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Design and Implementation of Grid Connected Photovoltaic Systems

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Abstract: Renewable energy sources in solar form is the most imperative sustainable energy source as it is the endless source of energy. Photovoltaic system is a power system designed to supply usable solar power by means of photovoltaic's. It consists of an several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC. MPPT(Maximum Power Point Tracking) is a technique used commonly with wind turbines and photovoltaic solar systems to minimize power extraction under all conditions. A grid-connected photovoltaic power system, or grid-connected PV power system is an electricity generating solar PV power system that is connected to utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connected equipment. Power Quality refers to the ability of electrical equipment to consume the energy being supplied to it.

This project presents complete simulation modeling and control of single phase grid connected solar photovoltaic module. The proposed grid connected PV system is developed on MATLAB\SIMULINK. The results are justified by hardware.

Keywords: Arduino, Grid, MPPT, Photovoltaic cell, Single phase inverter.

I. INTRODUCTION

Now a day's people are more concerned about the application of the renewable energy source, like wind, tidal, biomass, ocean and solar radiation (photovoltaic) because of the rising oil prices, fossil fuel deficit, global warming and negative impact of environment. Among all the renewable energy sources the energy through photovoltaic (PV) can be most effective because it's the most essential, sustainable source. Photovoltaic system can directly converts sunlight to direct current means it converts the solar radiation (irradiance) to DC electricity without environment impact. In photovoltaic system the main two inputs are solar irradiation and temperature, which are available free of cost. Temperature and irradiance are variable in nature. Solar irradiations are more sustainable in nature and unique. It's a pollution free system. We are seeing the demand of photovoltaic system; this is getting more important because of growing population condition in the worldwide. So the electricity demand will also increase as per the population ratio as it's a 21st century our need are more than our want, PV system, being semiconductor device, its static and don't have moving parts, so its operation and maintenance cost are little high among all the renewable energy resource though for current era the efficiency of the photovoltaic system is low. The output characteristics of PV module depend upon the solar irradiation, cell temperature. Though PV module has nonlinear characteristics because PV module is a semiconductor device, so it necessary to design and implement the simulation of maximum power point tracking (MPPT) for application of PV system. As we know PV system produces DC output (voltage, current), its output we can use directly or can be stored in battery as it's a DC source. PV system is of two types i.e. standing alone system or grid connected system. For the grid connected system the DC voltage obtained by the PV panel will be connected to the converters i.e buck converter, boost converter, buck-boost converter, then the output of the converters connected to the inverter that can be single-phase inverter or three-phase inverter for the optimized results. The main contribution of this paper is implementation of PV model in MATLAB/SIMULINK, which is user-friendly. From the photocurrent equation, the mathematical model of PV cell, module, and array can be designed in MATLAB/SIMULINK. There are various methods available in MPPT control like P&O algorithmic, Fuzzy logic methods, Neural network method etc, among all P&O method is chosen because of its implementation is easy and gives effective results.

II. RENEWABLE ENERGY SOURCES

A Renewable resource is a substance of economic value that can be replaced or replenished in the same or less amount of time as it takes to draw the supply down. The main types under renewable energy sources are Hydro energy, it is the energy derived from the power of moving water. Solar energy, it is the radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic's, solar thermal energy etc. Wind energy, it is a form of solar energy. It describes the process by which wind is used to generate electricity. Bio-mass energy, it is organic material that comes from plants and animals. Marine energy, it refers to the energy carried by ocean waves, tides, salinity, and ocean temperature differences. Geo-Thermal energy, it is the heat from the earth and it is clean and sustainable.

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III. SOLAR SYSTEM

Converting solar energy into electrical energy by PV installations is the most recognized way to use solar energy. Since solar photovoltaic cells are semiconductor devices, they have lot in common with processing and production techniques of other semiconductor devices such as computers and memory chips. With today's production, which reached a large scale, the whole industry production of solar cells has been developed and, due to lo low production cost, it is mostly located in the Far East. Photovoltaic cells produced by the majority of today's most large producers are mainly made of crystalline silicon as semiconductor material.

