# 10 MW Photovoltaic Power Plant Design and Simulation

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**Abstract:** The paper manages the parts plan and the simulation of a photovoltaic power age framework utilizing MATLAB and Simulink programming. The power plant is made out of photovoltaic boards associated in arrangement and parallel strings, a DC-DC support converter and a three-stage inverter which interfaces with a 0.4 kV three-stage low voltage matrix and a 20 kV medium voltage lattice by methods for a stage up transformer. The DC-DC support converter utilizes a MPPT controller and the inverter utilizes a control strategy in view of d-q hypothesis with a PI current controller. A few cases for which the dynamic conduct of the arranged photovoltaic framework presents intrigue are recreated. They address the sun based irradiance and temperature change.

***Keywords:*** photovoltaic, MPPT controller, DC-DC converter, PI current controller

## I. INTRODUCTION

The creation of electrical vitality without dirtying activities and on the earth and exhaustion of its assets is an exceptionally topical issue. The sun powered vitality radiation, considered in respect to the life on Earth, is by all accounts limitless. The photovoltaic sun powered vitality depends on the immediate age of power by methods for silicon cells. Under good atmosphere conditions, when sparkling, the sun gives a power of 1 kW/m2. The photovoltaic boards take into consideration coordinate transformation in power of 10… 15% from the previously mentioned vitality [1]. The proficiency of PV framework is a lasting concern [2].

The irradiance vitality of the sun to electrical vitality can be changed over through photovoltaic (PV) power age frameworks. On the off chance that the power age framework does exclude batteries to store the DC vitality, rather including a typical capacitor between the DC-DC and DC-AC converters to store the vitality in favor of DC-Link, at that point a completely non-contaminating source is acquired [3]. To get an advancement of the power provided to the system, contingent upon the irradiance force of the sun, it is liked to choose a setup in which the photograph voltaic power age framework utilizes a productive controller, for example, Maximum Power Point Tracking (MPPT) [4].

## II. DESIGN OF THE PV POWER GENERATION SYSTEM

The outline of a PV power age framework, with an introduced power of 10 MW, is proposed in what takes after. The electric power providing by utilizing a PV gear is made by the prerequisites forced by the electric vitality supplier who works at the PV site, two alternatives being accessible: the low voltage association (400 V) and the medium voltage association (20 kV), by methods for the progression up transformer (LV/MV). The outlined PV power age framework is made out of (Fig. 1):

1) A PV exhibit of PV boards assembled in arrangement or potentially parallel strings, for example, to get a greatest power of 10 MW;
2) A DC-DC support converter utilized as a heap controller and separately to change over the yield voltage of the PV cluster to an appropriate voltage for the inverter;
3) A three-stage DC-AC converter (i.e. inverter) to send out the electrical vitality to the three-stage framework;
4) A three-stage advance up transformer to adjust the 0.4 kV low voltage yield of the inverter to the 20 kV voltage of the framework;
5) The PV power age framework controller, which contains the MPPT controller for the DC-DC support converter and the inverter's controller.

The MPPT controller is utilized to control the obligation cycle keeping in mind the end goal to keep up the working point as close as conceivable to the most extreme power point PMP of the PV cluster. PMP is situated at the crossing point between the voltage-current trademark bend of the PV cluster and the proportionate load trademark (Fig. 2). In Fig. 2, VOL is the open-stack voltage of the PV cell, ISC speaks to its short out current esteem. Pixie and VMP are the current and voltage comparing to the most extreme power point PMP .A calculation was imagined and transposed in MATLAB, beginning from the underlying outline information.

### A. *Design of the PV array*

Each board (module) utilized by the outlined establishment comprises in cells of arrangement associated polycrystalline cells. The front side of the PV module incorporates a very straightforward glass sheet, described by a critical protection against workman stuns. The edge of anodized aluminum (secured through electrolysis by a layer of defensive oxide), shapes the auxiliary help of the module. All these give a sufficient insurance against environmental specialists like hail, snow, ice and tempest. Every module contains by-pass diodes presented in the association (dispersion) box. These diodes will permit the "off-coating" of the modules where the daylight does not reach, so as to keep their conduct as buyers for the boards getting radiation from sun and in this manner staying away from their undesired warming [12].

