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Speed Control of Dc Motor Using Pi Tuned Buck Converter Fed from PV System

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ABSTRACT:The electrical future moving very fast with continuous changes and less concerned about left out behind us. Deployment of electrical machines are coming as per demand & accordance with application requirement, but does not think about the power quality. Well known by us that without good power quality, any machine could not work efficiently and not take out the best output for the assigned applicable task.So taken into this consideration, we designed a circuit which will be very helpful for operating the electric machine efficiently.Solar PV is used as a main power source attached in the same circuit. Here batteries are used during the day-off time in place of the PV source for the smooth run of the system. PI technique used for switching transistor and flywheel circuit as a DC-DC converter to fed the ripple free power supply to DC Motor. DC-DC buck-boost converter is used in between DC Motor and Solar PV Source.With the control strategy implemented here, speed of dc motor is efficiently controlled and regulated. Result confirm the improvement in rise time and overshoot values.

KEYWORDS:PI Controller, PV System, DC Motor, Solar Energy, Buck Converter.

I.INTRODUCTION

Day by day power shortages will come in picture due to podcasted crisis in fossil fuel with the rise in demand with growth electric power. World wise Electricity Regulatory Authorities are already using best practices for the utilization of all available resources on a single platform in shape of smart grid. Photovoltaic (PV) is now available in many variants for electric power generation with best practices of distributions through good monitoring and controlling consumptions. PV cell comprising in such an arrangement to make a solar module with the combination of PV cells and with the combination of solar module in making of a solar Panel comes in such a shape from where give electric power generation.

Due to low cost solutions now these PV systems comes in domestic market in a huge way. As if now in INDIA especially north and middle zone having high irradiation areas, so now a days electricity board also imposing minimum installation segment wise i.e. for industries minimum 5% to 20% of total demand connected from electricity board.

Although PV panel's output (such as Current, Voltage & Resistance) varies according to the environmental conditions of incident sunlight change. During connected to external load, we can determined power consumptions and the alteration at the output due to disturb circuit characteristics with decrease power. Irrespective from the changes in irradiance & panel temperature cause of sunlight, to achieve maximum output from PV panel needs to be maintain STC – Standard Teat Conditions on the panel surface with a temperature regulated @250degC & irradiance of 1000W/m2.

Photoelectric conversion's cell equations is described by a mathematical model along with their SIMULINK model, Thermal Voltage Equation,

$$V_T = \frac{k_B T_{OPT}}{q} \quad .. (i).$$

Whereas,

V_T = Thermal Voltage
k_B = Boltzmann proportionality contact (1.38×10^{-23} J/K)
T_{OPT} = Temperature of operation
q = Charge on electron (1.602×1010^{-19} C)

Thermal voltage equation describes electron's energy diffused by growing irradiance & temperature on solar cell surface.

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II.DESIGN & MODELLING OF SYSTEM

Without a set model it is very difficult to understand an equivalent circuit of PV Solar Cell, it a diode in parallel with current source.

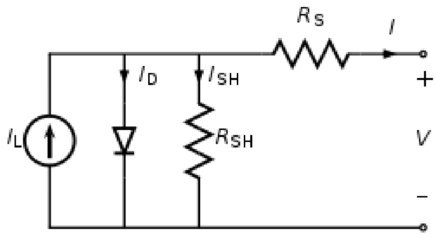

Figure 1 – Equivalent Circuit

Although there is no such ideal PV cell so shunt and series resistor are added in ckt.

Refer to KCL - Kirchhoff's current law which is applying in the PV cell equivalent ckt, the Ip current can be represent as

$$Ip = Id + Ish + I \quad ..(ii)$$

Whereas, Ip equal to Id of the diode with addition of Ish (Shunt Resistance Current) & I as terminal current. Below V + IRs is represent as voltage across Rsh and current of Rsh is represent as

$$Ish = \left(\frac{(V + IRs)}{Rsh} \right)$$

Whereas,

$$I = Ip - Id - \left(\frac{(V + IRs)}{Rsh} \right)$$

Then, pop in (2) & (3) into (1) results in

$$I = Ip - NpI0[e^{(V+IRs)/(nV_T)} - 1] - \frac{V + IRs}{R_P}$$

Commencing P-N junction theory,

$$Id = I0\ (e^{(V+IRs)/nV_T} - 1)$$

Where,

*I*0 = Diode's Reverse saturation current, which Depends on temp., as well as dependent on material including on the doping of the P – N junctions.