A. Functioning of Photovoltaic System

Photovoltaic systems use cells to convert sunlight into electricity. The light has a dual character according to quantum physics. Light is a particle and the particles of light are called photons. Photons are mass less particles, moving at light speed. The energy of the photon depends on its wavelength and the frequency, and we can calculate it by the Einstein's law, which is:

$$E = hv \text{ ………..(1)}$$

Where: E- photon energy
H- Plank's constant=6.626×10-34Js
V- Photon frequency
The usefulness of a photovoltaic solar cell is defined as the ratio of electric power provided by the PV solar cells and the solar radiation power. Mathematically, it can be represented in the following relation:

$$\eta = \frac{P_{el}}{P_{sol}} = U \times {}^{I}/_{E} \times A \text{…………..(2)}$$

Where: Pel- Electrical output power
Psol- Radiation power(sun)
U- Effective value of output voltage
I-Effective value of the electricity output
E-Specific radiation power(for example W/m^2)
A-Area.

B. Mathematical Modeling For Photovoltaic System

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity it has a equivalent circuit as shown below.

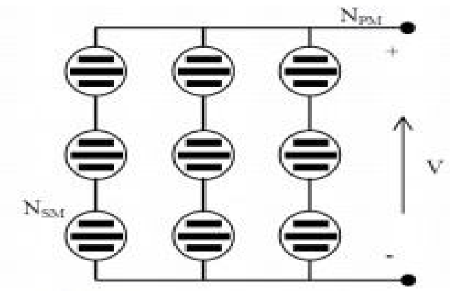

Fig.3.1 Photovoltaic cell

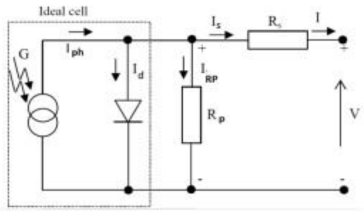

Fig.3.2 Electrical equivalent model of a PV cell

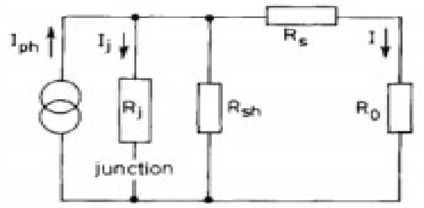

Fig.3.3 Equivalent circuit of PV cell

From figure1&2:

$$I = Is(e^{vd/nVt} - 1)\text{..............}(3)$$

$$I = Il - Id\text{.....................}(4)$$

$$Iph = Id + Irp + I\text{............}(5)$$

$$I = Iph - Irp - Id\text{............}(6)$$

$$I = Iph - Io\left[exp\left(\frac{V+Irs}{Vt}\right) - 1\right] - \frac{[v+Irs]}{Rp}\text{...........}(7)$$

Where, Iph= Insulation current or photocurrent,

Vt= Thermal voltage,

I= Cell current,

Io= Reverse saturation current,

K= Boltzmann constant,

V= Cell voltage,

T= Temperature in Kelvin,

Rs= Series resistance,

Rp= Parallel resistance,

q= Charge of electron.

From the figure,

$$I = N_p I_{ph} - N_p I_{rs}\left[exp\left(\frac{qV}{KTANs}\right) - 1\right]\text{..........}(8)$$

Where, I= PV array output current,

V= PV array output voltage,

Ns= Number of cells in series, and

Np= Number of cells in parallel.

C. Maximum Power Point Tracking (MPPT)

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the MPPT. This is a technique used to obtain the maximum power from a varying source. In photovoltaic system the I-V curve is non-linear, thereby making it difficult to be used to power a certain load.