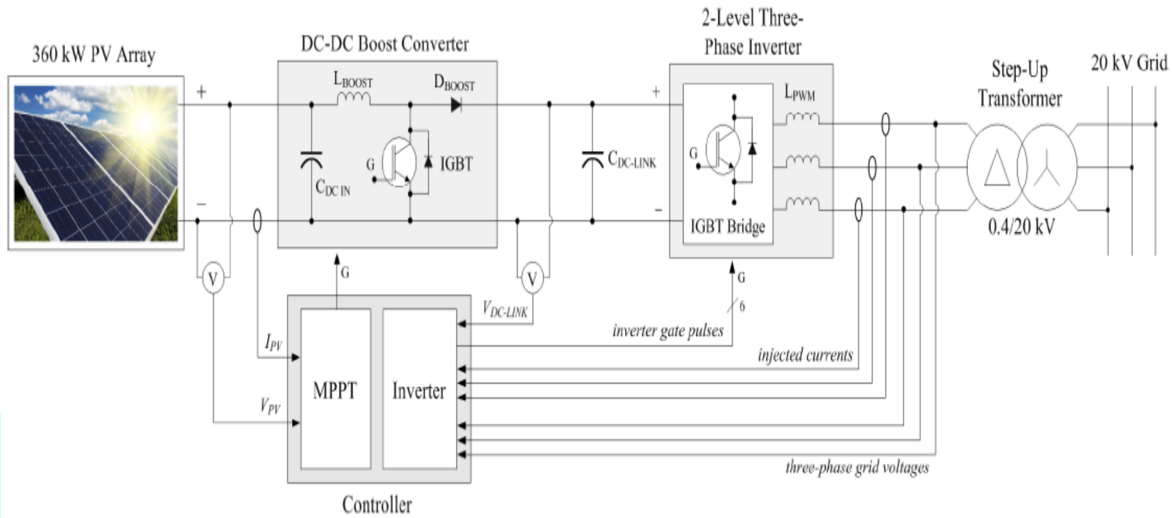


*Fig. 1. The basic schematic of one 360 kW photovoltaic array generator.*

A few models pf PV cells are accessible from producers like Mitsubishi, Sharp, Sanyo, LDK, BP Solar, Suntech. We chose Sanyo HIP-225HDE1 PV modules, with a most extreme power of 225 W. The specialized details for one module are given in Table I. The quantity of essential arrangement associated modules per string and parallel strings is dictated by the DC-DC help converter input voltage esteem and the inverter power. The evaluated DC input voltage for the lift converter is regularly picked a large portion of the yield voltage, i.e. the DC-Link voltage. Considering that the yield voltage of a series of arrangement associated PV modules is the whole of the segment modules, and furthermore considering the base DC-Link voltage for the inverter, one can acquire the quantity of PV modules associated in arrangement NSER in light of:

$$N_{SER} = \frac{1}{2} \cdot \frac{V_{DC-LINK}}{V_{MP}} \quad (1)$$

with: *NSER* = number of necessary series connected modules;

*VDC-LINK* = the DC-Link voltage at the inverter input;

*VMP* = PV module voltage at maximum power point;

TABLE I
TECHNICAL SPECIFICATIONS OF ONE SANYO HIP-225HDE1 PV MODULE

| | |
|---|---|
| Cell type | Silicon Polycrystalline |
| Number of cells per module: | 60 |
| Open circuit voltage $V_{OC}$ | 41.79 V |
| Current at maximum power point $I_{MP}$ | 6.63 A |
| Short-circuit current $I_{SC}$ | 7.13 A |
| Voltage at maximum power point $V_{MP}$ | 33.9 V |
| Temperature coefficient of $V_{OC}$ | -0.105 V/°C |
| Temperature coefficient of $I_{SC}$ | 0.00214 A/°C |
| Temperature coefficient of $V_{MP}$ | -0.101 V/°C |
| Temperature coefficient of $I_{MP}$ | -0.0006634 A/°C |

