Employing PSO Approach to Minimize Total Harmonic Distortion in a PV-Based Inverter Systems

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Abstract: ***The PV system's maximum power point (MPP) is nonlinear and depends on irradiance and temperature. Some situations allow many local maxima, but there is only one real MPP. This affects PV system power output, dependability, and complexity. Traditional approaches are slow and inaccurate for MPP determination. PSO is better for reducing steady-state oscillations in the inverter output current and voltage waveform. PSO is used to optimize inverter switching. In MATLAB, a PSO-based control algorithm and PI controller generate an error voltage, which is analyzed by the PSO controller to enhance switching. The photovoltaic bridge inverter system to reduce Total Harmonic Distortion (THD) and enhance power quality includes the PV array, DC-DC converter coupled in series, inverter fed by PSO-based controller, filter circuit, voltage and current sensors, and load. This model predicts PV system performance better when irradiance varies slowly. Photovoltaic power systems use controlled DC/DC boost converters called Peak Power trackers. Controlling the DC/DC converter conversion ratio maximizes solar panel output power. DC-DC converters connect modules and loads. Boost mode DC/DC converters are the most significant switching regulators. The PSO-based technology iteratively improves inverter switching and constant current and voltage waveform over a set time interval. This article analyses PV systems without and with PSO. PSO improves current and voltage waveforms, reducing steady-state oscillations. FFT study reveals that THD (IEEE Std.519) with PSO-based controller meets IEEE standards. System dependability increases.***

Keywords: Maximum power point, MPP, Total Harmonic Distortion, THD, Photovoltaic

1. Introduction

Due to expanding populations and technology, global energy consumption is rising daily. But our unstable electricity grid is causing major power shortages. India and China consume the most energy. Clean energy and energy efficiency are needed to fulfil projected energy demands due to worldwide warming. Energy engineers worldwide are focused on solar projects to increase generation capacity. Solar modules form solar systems. Cells create modules, which are joined to form the PV system. The panel's DC voltage is transformed to AC for grid power [1]. Notwithstanding advancements in technology, grid-connected PV systems are always complicated. The latest soft computing approaches enhance inverter switching under various environmental situations. PSO [2] is an efficient meta-heuristic for finding optimal solutions. Swarm behavior-based PSO is easy to design. PSO-based controller architecture improves inverters switching effectiveness.

According to the publication "An improved particle swarm optimization" by [3] a PSO-based control technique is crucial for damping steady-state oscillations. They suggest a new maximum power tracking method based on a modified PSO technique for inverter-fed PV systems. They also suggested a way to monitor the MPP in the face of severe climatic shifts, such as significant variations in insolation or a partially shaded area. In addition, MATLAB simulations are performed under highly difficult conditions, such as sudden changes in irradiance, sudden changes in load, and partial shadowing of the PV array, to assess the efficacy of the suggested strategy.

They propose a novel MPPT algorithm by introducing a PSO technique, as described in their paper titled "MPPT of multiple photovoltaic arrays: A PSO Approach, " which was presented at [4]. Using this PSO approach, the authors proposed a PV system in which the global MPP could be found in a relatively short amount of time. Lower costs, greater overall efficiency, and ease of implementation are the results of the suggested algorithm's use of a single pair of sensors to operate many PV arrays. The algorithm's reliability was tested under a variety of challenging partial shading scenarios.

In their study titled "Particle swarm optimization, " the authors [5] present a notion for the optimization of a non-linear function using particle swarm methods. Several models' histories are summarized, and a model's actual implementation is addressed. Use in Applications, such as the optimization of nonlinear functions and the training of neural networks, have been suggested and benchmark tests of the model are given. It is explained how PSO is related to both AI and genetic algorithms.

When applied to a single-phase grid-tied photovoltaic system, the research in [6] demonstrates that an MPPT strategy based on the PSO method is both practical and performance-oriented. Due to the nonlinear nature of the voltage-current characteristic curves of solar panels, local and global maximum power points can manifest under partial shade situations. However, most conventional MPPT approaches fail to localize the optimal PV array location for maximum power extraction. To get over this issue and get the most power out of photovoltaic setups, an MPPT-PSO based technique is employed to find the optimal global point. The efficiency of the suggested MPPT method may be shown through numerical simulations by contrasting it to the standard Perturb and Observe (P&O) method.