V_T = Temperature voltage equivalent or Diode's thermal voltage

N = Diode ideality factor, it also dependent upon material & for silicon it's value equal to 2 but different for other semiconductor materials.

Than,

$$V_T = KT / q = T / 11600$$

Where, *T* = Ambient Temperature

k = 1.381 × 100 23 J/K

q = 1.602 × 10-19 C

Here, nV_T comes to know, when m powered the KT & V_{GO} power of e in minus by nV_T, If (n=2),

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$$I0 = KT^{m}\, e^{-V_{G0}/nV_T} \quad ..(iii)$$

Where,

T = Cell Temperature in ^{o}K.
V_{G0}= Forbidden band gap energy, which is E_{G0} in ev.
V_{G0}=1.16 - 1.21v in respect to Si, If m=1.5 for Si

When PV Cells are connected in parallel if denoted by Np and in case of series connected than denoted by Ns, *I0*.

Where,

Np= Nos. of PV cells (connected in parallel),
Ns = Nos. of PV cells (connected in series),
I0 = saturation current of the diode,
N= diode ideality constant.

DC Motor Equation

Again we need an equivalent circuit to understand the DC motor equation in a better way, so than we will discuss about the EMF equation with voltage, current & power equation with efficiency level equations of a DC motor in details. It can be represent by three elements E, Ra and Vb as below:

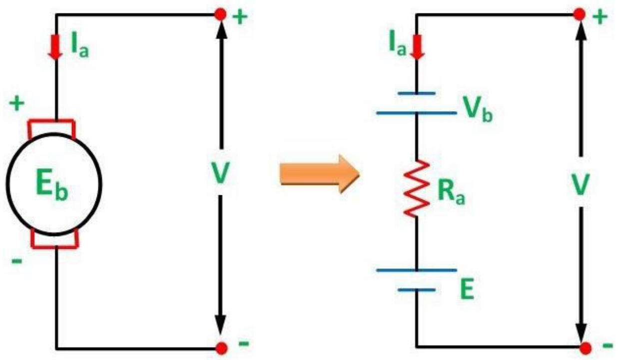

Figure 2 – DC Motor Equivalent Circuit

By applying KVL we can get the right equation, refer to the above equivalent circuit in the armature the current flow in line against the generated voltage …

$$V = E_b + I_a R_a$$

Where, V= Voltage at Motor Terminal
Eb = Back EMF
Ia= Armature Current
Ra = Armature Ckt Resistance

As because back EMF is much lesser then terminal voltage, so equation can be represent …

$$V = E_b + I_a R_a + V_b$$

Above equation shown Vb which means voltage drop across the brushes.

III.PI CONTROLLER& BUCK CONVERTER

PI Controller based circuit is really helpful for dc motor application in many areas as read out. This chapter also includes the past work done by various researchers in the field of PI Controller. So here we will discuss about PI Controller in details with its working principle which we will apply in our scheme of DC Motor speed control.

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A variation of PID (Proportional Integral Derivative) control is used in my project only the proportional & integral terms as a PI Control. The most popular variation is PI Controller even-though more than PID Controller. It was invented in 1910 but the conventional ZN (Ziegler Nichols) tuning method is in 1942. Most of the industries processes are design on these PID controllers techniques related to nethermost level applications.

PI Controller is defined by its two terms rules, which is linked with Kp and Ki, as follows,

- The Proportional Term :By all-pass reinforcement factor providing overall control action in comparable to the error signal.
- The Integral Term :By an integrator reduces the steady state errors through low Hz frequency in fixed condition.