A lower voltage can be chosen for the inverter input, however as the voltage diminishes (keeping the yield voltage consistent), a higher current will move through the DC-DC support converter. Along these lines higher evaluated IGBT-s are required. The base DC-Link voltage for the inverter can be registered with [13]:

$$V_{DC-LINK} \geq 2\sqrt{2} \cdot V_{PHASE} \quad (2)$$

with: *VPHASE* = the RMS value of the phase voltage at the inverter's output. Hence, the DC-Link voltage must be greater than 653 V. Considering (1) and (2), a DC-DC converter input voltage *VPV* of 350 V and a DC-Link voltage *VDC-LINK* of 700 V are selected. Returning to (1), the necessary number of PV modules connected in series *NSER* shall be rounded to 11. One can now compute the maximum power of a series connected PV string:

$$P_{STRING} = N_{SER} \cdot P_{MP} = 11 \cdot 224.89 = 2.47 \text{ kW} \quad (3)$$

where: *PMP* = maximum power point.

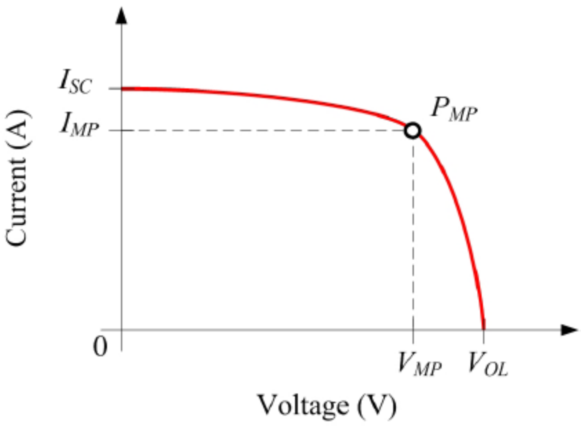


***Fig.2. the Voltage-Current Characteristic of a pv cell***

Once the quantity of arrangement associated modules is set, the quantity of strings in parallel is processed in view of the appraised power of one inverter. One chose a 360 kW 2-level inverter offered by IGBT maker Semikron. The essential number of strings in parallel progresses toward becoming:

$$N_{PAR} = \frac{P_{INV}}{P_{STRING}} = \frac{360 \text{ kW}}{2.47 \text{ kW}} = 146 \quad (4)$$

with: *PINV* = the power of one inverter.

Thus, in order to obtain an installed power of 10 MW, we need a number of inverters *NINV* and PV arrays *NARRAYS* given by:

$$N_{INV} = N_{ARRAYS} = \frac{P_{TOT\ MAX}}{P_{INV}} = \frac{10\ \text{MW}}{360\ \text{kW}} = 28 \qquad (5)$$

### B. Sizing the DC-AC inverter

Inverter's estimating is finished considering the 360 kW PV exhibit's pinnacle yield power for a 2-level inverter offered by IGBT producer Semikron. The particular Semisel online application is utilized, having the RMS yield voltage, yield power, effectiveness, exchanging recurrence and over-burden factor as sources of info. For the greatest power of 360 kW and a most pessimistic scenario effectiveness of 85%, the RMS current through inverter is equivalent to 611.3 A:_ 100 611.3 A

$$I_{INV\_RMS} = \frac{P_{INV}}{3 \cdot V_{PHASE}} \cdot \frac{100}{85} = 611.3\ \text{A} \qquad (6)$$

Measuring the PWM curls inductance is finished considering a 5% swell current from the pinnacle estimation of the infused current, which is:

$$I_{INV\_PEAK} = I_{INV\_RMS} \cdot \sqrt{2} = 864.5\ \text{A} \qquad (7)$$

Thus, the top to-top estimation of current swell is:

$$I_{RIPPLE\_PEAK} = 0.05 \cdot I_{INV\_PEAK} = 43.2\ \text{A} \qquad (8)$$

The PWM coils inductance is calculated with [13]:

$$L_{PWM} = \left(\sqrt{3} \cdot V_{DC}\right) / \left(12 \cdot \delta \cdot f_{COM} \cdot I_{RIPPLE\_PEAK}\right) = 0.62\ \text{mH} \quad (9)$$

with: $\partial$ = the overload factor;

with: *PTOT MAX* = desired installed power for the PV park.