There are many methods used for MPPT, in this project we use Perturb and Observe (P&O) method. In this method the operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples $dp/_{dv}$. If $dp/_{dv}$ is positive, then the algorithm increases the voltage value towards the MPP until $dp/_{dv}$ is negative. This iteration is continued until the algorithm finally reaches the MPP. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs the Maximum Power Point (MPP).

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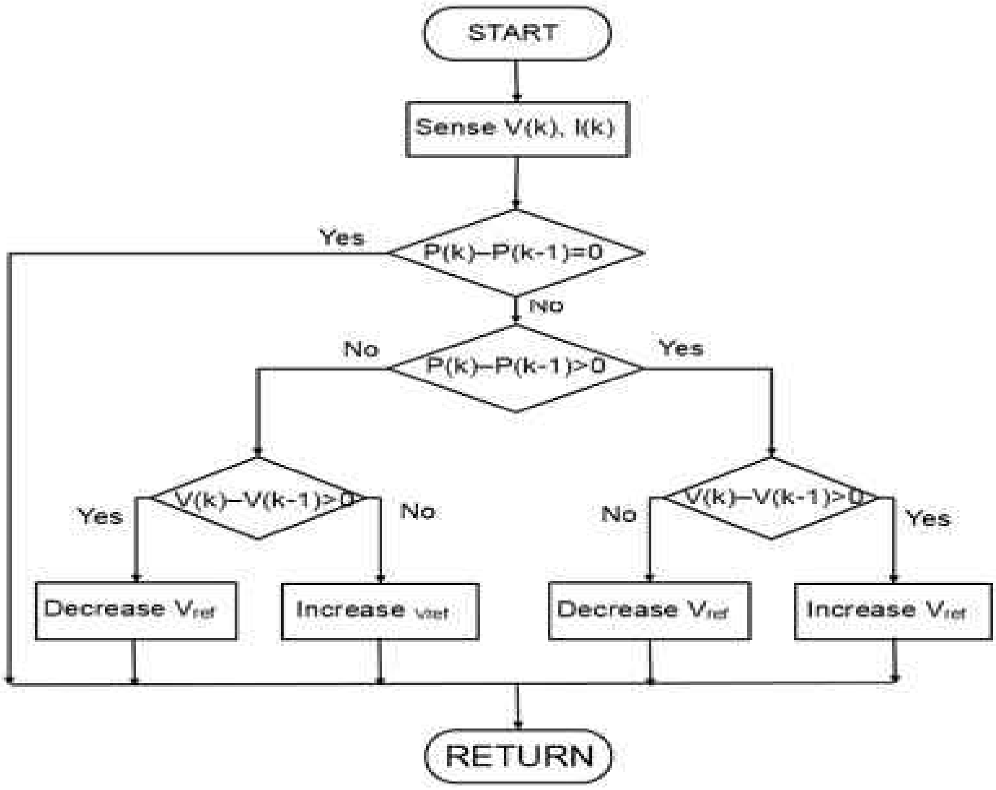
P&O Algorithm



IV. GRID CONNECTED PHOTOVOLTAIC SYSTEM:

A grid-connected photovoltaic power system or grid-connected PV system is electricity generating solar PV power system that is connected to utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range for small residential and commercial rooftop systems to large utility scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.
We developed a MATLAB code for photovoltaic system which gives output characteristics of photovoltaic system. The MATLAB code is shown below