According to the "Particle swarm optimization" study [7], it is possible to use PSO as an alternative MPPT methodology. When the PV setup is subjected to a circumstance like partial shading, the suggested method will locate the point of the highest global power output. Several PSO-based MPPT strategies have been detailed [8] in published works. The investigation's technique, nonetheless, encompasses a variety of approaches, both in terms of its mode of execution and the number of particles employed to locate the highest global PowerPoint.

the provisions of the article in the following order: Section 1 introduces the basics of the papers. Section 2 discusses the methodology and PV-based inverter research and methods for continuous output to improve switching. Section 3 explains system model development. Section 4 discussesthe finding of the paper and last section 5 concludes.

2. Methodology

The goal of this MATLAB/Simulation-based study is to bring total harmonic distortions down to inside a suitable range in a PV-based inverter system. Here, a soft-computing methodology known as PSO is employed for this reason. The article's central idea is to apply a PSO-based control technique to enhance the inverter's switching performance for PV systems. In order to meet the load requirement without interruptions, there are a number of ways to boost the system's switching effectiveness.

2.1 Inverter Modulation Techniques

To provide an output voltage that is as near to a sinusoidal waveform as possible, inverters employ a modulation method [9]. To lessen the impact of harmonics and cut down on switching losses, a wide variety of modulation methods have been devised. As may be seen in Fig.1 [9], inverters' modulation techniques can be categorized in terms of switching frequency. Many commutations of the power semiconductors occur during the fundamental output voltage period in methods that work at high switching frequencies. The traditional carrier-based sinusoidal pulse width modulation (SPWM) is widely used in industrial settings because of its efficacy at lowering load voltage harmonic distortion through phase shifting. The SVM approach [10], which has been implemented in three-level inverters, is still another intriguing alternative.

The output voltages of these methods have a staircase waveform because one or two commutations of the power semiconductors are performed per output voltage cycle at low switching frequencies. Both space-vector control (SVC) and PSO-based selective harmonic elimination fall under this category. Wide linear modulation range, reduced switching loss, lesser THD in the spectrum of switching waveform, easy implementation, less memory space, and less computation time on implementing in digital processors are just some of the goals of the various methods developed for inverters [11]. Carrier based PWM (sine-triangle PWM or SPWM) and space vector-based PWM are the two most used PWM algorithms for multi-level inverters. It is difficult to extend SPWM schemes into the over-modulation range, although they are more versatile and easier to implement than PWM. However, the maximum peak of the basic element in the output voltage is set at 50% of the DC link voltage. In SVPWM systems [12], the inverter switching vectors and their durations within a sampling period are calculated by repeatedly sampling a reference space vector. The instantaneous amplitudes of reference phase voltages are all that's needed in a space phasor-based PWM method for multi-level inverters.

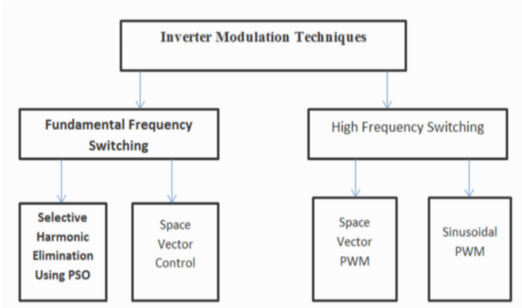

Figure 1: Strategies for Modulating Inverter Outputs

2.2 THD optimization using PSO

THD analysis of a PSO-optimized, single-phase, cascaded inverter. This will reduce the number of unwanted harmonics in the voltage signal produced by the inverter. To achieve a THD of less than 5% with as few semiconductors as possible, the inverter's operational settings have been varied in terms of stage count, source voltage, and switching pattern. Harmonic elimination and thus THD reduction in an inverter-based PV system are highly dependent on the inverters' control technique. Injecting sinusoidal current into the utility grid while keeping harmonic distortion to a minimum is the primary goal of every grid-connected PV inverter's design [13]. Because of this, the inverter’s current management and harmonic compensation approach is the focus of this study in order to effectively reduce the impact of the higher-order harmonics. PSO has been used effectively in a wide variety of fields. It is shown that PSO achieves better outcomes in a shorter amount of time and at a lower cost than competing methods [14]. PSO's simplicity in configuration is another selling point. With some tweaks, the same version can serve many purposes. Many different kinds of applications have found useful for particle swarm optimization, both general-purpose ones and those tailored to meet a very specific need.