The design of the DC-DC-AC converter is done backwards: firstly the inverter and then the DC-DC boost converter.

$f_{com}$ = the switching frequency of the inverter.

The over-burden factor $\partial$ produced by drifters shifts inside the range [120...180] % [5]. One chose an estimation of 150% for and an exchanging recurrence of 2.5 kHz, considering a trade off between the high cost and massiveness of the PWM loops for a low exchanging recurrence and the higher misfortunes at a high exchanging recurrence. Likewise, a higher exchanging recurrence offers a lower THD for the infused current and PCC voltage.

The estimation of the DC-interface capacitor is registered to restrict the DC-connect voltage swell to 5% of the DC-Link voltage.

For a sinusoidal waveform, the normal estimation of the current IAVG is 63.6% from the pinnacle esteem or 0.9 from the RMS esteem:

$$I_{AVG} = 0.9 \cdot I_{INV\_RMS} = 0.9 \cdot 611 = 550.18\ \text{A} \qquad (10)$$

The peak-to-peak ripple value of the DC-Link voltage is imposed to 5%:

$$V_{RIPPLE\_PEAK} = 0.05 \cdot V_{DC-LINK} = 0.05 \cdot 700 = 35\ \text{V} \quad (11)$$

The capacitor's value *CDC-LINK* can now be determined with [13]:

$$C_{DC-LINK} \geq \frac{I_{INV\_AVG}}{2 \cdot \omega \cdot V_{RIPPLE\_PEAK}} \geq \frac{550{,}18}{2 \cdot 314 \cdot 35} \geq 25018\ \mu\text{F} \quad (12)$$

where: $\omega$ = the angular frequency corresponding to the 50 Hz grid.

The rated voltage VRATED_CDC is recommended to be at least 20 % higher than the operating voltage:

$$V_{RATED\_CDC} \geq 120\% \cdot V_{DC-LINK} \geq 840 \text{ V} \qquad (13)$$

Considering (12) and (13), a few capacitors must be associated in parallel to accomplish the expansive capacitance required at this high voltage esteem.

The picked IGBT exchanging transistors of the inverter are SKiiP3614GB12E46DUW, fluid cooled. Sizing the DC-DC boost converter The parameters imposed for the DC-DC boost converter are centralized in Table II. Considering these values, the chosen IGBT switching transistor and diode of the boost converter is one SKiiP3614GB12E46DUW module, liquid cooled.

TABLE II
TECHNICAL SPECIFICATIONS OF THE DC-DC BOOST CONVERTER

| | |
|---|---|
| Rated input voltage | 350 V |
| Minimum input voltage $V_{MIN}$ | 300 V |
| Rated output voltage $V_{DC-LINK}$ | 700 V |
| Rated output voltage $I_{OUT\_RMS}$ | 611 A |
| Switching frequency $f_{COM\_BOOST}$ | 2 kHz |