PI Controller used for decrease the steady state errors & increase stability of DC Motors. Seeking the configuration, that is used closed loop type and by that desired output as speed of DC motor controlled by controlling the input variables current with voltage and load. By using ZN tuning method Kp and Ki gain can be set manually. Error from the set point is e(t), as follows,

$$e(t) = SP - PV$$

Where,

SP = Set Point (as target value)
PV = Process Variable (may deviate from desired value)

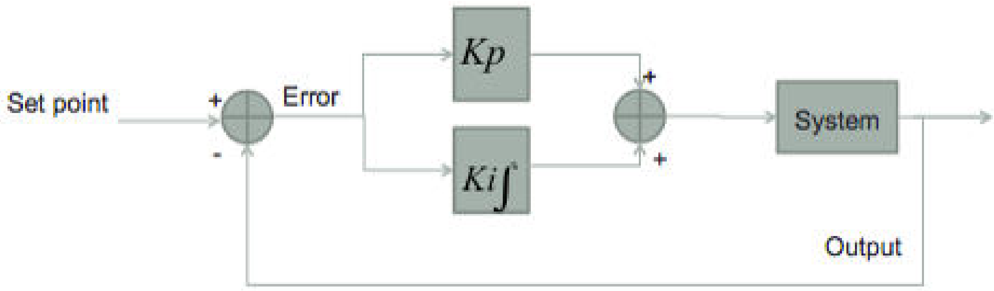

Figure 3– PI Controller Block Diagram

PI controller output u(t) as manipulated variable input fed in system, as follow ..

$$u(t) = u_{bias} + K_c e(t) + \frac{K_c}{\tau_I} \int_0^t e(t)dt$$

Where, ubias is Constant when it get first shift from manual to auto mode to the u(t) value and in the case of error is zero it gives bumpless transfer. As controller gain two value tuned T1 (Integral time constant) &Kc (Multiplier of Proportional error).

Table 1– Tuning Effect of Independent PI

Closed Loop Response	Rise Time	Overshoot	Setting Time	Steady State Error	Stability
Increasing Kp	Decrease	Increase	Small Increase	Decrease	Degrade
Increasing Ki	Small Decrease	Increase	Increase	Large Decrease	Degrade

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However transfer function calculation is very difficult for the right output but it is very easy by using MATLAB/Simulink and assist me to get the right transfer function to get desired output to control the input variance to control speed of a DC Motor. Current and voltage measurement received by the controller which used to calculate the power, which is drained from battery. Then by calculating from Set Point & power measured error signal calculated, which is then goes to the PI control loop for multiplying by the Kp (Proportional) & Ki (Integral) constant. After comparing from the control signal it goes to the controlled system which is least of the two. Then it drives through a power to 'PWM' signal converter.

Here we are using PI Controller as MPPT controller in a PV Solar System. MPPT tracks the maximum power point than the converter boost to the MPP of a solar panel output voltage, which resultant in improving the efficiency of a solar panel. So we can say we are using PI Controller based MPPT for a PV system.

Buck Converter & It's Uses

Basically for step down voltage & step up current, Buck Converter can described. The basic block diagram of working of Buck Converter is shown in figure:

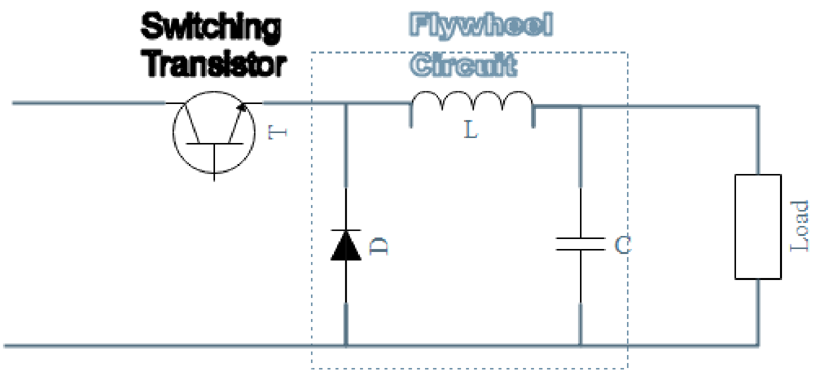

Figure 4 – Flywheel Circuit

From above circuit Buck converter working easily understand than there are two different zones from which output will vary in their respective nature as below.

