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Harmonic Minimization using PSO of meld µgird-MLCI

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Abstract
Microgrids are new approach of electrical systems consisting of distributed generators, renewable energy sources and sensitive loads. The objective of microgrid operation is to serve reliable and high-quality electric power regardless of faults or abnormal operating conditions. A transformation is being observed to advance the part of distributed generations from alternate the constitutional source in the network of microgrid. In this paper Microgrid with three important distributed generators & an effective solution for protection of sensitive loads against voltage disturbances in power distribution system are considered. The main objective is to lower the total harmonic distortion (THD) of the cascaded multilevel inverter, which is an optimization problem and can be clear up by applying particle swarm optimization (PSO) approach are considered in the paper. The simulation outcome fair that the prospective PSO method is truly adept of concluding outstanding attributes of the decision to eliminate the 3rd, 5th and 7th order harmonics and within the range of modulation index the total harmonic distortion must be reduced for meld µgrid-MLCI.

Keywords- Microgrid (µ-grid), Optimized harmonic stepped waveform (OHSW), particle swarm optimization (PSO), Total harmonic distortion (THD)

I. INTRODUCTION

The electrical grid is tending to be more distributed, intelligent, and flexible. The trend of this new grid is to become more and more distributed, and hence the energy generation and consumption areas cannot be conceived separately. Nowadays, electrical and energy engineering has to face a new scenario in which small distributed power generators and dispersed energy storage devices have to be integrated together into the grid. The use of distributed generation (DG) of energy systems makes no sense without using distributed storage systems to cope with the energy balances. Microgrids (MG), also named minigrids, are becoming an important concept to integrate DG and energy storage systems [1-3]. The concept has been developed to cope with the penetration of renewable energy systems, which can be realistic if the final user is able to generate, storage, control, and manage part of the energy that will consume. A trend for the change in the performance of existing distributed generations from backup to immediate energy supply and to have a malleable contact approach which sets up for the concept of Microgrid have become incipient. Managerial and technology, variation for power generation, environmental and economical enticements and the expansion of smaller generating systems like solar, wind, microturbine power generators have opened new goal for on-site power generation by electricity consumers [4]. Most of the home use appliances use DC power either from a battery or after rectification of the AC source.

Cascaded Multilevel inverters have drawn terrific importance in huge power operations. It organizes a crave output voltage from DC voltages as inputs. The desired output of a Cascaded Multilevel inverters is incorporating by several individual sources of DC voltages, with a hike of individual sources of DC voltages, the converter voltage output waveform approaches a nearly sinusoidal waveform while using a fundamental frequency switching scheme. There are three major multilevel topologies: cascaded H-bridge, diode clamped, and capacitor clamped.

Previously for harmonic elimination several methods have been presented in those mainly optimized harmonic stepped waveform (OHSW) is being used [5]. It is difficult to solve the OHSW equations as these are highly nonlinear in nature and may produce simple, multiple, or even no solutions for a particular value of modulation index. To solve the OHSW equations, they are changed into linear equations which are producing only one solution set, and even for this a proper initial opinion and starting value of modulation index for which the solutions exist, are required. Particle Swarm Optimization (PSO) for solving these equations and attain the harmonic distortion lesser compare to Newton Raphson (NR) methods which are used in OHSW method is implemented. This paper presents the analysis of 7-level cascaded inverter with three H-bridges, solution of three transcendental equations using PSO and elimination of 3^{rd} , 5^{th} and 7th order with minimum harmonic distortion and obtain desired fundamental voltage. In this paper Solar, Wind and Fuel cell are used as DC sources for Cascaded Multilevel Inverter