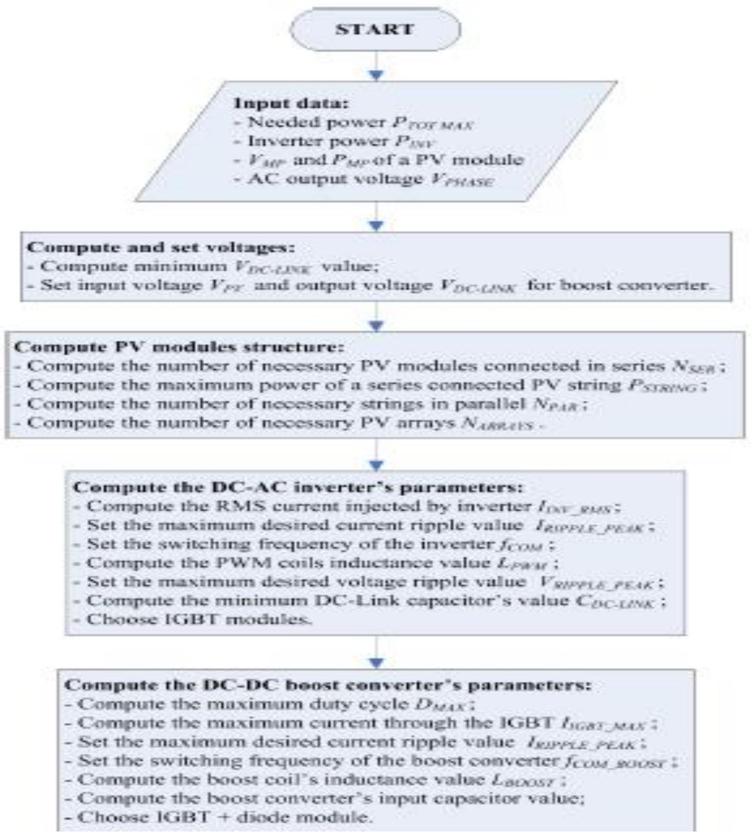


Fig. 3. The flowchart of the photovoltaic system design.

The specific Semisel online application was utilized. Considering the lift converter's curl protection of 35 mǒ and the IGBT and diode misfortunes, the productivity Ș of the converter is evaluated to be 90%. The obligation cycle DMAX at the base information voltage VMIN can be figured with [14]:

$$D_{MAX} = 1 - \frac{V_{MIN} \cdot \eta}{V_{DC-LINK}} = 0.61 \qquad (14)$$

The maximum current through the IGBT can be computed with [14]:

$$I_{IGBT\_MAX} = 2 \cdot I_{OUT\_RMS} \cdot (D_{MAX} + 1) = 1973.6 \text{ A} \qquad (15)$$

Measuring the LBOOST curl inductance is finished considering a 5% swell current from the most extreme current through the IGBT. Thus, the top to-crest estimation of current swell is:

$$I_{RIPPLE\_PEAK} = 0.05 \cdot I_{IGBT\_MAX} = 98.6 \text{ A} \qquad (16)$$

The minimum *LBOOST* coil inductance is calculated with [14]:

$$L_{BOOST} \geq \frac{V_{MIN} \cdot (V_{DC-LINK} - V_{MIN})}{I_{RIPPLE\_PEAK} \cdot f_{COM\_BOOST} \cdot V_{DC-LINK}} \qquad (17)$$

Considering (17), the base inductance is registered as 0.89 mH, so a 1 mH support inductor is picked. An info capacitor in fundamental for the lift converter's strength. Considering the power included, a 100 ȝF input capacitor is chosen [16]. The flowchart of the photovoltaic framework configuration is delineated in Fig. 3.

## III.SIMULATION OF ONE 360 KW PHOTOVOLTAIC ARRAY GENERATOR

By utilizing the outlining parameters of the PV stop exhibited beneath and the information from datasheet, a simulation of a field with PV cells comparing to one of the 28 inverters was done in the Simulink module which has a place with MATLAB. The Simulink model of the PV field is worked by utilizing components from the library SimPowerSystems. The understanding technique is of discrete sort and uses a fix venture of 1 ȝs. The control framework works at a testing venture of 100 ȝs, with a specific end goal to repeat as precise as conceivable the advanced control and separately to be suitable for stacking in microcontrollers and in creating stages as dSPACE seems to be. The Simulink model of the creating PV framework includes:an instrument to assemble signals identified with sunlight based radiation and boards temperature (Signal Builder Tool), keeping in mind the end goal to test the age framework's responses in various settings; The field with PV cells; The DC-DC converter, along with the dedicated control system MMPT (Maximum Power Point Tracking); The three-phase inverter along with the dedicated control system; The step-up transformer for connection to the network, of 0.4/20 kV; The network of 20 kV toward which the generated electric power is transferred. The model of PV field incorporates the setup of the quantity of PV cells in arrangement and in parallel, and the likelihood to get to various predefined models of boards from a few producers. The module Sanyo HIP-225HDE1 was chosen. The control framework MPPT considers a maximal vitality recuperating, regardless to temperature and light. The voltage VPV and the current IPV are ceaselessly measured in request to conclude the power removed from the board.

