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SIMULATION OF SINGLE-PHASE GRID CONNECTED DIGITALLY CONTROLLED SOLAR PHOTOVOLTAIC SYSTEM FOR IMPROVING ITS POWER QUALITY UNDER NON-LINEAR CONDITIONS

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Abstract:
Power quality is the most important thing to think about when putting together power systems for businesses and factories. Currents that are pulled by non-linear loads tend to be spiky and only last for a short time. Harmonics are made when these pulses cause the waveforms of the current to get messed up. Harmonics can cause problems with both the equipment that makes up the power distribution system and the loads that are plugged into it. In this paper, we simulate a single-phase grid-connected solar photovoltaic (PV) system made up of a DC-DC boost converter with a controller for Maximum Power Point Tracking (MPPT) and a DC-AC inverter that uses the unit voltage template method to get the signals needed to drive the inverter's switches. Together, these parts make up a DC-to-AC inverter that can track the Maximum Power Point. All the information about Total Harmonic Distortion (THD) is put together in one place. The MPPT controller makes the system stronger by making sure that as much solar energy as possible is collected. This makes the system more reliable. The performance of the power quality improvement has been proven by the results of the MATLAB/Simulink simulations.
Keywords--- Photovoltaic, Maximum Power Point Tracking, Total Harmonic Distortion, DC-DC Converter

1. Introduction

Solar PV systems are becoming more and more popular as a renewable energy source because they are good for the environment and don't cost much to set up. Unfortunately, the amount of power that PV systems produce depends a lot on the weather, which makes it hard to keep a steady power supply. Also, loads that don't follow a straight line can mess up the power quality of the system. More use of digital control techniques, which can also help solve this problem, can make PV systems that are connected to the grid work better. By simulating single-phase solar PV systems that are connected to the grid and controlled digitally, it is possible to see how the system responds to different situations and find ways to improve the power quality. In this paper a simulation model of a single-phase, digitally controlled, solar photovoltaic system that is connected to the grid is presented. MPPT and voltage control are two examples of digital control strategies that are added to the simulation model to improve the power quality of the system.

The simulation results will be looked at to see how well digital control approaches can improve the power quality of the system when it is working in a non-linear environment. The results of this study could improve the reliability and efficiency of digitally controlled solar PV systems.

2. Literature Survey

In recent years, the use of solar PV systems has increased significantly due to the depletion of conventional energy sources and environmental concerns. However, the performance of PV systems is affected by various factors such as non-linear loads, temperature, shading, and partial shading, which can result in power quality issues. To improve the power quality of PV systems under non-linear conditions, several researchers have proposed various control strategies and simulation models.

A model of a single-phase photovoltaic system that is connected to the grid was recently presented in order to mitigate the impact of non-linear loads (Pazhanimuthu et al., 2022). The suggested model was validated by running simulations in Matlab/Simulink and analysing the results of experiments. With the assistance of an adaptive neuro-fuzzy inference system (ANFIS), as defined by, it is possible to improve the overall performance of a single-phase PV system that is connected to the grid (Estifanos Abeje Sharew et al., 2019). The effectiveness of the suggested methodology was validated by simulations in Matlab and Simulink. In addition, (Sreekanth, T.et al., 2019) provided a model for a single-phase grid-connected photovoltaic system that uses a fuzzy logic controller (FLC) to address the challenges with power quality caused by non-linear loads. The PSCAD/EMTDC simulation of the model that was proposed turned out to be successful. In a single-phase grid-connected PV system, Power Quality Issues Caused by Non-Linear Loads Can Also Be Reduced With the Use of a Hybrid Fuzzy Logic Controller and Particle Swarm Optimization Method, as Presented by (Oliveira da Silva et al., 2020) Power Quality Issues Caused by Non-Linear Loads Can Also Be Reduced With the Use of a Fuzzy Logic Controller and Particle S The effectiveness of the suggested methodology was validated by simulations in Matlab and Simulink.
various researchers have proposed different control strategies and simulation models to improve the power quality of single-phase grid-connected PV systems under non-linear conditions. These studies have shown that the use of digital control strategies, ANFIS, FLC, and hybrid fuzzy logic controllers can effectively mitigate power quality issues and improve the performance of PV systems.

3. System Configuration

Solar PV systems are used a lot because people want to use renewable energy sources more and more. But a solar PV system's output voltage and current are not straight lines, and the system's ability to make electricity depends on the conditions around it. Harmonics, changes in voltage, and reactive power flow are all problems that can happen when a non-linear system is hooked up to the grid [5]. All of these problems are made worse by the fact that the system doesn't work in a straight line, which is one of the things that caused the problem in the first place. Because of this, it is a must to make a good control system to improve the power quality of the connection between the PV system and the grid.

The proposed single-phase grid connected digitally controlled solar photovoltaic system block diagram is as shown in figure 1. A solar panel, a DC-DC converter, an AC-DC inverter, a low pass filter, and a load are all parts of the proposed system. The main source of direct current (DC) power that goes to the inverter comes from the solar panels which converts the solar radiations into DC electrical energy. The amount of DC voltage is proportional to the number of panels used, how they are oriented, and how much sunlight they get [12]. By putting in a DC to DC converter, the DC voltage that the solar panels put out can be made higher. This device makes the necessary changes because the inverter won't work right if the voltage is too high or too low. If the DC voltage needs to go down, a buck converter will be used as the DC-DC converter. If the DC voltage needs to go up, a boost converter will be used. Here a boost converter is used. MPPT is a type of control circuit that is used to make sure that solar panels continue to work at their most productive levels. This MPPT feature makes solar power production more efficient by controlling the DC-DC converter's output voltage to match the time when the panels produce the most power. The inverter is the "brains" of the system because it changes the DC made by the solar panels into AC, which can then be fed back into the utility grid. Using a digital control technique the inverter makes a sinusoidal waveform with the right voltage and frequency so that it can connect to the grid. The grid connection is where the inverter can talk to the electricity grid. Here the control is done at two sides. First, at input side using MPPT control method to maximise the amount of energy that can be harvested by changing the duty cycle of the DC-DC converter. And secondly at the output grid side using feedback control to inverter which helps in reducing harmonics of the output current and improves power factor which improves the power quality of a single-phase solar PV system that is connected to the grid. The parameters of the PV module are tabulated in Table 1.