II. PROPOSED CASCADED MULTILEVEL INVERTER

The development of semiconductor technology has been done by many power electronics research communities to reach the higher nominal voltages and currents. In conventional multilevel inverters, the power semiconductor, switches are combined to produce a high frequency waveform in positive and negative polarities. However, there is no need to utilize all the switches for generating bipolar levels. This idea has been put into practice by the new topology. The Cascade multilevel inverter subsists of a series of the H-bridge inverter units. The cascade multilevel inverter is to incorporate a desired voltage from several separate DC sources as shown in Fig.1.[6] The number of output phase voltage levels is 2S+1, where S is the number of DC sources and 's' is the number of H-bridges connected in cascade per phase. Among 's' number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (s-1) switching angles are used to eliminate certain predominating lower order harmonics. In a three-phase system with isolated neutral, triplen harmonics are cancelled out automatically, and only non-triplen odd harmonics are present. The fundamental voltage is obtained from the calculated switching angles α_1, α_2, α_3… α_n and 'n' represents the order of the harmonics and the switching angles are identical to the number of DC-sources. The sum of all of the individual inverter outputs (V1+V2+V3=Vout) as shown in Figure.2 which are the AC output of each H-bridge inverter is connected in series such that the incorporated voltage waveform and accomplished by connecting the DC source to the AC output side by using different combinations of the switches .

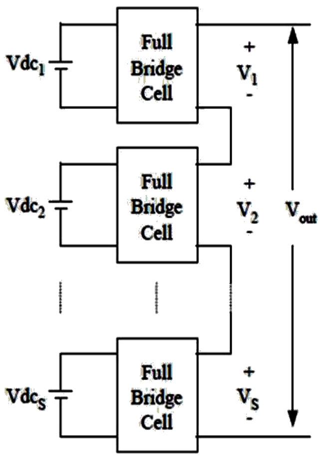

Fig.1: Schematic diagram of H-bridge series-connected multilevel inverter.

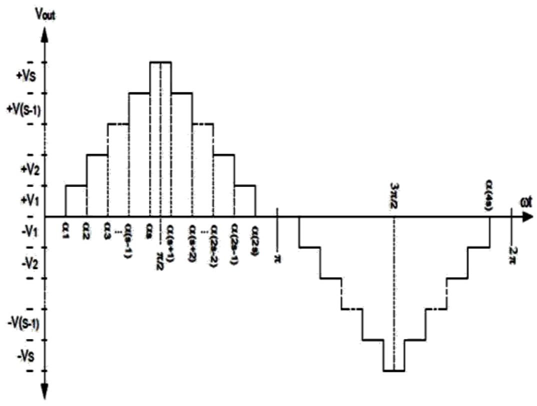

Fig.2: Switching angles of H-bridge MLCI.

As stated above, the general function of the multilevel inverter is to synthesize a desired voltage from several separate DC sources. Those general DC sources are replaced by a microgrid such as solar cells, wind, fuel cells in the H-bridge structure of a seven level cascade inverter as shown in Fig.3. It is required to find the switching angles in the range of 0 to π/2 considering 3rd, 5th and 7th order phase voltage to zero. The ratio of ratio of the fundamental voltage (V_1) to the maximum obtainable fundamental voltage (V_{1max}) is called Modulation index.
The Fourier series of the quarter-wave symmetry for staircase waveform is written as follows:

$$\mathbf{v_{out}}\,(\boldsymbol{\omega t}) = \sum_{n=1}^{\infty}\left[\frac{4E}{n\pi}\sum_{k=1}^{S}\cos(n\alpha_k)\right]\sin(n\omega t) \quad \textbf{(1)}$$

The fundamental voltage in terms of switching angles for seven level cascade inverter is given in equation (2).

$$V_1 = \frac{4E}{\pi}\sum_{k=1}^{S}\cos(\alpha_k) \quad \textbf{(2)}$$

When all the switching angles are zero
Maximum fundamental voltage $(V_{1max}) = 3 * (\frac{4V_{dc}}{\pi})$ & The Modulation index $(M) = \frac{V_1}{3*(\frac{4V_{dc}}{\pi})}$ **(3)**

The 7-level cascaded inverter requires three H-bridges. The non linear equations which are used to finding the switching angles and desired fundamental voltage of 7-level inverter are equations (4), (5), (6) and (7).