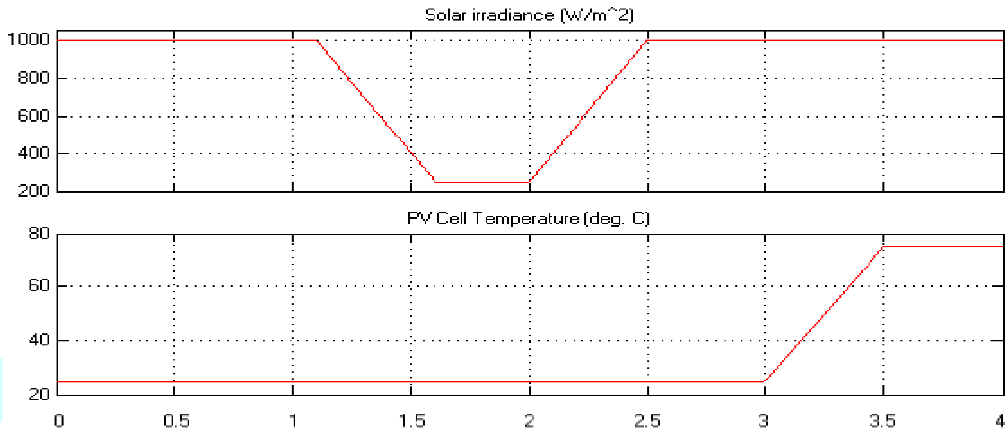


Fig. 4. The evolution of the solar irradiance (top) and PV cell temperature (bottom) during simulation.

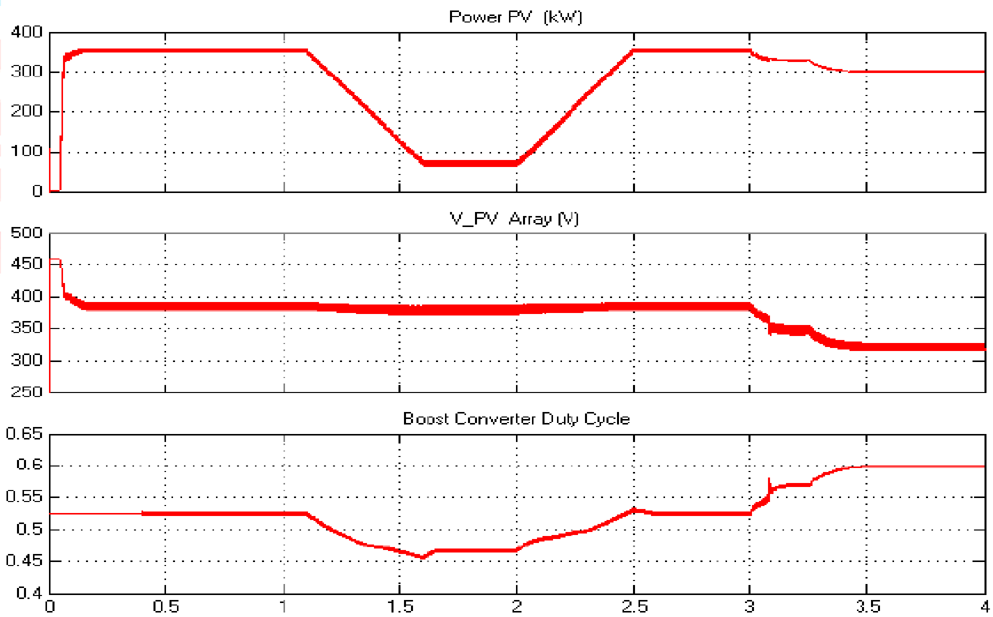


Fig. 5. The waveforms at the lift converter side amid simulation: the yield power (top), the information voltage (center) and the obligation cycle (base).

The power is contrasted with its past esteem. After examination, the voltage at board's terminals is expanded or diminished by methods for the obligation cycle from the contribution of the PWM generator. The control of the three-stage inverter is performed, for example, to send out the power gave by the PV field in the AC system of 0.4 kV, separately of 20 kV and to save a consistent voltage of 400 V at the yield terminals, alongside a steady voltage of 700 V over the DC bars, independent to the working conditions (power of PV boards). It comprises of a piece for test and change into the d-q facilitates, a DC voltage controller, a current controller, a reference voltage generator and a PWM generator for 2-Level three-stage inverters. The model of the system in which the PV creating framework sends out power incorporates a MV stack, advance up transformers, models for long lines and an equal generator of 24 kV associated by utilizing a stage up transformer 24/120 kV.

