Improvement of power quality of a 200 kW grid-connected PV system

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Article Info

Article history:

Receive Nov 8, 2021
Revised Mar 24, 2023
Accepted Apr 7, 2023

Keywords:

MPPT
PV system
PV-UPQC
PWM
SEPIC

ABSTRACT

In order to enhance electricity quality, a grid-connected photovoltaic (PV) system simulation is presented in this study. A 200 kW photovoltaic system is integrated to a utility grid and loads. A 25 kV 3-level insulated gate bipolar transistor (IGBT) bridge converter is used. Through this system integration of a renewable energy source with a non-renewable source is achieved. This system also wins over the intermittent nature of the renewable source (solar energy) and non-reliability of conventional sources (utility grid). Power and signal quality for various signals such as ripple factor and total harmonic distortion has improved. The suggested system is investigated using MATLAB/Simulink environment. Total harmonic distortion (THD) in voltage and current, ripple factor correction is also incorporate in the MATLAB model.

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1. INTRODUCTION

During past years, the integration of RES's has been increased to match current electricity demand. As the conventional energy sources are limited in amount and bound to extinct which also increase the demand of power generation from RES's. Additionally, because RES's are intermittent, grid connected integrated system with renewable energy sources is in demand. There are several RES's including solar, geothermal, tidal and wind. Here, a micro-grid side multipurpose grid integrated inverter (µG-MPGII) was developed using superconducting radio-frequency (SRF) theory [1]. Information supplied by the battery's level of charge, it provide the complete control the grid real power, eliminating harmonics at premature chromosome condensation (PCC), improving the PF and balance the grid current under the unbalance load condition. Detection of reactive and harmonics current of a PV generation distribution system using triangular function, full fill the power quality requirement of a smart grid system [2]. During weak grid conditions, to mitigate the harmonic currents and voltages with the help of the combination of FIR and IIR filter [3]. From distorted load current, basic active components are estimated using a fractional order notch filter. A prototype system is also developed using MicroLab Box [4].

Power quality improvement using trans ZSI-DVR and performance under severe interruption conditions have been analyzed [5]. Hybrid distributed generation system using DVR to power quality improvement. Fault conditions are tested using a fuzzy logic controller. Various distribution parameters were also analyzed [6]. Performance analysis of standalone and grid-connected mode of micro-grid (PV-UPQC) System with connecting shunt and series filters with common DC-link to address the various power quality issues [7]. Control of interactive charging station for electric vehicles based on renewable energy with AFF-SOGI-improvement DRC's of grid power quality, this system helps reference parameters to becomes harmonic free under the balanced and unbalanced condition with the help of +ve sequence extractor [8]. To balance the grid current and boost power factor, a grid-interfaced PV system should use an adaptive normalized notches filter. Satisfactory results are found developed prototype mode in the research [9]. Extended Kalman Filter algorithm for enabling ride-through operation of a grid integrated solar photovoltaic (GPV) system, during disturbance grid current harmonic content observed accordance to IEEE standard 519 [10].

In case of solar, direct current is produced as a result; this DC is converted to alternating current using inverters [11], [12]. A system with improved linear sinusoidal tracer (ILST) control algorithm feeds SPV energy to the grid as well as improves the power quality; hardware model results in THDs follow the IEEE 929 and 519 standards [13]. Grid-connected PV system performance is enhance by the hybrid sine-cosine algorithm and adaptive controller [14], this system stabilize the operation of MPPT and enhance the system performances under various disturbance, variation in irradiance, and temperature. By providing a grid-connected photovoltaic array system created using MATLAB/Simulink,this research provides a solution to the problem of the limited supply of fossil fuel resources as well as RES's sporadic nature.A three-level IGBT bridge AC-DC converter is used to link a 200 kW solar array to a 25 kV utility grid.The solar array, inverter control, utility grid, and system energy efficiency elements like total harmonic distortion and ripple factor are the main parts of the proposed PV grid-tied system. These components are described in detail below. One of the most prominent electricity sources deployed in power networks nowadays is the photovoltaic system [15]–[17]. With the advancement of science and technology, solar resources are being upgraded each time in an effort to maximise energy output. The grid systems coupled to a solar array are one of the most well-liked varieties of this technology, which feeds electricity directly into the power grid. Operation and modeling of the stand-alone RES PV system, research also focuses on the inverter operation in master mode [18].

