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# Investigation on load harmonic reduction through solar-power utilization in intermittent SSFI using particle swarm, genetic, and modified firefly optimization algorithms

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**Abstract**. A new Symmetric Solar Fed Inverter (SSFI) proposed with a reduced number of components compared to the classical, modified, conventional type of Multilevel Inverter (MLI). The objective of this architecture is to design fifteen-level SSFI, this circuit uses a single switch with minimizing harmonics, and Modulation Index (MI) values. Power Quality (PQ) is developed by using the optimization algorithms like as Particle Swarm Optimization (PSO), Genetic algorithm (GA), Modified Firefly Algorithm (MFA). It's determined to generate the gating pulse and finding optimum firing angle values calculate as per the input of MPP intelligent controller schemes. The proposed circuit is solar fed inverter used for optimization techniques governed by switching controller approach delivers a major task. The comparison is made for different optimization algorithm has significantly reduced the harmonic content by varying the modulation index and switching angle values. SSFI generates low distortion output uses through without any additional filter component through utilizing MATLAB Simulink software (2020a). The SSFI circuit assist Xilinx Spartan 3-AN Filed Program Gate Array (FPGA) tuned by optimization techniques are presented for the effectiveness of the proposed model.

Keywords: Symmetric solar fed inverter, particle swarm optimization, genetic algorithm, modified firefly algorithm, power quality

## 1. Introduction

Electrical or mechanical loads are governed by the power supply. The electrical power or voltage is trans-

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ferred to certain loads should comply with Power - Quality (P-Q) standards. The requirements of P-Q depends on the voltage or current for either input or output side within certain boundaries. The P-Q is still a major universal issue that outcome is enriched by power converters. The electrical power is enhanced by energy resources that have rapidly simulated the change of energy resources every year [1]. The P-Q issues are the hidden problems in the solar power distribution system, which has resulted in higher demand for electrical equipment. Therefore, the development of electrical power is dramatically shifted to sustainable energy sources [2]. The necessity for sustainable energy has grown up considerably over the years due to the fast depletion of fossil fuel, greenhouse effect in particularly solar, and also the wind has become more popular demanding requirements. However, it is necessary to improve the quality of the energy from these sources to safeguard the load connected equipment and maintain the customer continuity of supply ithout any disturbances. To fulfill the goal, it is necessary to connect intelligent techniques assists by the power electronic-based multilevel inverter which enables the P-Q improvement in between the input source, and loads.

The P-Q analysis in electrical load is generally divided into two categories; Non-linear load and linear load. The power factor improvement in Linear Load (LL) & Non-Linear Load (N-LL) observed much attention in the recent scenario for engineering researchers. DC/AC conversion can be functioned into two input environments: Symmetric MLI and Asymmetric MLI. Each and every type has become several circuits will apply the modulation for increasing number of levels, medium, and high output voltage applications. The various inverter topologies are proposed for DC/AC conversion in solar-Photovoltaic (S-PV) systems [3, 4]. There are three types of MLI structures such as diode clamped, flying capacitor and cascaded H Bridge. The drawback of this converter topology includes an increased number of devices required and control complexity. Where the conversion is generally focused on multiple repeating parts, but the system design introduces the development of SSFI technique which can reduce the repeating components.

The solar photovoltaic (S-PV) array module is consist of S-$PV_1$ to S-$PV_4$ made a voltage level of (12*4) 48 V and 4.90A. The parameters are open circuit voltage and short circuit current 64 V, 4.8A respectively as shown in Table 1. The ultimate aim of Maximum Power Point (MPP) is tracking the parameters are maximum voltage ($V_{max}$) and current ($I_{max}$) using the method of incremental conductance to determin-

Table 1
Implementation parameter of PV array

| S.no | Parameter | Range |
|---|---|---|
| 1 | Voltage at MPP, $V_{mp}$ | 64.35V |
| 2 | Power at MPP, $P_{mp}$ | 1 kW |
| 3 | Current at MPP, $I_{mp} = P_{mp}/V_{mp}$ | 4.8A |
| 4 | No. of series connected module, $N_{Ser} = V_{mp}/V_{mpp}$ | 9 series and 25 parallel strings |
| 5 | Module Type | SPR-306 Watts |

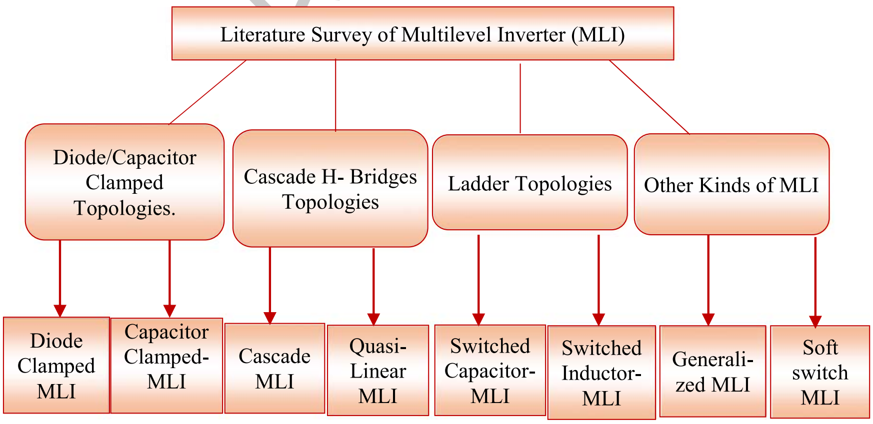



Fig. 1. Literature survey of multilevel inverter.

ing the duty cycle and generate digital pulses to both converter switches. The incremental conductance of the solar is to be determining an optimum operating current and maximum output energy passing to next juncture of the converters. Here, the first time is employed SSFI based on different optimization methods, and it's commonly applied to interface renewable energy systems. The literature review of MLI topologies is briefly described of reduces components such as a capacitor, power switch, diode, and DC source, etc., as shown in Fig. 1.

The sustainable energy technologies such as Solar-Photovoltaics (S-PV) and wind power have a key role to play for electricity generation. To minimize the pollution with low-cost interface inverters are increased to continuous power development by using meta-heuristic algorithms [5–10], which is determine the optimum switching angle and MI values. As one of the most critical problems is the electric input stage into a consumer stage, the consistency of the voltage should be taken as a good quality output level. As a result, a lot of investigation based on their attention to MLI, and it has been increased the electrical power efficiency by the way to reduce the harmonics level. The importance of staircase output voltage is has been enhanced as the multiple voltages with the help of minimum power devices required. SSFI increases the output voltage gain uses to modulation index and switching angle value based on optimization methods as compared [11–13], which is relatively higher than that of the traditional or conventional or modified MLI [14–16]. This system is designed with optimization control techniques such as PSO, GA, and MFA tuned control to reduce THD for simulation and experimental setup.

## 2. Design of solar-PV array

The solar-PV array module type is normally designed as sun-power 306 Watts shown in Fig. 2. The design of a single-phase inverter depends upon the input rating of Solar-PV. It contains the series-connected modules as per the string is 9, modules as per the number of cells are 96, and the parallel number as per string is 25 as shown in Table 2. PV panel efficiency and parameters as given in Equations (1) and (2).

$$\text{Fill Factor (F.F)} = \frac{P_{in}}{V_{oc \times} I_{sc}} \tag{1}$$

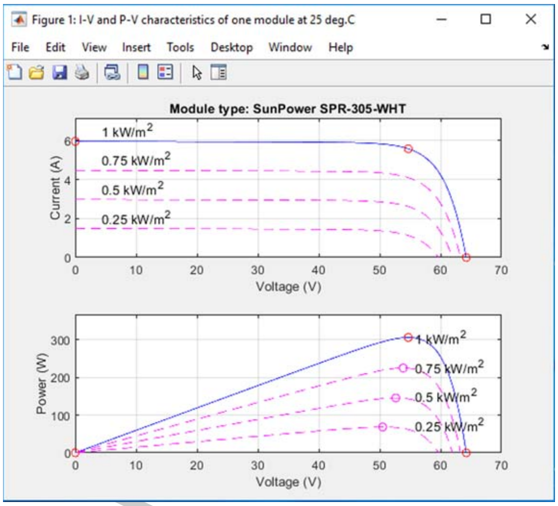



Fig. 2. Solar irradiation for module type (SPE-305 W).