Table 1: Parameters of PV module

Parameters	Values
Open Circuit Voltage(Voc)	44.3 V
Short circuit current(Isc)	4.5 A
Modules in series	3
Modules in parallel	1
Panel Ratting	450 W
Number of cells per module	72
Input Voltage Vin	110 -135 V
DC Voltage Vdc	250 V

Grid Voltage Vgrid	230 V
Inverter Voltage Vinv	110 V

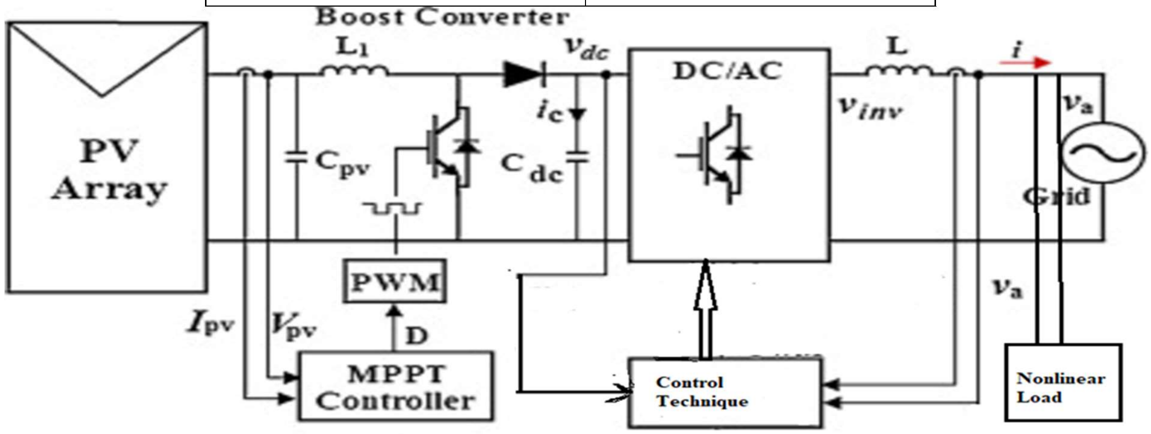

Figure 1. Block Diagram of Single-Phase Grid Connected Solar Photovoltaic Inverter

3.1 Proposed algorithm for simulation

The complete MATLAB simulation of the proposed system is as shown in shown in Figure 2. The proposed algorithm for the system works as given. Measure the input parameters of the system including solar irradiance, temperature, and load demand. Calculate the MPP [10] using a suitable algorithm such as perturb and observe (P&O). Convert the DC output from the solar panel to AC voltage using a DC-AC inverter. Apply a digital control algorithm to the inverter to maintain the grid voltage within the specified limits. Implement a non-linear load emulator to replicate the non-linear behavior of loads in the system. Use a filter to eliminate harmonics and improve the power quality of the system. Monitor the system performance by measuring the output voltage, current, and power. If the power quality is not satisfactory, adjust the control parameters of the system to improve it. Overall, the proposed algorithm involves measuring input parameters, implementing MPPT, converting DC to AC, applying digital control algorithms [11], simulating non-linear loads, filtering harmonics, monitoring performance, adjusting control parameters, evaluating performance, and ensuring safety. By following this algorithm, the power quality of a single-phase grid-connected digitally controlled solar photovoltaic system can be improved under non-linear conditions.

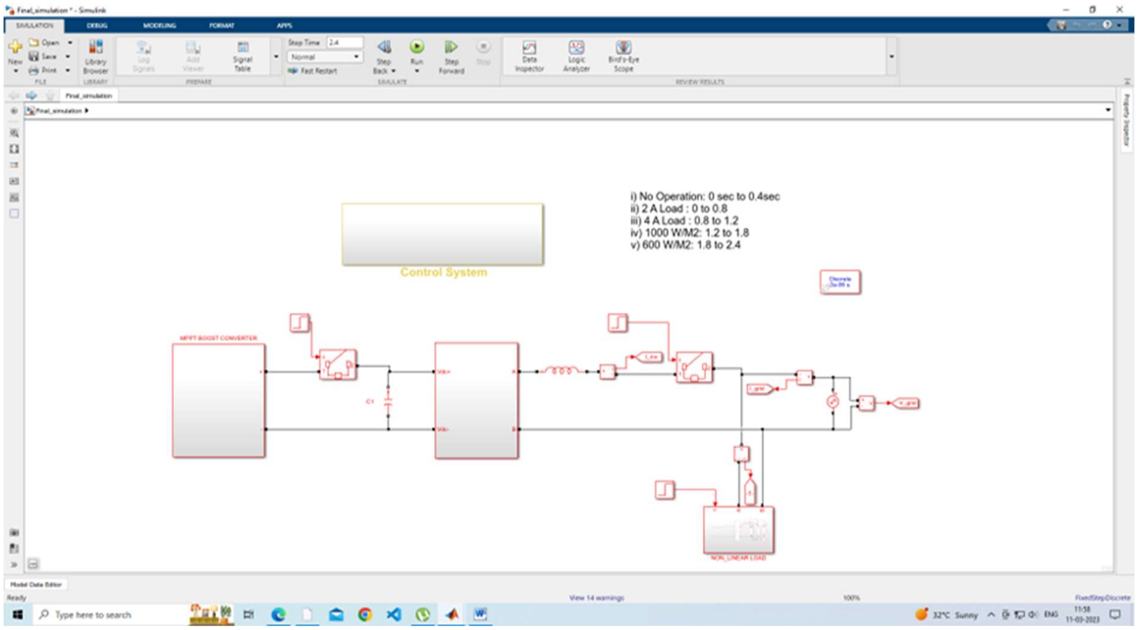

Figure 2. MATLAB/Simulink Modelling of the Overall System

3.2 MPPT Control

To extract the maximum power from PV panels the MPPT technique is used which keeps an eye on the panel's MPP and adjusts the duty cycle of a DC-DC converter. Due to accurate performance and ease of implementation we have selected the P&O MPPT algorithm which operates by periodically perturbing the array terminal voltage or current and compares the PV output power with that of the previous perturbation cycle. Figure 3 shows the MATLAB Implementation of the P&O MPPT. The P&O algorithm is used to make small changes as the duty cycle of the DC-DC converter is changed and the power coming out of the PV panel is watched. Since the duty cycle is related to power, a higher power output will lead to a higher duty cycle, while a lower power output will lead to a lower duty cycle [9]. This is done again and again until the maximum power point is reached, when that happens, the process is over. P&O algorithm includes a perturbation in the voltage and observing the power yield [17].