$$[\cos(\alpha_1) + \cos(\alpha_2) + \cdots + \cos(\alpha_s)] = \frac{sM\pi}{4} \quad \textbf{(4)}$$
$$[\cos(3\alpha_1) + \cos(3\alpha_2) + \cdots + \cos(3\alpha_s)] = 0 \quad \textbf{(5)}$$
$$[\cos(5\alpha_1) + \cos(5\alpha_2) + \cdots + \cos(5\alpha_s)] = 0 \quad \textbf{(6)}$$
$$[\cos(7\alpha_1) + \cos(7\alpha_2) + \cdots + \cos(7\alpha_s)] = 0 \quad \textbf{(7)}$$

By using equations (4), (5), (6) and (7) which are nonlinear equations, eliminate lower order harmonics switching angles and lower THD with the values of M

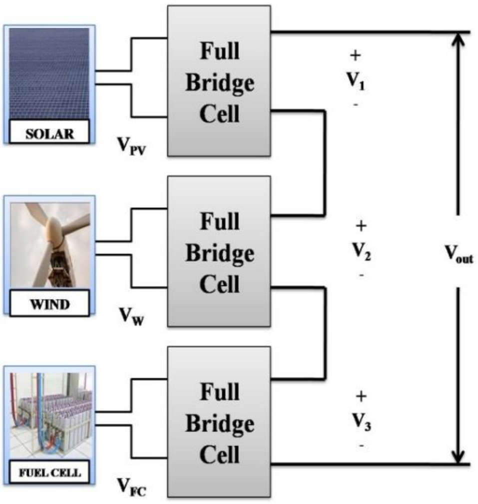

Fig.3: Schematic diagram of an H-bridge series-connected cascaded multilevel inverter with Microgrid as DC Sources.

All the above Equations are evaluated by considering input voltage values of the Solar (V_{pv}), Wind (V_W) and Fuel Cell (V_{FC}).

III. MICROGRID (μ-GRID)

A. Solar PV:

The PV cell is a specially designed PN junction or Schottky barrier device. The well-known diode equation describes the operation of the shaded PV cell. [7]. In order to obtain an adequate output voltage, which is a constant DC whose magnitude depends on the composition in which the solar cells/ modules are connected PV cells are connected in series to form a PV module.

The process of regulating the voltage and current output of the array must be upgraded based on the weather conditions such as irradiation. Maximum power point tracking (MPPT) algorithm is developed for constantly extract the maximum amount of power from the array under varying conditions which control process and the voltage boosting are usually implemented in the DC-DC converter. Figure 4. Represents the simulation results of solar with and with MPPT, Guide for I-V and P-V characteristics, output Power can we calculate by voltage (*V*) and current (*I*)

$$I = I_{irr} - I_d \quad (8)$$

Where $I_d = I_{LCd} * \left[\exp\left({}^{qV}/_{\grave{a}kT}\right) - 1\right]$

$$I = I_{irr} - I_{LCd} * \left[\exp\left({}^{qV}/_{\grave{a}kT}\right) - 1\right] \quad (9)$$

Where, the current generated by the sun irradiation = I_{irr} , diode equation = I_d, the leakage current of the diode= I_{LCd}.

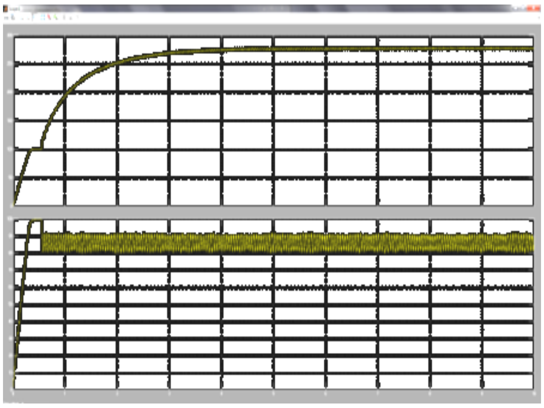

Fig.4: Simulation Output of Solar with and without MPPT

q is the electron charge and the value is [1.60217646*10-19C], ***k*** is the Boltzmann constant and ***T*** is the temperature of the p-n junction, and ***'à'*** is the diode ideally constant.