3. System Development

The I-V Characteristic of an STC-Tested PV Considering into account just one PV module hooked up to a load, as in Fig.3. The load could be a battery or a dc motor powering a pump. The module in the sun will generate an open-circuit voltage V_{OC} before the load is connected, but no current will flow. The short-circuit current I_{SC} will flow if the module's terminals are connected, but the output voltage will remain at 0 volts [15]. No energy is transferred from the module to the load or vice versa since power is the product of current and voltage. Some current and voltage will result and power will be transmitted when the load is truly connected. The I-V characteristic curves of both the module and the load must be taken into account in order to calculate the required amount of power.

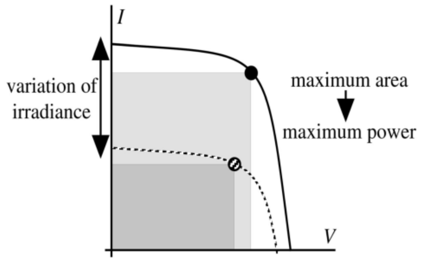

Figure 2: The Solar Cell's I-V Phenomenon

Figure 2 depicts an I-V curve typical of a PV module, from which we may determine the open-circuit voltage V_{OC} and the short-circuit current I_{SC}, among other important metrics. The module's output power, calculated by multiplying the voltage by the current, is also displayed. Because either the current or the voltage is 0 at the two extremes of the I-V curve, the output power is also zero. The MPP occurs when the product of current and voltage is at its highest point at the knee of the I-V curve [16]. Depending on the particular facts that align with theoretical test settings [17], the voltage and current at the MPP may be referred to as V_m and I_m for the overall scenario, or V_R and I_R (for rated voltage and rated current), respectively

3.1 Fill Factor

Finding the largest rectangle that fits under the I-V curve is another mental exercise that might help you picture where the maximum power point is located. Figure 6 illustrates that power is represented by the size of the rectangle whose sides represent current and voltage. The fill factor (FF) is another metric used to describe module effectiveness [17]. The FF can be thought of as the ratio of two square areas since it is the ratio of the power at the greatest power point to the product of the volume of the enclosure (V_{OC}) and the internal surface area (I_{SC}).

Fill Factor = Vm * Im

$$V_{OC}*I_{SC} \qquad (1)$$

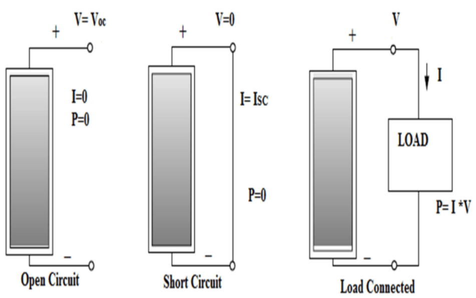

Figure 3: Open circuit PV Figure 4: Short circuit PV Figure 5: Load connected PV

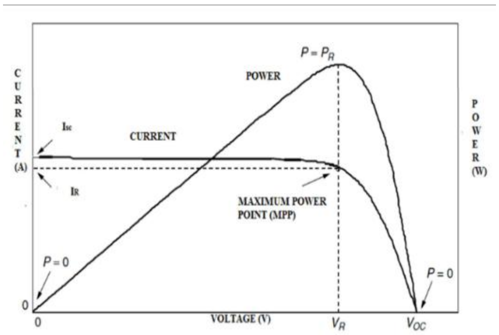

Figure 6: Under Standard Test Conditions, the I-V curve and power output of a solar cell module

Standard test conditions (STC) have been devised to allow for fair comparisons between modules, as PV I-V curves fluctuate all over the place when insolation changes and as the temperature of the cells varies [**18].** These conditions involve an air mass ratio of 1, which is equivalent to a solar irradiation of 1 kW/m2 with a spectral distribution. For most tests, it is recommended that the cells be kept at 25 degrees Celsius (this refers to the temperature inside the test cells, not the room temperature).

3.2 Total harmonic distortion (THD)

To quantify the degree of harmonic distortion in a signal, we can calculate its THD by dividing the sum of the powers of all harmonic components by the power of the fundamental frequency [19]. Both the linearity of audio systems and the quality of electric power are measured and described with THD. The phrase distortion factor can be considered a synonym for this one. The THD of a power system can be reduced by decreasing peak currents, heating, emissions, and motor core loss. The efficiency and effectiveness of power management and use are profoundly impacted by [20] distribution system power quality. Particularly after the second part of the twentieth century, when various new electronic power sources distorted power system waveforms, this became the case.