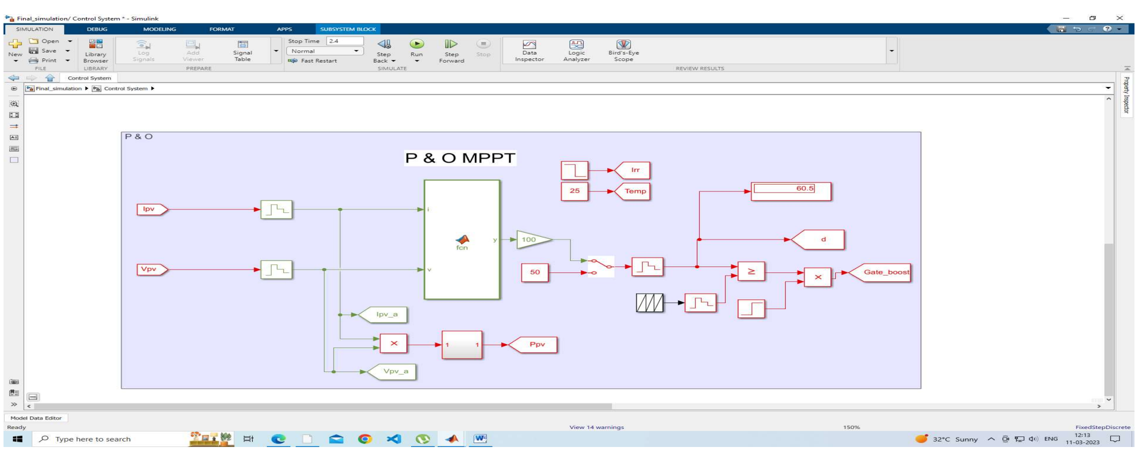

Figure 3. MATLAB Implementation of the P&O MPPT

The MPPT algorithm as shown in figure 4

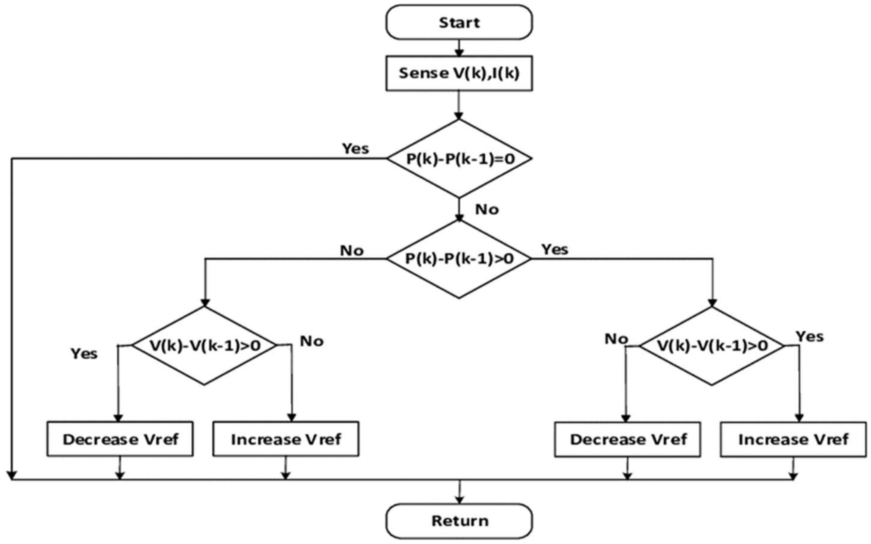

Figure 4. P&O Algorithm flow chart.

3.3 DC to DC Converter

In the grid-tied PV system to match the output voltage/power of PV system with grid the DC-DC converter is used to step-up or step-down the PV output voltage as per the requirement. In this proposed system the DC-DC converters handles two important tasks, integration of PV power in grid and detection of MPP using P&O MPPT control algorithm. Here Boost converter circuit is designed and simulated in MATLAB Simulink as shown in figure 5 to step up a low voltage DC input to a higher DC output voltage. The basic operation of the DC-to-DC boost converter involves using an inductor, a switch, a diode, and a capacitor. The input voltage is applied to the inductor, which stores energy in the form of a magnetic field. The switch is used to control the current flow through the inductor, and the diode is used to prevent the current from flowing back to the input source. The capacitor is used to smooth out the output voltage and reduce any ripple or noise. During the operation of the boost converter, the switch is turned on and off at a high frequency. When the switch is turned on, the input voltage is applied to the inductor, and the magnetic field begins to store energy. When the switch is turned off, the magnetic field collapses, and the inductor releases the stored energy to the output circuit through the diode. This results in an output voltage that is higher than the input voltage. The output voltage of the boost converter is controlled by adjusting the duty cycle of the switch, which is the ratio of the on-time to the off-time. By increasing the duty cycle, the output voltage can be increased. However, the boost converter has a maximum output voltage limit, which is determined by the input voltage, the inductor and capacitor values, and the circuit topology.