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \tag{2}$$

## 3. Control strategy of optimization algorithm

The SSFI includes the S-PV input unit to enhance the DC power, and it's an optimization of the control algorithm as shown in Fig. 3. It comprises the control and optimization of bio-inspired based approach such as PSO, GA, and FA. The main objective of these optimizations approach minimizes the time, find out the optimum value, and also reduces the THD level. In general, the MLI's are power conversion system, it's containing and consist of a PV array based solid-state applications [17, 18]. The solar PV power is delivered energy to the converter, and it depends on 2 important parameters being designed Inductor and Capacitor (L&C). The major parameters are L&C furnished in proposed method, it will enhance the energy factor mention as $V_{PV}$ & $I_{PV}$ or $V_{DC}$ & $I_{DC}$. The proposed configuration of SSFI is related with line impedance. The merits of these control technique for power electronic systems, it's potential to use the limits of Linear Load (LL) and Non-Linear Load (N-LL). The SSFI will generate a multi-step waveform, which is verified in variable load frequency, phase voltage, and current with enriched power quality measurements. The control algorithm has calculated the independent variables of MI ($ma_1$, $ma_2$, $ma_3$, $ma_4$, $ma_5$, and $ma_6$), and the switching angle ($\theta$) depends on the various inverter switching state. That is required for every

Table 2
Deviation report of S-PV module

| Parameters | Without power tracking VLI | With power tracking MPP using VLI |
|---|---|---|
| Maximum power (Pmax) | 280watts | 305watts |
| Voltage at Pmax (Vmp) | 50V | 58.7V |
| Current at Pmax (Imp) | 4.01A | 4.98A |
| Open-circuit voltage (Voc) | 59.8V | 64.3V |
| Short-circuit current (Isc) | 4.0A | 4.8A |

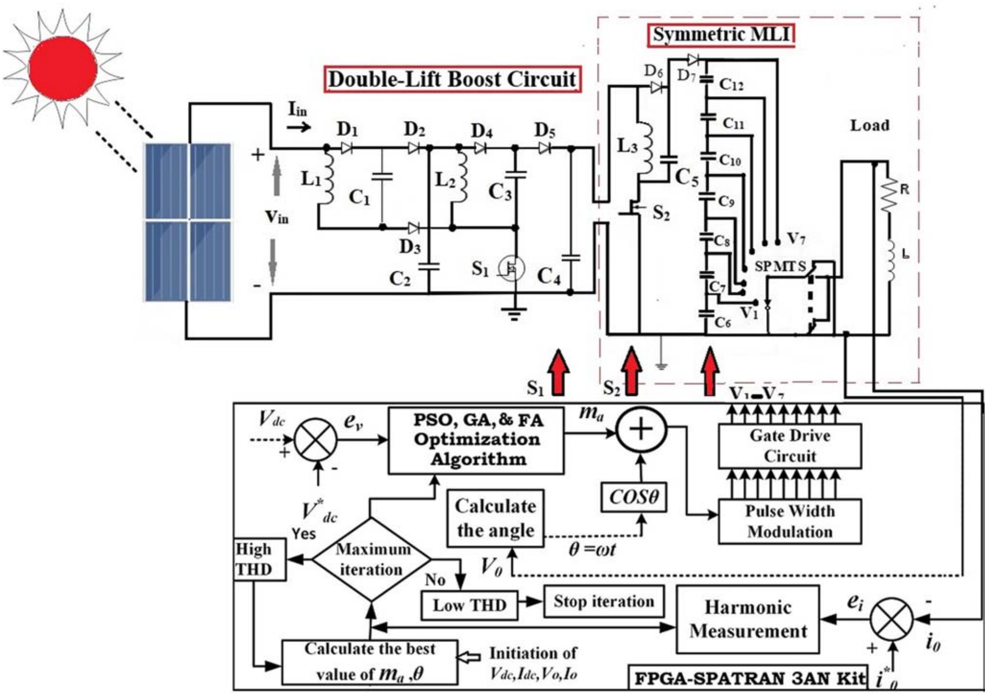



Fig. 3. Control and optimization algorithm implementation in 15-level SSFI.

inverter even or odd harmonics level. The lowest error of the expected value ($E_v$), and it's connected to the system integration of optimization function block. Usually, the control algorithms such as PSO, GA, and MFA have quicker control dynamics. This may be helpful to measure the total iteration within the time period, and it can be evaluated and compared with the least THD. In a comparison of FPGA is one of the key components of high performance processors. It's specifically in control and converts the electric power conversion utility.

The processor has been verified the latest innovations in the field such as the strongest variables with HDL operating code. These factors are used to determine the lowest THD. The optimization of FPGA processor would be operated continuously, once the optimum value found within the computational period or otherwise, the iteration is never stopped.

## 4. Implementation procedure of PSO algorithm

In 1995, Kennedy and Eberhart presented basic information and design of the PSO approach, which is an investigative method essentially present, and learned from the fundamental scenario. The particle optimization is originated from a population based, stochastic, and the natural behavior of a swarm of bee optimization. A population based search method with the position of the particle is representing a solution. It's also to solve the optimization non-linear problem-solving approach. The particle's basic algorithm and information are modified based multilevel DC-link converter, and the cost objective function should be minimized with three modified MPP methods are verified [19]. Compare to GA, benefits of the modified or conventional PSO's are all easy to incorporate within a single system. There are few parameters to be changed in the computational approach. The particles are flowing through the problem area by tracking the current optimum particles. Modified species and parameter estimation based particle swarm techniques have been developed by [20], and it has been described to determine the optimum switching angles for a multi-level converter and cannot be determined using either traditional iterative techniques or resulting theory method. The PSO techniques are producing the required voltage with lower order harmonics while minimizing the objective function and investigate the switching pattern of both bipolar and unipolar case. CH-B eleven level PSO based harmonic elimination [21] has been to solve a non-linear transcendental equation for different MI and eliminate the lower order harmonics with a less computational period.

### 4.1. Procedure for switching angle calculation

In recent [21], have dealt with single-phase modified PSO, there are plenty of optimization techniques in the determination of switching angles compared to GA, but the PSO algorithm requires less time to calculate and minimizes the harmonics problems of the multilevel output waveform. The SSFI have been also defined as the method of fewer harmonics level with reduced THD and to find switching angle with PSO optimization algorithm. The original formulations that can boost its efficiency with the particles changes, according to the principle are the following steps:

- ▷ The particle swarm algorithm starts with the development and assignment of initial velocity to the initial particles, the parameters are fixed by multilevel inverter constraints. In each particle location, it evaluates the objective function of the optimum location value and determines the best function of the switching angle 0 to $\pi$.
- ▷ The particle chooses a new velocity position, it is also based on the current velocity to determine the individual best location and fitness values with their neighbors. In PSO, a group of random particle swarm initialized and then optimized by updating generation. Each particle is updated with two best switching angle values in each iteration whether it appears in high or low in a different dimension as shown in Fig. 4.

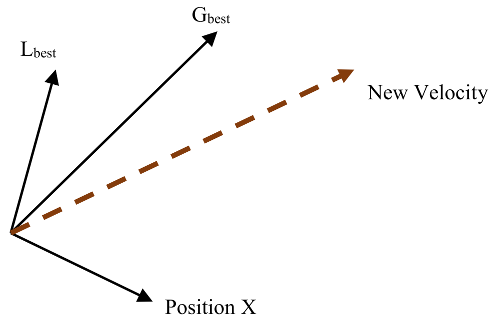


Fig. 4. Concept of PSO Velocity diagram.