Non-linear loads posed by power generators cause a distorted, harmonically rich waveform to be drawn [21]. In addition to disrupting phone transmissions, these harmonics can damage motors and transformers by degrading their conductors and insulators. The cumulative impact of these harmonics must be calculated. THD refers to the accumulated effect of all the system's harmonics. This section will make an effort to define THD and discuss its implications for electrical devices [22]. APT's series of programmable sources have a low THD, which will be discussed along with its usefulness in testing. Understanding THD can be difficult. It's not hard to grasp the concept once you learn the fundamentals of harmonics and distortion. Think of an AC power supply and an electrical demand.

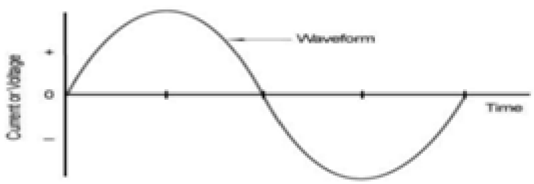

Figure 7: Ideal Sine wave

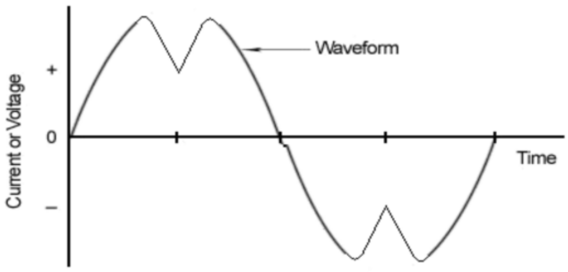

Figure 8: Distorted Waveform

Now, picture this burden falling into one of two broad categories: linear or nonlinear. The power quality of the system is going to change depending on the sort of load. This is because different loads require different amounts of current. Sinusoidal in nature, the current drawn by linear loads does not significantly alter the waveform. Typically, we refer to home appliances as linear loads. However, non-linear loads are capable of requiring a non-sinusoidal current draw [23]. Due to the deviation of the current waveform from a pure sine wave, distortions in the voltage waveform are produced.

The sinusoid's shape may be significantly changed by waveform distortions, as seen by the pattern of waves in Figure 8. The fundamental waves are a combination of several waveforms known as harmonics, regardless of how complicated they may be. Integer multiples of the fundamental frequency of the shape of the wave make up the ranges of harmonics. The second, third, fourth, and fifth harmonic parts, for instance, will be at 100Hz, 150Hz, 200Hz, and 250Hz, accordingly, for a waveform with a fundamental frequency of 50Hz. As a result of adding together all of these harmonic components, distortion caused by harmonics is the degree to which a waveform departs from perfect sine values. The perfect sine wave contains no harmonics. In such a situation, nothing can alter this flawless wave. The average of all the harmonic elements that make up a voltage or current waveform measured versus the basic element is known as a total distortion of harmonics or THD. The ratio of the root-sum-square value of the harmonic makeup of the voltage to the root-mean-square value of the basic voltage is referred to as the overall harmonic distortion of the voltage waveforms.

$$\%V_{THD} = \sqrt{\frac{V_2^2 + V_3^2 + V_4^2 + V_5^2}{V_1}} \times 100 \quad (2)$$

Harmonic to the max root sum square value of the harmonic substance of the current divided by the root mean square value of the simplest present is the distortion of the waveform at the moment.

$$\%I_{THD} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + I_5^2}{I_1}} \times 100 \quad (3)$$

The eqn. (2) & (3) calculate %THD for voltage and current signals. The outcome is a percentage of harmonic elements that correspond to signal fundamentals. The main signal aberration increases with percentage. Harmonic distortion destroys electrical components. Inappropriate distortion raises electrical system current & neutral conductor along with distribution transformer heat. Higher frequency harmonics induce motor core loss and overheating. Higher order harmonics that oscillate at the transmit frequency can likewise impact with information lines. Extreme temperatures and interference can harm electrical systems and limit the lifespan of electronic gadgets.

3.3 Modifying Inverter Switching with PSO

When used in conjunction with a PI controller, PSO can improve power quality by bringing THD levels down to within IEEE tolerance limits by maintaining a constant output waveform of current and voltage at the inverter's output. PSO searches begin with a random beginning guess, and the search region can be explored through continual duty cycle updates, which aid in dampening steady-state oscillations near MPP. The capacity to enhance inverter switching in harsh environments and the lack of steady-state oscillations at MPP are the two main features. The initial duty cycle selection is a drawback. When the duty cycle values fall outside of a known range, the number of iterations required by the method to find the global maximum increases. Because of this, power generation is diminished. As a result, initial duty cycle constraints must be defined.