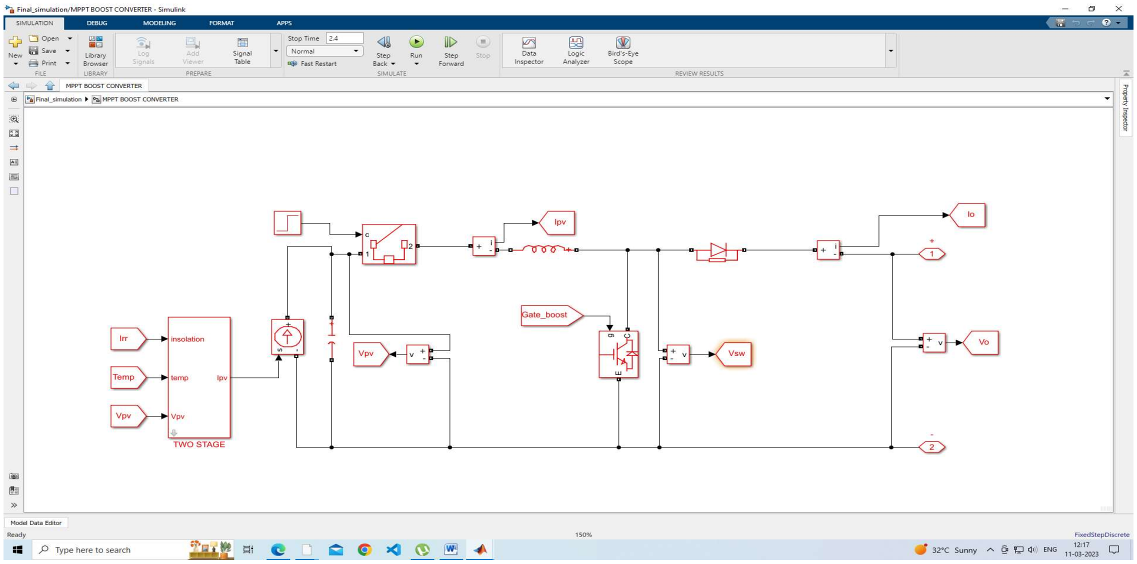

Figure 5. MATLAB Implementation of the DC-to-DC Boost Converter

3.4 Single Phase Voltage Source Inverter

The conversion of DC power into AC is done using single phase full bridge voltage source converter as shown in figure 5. Which consist of an input decoupling capacitor and four semiconductor insulated-gate bipolar transistor (IGBT) switches along with antiparallel diodes. The DC to AC conversion is done by properly by switching the IGBT through its gate control in a sequence. The gate signals are generated by a digitally controlled feedback loop technique designed for this system as shown in figure 6.

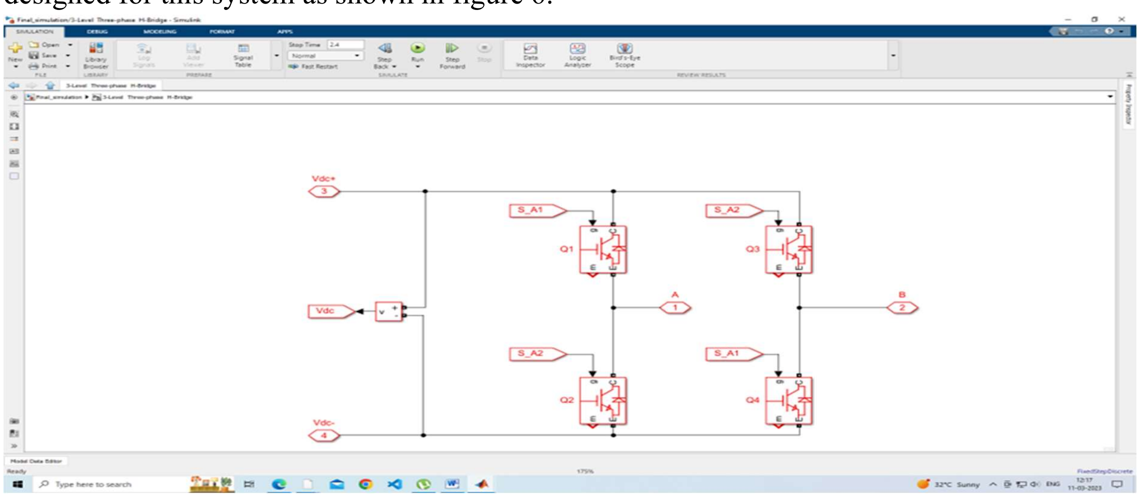

Figure 6. Single-Phase Full Bridge Voltage Source Inverter Modelling in MATLAB Simulink

3.4.1 Proposed System Control Technique:

The figure 7 shows how the suggested control is put to use to get the right switching logics. The suggested control architecture for grid-connected PV systems is made up of two different parts: the MPPT control and the grid-connected converter control. The grid-connected control has many functions, such as synchronising the grid, converting DC to AC, getting rid of harmonics, and keeping the grid current sinusoidal at Unity Power Factor. The Vdc reference of 250 V is fixed and the DC link voltage of inverter is filtered by using a first order low pass filter from which the controlled signal Vdc control is obtained. The reference DC and Vdc control signal is added and the error signal is given to the PI controller. The output of the PI controller is the controlled current I_cpv. The unit voltage template is obtained from Vload and the product of unit voltage and Controlled current I_cpv is the I_cactive current. The fundamental load current from the non-linear load is applied to the band pass filter to eliminate any harmonics resulting in a controlled load current $IL\_{load\ grid}$ which is added together with I_c_{active} current producing command current I_{cmd}, This I_{cmd} and the actual grid current I_{grid} is given to a function where a hysteresis band is selected and according to this the switching pulses will be generated S_A1 and S_A2. This will cause the load current to be in phase with the grid current and voltage. This will improve the power factor and reduce harmonic distortion in non-linear conditions. When the command current I_cmd is less than the grid current, the first-leg upper IGBT and second-leg lower IGBT will work. When the command current I_cmd is more than the grid current, the opposite will happen. Both of these IGBTs will work when the grid current is less than the command current I_cmd.