Inverter performance of PV system is enhance by using an adaptive reference PI controller and converter use P&O algorithm for MPPT under various environmental conditions [19]. For test the effectiveness of the above said model harmony search is introduced. During three phase fault condition at PCC, PV system not disconnected. A proposed test 53-bus distribution network integrating 12 MW SPV system, for enhancing power quality using STATCOM and Tunisian grid code is discussed here. Steady-state stability analysis and P-Q power is also injected in distribution system via STATCOM. This model increases the power transfer capability and static voltage stability margin [20]. Designed proposed model obtain the benefits of the integrated operation of the energy storage system and electric vehicles, also provide the enhancement techniques benefits [21]. A transient current limiter has been incorporated in hybrid generator based (wind and PV) system [22]. SVPWM inverter maintains the AC power quality. PQ is improved using a hybrid method in grid-connected PV systems [23]. Radial basis function on the grid side, a neural network is trained using adaptive gain parameters to enhance grid power.Two controllers with strong dynamic responsiveness are based on artificial neural fuzzy inference systems and hysteresis. Modern logic-based phase locked loops measure the positive sequence current when the occurrence of a single phase to ground fault [24].

2. THE DETAILED THEORETICAL FOUNDATION

2.1. Photovoltaic array

A photovoltaic module array is created with the photovoltaic array block. The modules are organised into parallel strings in the array, each string having a group of modules. The solar array block from the system advisor of the NREL simulate allows users to model a variety of pre-set photovoltaic modules additionally user-defined photovoltaic modules block of the solar system is a five-parameter model used in order to describe the current-voltage characteristics that are temperature and irradiance dependent of the photovoltaic modules. It employs a photovoltaic cell produced current source (I_L), series and shunt resistance (R_s and R_{sh}). The following list includes the equations that describe the diode current-voltage characteristics for a single solar module.

$$Id = I0\,[exp(VdVT) - 1] \quad (1)$$

$$VT = kTq\ x\ nI\ x\ Ncell \quad (2)$$

Where I_d (Diode current), V_d (Diode voltage), nI (Diode ideality factor), k (Boltzmann constant = 1.3806e^{-23} J.K-1), q (Electron charge = 1.6022e-19 C), I_0 (Diode saturation current), T (Cell temperature in Kelvin), and N_{cell} (Quantity of series-connected cells in a module). The parameters utilized to generate 200 kW from a solar array are listed here, i.e No. of photovoltaic parallel strings used is 80, series-connected photovoltaic module per string is 6, photovoltaic module SunPower SPR-415E-WHT-D, irradiance value input to array is 1000 W/m^2, temperature 45. I-V and P-V characteristics of the same array are displayed in Figure 1.

2.2. Inverter control

The converter is modeled by a PWM-controlled, 3-level IGBT bridge. The harmonics of the IGBT bridge are filtered by the inverter choke RL and a tiny harmonics filter C. The connection between the inverter and the utility distribution grid is made via a 250 kVA 250 V/25 kV three-phase transformer

2.2.1. MPPT controller

MPPT controller is run using the "P&O" method. The inverter VDC regulator's VDC reference signal is automatically adjusted by this MPPT system to get a DC voltage that enhances the solar array's ability to produce power [25], [26]. MPPT is utilized in controlling the converter by working the cluster at its greatest power notwithstanding of the relative multitude of potential adjustments to the load impedance as displayed in Figure 2 underneath.