3.4 PSO Technique for Utilization

First, establish a bound on the particle's position and velocity, as well as the number of particles and search parameters. Phase two: Initiate at Sporadic Particle position and motion is calculated. Phase three: Determine each particle's fitness level. In the fourth stage, the particle with the highest fitness value is designated as Gbest (Global Best). The fifth step is to revise each particle's position and velocity in light of the G_{best}. Repeat steps 3 and 4 until an optimal solution is found (6^{th} step). The last iteration's value, indicated by the variable G_{best}, is the one that has been optimized. Eighth, use the provided formula to determine the duty cycle.

3.5 PSO with Adapted Species for Harmonic Elimination in Inverter Devices

A particular strategy employs a specialized form of PSO to cut down on inverter harmonics. An inverter's harmonic elimination issue is a nonlinear transcendental solution optimization issue with many local minima. Species-based PSO (SPSO) represents a revolutionary PSO strategy, and it is used here to solve the harmonic elimination issue. The initial version of SPSO was tweaked, making it a more reliable method for locating the search space's global optimum. When the number of switching angles increases, the suggested approach has the ability to locate the optimal ones, whereas traditional iterative approaches and the resulting theory method are unable to do so. The output voltage has very low overall harmonic distortion and switching frequency, and the findings reveal that the suggested approach successfully minimizes a significant number of specific harmonics.

3.6 Simulation Study

Power electronics & MATLAB have many uses, including but not limited to: robotic controls; industrial automation; automotive; industrial drives; power quality; energy from renewable sources system; and automation in industries. Particularly, MATLAB can be utilized to choose the system according to needs and to determine particular parts for the Solar PV applications when the power plant is even installed. In this article, we'll investigate the usefulness of MATLAB & the toolboxes it comes with for modeling and simulating solar PV systems, with a focus on evaluation and development.

Here, different subsystems are built in a MATLAB program for constructing a PV system with or without PSO. The PV system is one such thing. Analyzing PV modules using their own data sheets. This device is set up for series connections thanks to its I_{PV} input. It is a temperature-independent static model. Logic Gate The developed subsystem has the following specifications: Short Circuit current = 8.83 A, V_{oc} = 37.4V, I_{max} = 8.31 A, and V_{max} = 30.1V. The diode is used as a bypass. This is done to prevent hotspots in partial shade situations and to avoid reverse current flow when connecting strings in parallel.

3.7 Implementation of PV based Inverter System without PSO

Both the PSO-free and PSO-based versions of an MPPT-based photovoltaic converter can be implemented in MATLAB. A PV array, DC/DC boost converter, inverter, PID controller, and RL load make up the system. The controlled voltage for the boost converter comes from the PV voltage VPV produced by the PV array. To dampen voltage swings from the PV array, a MOSFET switch, an inductor L of 0.1mH, and a capacitor connected across the array make up the DC/DC boost converter. The PWM technology used to operate the switch has a switching frequency of 20kHz.

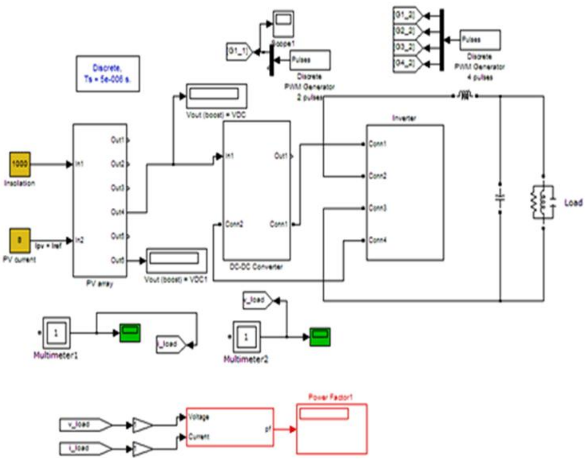

Figure 9: Using MATLAB/Simulation to Build a PV Inverter Without a Power-Sharing Organizer.

4. Findings and Discussion

Figures 10 and 11 display the current and voltage waveforms without PSO, while Figures 12 and 13 display the same data with PSO. This suggests that the output power changes and does not remain constant over the stated time frame, as evidenced by the current and voltage waveforms showing some peaks over this range. That's why they're to blame for the strategy complicated burden

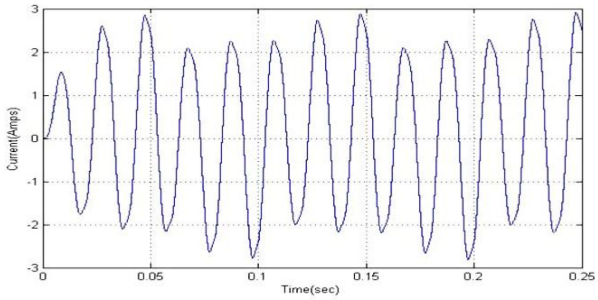

Figure 10: Current waveform excluding PSO

On the contrary, it has been noted that if the photovoltaic system is modelled and simulated using the PSO control method, the resulting current as well as voltage waveforms indicates steady state value for both current and voltage, thus the output power is kept constant throughout the time interval.