A. Output Characteristics

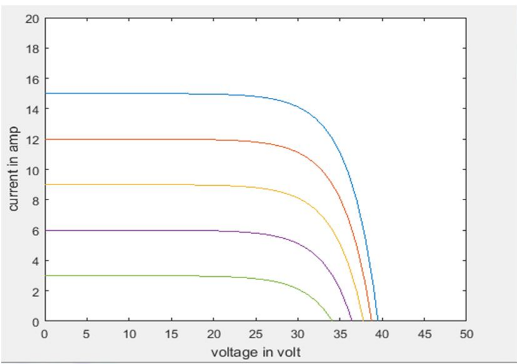


Fig.5.3: V-I characteristics of PV cell

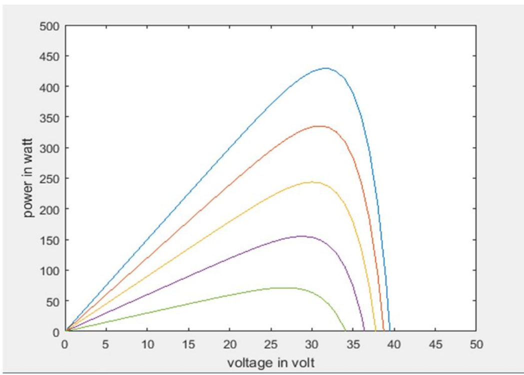


Fig.5.4: P-V Characteristics of PV cell

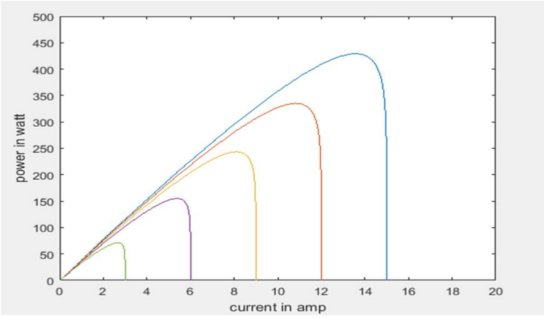


Fig.5.5: P-I Characteristics of PV cell

The simulation block for a grid connected photovoltaic system is shown below.

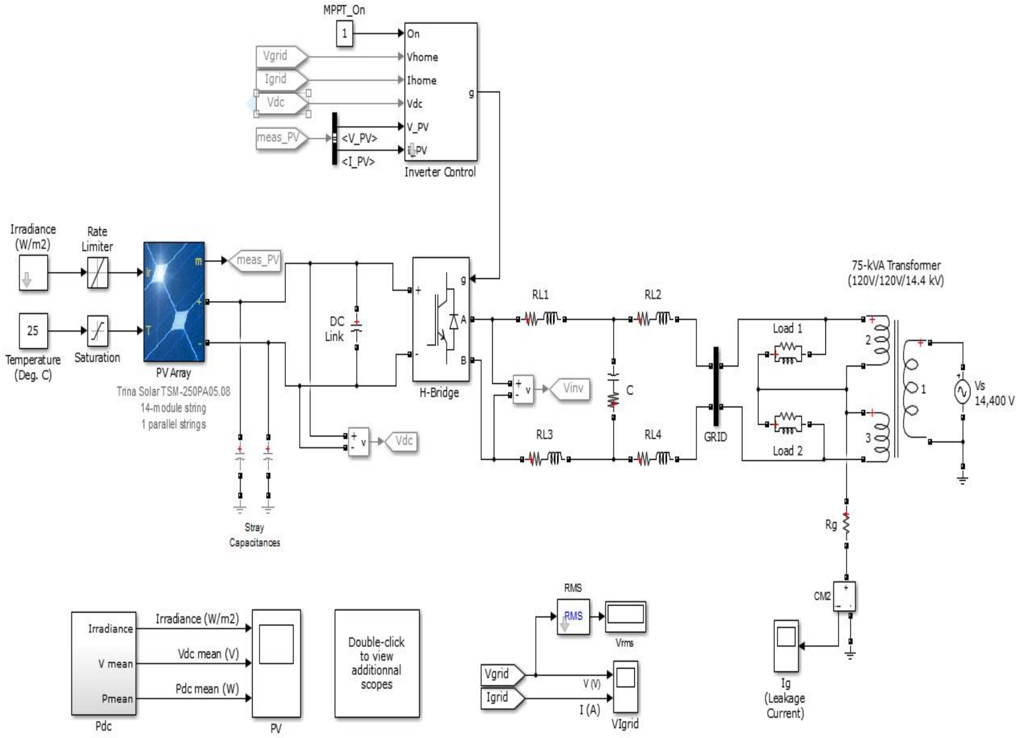
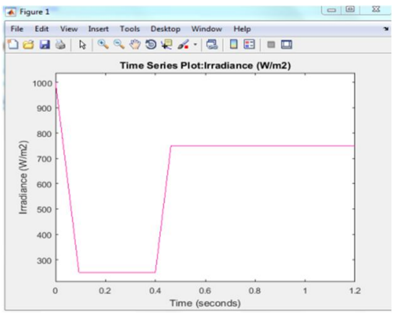
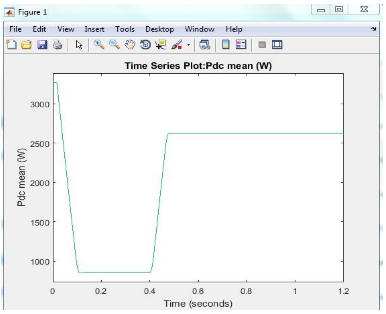