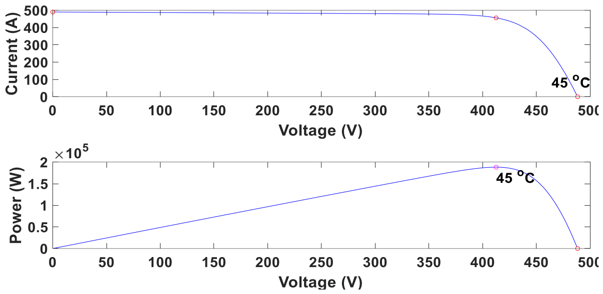

Figure 1.I-V and P-V characteristics

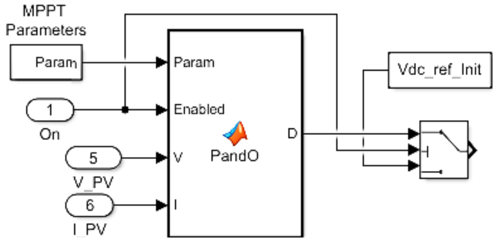

Figure 2. MPPT using the strategy perturb and observe

2.2.2. PLL and measurements

Phase-locked loop (PLL) circuits are primarily used to synchronise output oscillator outputs with reference signals. The system is said to be "locked" when there is no longer any phase difference between the two signals. A closed-loop system with a control mechanism is called a phase-locked loop, and it is utilised to lessen any potential phase errors. The components of PLL and measurement's subsystem are shown in Figure 3.

2.2.3. Current regulator

The given regulator's functioning is similar to that of a voltage regulator, with the main distinction being the parameter that they regulate and the quantity that they alter to produce their output. Current is varied in voltage regulators to obtain the needed voltage level, whereas voltage resistance is generally varied in current regulators to achieve the required current output. As a result, while it is conceivable, regulating voltage and current in a circuit at the same time is generally challenging. The regulator determines the reference voltage which, depending on the existing references Id and Iq, is required for the inverter (reactive current). In our scenario, the Iq reference is set to 0. The components are shown in below Figure 4. Current leaving the converter is positive current, according to the sign convention. I_d positive → In "inverter mode," the converter produces active power, which is P positive. I_q positive → reactive power is absorbed by the converter ("inductive mode"), making reactive power Q negative.

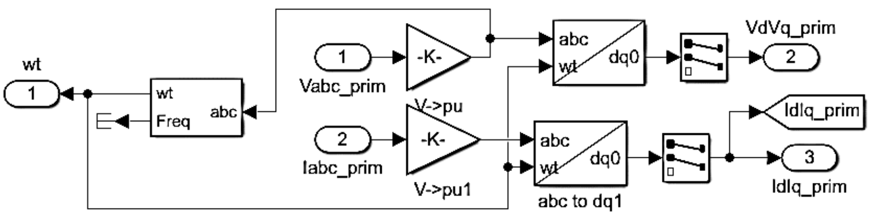

Figure 3. Phase locked loop

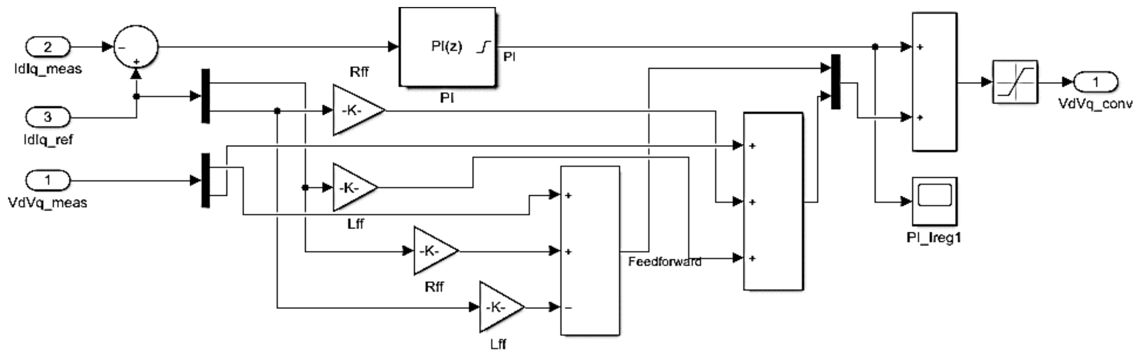

Figure 4. Current regulator

2.2.4. VDC regulator

Calculate the existing regulator's appropriate Id (active current) reference. Below in Figure 5, the VDC regulator's Simulink components are illustrated. A PI controller is used to maintain the output DC voltage constant. Controller got input signal based on error signal i.e Vdc_meas - Vdc_ref.