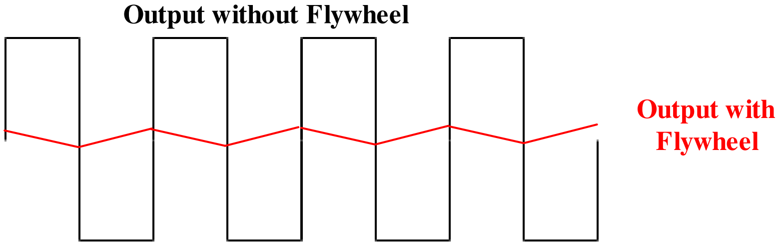

Figure 5 - Output With / Without Flywheel

Main component used in circuit are MOSFET/ BJT Switching Transistor, Diode, Capacitor & Inductor with output load resistance. To switches by turning it ON the MOSFET in conduction mode, in this mode it is used to monitor the O/P voltage from converter by a control circuit. In turning off condition inductor opposes drop in I current by sudden reverse in its EMF & supplies I current to load itself.

IV.MATLAB SIMULATION & WORKING SCHEME

Main MATLAB/Simulink Model with working scheme shown in below figure. In this diagram Solar panel is connected to the main circuit to give the input supply and a scope is connected to the Solar Panel to get the respective waveform of electrical parameter a scope is connected to generate and show the same. We have used :

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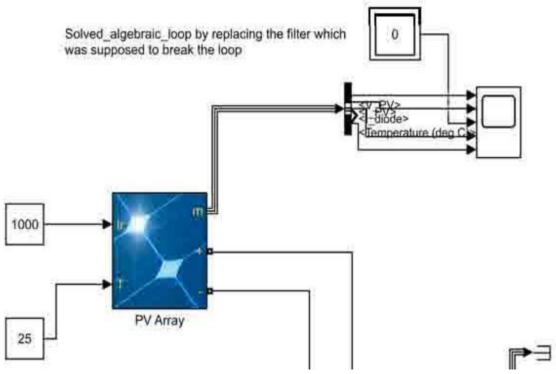

Figure 6– PV Array using in MATLAB/Simulink

Table 2 – Module Data

Make of Module	Maximum Power (W)	Cell per Module (Ncell)	Open Circuit Voltage Voc (V)	Short Circuit Current Isc (A)	Voltage at MPP Vmp (V)	Current at MPP Imp (A)	Temperature Coefficient of Voc (%/deg.C)	Temperature Coefficient of Isc (%/deg.C)
aleo solar S16.170	169.884	50	29.8	7.82	23.4	7.26	-0.34	0.040997

Table 3 – Model Parameter

Light Generated Current IL (A)	Diode Saturation Current I0 (A)	Diode Ideality Factor	Shunt Resistance Rsh (Ohms)	Shunt Resistance Rs (Ohms)
7.8811	1.2589e-10	0.93435	118.4721	0.40022

In flywheel zone stage R-L (in series) & R-C (in parallel) plays their respective role in buck converter, because transistor circuit produce square wave in the circuit but these R-L & R-C circuit chopped the square wave and convert it in triangular wave as shown in Buck Converter section.

So there remains a ripple waveform instead of square wave which is going to appearing across the load, i.e. ripple / triangular wave form has a small amplitude with high frequency with a DC level of,

$V_{OUT} = V_{IN}$ x (Switching waveform on time (t_{ON}) / Switching waveform periodic time (T))

i.e.

$$V_{OUT} = V_{IN}\frac{t_{ON}}{T}$$

PI controller based MPPT used to make more efficient the solar panel by boosting the output voltage to the maximum power point voltage. By using PI controller MPP reaches very rapidly with close to zero oscillation. MPPT is necessary for MPP as because by this whole PV system becoming more efficient.

In below Simulink scheme PI controller is used as MPPT and by following the circuit we can see we are connecting the PI controller to the transistor circuit (MOSFET) of a buck converter, here proportional plus integral controller play its role to produces an O/P signal, where u(t) proportional to both the signals, vi(t) & input signal integral.