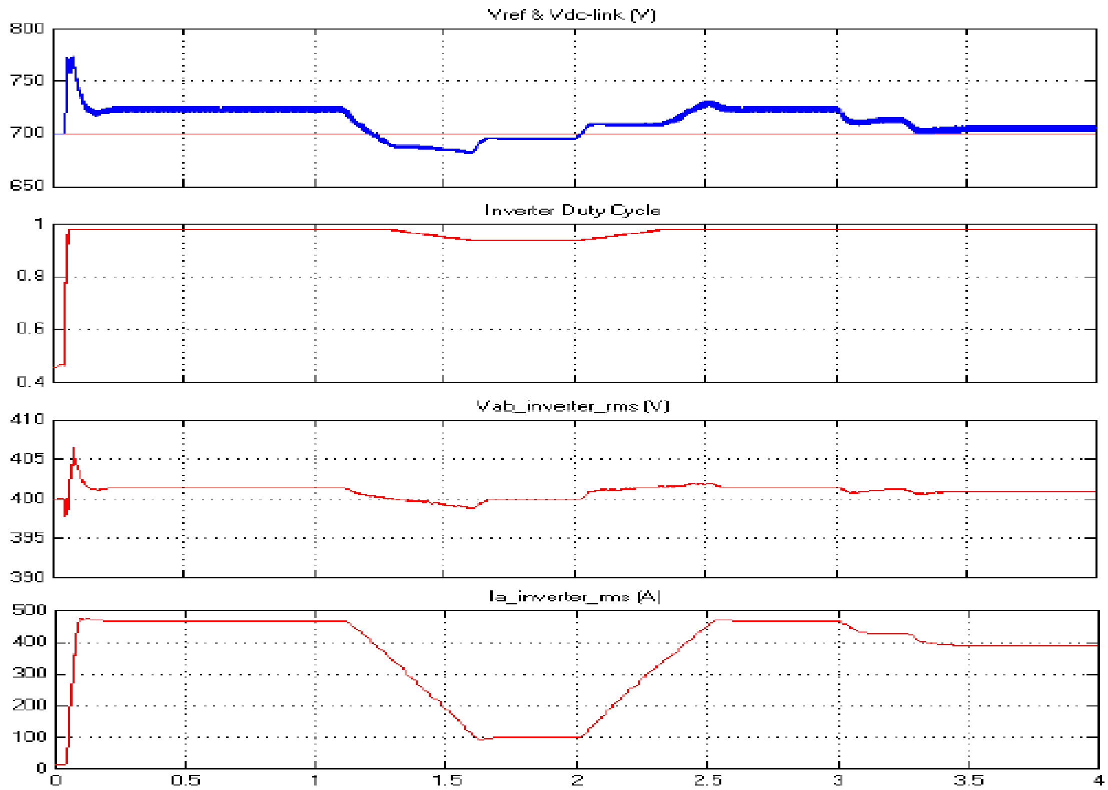


Fig. 6. The waveforms at the inverter side amid simulation. Start to finish:

the reference and measured DC-Link voltage, the obligation cycle, the RMS line voltage, the RMS stage current. The inverter's control beats are contributions for a square used to present exchanging blackouts of 3 ɜs, keeping in mind the end goal to maintain a strategic distance from the shortcircuits between the IGBT-s from a similar side. The chain of occasions was chosen to most recent 4 seconds, as takes after (Fig. 4):the sunlight based radiation has an underlying estimation of 1000 W/m2, (normal esteem), than falls up to 250 W/m2 , easily along 0.5 seconds keeping in mind the end goal to recreate the nebulous vision of a few mists; in the second, the sunlight based radiation returns to 1000 W/m2 along a time of 0.5 seconds; the temperature of the PV cells is expanded from 25°C up to 75°C start with the third second, along 0.5 sec. The development of voltage and power of the PV field is delineated by Fig. 5. The boards' power diminishes from 360 kW (comparing to greatest sun powered radiation) up to 80 kW at 250 W/m2. One can see that the voltage does not diminish altogether. It implies that the control calculation MPPT works in a right way by restricting the current infused into the system. Near the finish of the simulation time frame, the information voltage diminishes up to 320 V in light of the fact that the PV cells increments. The obligation cycle increments to 0.6 to keep the yield voltage consistent (Fig. 5). The waveforms at the inverter side amid simulation are delineated by Fig. 6. No expansive deviations from the DC-Link reference voltage or the RMS standard 400 V voltage esteem on the LV transport are watched.The active powers in the transformation chain are delineated by Fig. 7. The productivity of the power transformation depends enormously on the lift and coupling inductors protections.