2.2.5. PWM generator

The pulse width modulation (PWM) signal generator block, as the name suggests, implements a pulse width modulation generator. What the pulse width modulation technique does is that by swiftly alternating between full power transmission and no power transfer, it regulates the transfer of power from one electrical component to another. When the duty cycle exceeds the carrier counter value, the pulse width modulation generator block produces 1, otherwise it outputs 0 [27], [28]. Using the appropriate reference voltages as a basis, create the firing signals for the IGBT's, 1980 Hz (33*60) is the carrier frequency in this scenario. To conduct all the major sub-components of the inverter control, i.e., maximum power point tracking, VDC controller, current controller, phase-locked loop, pulse width modulation and measurements as illustrated in Figure 6, an inverter control subsystem is constructed and simulated.

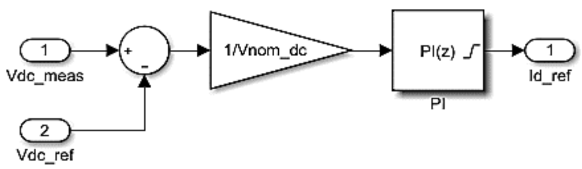

Figure 5. VDC regulator

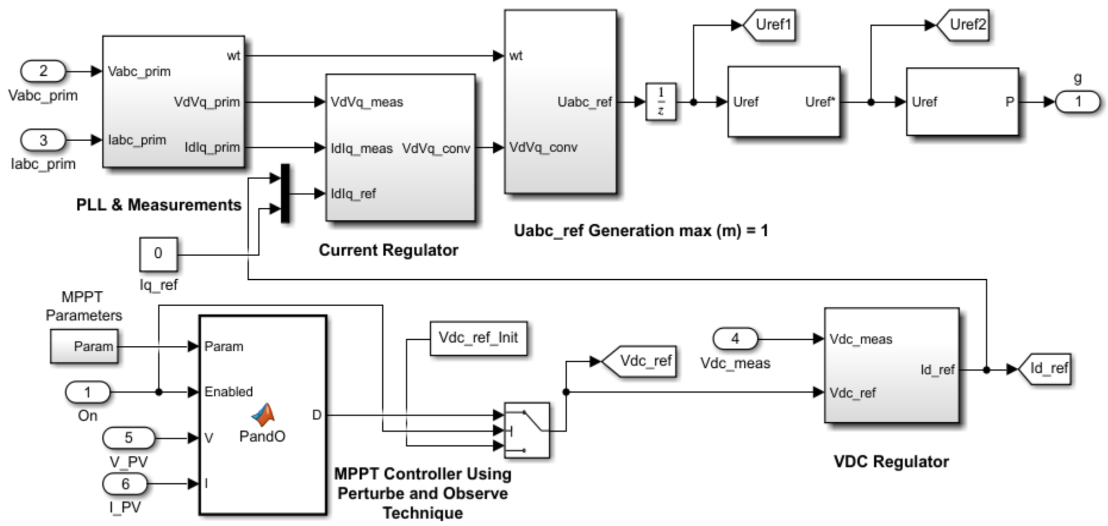

Figure 6. Subsystem of inverter

3. SIMULATION MODEL

A 3-level IGBT bridge AC-DC converter using MPPT is used to design and simulate a 200 kW solar array linked to a utility grid that is coupled to a 200 kW load and a 25 kV electricity utility grid. The design uses a constant of 1000 W/m^2 irradiance and a constant temperature of 45 ℃. The photovoltaic array, which generates solar power, is its most important component, which is seen in Figure 7. It uses the sun's exposed irradiance to generate DC electricity. The MPPT method restricts the amount of DC generated by using P&O computing to track the maximum power. This modification affects the photovoltaic side of the framework's control. A three-stage inverter converts DC to AC and prepares the system for grid interfacing. An inverter control unit manages the grid side management and employs perturb and observe computation. To remove harmonic segments, the inverter's yield voltage is linked to a capacitive filter.