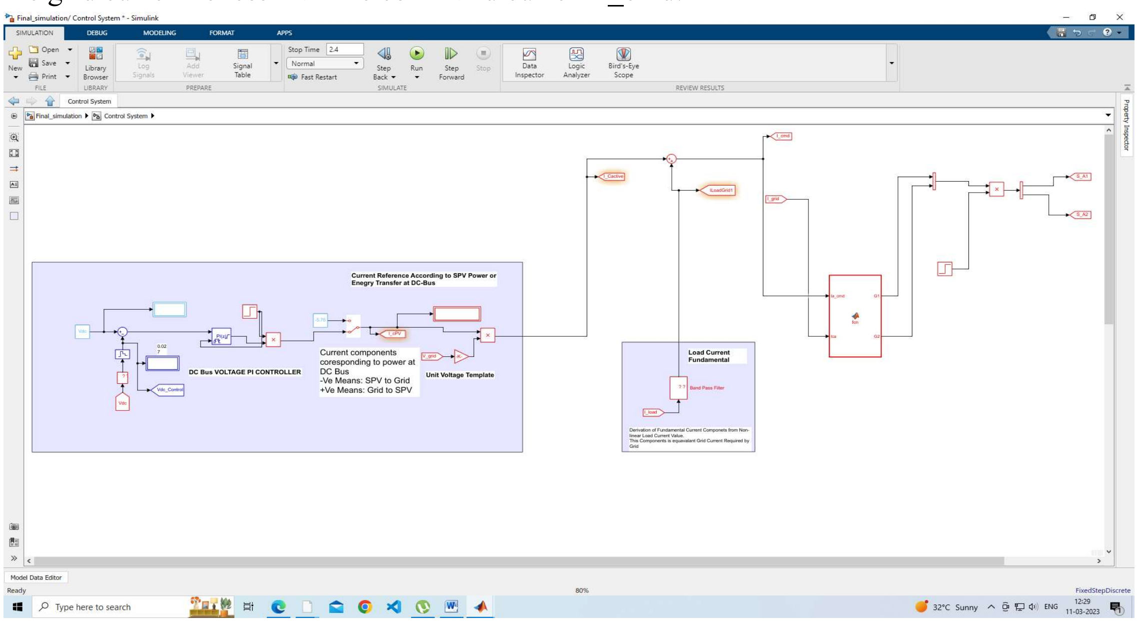

Figure 7. MATLAB Implementation of the Control Technique

4. Simulation Results and Discussions:

In a digitally controlled single-phase grid-connected PV system, the waveforms of various parameters play a crucial role in determining the overall power quality. Under non-linear conditions, the system must be able to improve its power quality to ensure stable and reliable operation. The validation of the proposed control technique algorithm of this single-phase grid connected system is done by simulating system using MATLAB/Simulink software with simpower toolbox. The system is tested for varying load conditions and varying solar radiations and temperature and the results is tabulated in Table 2. Figure 8. shows the simulation waveforms of Grid Voltage (V_{grid}), Grid Current (I_{grid}), Inverter Current (I_{inv}), Load Current (I_{load}) of the system for nonlinear loads. The load current waveform I_{load} will depend on the characteristics of the connected load. In a system with non-linear loads, the load current waveform may have harmonic distortion and may not be in phase with the grid voltage waveform.

The proposed system is tested in MATLAB/Simulation with standard test conditions of 25 °C and 1000 W/m². As shown in figure 8, From t=0 sec to 0.4 sec the inverter is not used making inverter current I_{inv} zero and grid current I_{grid} consist of THD of 81.54% and fundamental current component of 3.122 A. Varying the nonlinear load, from t=0.4 sec the converter along with its control technique is connected such that between t=0.4 sec to 0.8 sec the load is 2A and from t=0.8 sec to 1.2 sec 4A load is connected. It is seen that as load increases the magnitude of load current I_{load} increases and the grid now absorbs less power from the PV system and decreases grid current Igrid magnitude and becomes sinusoidal having THD of 1.76% which is within limits as specified by IEEE-519 standards and fundamental current component of 5.663A. Also as shown in waveforms of figure 9 and The DC link voltage V_{dc} is maintained constant and the system operates at nearly unity power factor thus improving the power quality under nonlinear conditions.

The Solar Insolation is varied from 1000 W/m^2 at t=1.2 sec to 1.8 sec to 600 W/m^2 from t=1.8 sec to 2.4 sec shows that varying solar insolation levels the MPP is shifted and it decreases the magnitude of PV power and grid power but the load power and Vdc is maintained nearly constant having THD of 3.91% with nearly unity power factor which compensates the reactive power and improves the power quality. Through digital control, the system can adjust the inverter current waveform to cancel out the harmonic distortion in the grid current waveform, and to ensure that the load current waveform is in phase with the grid voltage waveform. This improves the power quality of the system and reduce the impact of non-linear loads on the grid.