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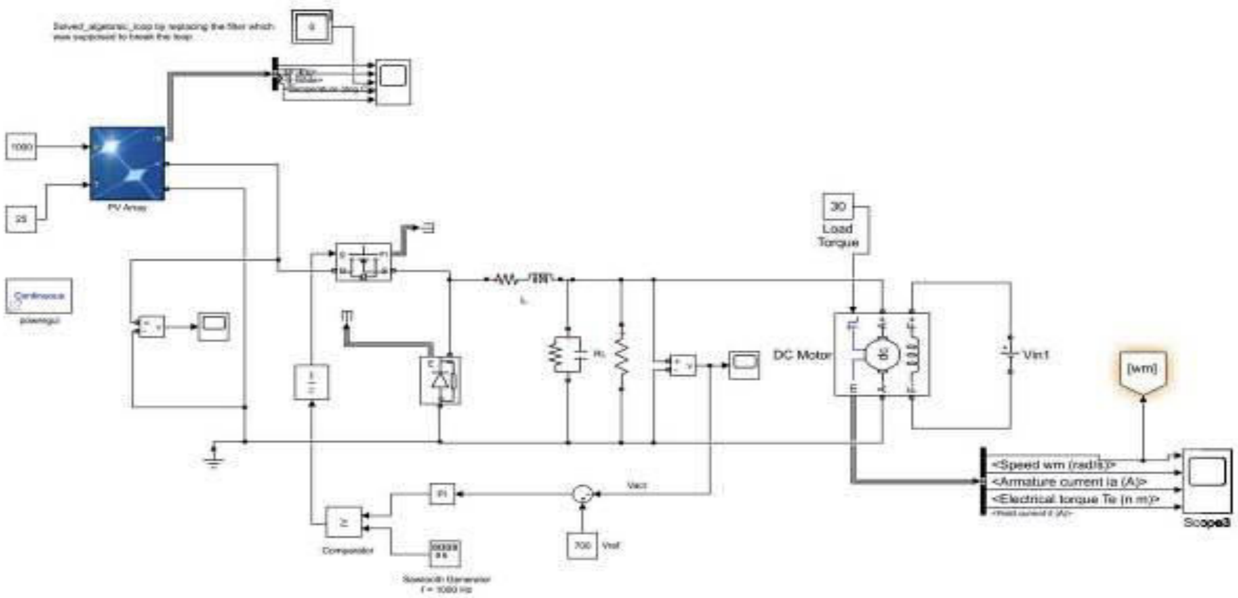

Figure 7 -PI Controller MPPT Circuit

PV voltage is compared with Vref as obtained, which is given to the PI Control with as error signal with Vpv. Gain of proportional Kp and integral Ki we can acquired desired response. After boost converter shoot up getting power from PV panel and by that PI controller start working, it varies (after sensing by PI controller) the value of duty cycle, which can change the I/p value.So, by improving the power parameter before delivered to the DC motor, as because on these improved signal DC motor will work more efficiently and give desired mechanical power required for the set applications, even-though dc motor efficiency also enhanced.

V. RESULT AND DISCUSSION

In this section, we discussed in detail about the simulation results and Buck converter design, modelling & transfer derivation of the observer controller has been fragmented.

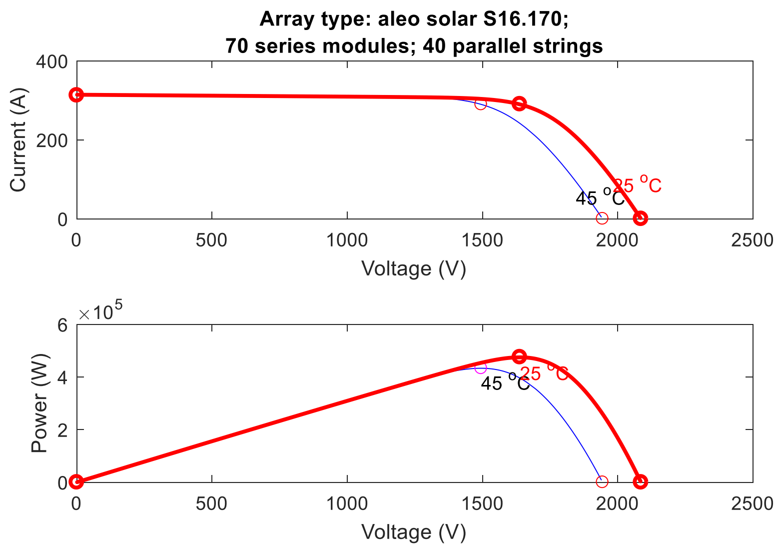

Figure 8 - IV and PV characteristic of PV panel

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Using MATLAB/ Simulink in continuous conduction mode & simulated the performance of Buck Converter with designing it. Eventually aim is to achieve & design a robust controller taking in consideration of huge load disturbance with ambiguity/uncertainty. Taking under consideration of parameters for performance of this converter are maximum peak overshoot, rise time, steady state error and settling time etc. We come on the apparent results about this converter that the rise time is 0.0125s and the converter settles down at 0.015s. Steady state error obtains is 0.02v of the order and there is no any overshoot as well as no any undershoots are marked.