- ▷ Iterations proceed with the particle locations, velocities, and updates neighbor until the algorithm reaches a stopping criterion as shown in Fig. 5. There is two PSO approach that differs in the size of their neighborhoods have been developed. The first one is $G_{best}$ PSO, for each particle, the neighborhood is entire in a single particle calculated in the population.

Which particle is the best swarm optimizer, and this value is called $P_{best}$. Another second best value, that is takes a part of the neighbor population followed by $L_{best}$, where smaller neighborhoods for each particle are defined as in the population as shown in the given velocity ($v$) Equation (3). In the PSO approach, the moment of particles is influenced by local best, and its search space or allow to the parallel exploration.

$$V_{ij} = V_{ij}(\mathrm{t}) + C_1 R_1(\mathrm{t}) \left[Y_{ij}(\mathrm{t}) - X_{ij}(\mathrm{t})\right] + C_2 R_2 j(\mathrm{t})[^\wedge Y_j(\mathrm{t}) - X_{ij}(\mathrm{t})] \quad (3)$$

where, $V_{ij}(t)$ - Velocity of the particle at a time (t), $X_{ij}(t)$ - Position of the particle time (t), i- Particle dimension (j - 1, 2, . . . . . . .N), $C_1$, $C_2$- Positive acceleration constant, $R_1$, $R_2$ - Random values, ranges from 0 to 1. The individual best position $Y_i$, it's associated with particle 'I'. that is the best position visited by the particle since, the first time particle step is falling local minima, and slow down convergence speed with the next step $(t+1)$ calculated as given in Equation (4),

$$X(t+1) = X(t) + V(t+1) \quad (4)$$

The particle velocities of the group are divided into 3-sorts, (1) Past velocity, (2) Cognition element, and (3) Social element. The contribution to ensuring sta-

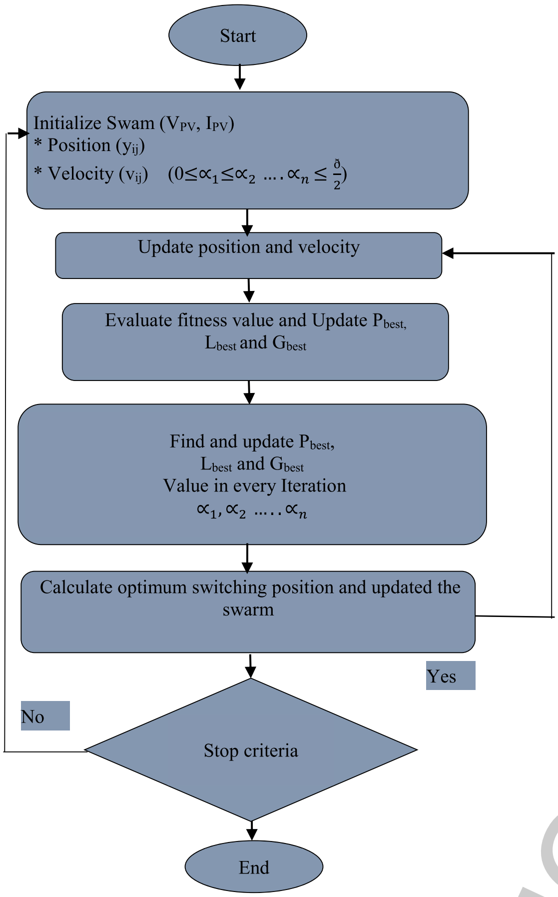



Fig. 5. Flowchart for PSO implementation.

ble cognitive convergence and social element inertia weighted by the stochastic amount is $C_1$, $R_1$, or $C_2$, $R_2$ respectively. When a particle takes the part of large inertia weight at the end of population as its convergence ability in topological neighbors, and the best new search switching value is a $G_{best}$. Where each particle can multiply in the new search criteria depend on the recent best value, after that finding the two best value of the switching angle. Finally, the particles are updated new velocity position of the switching angle. The objective function of the particles is to evaluate the fitness value of the harmonic minimization problem as given in Equation 5. The objective derivative function has been chosen to achieve optimal switching angles $\alpha_1$ to $\alpha_7$. Where, M is a modulation Index,

$$Fitness\,(\alpha 1 \text{ to } \alpha 7) = 100 \left[\left(M - \frac{V_1}{V_{PV(1-7)}}\right) + \frac{|V_3 + V_5 + V_7 + V_9 + V_{11} + V_{13}|}{V_{PV(1-7)}}\right] \tag{5}$$

### 4.2. Simulation results for PSO algorithm

The swarm based optimization has been approached with the MATLAB platform. The PSO function optimizes and provides the best MI value is 0.6. The MI value has been employee and generate the optimum switching angle ($\theta_1 = 18.95$, $\theta_2 = 24.50$, $\theta_3 = 53.91$, $\theta_4 = 63.91$, $\theta_5 = 70.9$, $\theta_6 = 76.87$, & $\theta_7 = 81.02$). The model of SSFI is obtained to maximize switching position while varied from $\theta_1$ up to $\theta_7$, and it can produce in between the quadrant part of the sine-wave 0 to $\pi/2$. The next part of the quadrant sine wave is while varied from $\theta_8$ up to $\theta_{15}$, and it can generate quadrant part of the sine wave in between $\pi/2$ to $\pi$. The harmonics are analyzed from equal DC voltage, and the switching angles have been determined by as per minimum harmonic voltages. It gives the minimum computational and population among the particles and parameters of implementation PSO optimization as shown in Table 3. It will generate the low order harmonics without the way of unsolved equation set. The output of R & RL load has been verified in voltage (Vrms) as shown in Fig. 6 (a&b). The minimum harmonics value of SSFI R-load (6.5%) & RL load (9.88%) as shown in Fig. 7 (a&b).

## 5. Implementation procedure of genetic algorithm

For many applications, the GA has been applicable for recognized techniques for achieving constraint, unconstrained problems, and it will give to create a solution for achieving maximum or minimize optimization problems. GA approach like nature, biological evaluation control, and design of individual machine tool solution. The GA is employed in this time equal amplitude of DC source. At each generation, GA is select random variables of the current population parents to use them to generate the next generation of children. GA optimization used to reduce harmonic method with unequal DC source [22]. The objective function of each point GA is encoded solution into a binary byte. It is associated with the fitness value of optimization, and the chromosomes are not constantly growing for all the time of generation. To determine the suitable fitness value with the help of optimization technic by using GA [23], which is use to eliminate harmonic level through switching angle variations. The same parameters are tuned and control the switching angle and MI values in proposed SSFI circuit.

Table 3
Control parameters of PSO

| Parameters | Value |
|---|---|
| Inertia weight, *w* | 09∼0.3 |
| Random variables [$R_1$, $R_2$] | [0,1] |
| No. of particles | 50 |
| Max. criteria | 90 iteration |
| Cognitive factor, $C_1$ | 0.02 |
| Social factor, $C_2$ | 0.91 |
| No. of population | 50 |
| Best MI (Ma) | 0.53 |
| Optimum switching angle ($\theta_n$) | $\theta_1 = 18.95$, $\theta_2 = 24.50$, $\theta_3 = 53.41$, $\theta_4 = 60.91$, $\theta_5 = 69.9$, $\theta_6 = 76.17$, & $\theta_7 = 81.02$ |

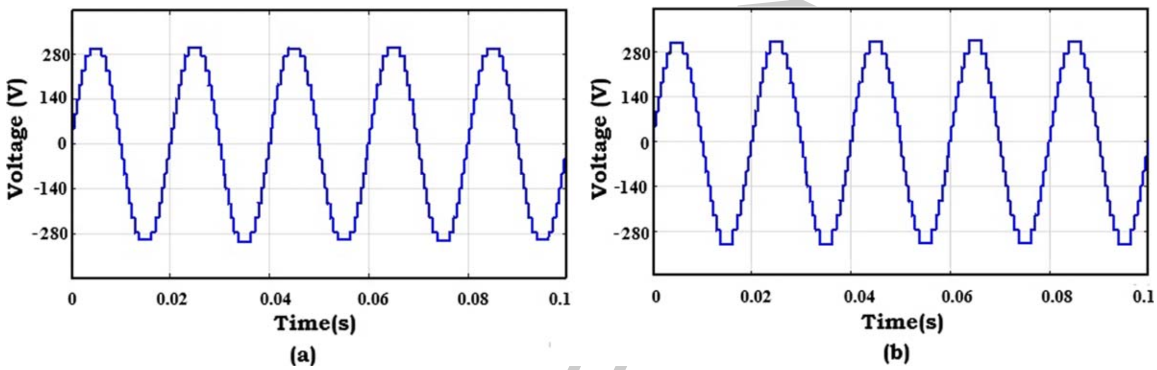



Fig. 6. SSFI output voltage with PSO (a) R-Load, (b) RL Load.