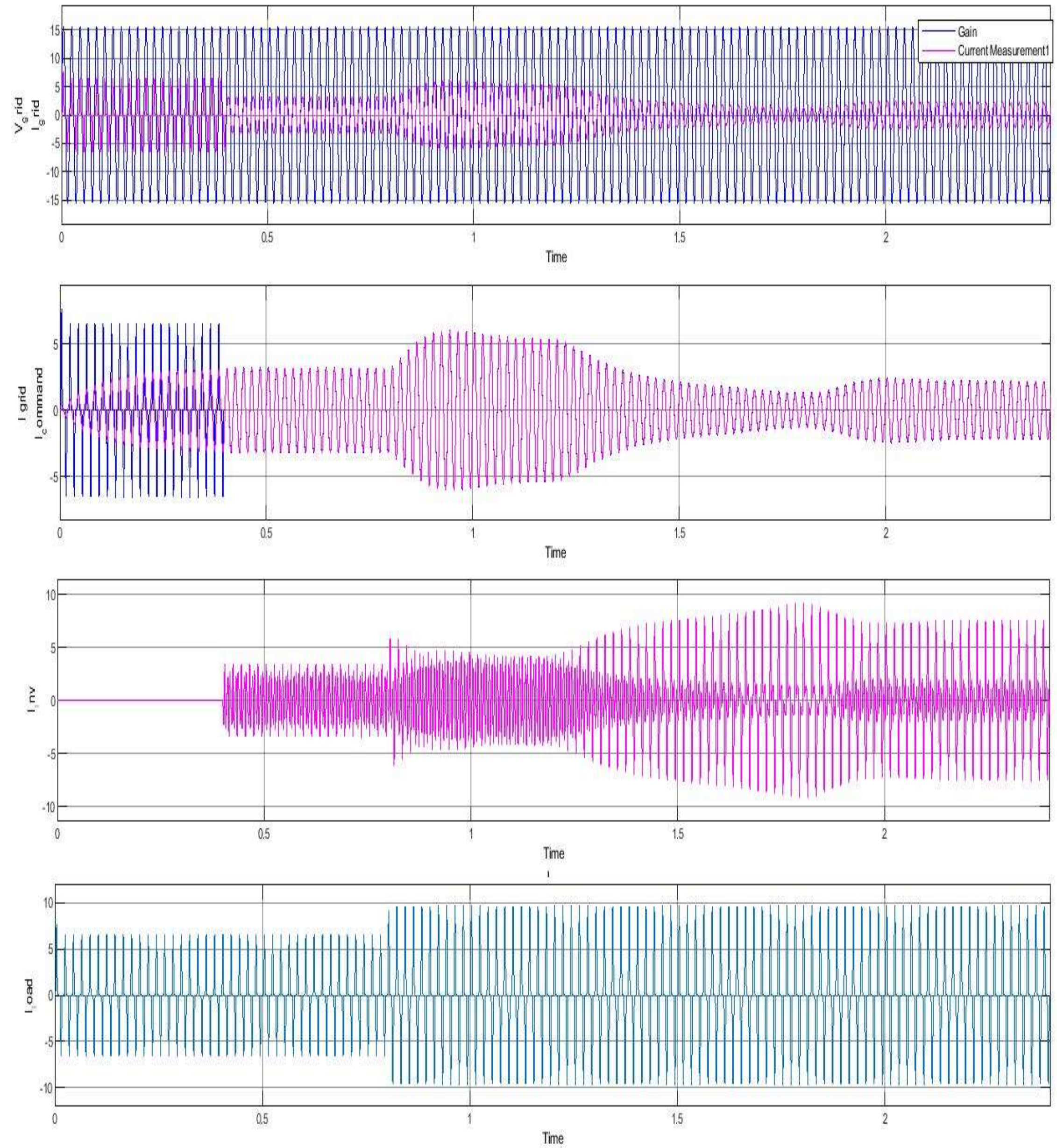

Figure 8. Simulation Waveforms of Grid Voltage (V_{grid}), Grid Current (I_{grid}), Inverter Current (I_{inv}), Load Current (I_{load})

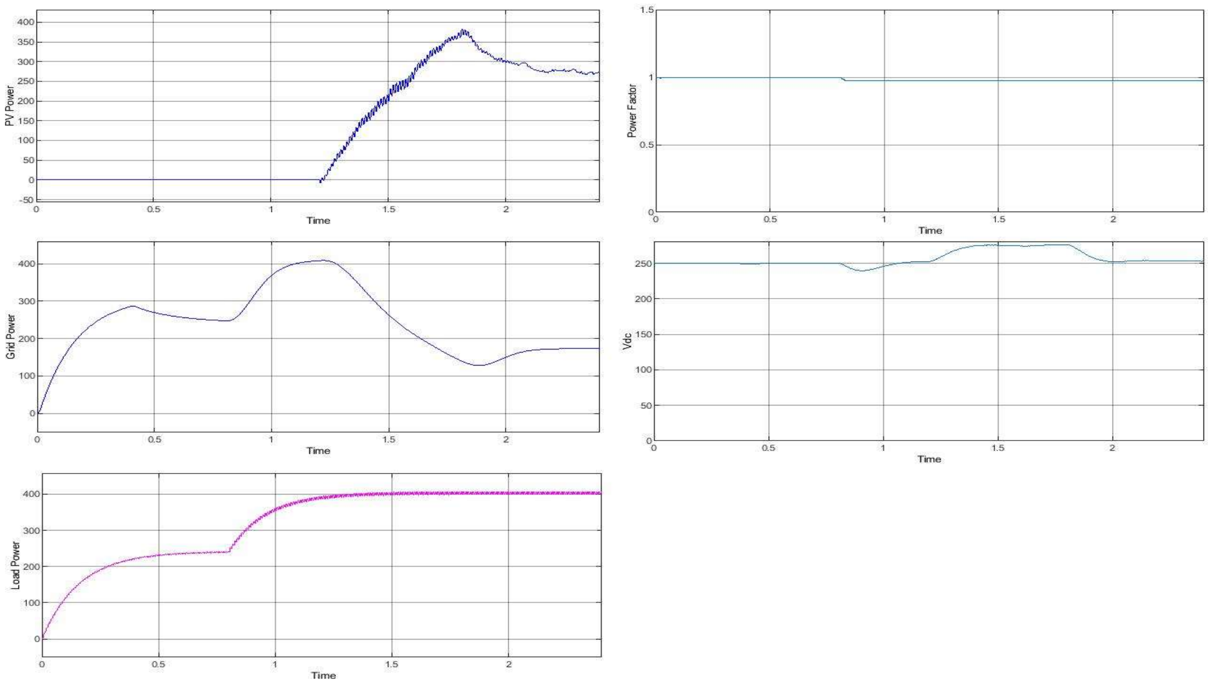

Figure 9. Simulation Waveforms of PV Power, Grid Power, Load Power, Power factor and Vdc (DC Link Voltage)