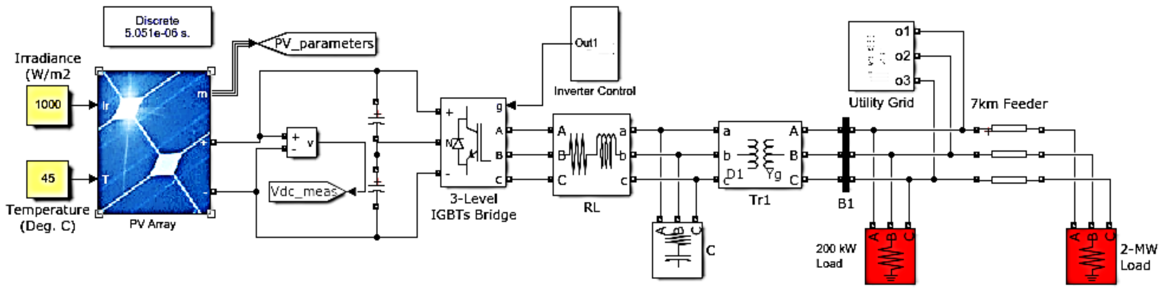

Figure 7. MATLAB/Simulink model of test system

4. RESULTS

The effects of developing and modelling the PV-based system are segregated into their respective DC-AC side. Since there was an initial inrush current, waves continue to increase from zero and eventually reach overshoot esteem on the DC side. Due to input DC bus capacitance, photovoltaic inverters have a pre-energize at the start. The AC current started on the AC side began with an inrush value of 7.4 A and ended with a value of 5.9 A at t = 0.3 sec. The AC power begins with an overshoot of 150 KW then, at that point increments till arriving at the worth of 184 KW at t = 0.3 sec Figure 8 shows the DC side photovoltaic parameters. Figure 9 shows the AC side current and voltage waveforms, and Figure 10 shows the AC power respectively.

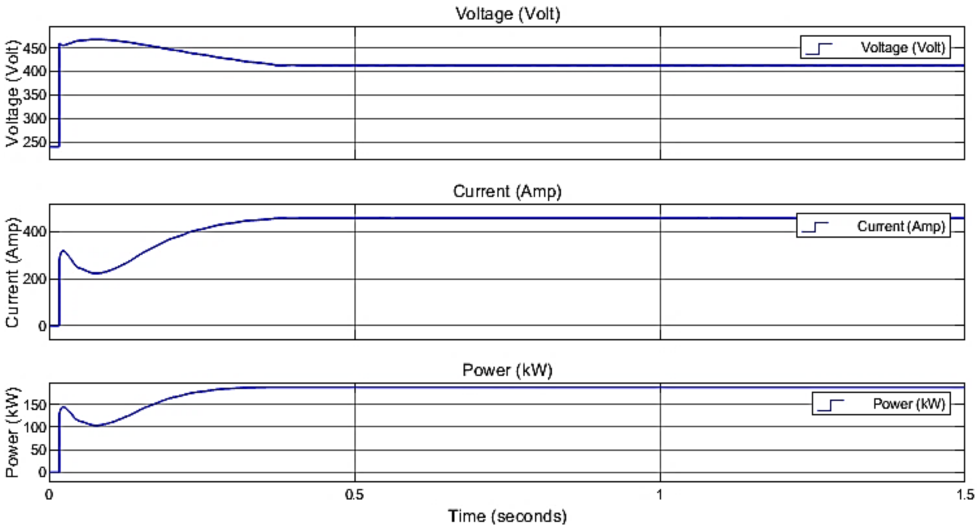

Figure 8. Response of DC side parameters

The ripple factor is one of the quality criteria considered in power electronic research. Switched-mode power supply, include buck & boost converters, single-ended primary-inductor converters (SEPIC) converters, flyback converters, forward converters, push-pull converters, and so on have ripple in their output voltage. The ripple factor of a decent SMPS is minimal (1% is recommended). The ripple factor of the DC voltage came out to be around 0.04, which is a suggested esteem and the plot is displayed in Figure 11.