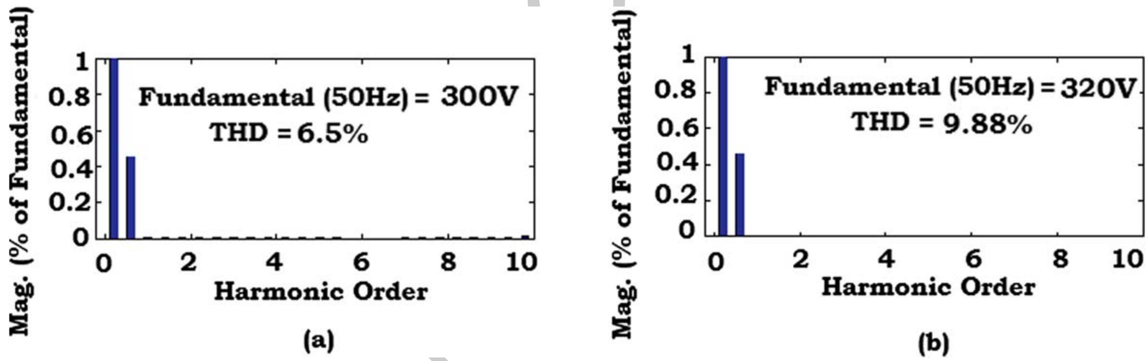



Fig. 7. FFT-spectrum analysis of PSO (a) R-Load, (b) RL Load.

### 5.1. Calculation of switching angles

Figure 8 shows the complex optimization problem-solving GA procedure flowchart. GA constructs a new population using a genetic operator, which is a process of mutation and cross-over. The members of greater fitness value of participation, and it will be like to evaluate the process of mating pattern arrangements. GA is heuristic for the search to mimic natural assessment process. The GA is used to find the operating switching angle into the various process in a SSFI circuit. These are the 6-stage of the proposed approach; (1). Generation of chromosomes initializes process, (2) Fitness, (3) New population, (4) Selection and cross-over, (5) Mutation, and (6) End of termination.

The first step process of the optimization, (1) Generation of chromosomes is initialized the first step of the process, and the population size is required to purpose of first random searching. There are twelve sets of chromosomes are used, to finding the 7-switching angle position ($\theta_1$ up to $\theta_7$) among the population.

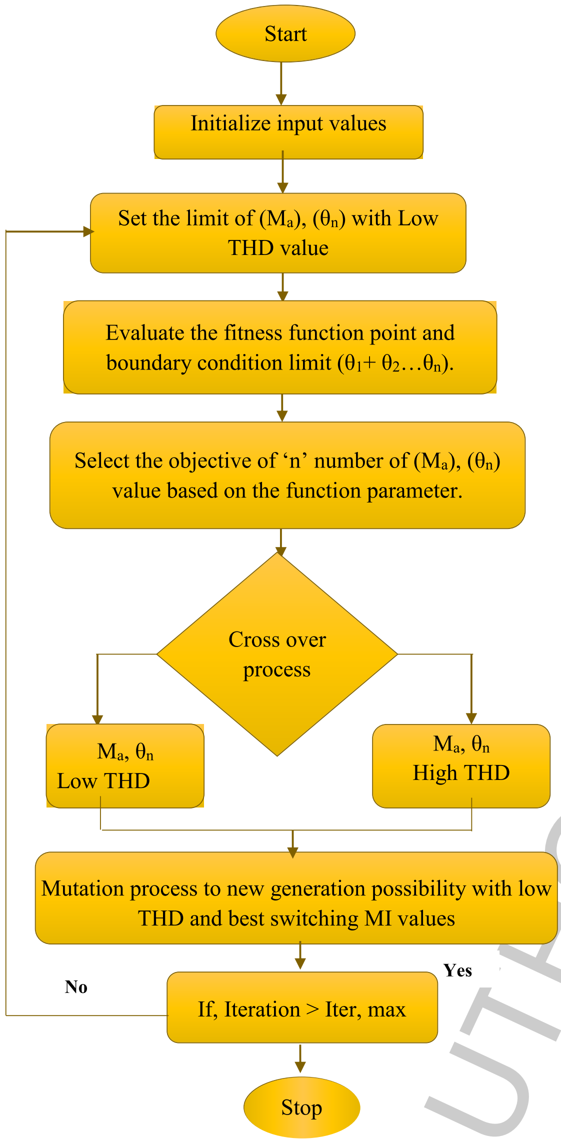



Fig. 8. Flow chart for GA optimization process.

The number of a specific value of the variables is proposed by SSFI. The second step optimization process is a fitness function. The GA is already delivered by the number of genes, and it is executed the fitness value. The one set of chromosomes population is verified by the MI and switching angle values (0 to 90° & 90° to 180°), and it's estimated to gives into consideration half-wave generation of best MI value minimized harmonic process. The optimization is derived by the best solution until the process should be again iteratively continued. The third step optimization process is new population approach, the proposed MLI switching position is equalized into the new generation. It will be a random switching position of the corresponding harmonic measured by FFT, and it has been optimizing and executed with the help of new chromosomes set.

The fourth step optimization process is selection and cross-over, the process of chromosome set which is followed by a low or high-intensity population, and each chromosome solutions are comprised of switching levels, that produce several switching angles of the best fitness value. There are various types of probability cross-over in the new set of parent's offspring, it also gives the different solution in the form of modulation indices. The each of cross-over method can be used to minimize harmonics. The fifth step optimization process is a mutation, at each gene mutation is modified by the new solution possibility of mutation generation. The sixth optimization step is end of the process is called Termination. The chromosomes were selected based on the fitness function. The end of the above process is continuous until the attained level moves into the maximum generation. Once it is satisfied in the current solution, the entire program stop with a new solution, or otherwise, it will move into step 2. The objective function of the proposed approach is to minimize the 3rd, 5th, 7th, 9th, 11th, and 13th harmonic order. To cost of the function is related to the harmonics of the SSFI circuit. Then F is cost of the fitness function selected to sum of these (THD) harmonics fundamental formula as given in Equation 6. In each chromosome are generated the output voltage created by using the switching angle, and it is required the harmonic magnitudes calculated by using FFT techniques.

$$Fitness\,(\alpha 1 \text{ to } \alpha 7) = 100 \times \left[ \frac{|V_3 + V_5 + V_7 + V_9 + V_{11} + V_{13}|}{V_{PV(1-7)}} \right] \quad (6)$$

### 5.2. Simulation results for genetic algorithm

The GA simulation results are carried out for MATLAB environment using a suitable toolbox. It has been verified with 15-stage topology, which is verified input from the S-PV panel. Table 4 shows the optimization of GA parameters is used for the entire program.

Figure 9 (a&b) shows the fifteen stage output voltage ($V_{rms}$) of MLI, the performance of the inverter is verified by different load (R & RL) load conditions. The FFT spectrum analysis of the proposed MLI is shown in Fig. 10 (a&b).