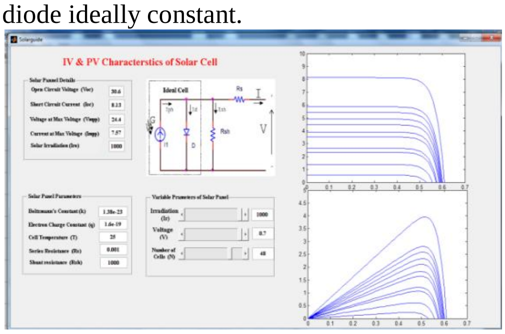

Fig.5: I-V, P-V characteristics using the Guide

B. Wind:

The main components of a wind energy conversion system, including turbine blade, a gearbox, Converters, Inverters, Control circuits, etc., along with cables, filters, ground support equipment and interconnection equipment [8]. Wind turbine captures power from wind by means of turbine blades and converts it into mechanical power and Fig.6 represents the simulation output of Wind. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time as follows

$$P_w = \frac{1}{2}(Mass\ of\ air\ per\ unit\ time) * (Wind\ velocity)^2$$

$$= \frac{1}{2} * \rho * A_r * V_w^{\ 3} \quad (10)$$

Where P_w : Power contained in the wind (in watts),
ρ : Air density,
A_r : Rotor area in (square meter)
V_w : Wind velocity without rotor interference,

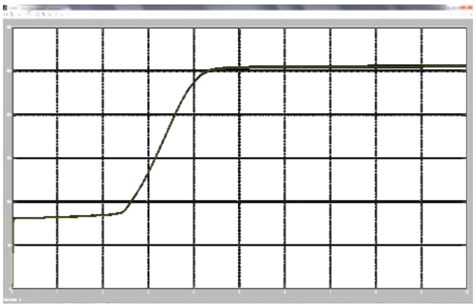

Fig.6: Simulation Output of Wind

C. *Fuel cell:*

Fuel cells generate power through the electrochemical reaction between hydrogen and oxygen. The conversion is highly efficient and leaves only water and heat as by-products, which is the main motivation for the increasing interest in the technology. Fuel cells could potentially replace the internal combustion engine and many other energy generation devices used today [9]. Reduced emissions of greenhouse gases and increased efficiency are two of the major reasons that fuel cells are being seriously researched as a replacement to the internal combustion engine. Perhaps the simplest system, a Proton Exchange Membrane Fuel Cell (PEMFC), combines hydrogen fuel with oxygen from the air to produce electricity, water, and heat. A Basic Proton Exchange Membrane Fuel Cell consists of three components: an anode, an electrolyte in the center, and a cathode. Fig 7 represents the simulation output of a Proton Exchange Membrane Fuel Cell

$$\boldsymbol{V = -2.547 * 10^{-6} I^3 + 1187 * 10^{-3} I^2 - 0.1967 I + 39.2082} \quad \textbf{(11)}$$

$$\boldsymbol{V * I = I^2 * Z,\ V = I * Z} \quad \textbf{(12)}$$

Where V is the fuel cell terminal voltage, I is the current and Z is the load impedance

Equations (11) and (12) are solved simultaneously to obtain an equation in terms of the current and the load impedance as follows

$$\boldsymbol{f(I) = -2.547 * 10^{-6} I^3 + 1187 * 10^{-3} I^2 - 0.1967 I + 39.2082 = 0} \quad \textbf{(13)}$$

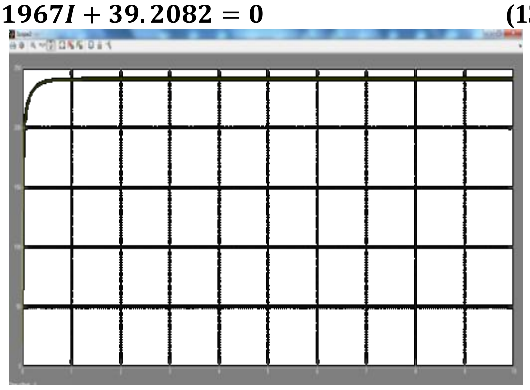

Fig.7: Simulation Output of Fuel cell

IV. PARTICLE SWARM OPTIMIZATION (PSO)

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively exacting to advance a successor solution with a view to a given part of quality. PSO optimizes a problem by having a population of successor solutions, here designate bit, and moving these bits around in the search-space according to simple analytical formulae over the successor 's position and velocity. Each successor’s movement is controlled by its local best known solution but, is also govern toward the best known solution in the search-space, which are updated as better solutions are found by other successors. This is expected to move the swarm toward the best solutions. It indicates to an approximately new group of algorithms that may be used to find optimal solutions to numerical and qualitative problems [10]. PSO was introduced by Russell Eberhart and James Kennedy in 1995 inspired by social behavior of birds flocking or fish schooling. It is easily implemented in most programming languages and has justified being both very fast and effective when applied to a diverse set of optimization problem.