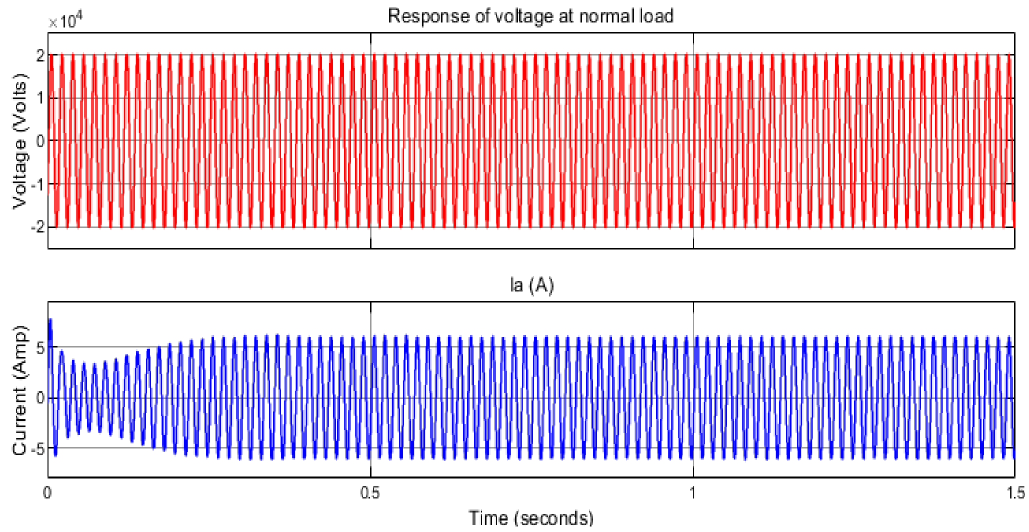

Figure 9. Response of AC side parameters (phase A)