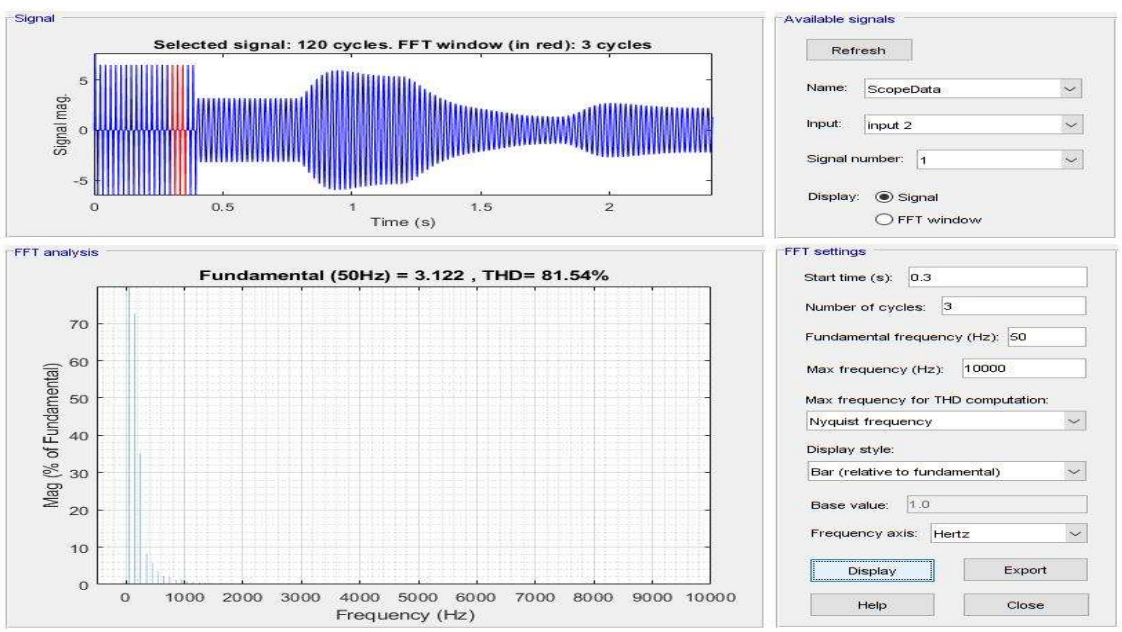

Figure 10. FFT Analysis without control technique

Fast Fourier Transform (FFT analysis) is a useful tool for analysing the frequency content of signals, and it can be applied to a variety of systems, including solar photovoltaic systems. In this case, we are interested in improving the power quality of a single-phase grid-connected digitally controlled solar photovoltaic system under non-linear conditions. The THD for the proposed system is obtained by using FFT analysis function on Simulink. FFT analysis was performed on the grid current and output voltage waveform and the frequency spectrum of the current harmonics without inverter and control technique is shown in figure 10 showing high THD and figure 11 shows FFT analysis using inverter with digital control technique for radiations of 1000 W/M^2 showing reduction of THD. Figure 12 and 13 shows the FFT analysis for varying nonlinear load conditions of 2A and 4A respectively with reduced THD of 1.76%, which is within the limit of 5% as per IEEE standard.