Particle swarm optimization is a heuristic global optimization method and also an optimization algorithm, which is based on swarm intelligence. It comes from the research on the bird and fish flock movement behavior. The algorithm is widely used and rapidly developed for its easy implementation and few particles required to be tuned. In the basic particle swarm optimization algorithm, particle swarm consists of “n” particles, and the position of each particle stands for the potential solution in D-dimensional space. The particles change its condition according to the following three principles: (1) to keep its inertia (2) to change the condition according to its most optimist position (3) to change the condition according to the swarm’s most optimist position.

The position of each particle in the swarm is affected both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surrounding (near experience). When the whole particle swarm is surrounding the particle, the most optimist position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO. If the narrow surrounding is used in the algorithm, this algorithm is called the partial PSO. Each particle can be shown by its current speed and position, the most optimist position of each individual and the most optimist position of the surrounding. In the partial PSO, the speed and position of each particle change according the following equation (Shi Y, Eberhart R C, 1998):

$$v^{k+1}{}_{id} = w * v_{id}^{k} + c_1 * rand_1 * (Pbest_{id} - xidk + c2 * rand2 * Gbestgd - xidk \quad (14)$$

$$x^{k+1}{}_{id} = x_{id}^{k} + v_{id}^{k+1} \quad (15)$$

In this equality, v_{id}^{k} and x_{id}^{k} Stand for separately the speed of the particle "*i*" at its "*k*" times and the d-dimension quantity of its position; $pbest_{id}^{k}$ represents the d-dimension, quantity of the individual "*i*" at its most optimist position at its "k" times, $gbest_{id}^{k}$ Is the d-dimension, quantity of the swarm at its most optimistic position. In order to avoid particle being far away from the searching space, the speed of the particle created at its each direction is confined between $-v_{dmax}$, and v_{dmax}. If the number of v_{dmax} is too big, the solution is far from the best, if the number of v_{dmax} is too small, the solution will be the local optimism; c_1 and c_2 represent the speeding figure, regulating the length when flying to the most particle of the whole swarm and to the most optimist individual particle. If the figure is too small, the particle is probably far away from the target field, if the figure is too big, the particle will maybe fly to the target field suddenly or fly beyond the target field. The proper figures for c_1 and c_2 can control the speed of the particle's flying and the solution will not be the partial optimism. Usually, c_1 is equal to c_2 and they are equal to 2; r_1 and r_2 represent random fiction, and 0-1 is a random number.

In local PSO, instead of persuading the optimist particle of the swarm, each particle will pursue the optimist particle in its surroundings to regulate its speed and position. Formally, the formula for the speed and the position of the particle is completely identical to the one in the whole PSO.

The minimization of THD in multilevel inverters is achieved by using this PSO algorithm because of its simple in nature and easy to implement, computationally efficient. The procedure for getting optimized results the objective function is taken as the THD equation is as follows

$$\% THD = \frac{\sqrt{(V_2^2 + V_3^2 + V_n^2)}}{V_1} * 100 \quad (16)$$

The proposed PSO algorithm is given as the following steps:

Step1: create the random initial population size of switching angles by considering their limitation is 0 to π/2

Step2: initialize the velocity, *Pbest, Gbest*, iteration count for computing switching angles

Step 3: update the iteration count

Step 4: update the velocity and position according to the equations (14) & (15) for moving of successors in the search space

Step 5: evaluate the fitness or the objective function by using equation (16)

Step 6: update the values of Pbest and Gbest

Step 7: Is criterion achieved and then go for next step otherwise repeat the step3 to step6 for the best solution

Step 8: select the best solution of fitness value.