Above figure 8 shows the I-V & P-V characteristics of PV panel under consideration here we considered ALEO solar S16.170 panel which is having 70 series module with 40 parallel string. Figure depicts the curves for 45 degree Celsius 25 degree Celsius parameter variation. It is also observed that around 1600 volt maximum power point is achieved.

DC Motor's Characteristics using PI Controlled MPPT

In below figure 9 the output of dc-dc buck boost converter, which is fed from a PV source. Here it is observed that the dc-dc converter is approximately 688 V which is feeded to the DC motor.

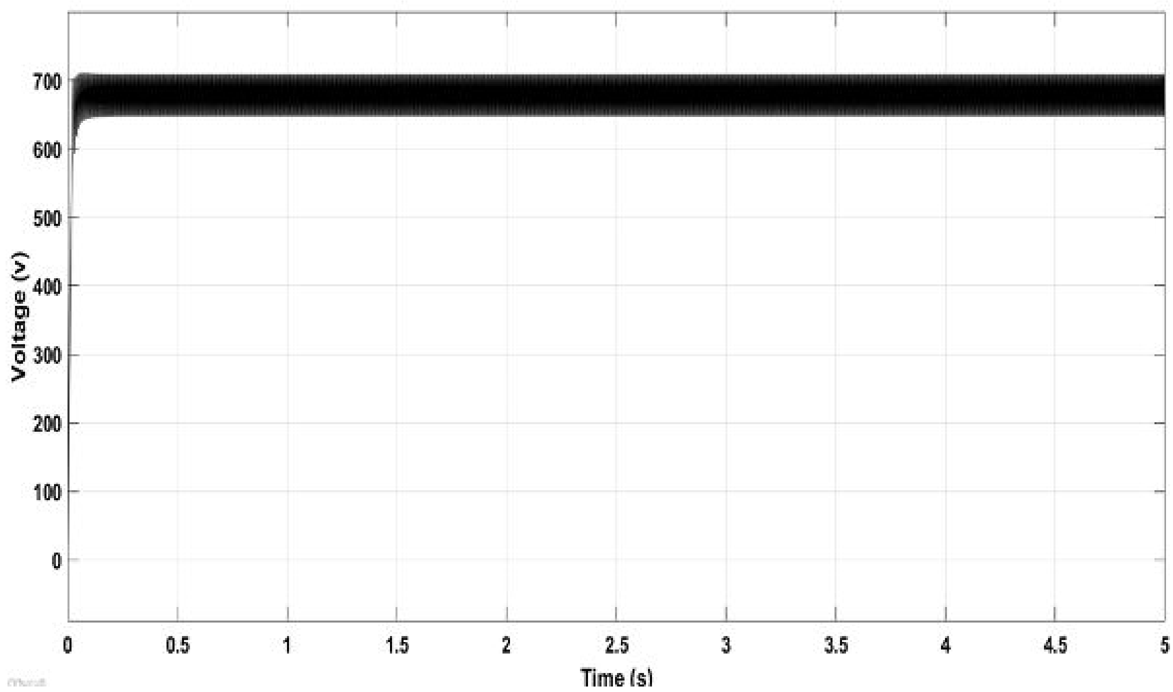

Figure 9 -Output waveform of PI controlled DC-DC boost converter fed from PV plant.

In below figure 10 speed of the DC motor in radian per second, armature current in ampere and electrical torque DC motor in Nm respectively. In case of PID controller the speed of the DC motor initially get overshoot and settle down up 2.2s thereafter it settle down around 205 rad/s also the armature current rises abruptly when supply in switched on and take initial inrush current of about 40 ampere get settle down after overshoot to 7 ampere and finally settled down tank and remain constant afterwards. In third part of figure electric torque of DC motor is shown here also we observed that electric torque of DC motor initially rises up to 160 Newton meter and settle down within point to second to the value 30 Newton per meter.