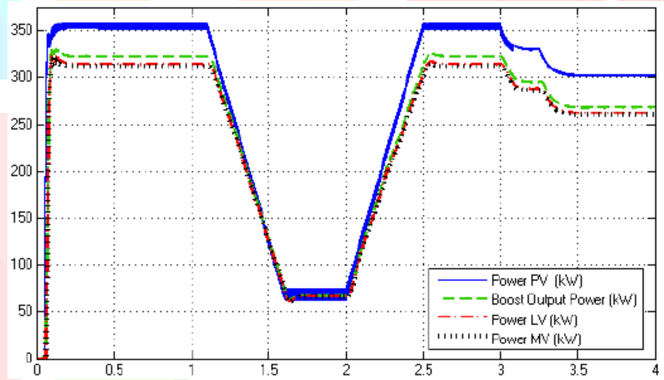


Fig. 7. The evolution of the active powers during simulation, from the PV array to the MV grid.

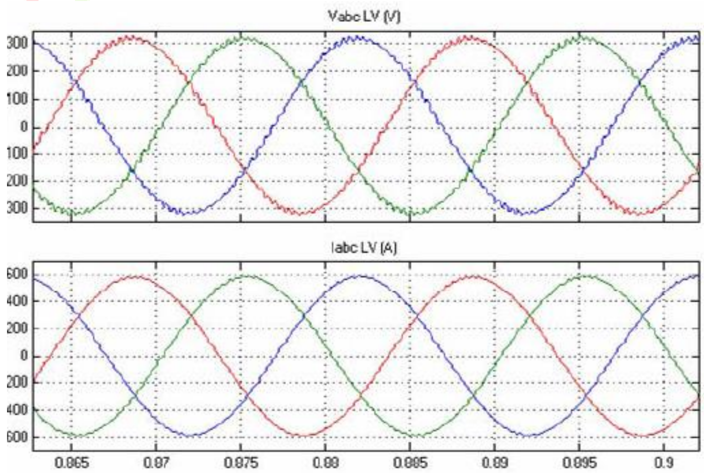


Fig. 8. Detail of the waveforms of the stage voltages (best) and currents (base) at the yield of the inverter.

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An effectiveness of 0.88 is acquired for the lift converter and a proficiency of 0.94 is gotten for the inverter.Keeping in mind the end goal to gauge the symphonious twisting level for the voltage in the 0.4 kV bars, and in addition the current infused into the system, an uncommon investigation device was utilized (FFT Analysis Tool) from the client realistic interface "PowerGUI". By utilizing this instrument one can see the proficiency of the curl utilized for coupling to the system with the exchanging recurrence 2.5 kHz and little esteems for the consonant mutilation of voltage (2.3%) and separately for current (0.8%). The waveforms of the stage voltages and currents at the yield of the inverter are portrayed in Fig. 8. In the 20 kV the aggregate consonant bending is considerably littler (< 1%) on account of the transformer's inductance.

## IV.CONCLUSIONS

The simulation of the planned PV stop by utilizing Simulink mentioned conceivable the testing and objective fact of its steadiness and effectiveness. The PV age framework acts well in various states of sunlight based brilliance and temperature of PV boards, saving its dependability and prevailing with regards to removing the most extreme power from the PV boards attributable to the control calculation MPPT. The PV age framework is additionally giving a voltage portrayed by a decent quality: the aggregate symphonious contortion in the 0.4 kV boards has a low esteem (2.3%) and in the 20 kV bars the mutilation is much littler (< 1%). These conclusions can be derived in view of the got information and waveforms. We can presume that the PV creating framework was composed appropriately.

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