From the above procedure the population size and using the decreasing inertia function with initial and final weights the best solutions of fitness value, maximum iterations are manipulated. The Objective function is taken as a total harmonic distortion equation for obtaining the lower value of total harmonic distortion and minimization of lower order harmonics and total harmonic distortion is updated for each iteration with their suitable best values by changing the velocity and position of the current particles. Similarly the values of switching angles also updated for optimum values to get lowest value of THD.

V. SIMULATION RESULTS

Table 1: Switching Values of different Iterations using NR Method

NR Method					
	α1	α2	α3	α4	THD%
ITR 1	18.113	47.755	76.420	89.9	16.47 %
ITR 2	10.536	35.286	65.172	89.358	16.18 %
ITR 3	10.222	34.287	61.170	88.682	15.70 %
ITR 4	13.291	35.605	65.702	89.499	15.19 %
ITR 5	16.818	38.241	69.090	89.8	14.27 %
ITR 6	16.414	38.147	65.921	89.785	13.54 %
ITR 7	16.102	36.213	65.919	89.710	13.27 %

Table 2: Switching Values of different Iterations using PSO Method

PSO Method					
	α1	α2	α3	α4	THD%
ITR 1	16.537	23.752	53.305	70.486	13.38 %
ITR 2	20.308	39.848	62.123	86.176	13.38 %
ITR 3	19.906	37.443	57.798	80.911	12.99 %
ITR 4	19.011	37.183	57.475	80.164	12.75 %
ITR 5	18.235	30.573	57.046	74.896	12.50 %
ITR 6	18.190	25.101	53.868	71.118	12.22 %
ITR 7	15.677	23.107	49.244	68.547	11.60 %