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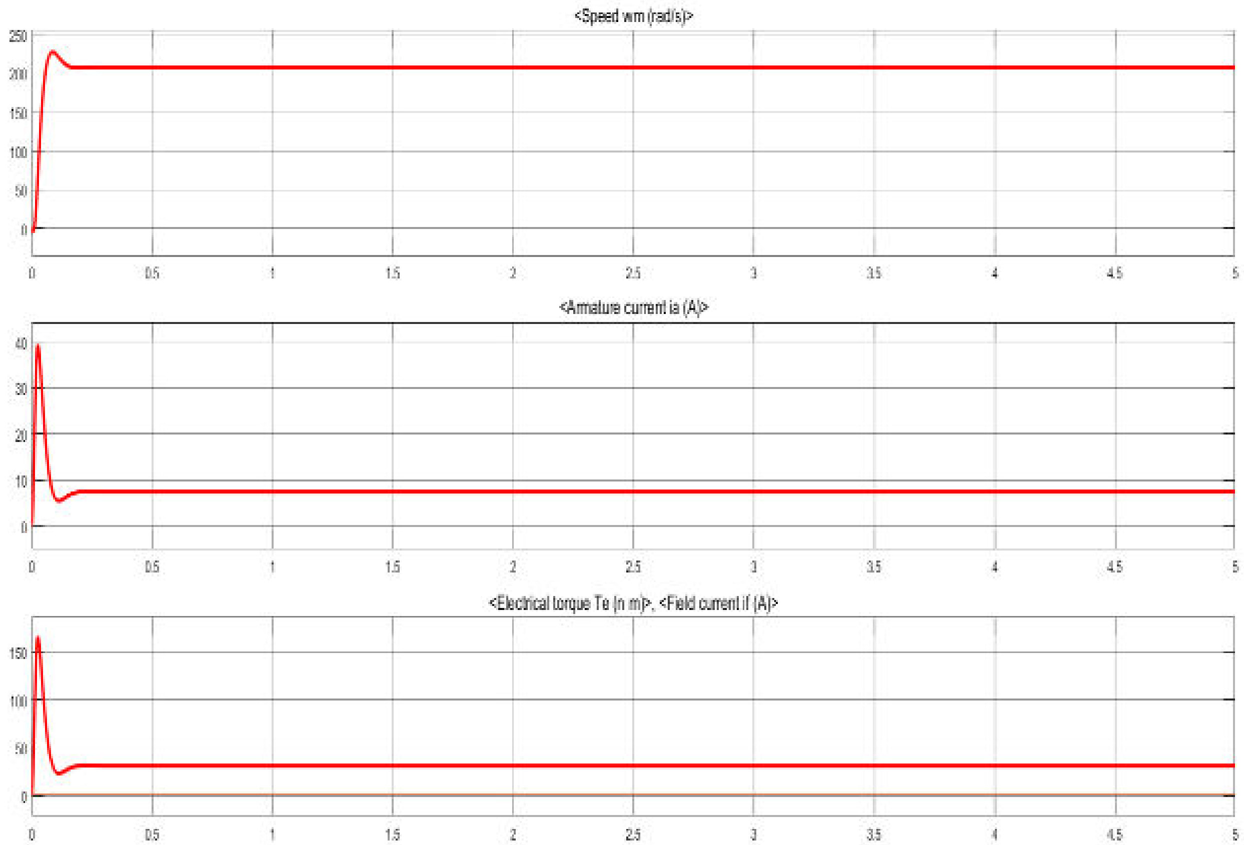

Figure 10 -Speed, armature current and electrical torque characteristics of DC motor subjected to PI controller.

Refer to the all graphs obtain from the results of each controller circuit and after doing all above analysis with PI Controller, the data is mentioned in below table 4.

Table 4- Output of PI Tuned Buck Converter

Tuning Method	PI Controller
Rise Time	99.591ms
% Overshoot	9.341%
Slow Rate	4.939/sec
Undershoot	1.998%

VI.CONCLUSION

In this paper we take the conclusion about PI controlled MPPT techniques, we come across the concept and analysis of PI controller. DC Motor of rated 5HP 500V 1750 rpm is considered here with field voltage of 300V.The steady state operation and its various torque-current, torque-speeds.PI controller gives speed characteristics of DC Motor, in PI control a rise time of 99.591s and slow rate of 4.939 per sec is recorded. Also a overshoot of 9.341% is observed. Here refer to the graph we found that there is a stability in curve with slight rise in the speed response of separately excited DC Motor.

