to improve PQ features.

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