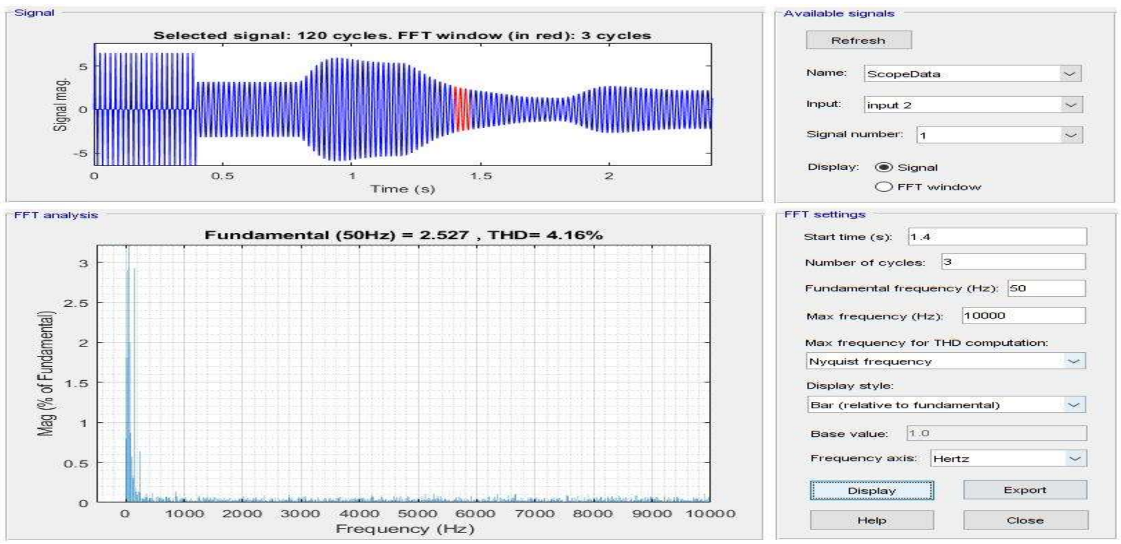

Figure 11. FFT Analysis at radiations of 1000 W/M^2

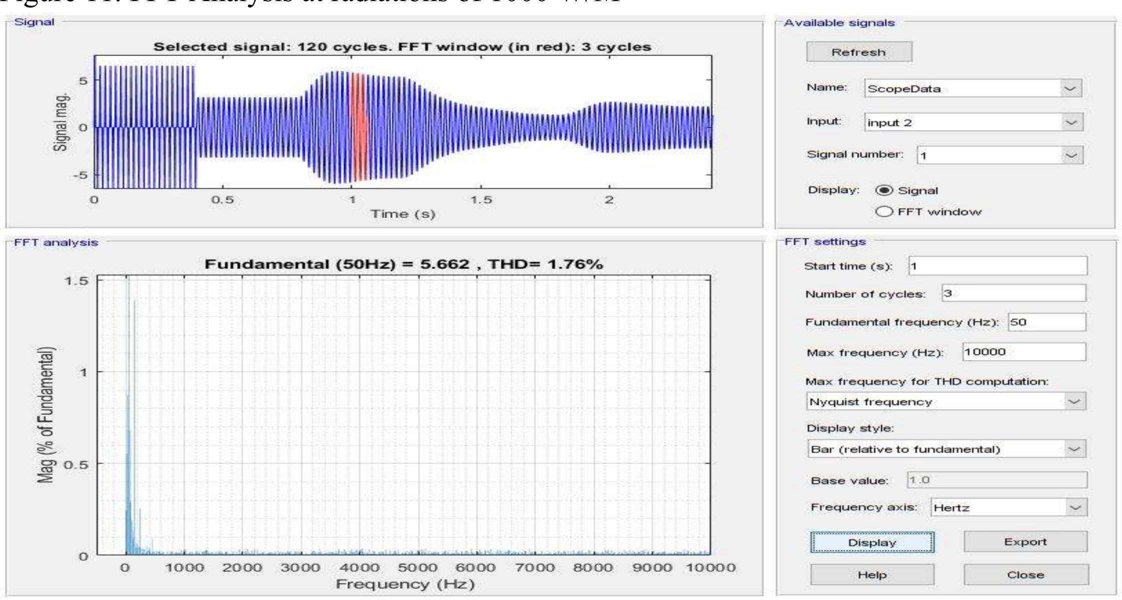

Figure 12. FFT Analysis at 4 A load

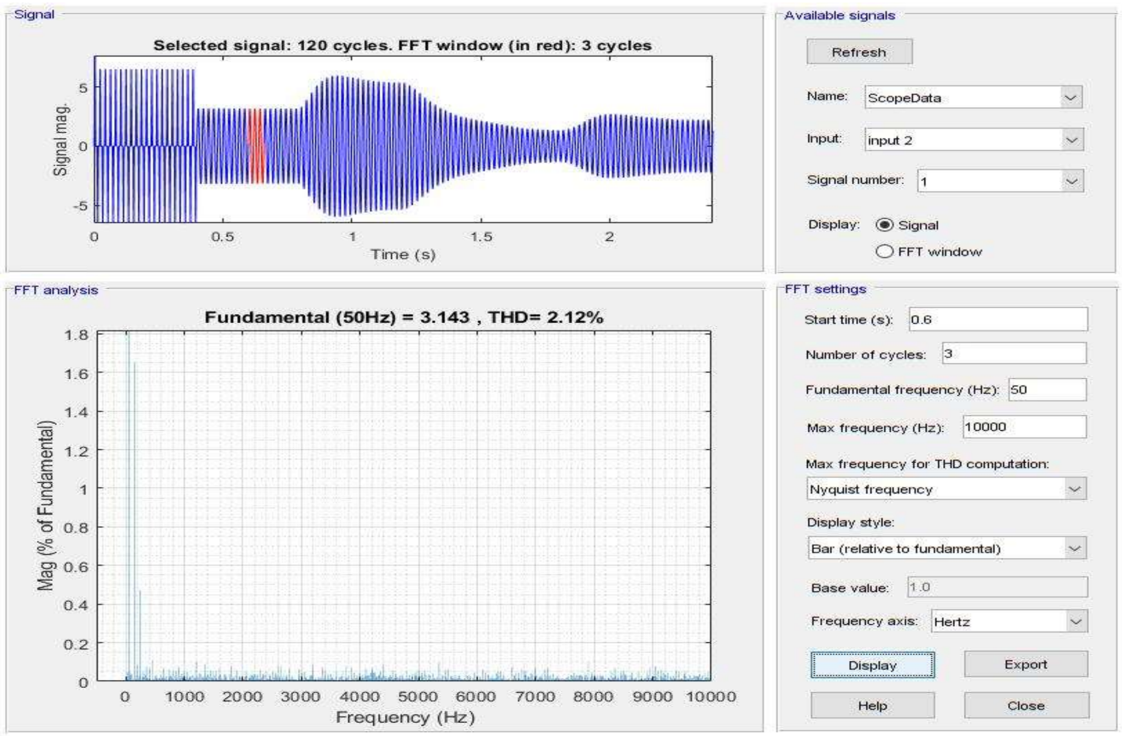

Figure 13. FFT Analysis at 2 A load

5. Results:

Modelling a single-phase solar photovoltaic system that was connected to the grid and managed digitally to improve the power quality of the system under non-linear conditions led to some interesting findings. The goal of the study was to find ways to fix the problem of grid instability caused by harmonics, changes in voltage, and reactive power from solar PV systems that are connected to the grid. The results of the simulations showed that the proposed digitally controlled solar PV system was able to reduce the number of problems with the power quality when used in non-linear situations. The system kept the THD of the output voltage at less than 5%, which is as per the limits given by IEEE standard for grid-connected systems. In order to make the grid even more stable, the system was able to keep the output voltage constant within the parameters that were set, even when the input voltage changed because of shifting loads. Different levels of solar irradiance were also used to test how well the recommended system worked. The results showed that when a DC–DC boost converter is included, the MPPT control becomes easier, and the operating time of the PV systems is then extended increasing the efficiency of the system. This can lead to increased efficiency, reduced power losses and improved overall system performance. The study's simulation showed, in a nutshell, that the proposed digitally controlled solar PV system did a good job of reducing concerns about power quality when used in non-linear environments

Table 2: Results analysis

Time Duration	Condition	Time in Sec	THD	Fundamental Current Component
0 to 0.4 Sec	No Converter connected	0.2 Sec	81.54 %	3.122
0.4 to 0.8 Sec	2 A Load Connected	0.6 Sec	2.12 %	3.143
0.8 to 1.2 Sec	4 A Load Connected	1 Sec	1.76 %	5.662
1.2 to 1.8 Sec	At radiations of 1000 W/M^2	1.4 Sec	4.16%	2.527
1.8 to 2.4 Sec	At radiations of 600 W/M^2	2.2 Sec	3.91 %	2.256

6. Conclusion

This paper presents the modelling and simulation of a single-phase, digitally controlled, grid-connected solar photovoltaic system to improve the power quality of the system under non-linear conditions with DC-to-DC converter using Perturb and Observe MPPT Algorithm to maximize the efficiency under varying weather conditions and obtain improved power quality under nonlinear conditions using digitally controlled inverter. An effective digital control technique for the single-phase grid connected PV system with self-adjusting capability has been proposed here to get around problems that come up when putting solar photovoltaic systems on the grid. This method works well and is easy to use. The simulation results show that the provided control strategy works to reduce the THD to 1.76% and operates system nearly at unity power factor even when the load is nonlinear. The system's use of digital control techniques is flexible enough that it can be changed to meet the needs of any given application. The results of this study will help make solar photovoltaic systems that are connected to the grid more efficient and reliable. This will make it easier to add renewable energy to the grid, which will reduce carbon emissions and make the energy system more stable in the long run.

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