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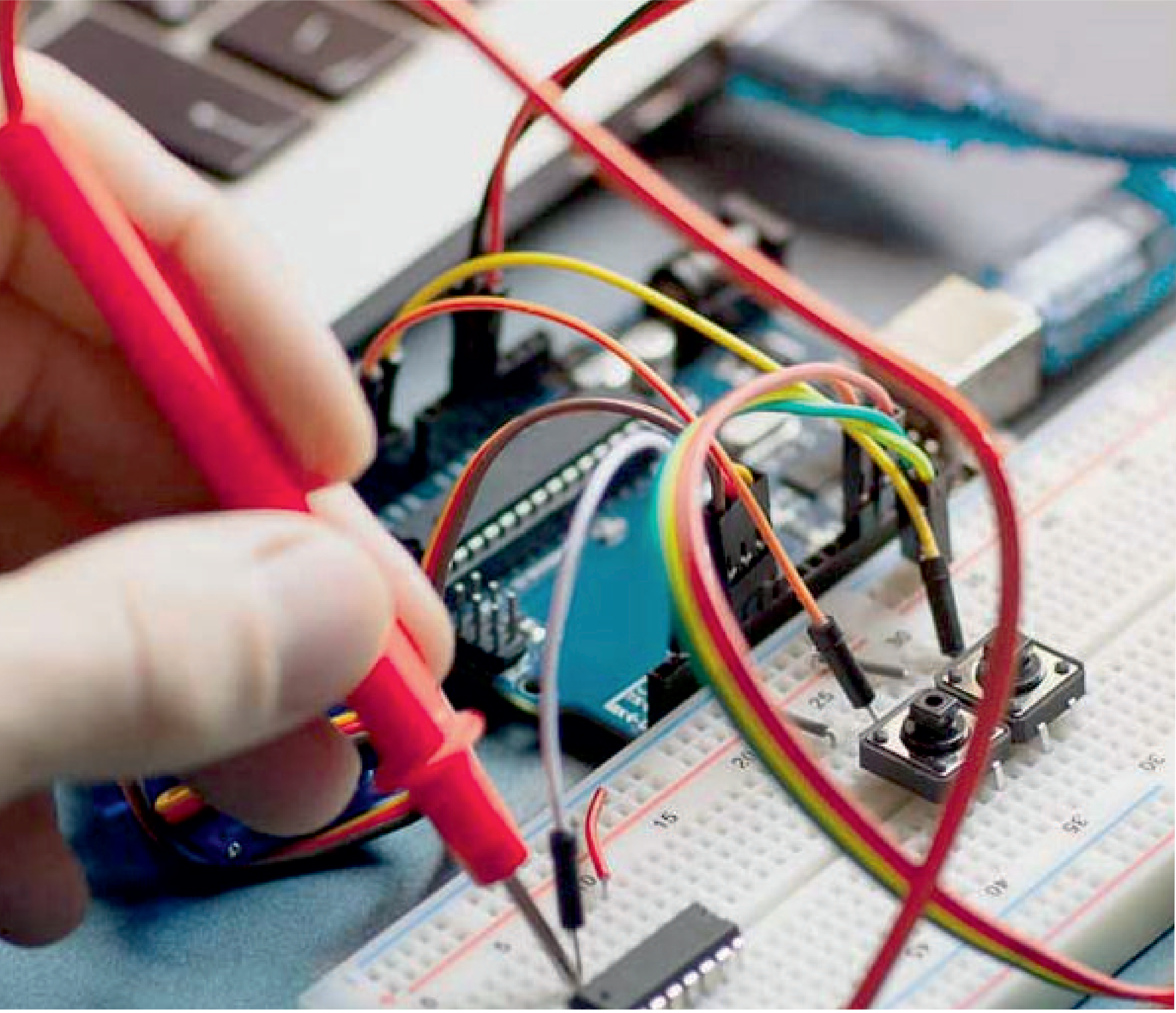

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