Table 4
Control parameters of GA

| Parameters | Value |
|---|---|
| Size of the population | 30 |
| Structure of the Chromosomes/Selection pattern | Binary code/Roulette wheel |
| Cross-over | 0.52 |
| Max. criteria | 100 iteration |
| Probability of the mutation | 0.298 |
| Best MI value ($M_a$) | 0.61 |
| Optimum switching angle ($\theta_n$) | $\theta_1 = 8.95$, $\theta_2 = 20.5$, $\theta_3 = 43.31$, $\theta_4 = 50.90$, $\theta_5 = 62.39$, $\theta_6 = 74.37$, & $\theta_7 = 79.02$ |

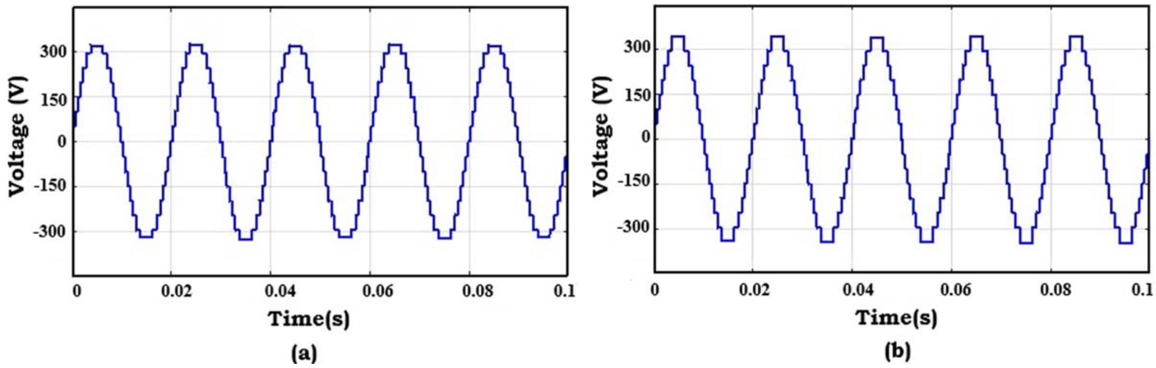



Fig. 9. SSFI output voltage with GA (a) R-Load, (b) RL Load.

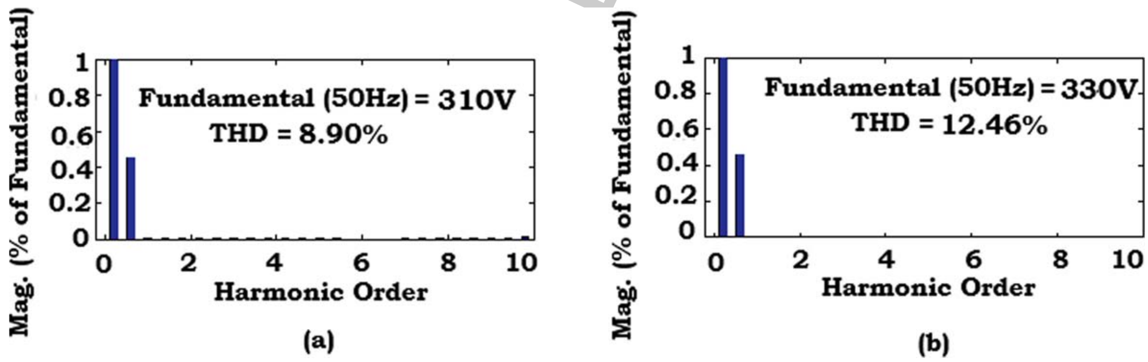



Fig. 10. FFT-spectrum analysis of GA (a) R-Load, (b) RL Load.

The MI ($M_a$) values are employed and produce the best switching angle ($\theta_1 = 8.95$, $\theta_2 = 20.5$, $\theta_3 = 43.31$, $\theta_4 = 50.90$, $\theta_5 = 62.39$, $\theta_6 = 74.37$, & $\theta_7 = 79.02$). The SSFI is obtained to maximize switching position while varied from $\theta_1$ up to $\theta_7$, and it can produce in between the quadrant part of the sine-wave 0 to $\pi/2$. The next part of the quadrant sine-wave is while varied from $\theta_8$ up to $\theta_{15}$, and it can generate quadrant part of the sine-wave in between $\pi/2$ to $\pi$. The harmonics are analyzed from equal DC voltage from the output side of the inverter, and the switching angles have been determined by as per minimum harmonic voltages. The minimum harmonics value of SSFI R-load (8.90%) & RL load (12.46%) has been presented in a GA approach.

## 6. Implementation procedure of modified firefly algorithm

The interpreted metaheuristic of MFA program was developed by [24], which is tested on flashing characteristics and behavior of firefly. Finding the best solution among the population to finding the optimum switching position in SSFI, and it was basic principles to attract mating partners of the fireflies to find out the better solution among the population. In general, the fireflies are progressed with lower light intensity, it will against the higher light intensity fireflies, and each other concerning the objective function. But, in this research modified random movement of brighter firefly will deal with random direction. In order to determine the best direction and find the best brightness of nonlinear model. The minimizing the objective function of multimodal optimization, and also minimized velocity function. Note that the light intensity and absorption can differ in each level along with the distance from the insect. Hence, there are no problems those correlated once such as GA and hybrid PSO.

### *6.1. Procedure of switching angle calculation*

The speed of the convergence of modified firefly program for acquired THD is given a very high performance within the chance of finding the global optimizing solution. The convergence improved by 2 firefly subgroup of difference search gender equation, and it gives higher search computational accuracy in less period of time [25]. The MFA based optimization is clarified in the following steps:

**Step (1) Initialization:**

In a primary progression of MFA optimization, initial PV input current ($I_{PV}$) and voltage ($V_{PV}$) are verified with the MFA parameters ($\beta_0$, n, $\alpha$, $\gamma$, & N), and the termination criteria. Now, the firefly's primary position is decided to be a switching position of the MLI. It enhances, the brightness of every firefly is taken as produced power from ($P_{pv}$), and it is dependent as to the position of the fireflies. The fireflies depend on the 2 essential functions, which produce bioluminescence flashes to draw in mating partners and to draw in potential prey. The objective function is given in the Equation (7),

$$I(r) = \left(\frac{I_s}{r^2}\right) \tag{7}$$

Where, Ir- intensity of source, r- the source observers from the distance.

**Step (2) Evaluation of Brightness:**

MFA optimization in a second step, the SSFI is operated depends on the updated position of each and every one firefly in sequential order. $P_{pv}$ is taken as the brightness (or) light intensity of the respective firefly for each switching angle ($\theta$), and the corresponding output power is to find among the population. The updated position of every firefly in the population is repeatedly taken. Now, decide the light intensity of each firefly is to find out to the brightness by using as given in Equation (8). Where, $\gamma$- absorption coefficient, and the Light intensity 'I' is varied with square of the distance r.

$$I = I_0 e^{-\gamma r^2} \tag{8}$$

**Step (3) Update Firefly's Position and Termination**

The firefly remains in position with improved brightness, and the other fireflies are updated. The firefly stays in place with greater visibility, while the other fireflies change their position. If the termination requirement is satisfied, the MFA optimization was terminate the program software or otherwise, it is moved into step 1. If all fireflies have dislocated in consecutive steps, the FA rule of optimization is terminated, and it's achieved a predefined set of reduction value in the FA population. Once the program is completed, the firefly population is initialized by evaluating the subsequent equation shown in (9);

$$x_{t+1} = x_t + \beta_0 e^{-\gamma r^2} + \alpha\varepsilon \tag{9}$$

Where the second term is due to the attraction, and the third term is the randomized parameters. It is calculated firefly's Attractiveness is given by the equation in (10),

$$\beta = \beta\_0 e^{-\gamma r^2} \tag{10}$$

The motion of several brighter fireflies towards a move into a brighter one, the displacement of firefly 'I' is attracted to an altered bonus attractive (brighter) firefly. J is the determined by the equation in (11),

$$x_i = x_i + \beta_0 e^{-\gamma \mathrm{ri,j}}(xj - xi) + \alpha\varepsilon \tag{11}$$

Check the concentrated lightweight of the firefly, and identify the fireflies in the present generation. Once fireflies have been ranked, the process of current optimal switched angle and MI ($M_a$) values are shown in Fig. 11. The optimization of FA is minimum estimation time compare with less THD in other metaheuristics approach such as PSO, GA, and bee colony algorithms [26]. The validation of simulation verified with experimental setup is confirmed by Spartan 6A (DSP) FPGA kit. The FA has been a minimum computation period hence, it's proved with less THD compared with PSO and GA approach. They are aimed at lowering the THD level by the minimum level of the SSFI. The values of firefly implementation of the MATLAB / Simulink platform were given in Table 5.