Fig: Simulation diagram

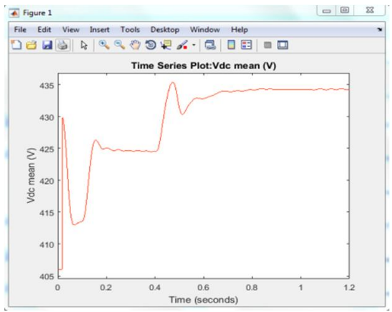
B. *Simulation Results*



fig(a)

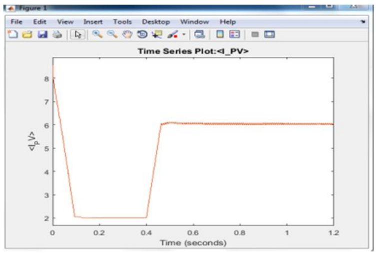


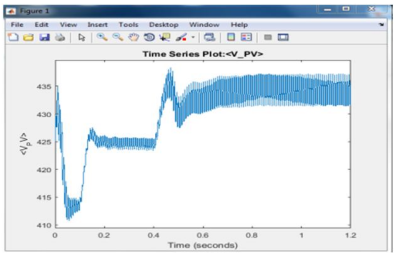
fig(b)

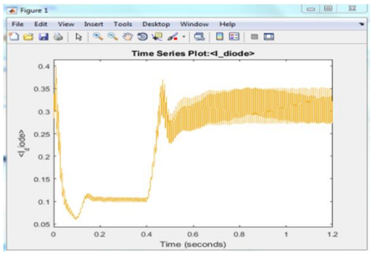


fig(c)

Results of PV cell(a)Irradiance, (b)Pdc_mean, (c)Vdc_mean

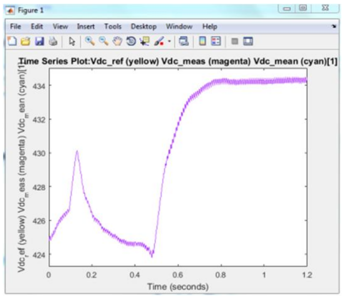


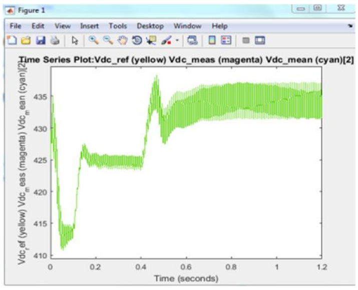


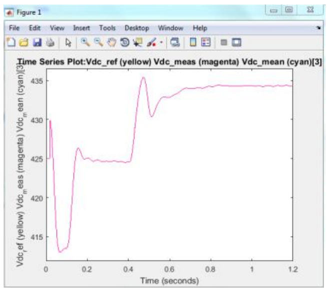


Fig(d) fig(e) fig(f)