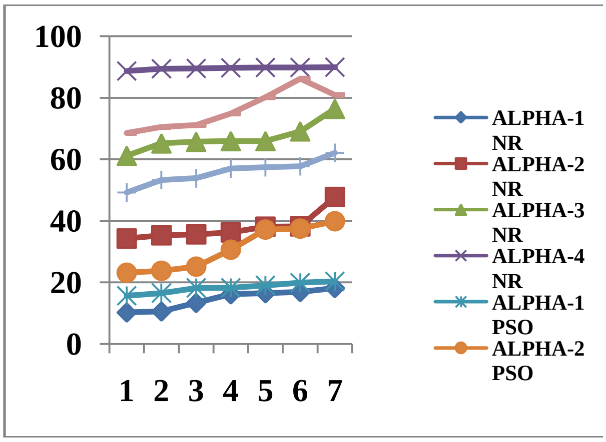

Fig.8: Graphical representation of different Switching Values

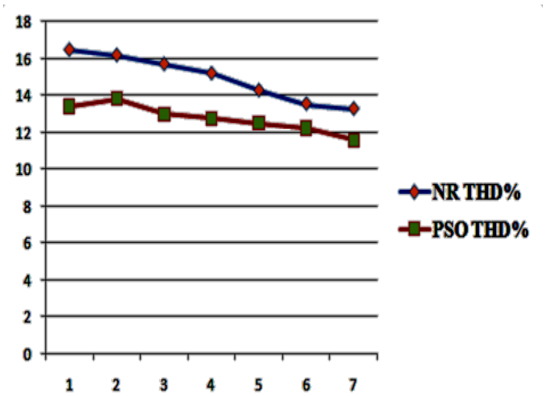

Fig.9: Graphical representation of THD% Comparison of NR and PSO methods

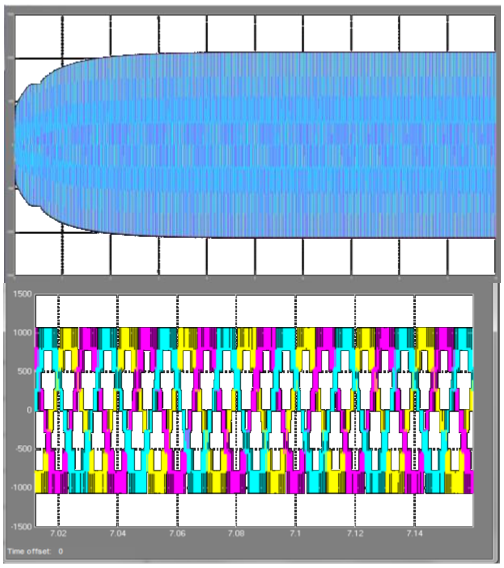

Fig.10: Simulation Output of three Phase Cascaded Multilevel Inverter

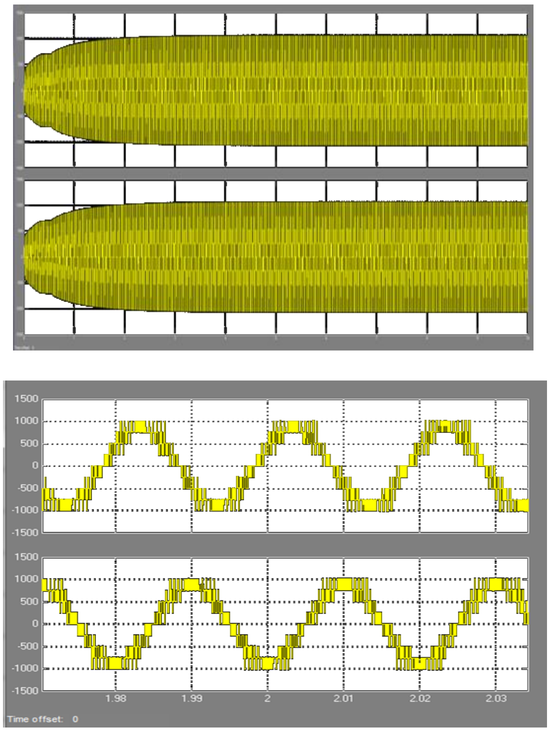

Fig.11: Simulation Output of Distributed generation- Cascaded Multilevel Inverter

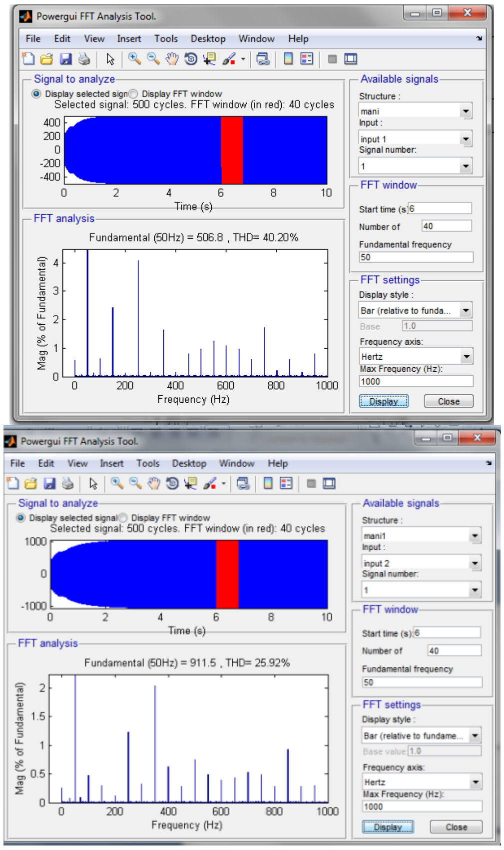

Fig.12: Simulation Output of THD% for Single phase and three phases Cascaded Multilevel Inverter

VI. CONCLUSION

As the renewable energy sources increase in day to day life, microgrid will have more advantage in having for the perfect effective DC source for different resources and connected to the different application. The Transmission and Distribution network are already loaded to their full capacity and more energy can be fed to the customers only with additional spending on Transmission and Distribution expansion. The Microgrid is an aggregation of these resources and connected to the different application as DC source. The PSO method gives the lower THD% compared to the other Iterative methods like NR method. In recent years the approach for the elimination of harmonics in multilevel inverters by using PSO method has been done by taking better switching angles as the objective function. The paper discusses about the effective elimination of lower order harmonics and better results in minimization of THD% are a presented for meld µgird-MLCI for the benefit of the

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