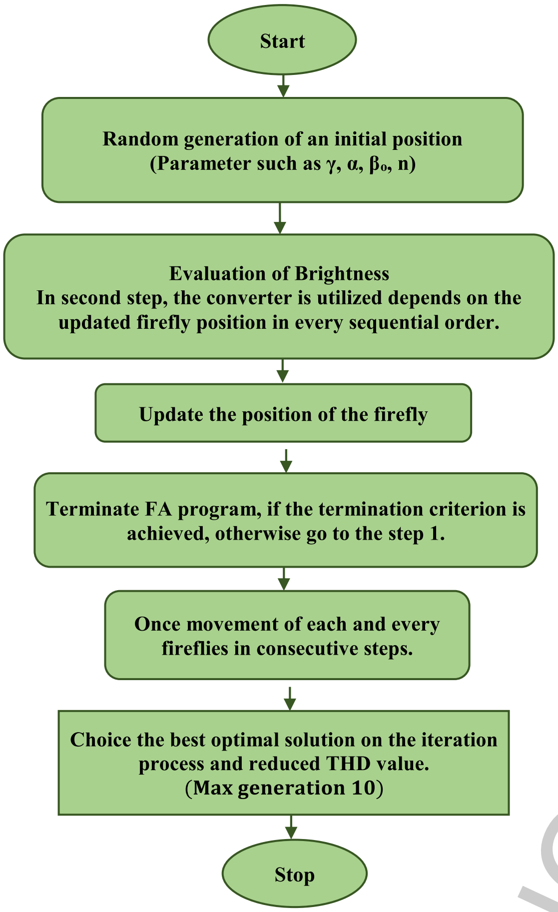



Fig. 11. Steps for MFA optimization to minimize THD.

### 6.2. *Simulation results for modified firefly algorithm*

The MFA simulation results are carried out fifteen level-SSFI. It has been verified with MATLAB/Simulink environment, which was verified the input source from S-PV panel. Figure 12 (a & b) shows the fifteen stage output ($V_{rms}$) voltage of MLI, the performance of the inverter is verified by different load (R & RL) load conditions. The FFT spectrum analysis of the proposed MLI is shown in Fig. 13 (a&b). The MI ($M_a$) values are employed and produce the best switching angle ($\theta_1 = 5.25$, $\theta_2 = 21.30$, $\theta_3 = 33.71$, $\theta_4 = 49.05$, $\theta_5 = 50.89$, $\theta_6 = 65.67$, & $\theta_7 = 76.03$). The SSFI is obtained to maximize switching position while varied from $\theta_1$ up to $\theta_7$, and it can produce in between the quadrant part of the sine-wave 0 to $\pi/2$. The next part of the quadrant sine-wave is while varied from $\theta_8$ up to $\theta_{15}$, and it can generate quadrant part of the sine-wave in between $\pi/2$ to $\pi$.

The harmonics are analyzed from equal DC voltage from the output side of the inverter, and the switching angles have been determined by as per minimum harmonic voltages. The minimum harmonics value of 15 level inverter R load (4.35%) & RL load (1.46%) has been presented in a MFA approach.

## 7. Comparison of simulation results

Simulation results are shown the determination of optimum MI value while varied from 0 to 1, and the switching position of angle should be evaluated in between (0 to $\pi$) interval. That is verified by the control optimization algorithm as shown given in Table 6. The proposed method is minimized by several power semiconductor devices, and it is based on the optimization technics like PSO, GA, and MFA. Discriminate in between of these optimized algorithms tested originally in proposed solar fed SSFI, and it is evaluated properly with the least THD process attained in FA control algorithm. Therefore, the simulation method is approached for a best current optimum solution in MFA algorithm, it has been given in optimal MI values within the precise boundary condition as shown in Fig. 14. The ultimate aim of proposed simulation results is to find the low order THD. Hence, the present FA optimization is given



Table 5
Control parameters of FA

| Parameters | Value |
|---|---|
| Maximum generation ($\gamma$) | 10 |
| Population (p) | 20 |
| Alpha ($\alpha$) | 1 |
| Attractiveness ($\beta o$) | 50 |
| Number of fireflies (n) | 50 |
| Best of MI values ($M_a$) | 0.7 |
| Optimum switching angle ($\theta_n$) | $\theta_1 = 5.25$, $\theta_2 = 21.30$, $\theta_3 = 33.71$, $\theta_4 = 49.05$, $\theta_5 = 50.89$, $\theta_6 = 65.67$, & $\theta_7 = 76.03$ |

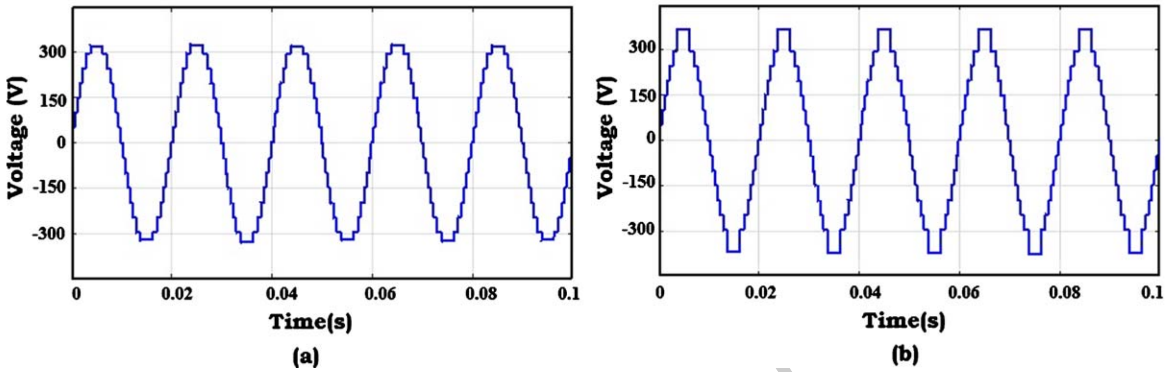



Fig. 12. SSFI output voltage with MFA (a) R-Load, (b) RL Load.

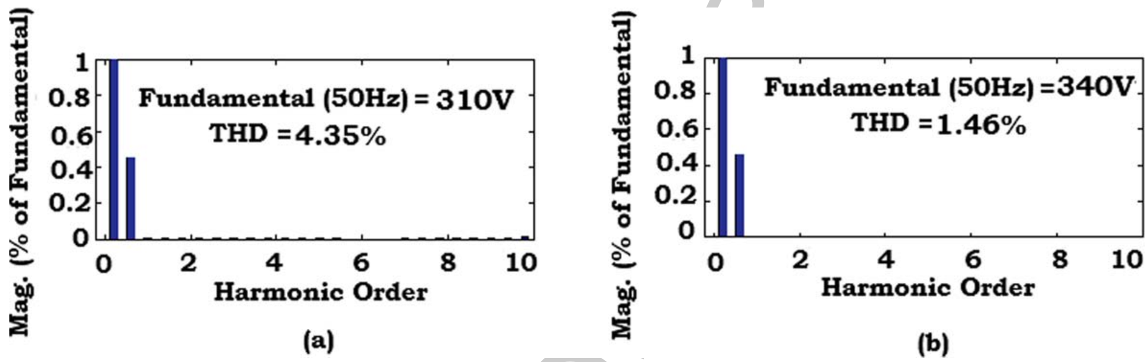



Fig. 13. FFT-spectrum analysis of MFA (a) R-Load, (b) RL Load.