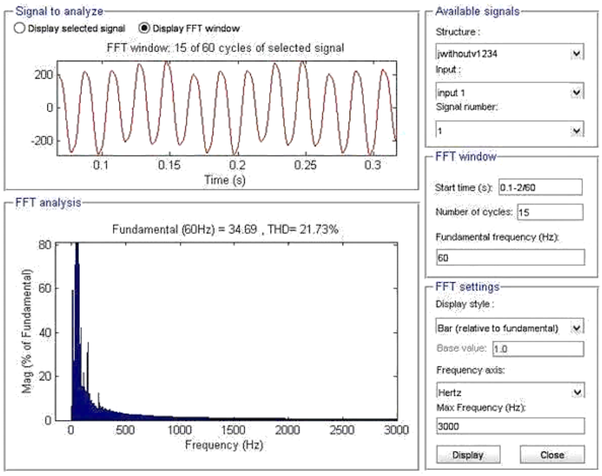

Figure 11: FFT analysis excluding PSO

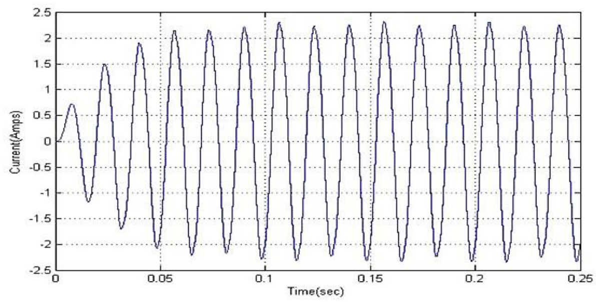

Figure 12: Current waveform including PSO

FFT investigation is performed with waveform evaluation. Figure 12 shows that without PSO, the PV technique's Total Harmonic Distortions represent 21.80%, while Figure 13 shows that they are a manageable 2.80%, well within IEEE limits

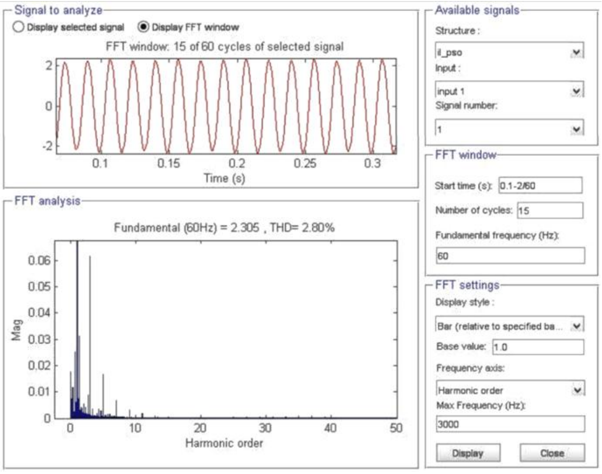

Figure 13: FFT analysis including PSO

Total Harmonic Distortions are 21.80% for a PV system without PSO, as shown, while Fig.13 shows that the entire system meets the requirements of the IEEE with just 2.80%. Thus, PSO allows for more exact implementation of PV based inverter systems by reducing %THD when compared with systems having PSO. The advantages are self-evident

5. Conclusion

This article creates a MATLAB simulation of a PV-based inverter system utilizing PSO without including it. The presented model shows that this PV system is employed to lower THD and, by extension, boost the quality of the electricity produced. It is made up of a digital controller, the PSO based controller, that can improve the inverter switching and make the system work for any given load and duration. The THD has been decreased by this. By contrasting the inverter's output both with and without the PSO method, one can find that the latter yields better outcomes.

Therefore, the PSO method can be used in photovoltaic systems to bring down THD to manageable levels. Last but not least, this boosts the system's dependability. Not only does this system increase the inverter's switching under extreme circumstances, yet it additionally stabilizes itself by decreasing steady-state oscillations at MPP. Yet, ensuring optimal performance of the equipment and a longer life lifetime is made possible by maintaining low THD levels on an entire system

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