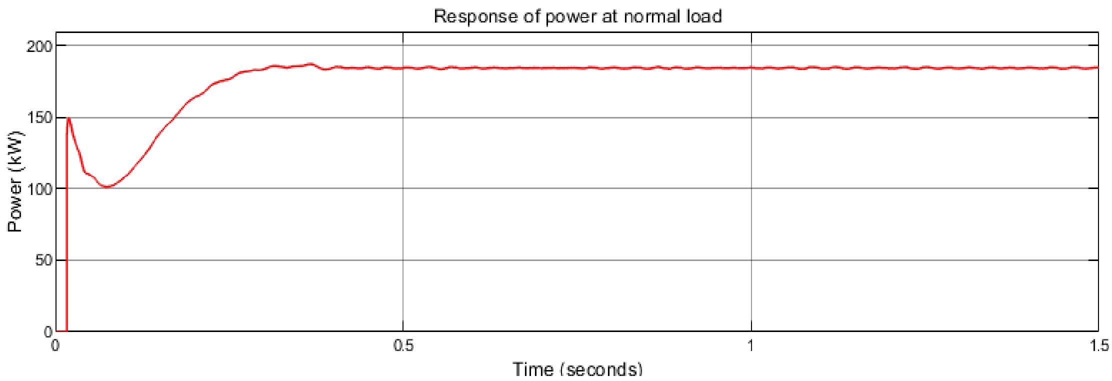

Figure 10. AC power

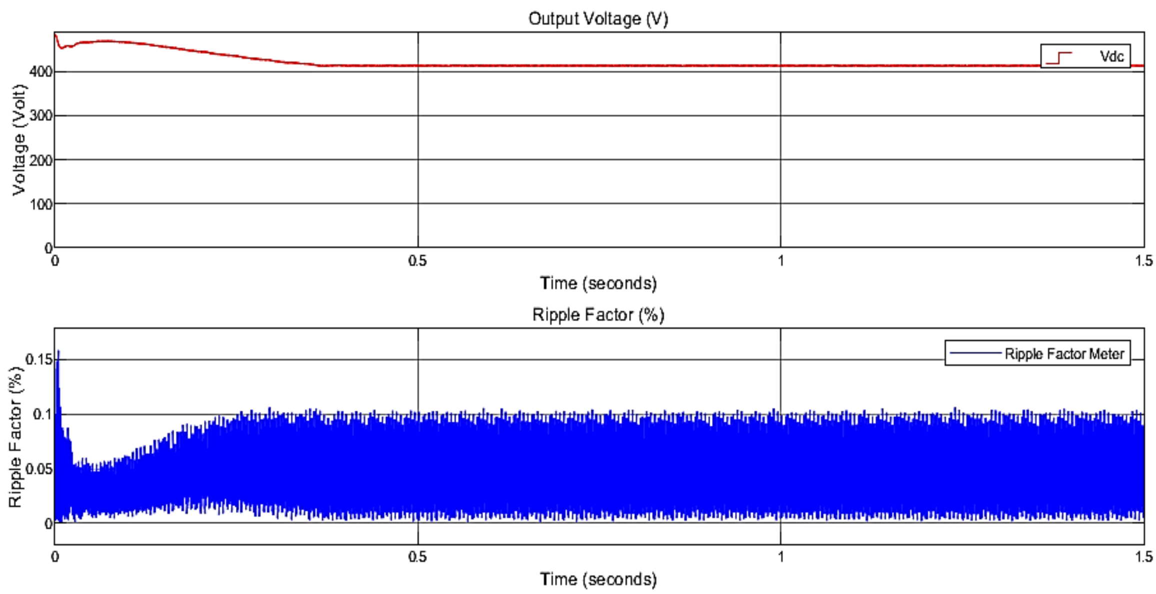

Figure 11. DC voltage profile and corresponding ripple factor

THD is determined by comparing the sum of all harmonic component powers to the fundamental frequency power. A much-related word, distortion factor, is occasionally used as a synonym. Less peak currents, less heating, less electromagnetic emissions, and less core loss in motors all result from reduced overall harmonic distortion in power systems. While there is no national standard prescribing THD limitations for systems, there are acceptable harmonic distortion values that are advised. Consequently, 3% is chosen as the single harmonic limit, while 5% is the THD cap for voltage harmonics. The THD for the voltage and current signal for this proposed grid-connected PV system is coming out to be 0.07% and 2.25% and is show in Figure 12 and Figure 13.

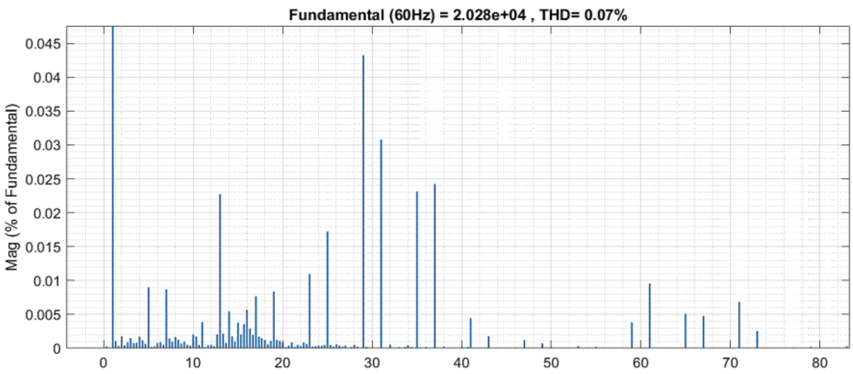

Figure 12. Voltage THD at load end

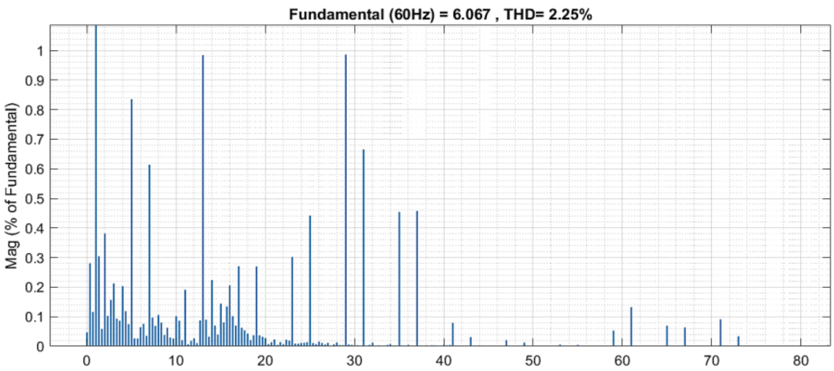

Figure 13. Current THD at load end

5. CONCLUSIONS AND FUTURER SCOPE

Using a three-stage voltage source inverter (VSI), a 200 kW solar array linked to a 25 kV utility grid is planned and simulated. In order to retain the sun's irradiance and produce DC electricity, a photovoltaic array is used. MPPT technique is used based on perturb and observe calculation. To get the most power output, a 3-stage VSI with PWM control is employed. Filters are tuned to remove the harmonics produced by the inverter's swapping concept. The PLL circuit also served as a means of phase synchronization. The proposed model of solar system integrated with utility grid is able to maintain reliability of the system. With the aid of MATLAB-Simulink, the test system is simulated. The suggested model can also be extended to integrate more RES's like, wind, tidal geothermal. to increase the system's overall dependability. Aside from, incorporating RES's is pollution free and cost-effective solution in electricity generation.

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