Table 6
Simulation comparison results

| Control optimization algorithm | Comparison of an optimization algorithm | | |
|---|---|---|---|
| | Optimum switching angle ($M_a$) | THD | |
| | | R-Load | RL Load |
| PSO | $\theta_1 = 18.95$, $\theta_2 = 24.50$, $\theta_3 = 53.41$, $\theta_4 = 60.91$, $\theta_5 = 69.9$, $\theta_6 = 76.17$, & $\theta_7 = 81.02$ | 6.5% | 9.88% |
| GA | $\theta_1 = 8.95$, $\theta_2 = 20.5$, $\theta_3 = 43.31$, $\theta_4 = 50.90$, $\theta_5 = 62.39$, $\theta_6 = 74.37$, & $\theta_7 = 79.02$ | 8.90% | 12.46% |
| FA | $\theta_1 = 5.25$, $\theta_2 = 21.30$, $\theta_3 = 33.71$, $\theta_4 = 49.05$, $\theta_5 = 50.89$, $\theta_6 = 65.67$, & $\theta_7 = 76.03$ | **4.35%** | **1.46%** |

better results to compare with other optimization. As per simulation outputs are similar but, the output voltage values ± 10 V to 20 V may varied for different optimization algorithm, due to choosing the parameters to find a set of inputs into an objectives functions are almost the same.

## 8. Experimental results

The experimental validated of proposed approach is solar fed fifteen level-SSFI using for equal DC source incorporate with MPPT intelligent algorithm. The experimental approach comprises of S-PV mod-

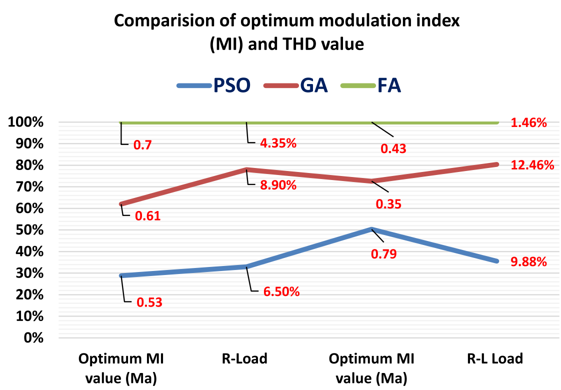



Fig. 14. Comparison of MI Vs THD values.

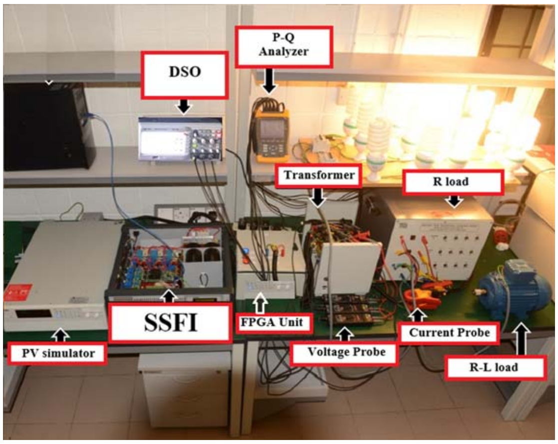
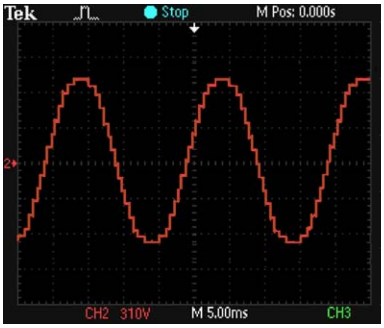
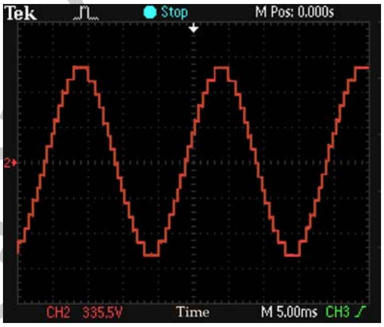



Fig. 15. Experimental MLI load setup.




(a)




(b)

Fig. 16. (a) R-load output for SSFI. (b) RL load output for SSFI.

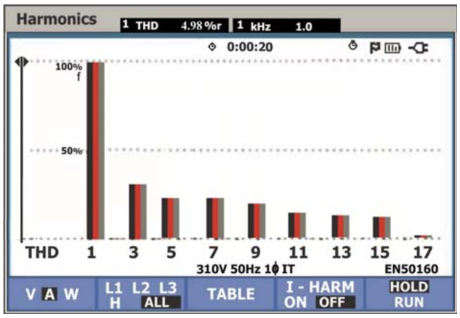
ule simulator, proposed SSFI module, FPGA-Spartan 3A control module, sensing voltage, and current probe for output voltage inverters, and N-LL. Figure 15 shows the optimization algorithm using for 15 level of experimental setup. The ultimate aim of the proposed approach verifies with the R & RL load condition with their performance and output voltage ($V_{rms}$) measurements are verified in Fig. 16 (a&b). The symmetrical voltages of S-PV are passed through converter, which is converts voltage into two times the input.

The boost up voltage is fed with SSFI. The methods of optimization such as GA, PSO, and MFA control algorithms are performed in real-time utilizing Spartan 3A FPGA framework in Xilinx software using HDL code. The inverter performance control has been tested by using for FPGA optimization control algorithm. It is working under a quick response of inverter pulse utilizing optimization algorithm tuned FPGA control signal. It is access to operate in LL and N-LL conditions. The load parameters are detected by using a sensor unit, in this voltage and current signals are transformed to analog FPGA channels employing the signal conditioning unit. To improve this work to analysis, and be enhanced by two simulators with synthesizers were used.

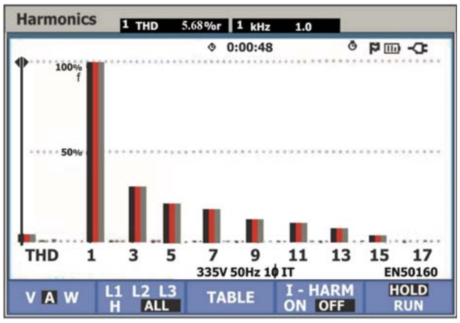
The design of the inverter portion is interfaced with model-sim for simulation in a digital formation using by MATLAB / Simulink tool. However, the various optimization algorithms are coded in a single FPGA kit, the single-phase module is decided on the modulation index value (Ma1 up to Ma5), and also measure the voltage THD in a lower order level. The interface circuit has been developed by using VHDL, and the TPS2014b device is used for measuring the input, switching, frequency, and output measurements. The HDL program for construct in four modules: (1) 50 Hz clock divider, (2) 20Ω, 30 mH (R, RL load), (3) switching position of the angle, and (4) pulse generator.

The pulse generator has been generated the pulse by using 50 Hz clock divider, and it has been used to 2 kHz to 5 kHz switch $S_1$, and $S_2$ in SSFI circuits. The optimization program has been produced the optimal switching angle for each half cycle (positive or negative cycle). The inverter SPMT switch is operated with on and off delay timer relay.

The function of relay pulse is maximum at 40 ms, and the operating frequency is varied from 30 to 956 Hz. The electronic relay has been operated for both positive and negative cycles in a series capacitor unit. The terminal output voltage of capacitor switching is $V_0$-$V_7$ (or) $V_7$- $V_0$, and it can interface with the voltage of R, RL load. It gives the least number of low harmonics levels in FFT spectrum up to 17th order. When PV module has been integrated with the off-grid, R, and RL load, this proposed inverter is supported the reactive power in an electric load connected system without any additional filter equipment. However, due to the lack of filter components, the THD level of N-LL is increased




(a)




(b)

Fig. 17. (a) FFT spectrum analysis of proposed R-load. (b) FFT spectrum analysis of proposed RL load.