Results of (d)I-PV,(e)V-PV,(f) I-diode

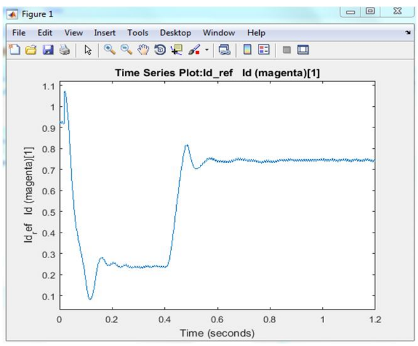


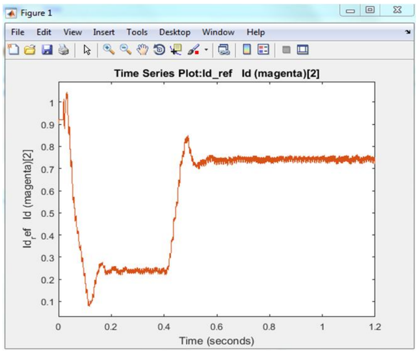


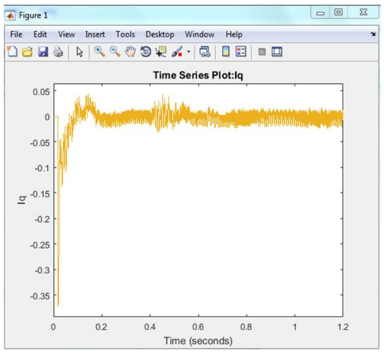


fig(g) fig(h) fig(i)

Results of (g)Vdc ref, (h)Vdc_meas, (i)Vdc_mean

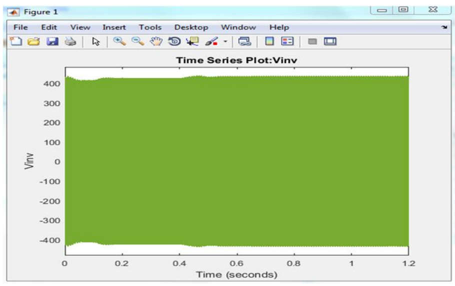


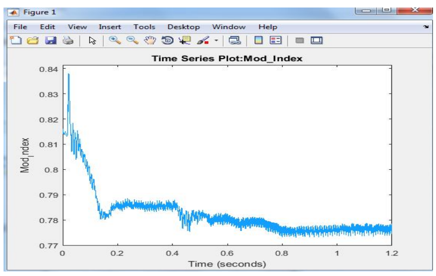


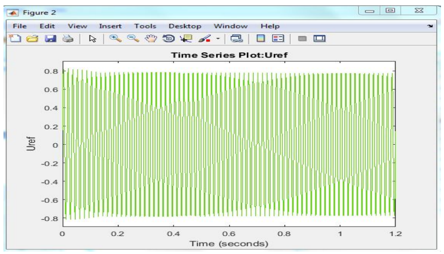


fig(j) fig(k) fig(l)