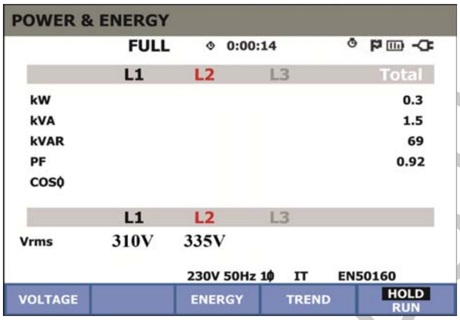
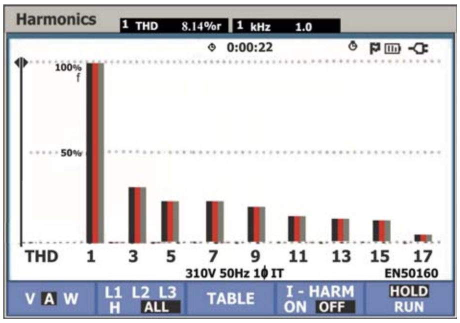
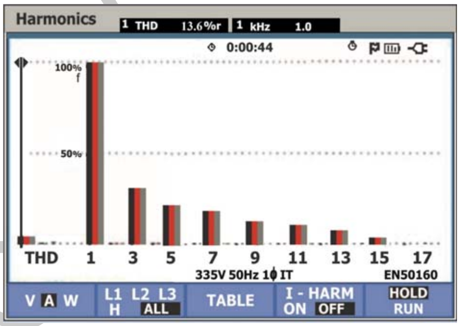



Fig. 18. Output with different operating load conditions.

due to the change of impedance values. The series capacitor bank should be decreased blocking voltage around each semiconductor unit. It helps to generate the reactive power to meet the inductive load requirements. The FFT approach is implemented in LL (R-load) harmonic analysis of FA optimization algorithm Ma = 0.63, and it has been generated lower-order output THD 4.98% as shown in Fig. 17 (a). The FFT approach is implemented in N-LL (RL load) harmonic analysis of FA optimization algorithm Ma = 0.51, and it has been generated lower-order output THD 5.68% as shown in Fig. 17 (b). The firefly

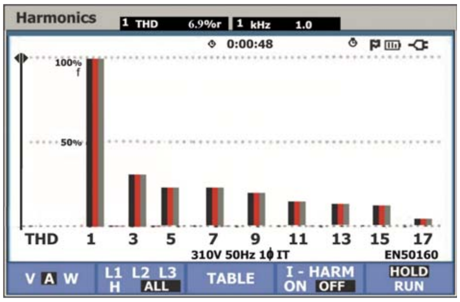



(a)

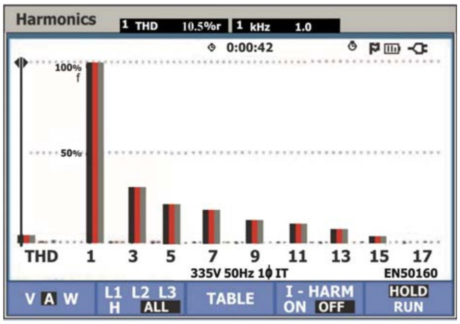



(b)

Fig. 19. (a) FFT spectrum analysis of proposed R-load. (b) FFT spectrum analysis of proposed RL load.




(a)




(b)

Fig. 20. (a) FFT spectrum analysis of proposed R- load. (b) FFT spectrum analysis of proposed RL load.

Table 7
Comparison of linear and non-linear load results

| Control optimization algorithm | Comparison of linear and non-linear load | | | |
|---|---|---|---|---|
| | R-Load | RL Load | R-Load | RL Load |
| | Simulation (THD %) | | Hardware (THD %) | |
| PSO | 6.5% | 9.88% | 6.9% | 10.5% |
| GA | 8.90% | 12.46% | 8.14% | 13.6% |
| MFA | **4.35%** | **0.46%** | **4.98%** | **5.68%** |

Table 8
Comparison of hardware results with the existing topologies and proposed topology

| Existing topologies and optimization approach | | | |
|---|---|---|---|
| Author | Algorithm | Output level | THD |
| Khalili TajEddine et al. [31] | GA | 7 | 12.85% (R load) |
| Vivek Kumar Gupta et al. [11] | PSO | 15 | 17.5% (RL load) |
| Riadh El Mehdi Belkacemi et al. [25] | FA | 15 | 11% (RL load) |
| Shivam Prakash Gautam et al. [34] | GA | 13 | 13.8% (RL load) |
| Salehi, Reza et al. [36] | GA | 13 | 26.72% (RL load) |
| Kaibalya Prasad Panda et al. [28] | PSO | 15 | 11.55% (R load) |
| Pratik Kumar Kar et al. [29] | FA | 11 | 7.51% (R load) |
| Ali Ajami et al. [30] | PSO | 9 | 12.75% (RL load) |
| Nawaz, Faiza et al. [32] | FA | 15 | 8.18% (RL load) |
| Sundari, M. et al. [33] | FA | 15 | 3.19% (RL load) |
| Etesami, M. H et al. [35] | ICA | 9 | 4.46% (RL load) |
| Anand,V et al. [37] | – | 15 | 5% (RL load) |
| Ponraj, R.P et al. [38] | GA | 9 | 3.6% (RL load) |
| Arif, MSB et al. [39] | – | 15 | 5.47% (R & RL load) |
| M.A. Memon [40] | APSO-GA | 9 | 1.62% (RL load) |
| M.M. Zais et al. [41] | – | 13/17 | 1% to 4% (RL load) |



algorithm resultant output voltage of fifteen level has been enhanced the reactive power up to 69 VAR in a different LL and N-LL condition as shown in Fig. 18. The FFT approach implemented in LL (R load) harmonic analysis of the GA optimization algorithm Ma value is 0.50, and it has been generated lower-order output THD 8.14% as shown in Fig. 19 (a). The FFT approach implemented in LL (R load) harmonic analysis of the GA optimization algorithm Ma value is 0.43, and it has been generated lower-order output THD 13.6% as shown in Fig. 19 (b). The FFT approach implemented in LL (R-load) harmonic analysis of PSO optimization algorithm Ma value is 0.76, and it has been generated lower order output THD 6.9% as shown in Fig. 20 (a).

The FFT approach implemented in N-LL (RL load) harmonic analysis of PSO optimization algorithm Ma value is 0.60, and it has been generated lower-order output THD 10.5% as shown in Fig. 20 (b). There are 3 different optimization control algorithm is applied in SSFI, it has been improved P-Q with lower THD value. The comparison of prototype and simulation model with the least harmonics levels are presented in FA as shown in Table 7. The comparison of results with other different level topologies, this type of control algorithm is approached with minimum THD, and different optimization, which is functioned with better results than the literature study.

## 9. Conclusion

The research involved the creation of a single phase load harmonic reduction through solar-power utilization without any additional filters and control power switching devices. The P-Q enhancement strategies for the proposed SSFI have been implemented using three separate approaches such as PSO, GA, and MFA optimization approach. The ultimate aim of the overall proposed method is improved P-Q enhancement in various factors such as reactive power development in a different load conditions with reduced harmonic conditions. A 305 W S-PV system has been examined with a hardware prototype model (FPGA unit). The implementation of solar fed MLI gives better results especially MFA optimization method.

In addition to that, the non-linear (R-L) load is controlled by PSO, GA, and MFA, which is compared with the performance of 50% and 100% P-Q load development. Memory-based metaheuristic method such as PSO, GA, and MFA achieved by better THD, it can depends upon the optimum modulation index value, switching position of the angle found through optimization approach. The SPARTAN-3A FPGA hardware board is regulated, and the minimum harmonics level are obtained to improve the PQ. A comparison of THD values with an existing methods shown in Table 8. The comparison between optimization algorithms shows the result of MFA with the lowest THD based on simulation and hardware results.

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