Results of (j)Id—ref, (k)Id, (l)Iq







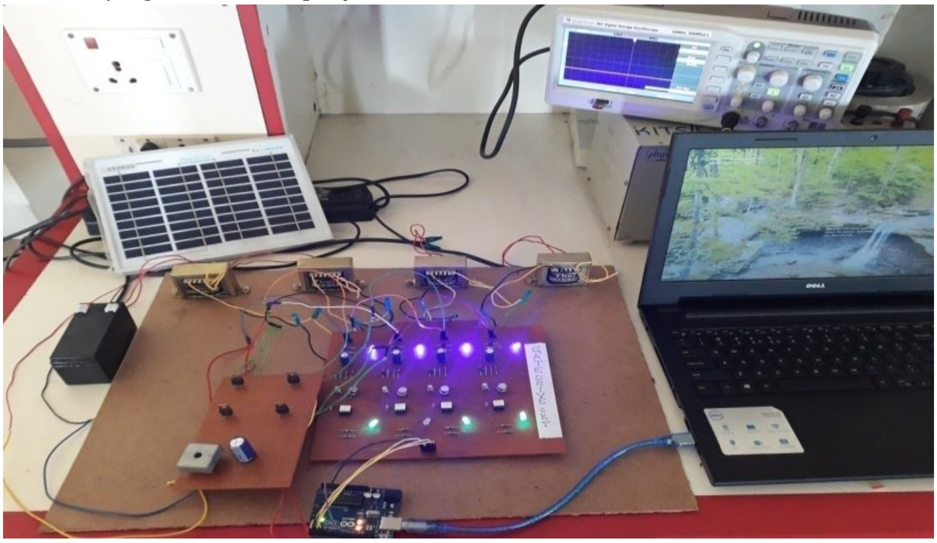
fig(m) fig(n) fig(o)

Result of (m)Vinv, (n)mod_index, (o)U_ref

V. HARDWARE RESULTS

This chapter includes different hardware components use in this project with detailed explanation of working, pin configuration, and connections. And also each and every component outputs are shown below using digital CRO.

A. Hardware implementation for grid connected pv system:



Hardware kit

B. Module for Proposed Model

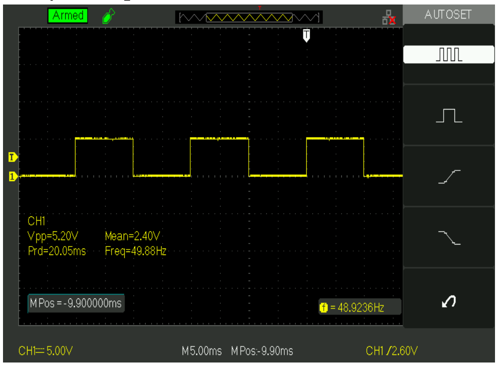


Fig 6.1 result of mosfet-1

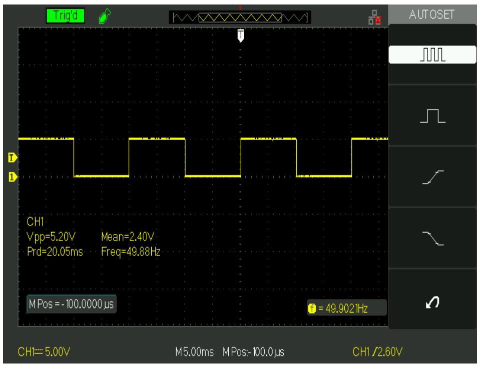


Fig 6.2 result of mosfet-2

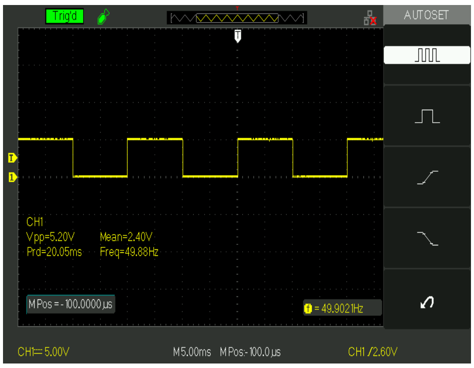


Fig 6.3 result of mosfet-3

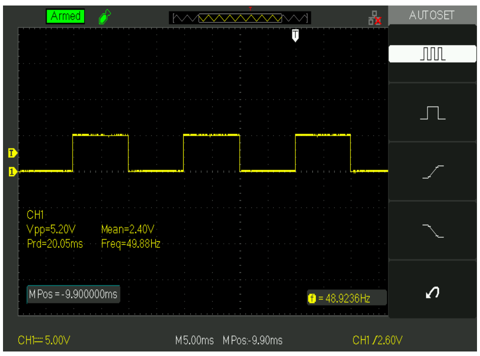


Fig 6.4 result of mosfet-4

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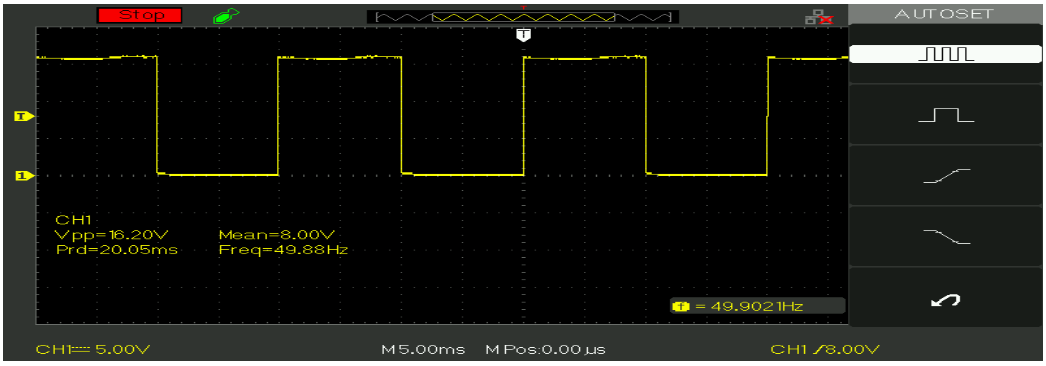

Fig 6.5 Result of gate drive pulse

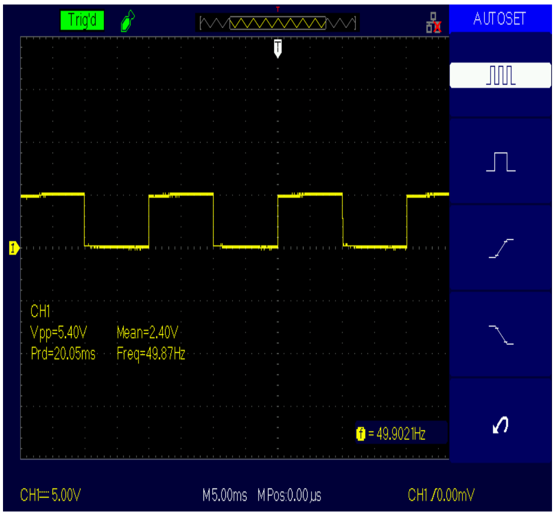

Fig 6.6 Input pulse

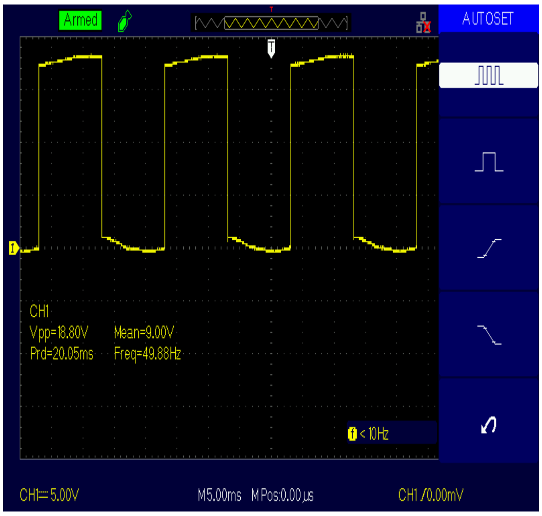

Fig: Output pulse

VI. CONCLUSION

Design and simulation model of photovoltaic cell from mathematical modeling is established in this project, and the output I-V and P-V characteristics of the cell is studied and analyzed by taking different conditions, i.e. by varying temperature or by varying irradiance. Then the common P&O algorithm for MPPT control is described and a MPPT control is described and a MPPT control photovoltaic system is built and simulated in the MATLAB/SIMULINK.

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