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Solar Powered Boost Converter Fed BLDC Motor using PID based Fuzzy Controller

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Abstract:- This dissertation work proposes a solar powered boost converter fed Brushless DC (BLDC) drive system for controlling speed at different variation of load using the fuzzy tuned PID controller. The Boost converter used for Maximum Power Point Tracking (MPPT) is chose because of the advantages of continuous and low ripple in the output current. The Boost converter is controlled by Perturbing and Observing Maximum Power Point Tracking (P & O-MPPT) algorithm results in soft starting of the BLDC motor. A fundamental switching frequency of the Voltage Source Inverter (VSI) is accomplished with the electronic commutation of the BLDC motor, thereby eliminating the VSI losses caused owing to the high frequency switching. The proposed drive is designed for various application considering the dynamic operating conditions. For a constant speed control of BLDC motor a PID tuned fuzzy controller is used with torque and phase current as load changing parameters. The desired speed is achieved by the proper tuning of gains of PID controller using fuzzy controller.

I. INTRODUCTION

Today the world is in predicament of energy crunch. Conventional energy sources are depleting at a very rapid rate which has led to the research and exploitation of nonconventional energy sources like wind, solar and tides. A solar radiation are available to us easily for the most of time and is easy to harness, therefore the research towards solar energy is emphasized more. To improve PV systems we need power electronics for interfacing and augmenting its efficiency. Sunlight is the source of electromagnetic radiation which produces electricity from solar cells without any moving parts hence minimal maintenance is required. BLDC motors are high efficiency, noise less operation, controllability, reliability and high power and torque density.

In the present scenario, renewable energy sources have become popular. The project includes the control of BLDC motor by using PV array by which the power consumption for the domestic appliances can be reduced. The electricity consumed by the domestic appliances comprised of 17% of the total world's consumption. Now-a-days every house is equipped with ceiling fan which is of induction type. So, by replacing this induction type of ceiling fan by BLDC ceiling fan there will be a huge reduction in power consumption. The electronic commutation and Voltage source inverter are key for BLDC motor operation. With advancement of power electronic devices and digital controllers make the controlling of BLDC motor very easy.

BLDC motors is offering many advantages compared to brushed DC motors, including higher torque per weight ratio, reliability, efficiency, reduction in noise, longevity, sparks elimination because of ionization from the commutator, more power, and reduction of electromagnetic interference (EMI).

II. MODELING OF BRUSH LESS DC MOTOR

Brushless DC motors (BLDC motors, BL motors) are also called as electronically commutated motors (ECMs, EC motors)which are synchronous electric motors driven with DC power and have electronic commutation systems, rather than brushes and mechanical commutators.

Three phase star connected BLDC motor is explained with the four equations given below:

$$V_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \quad (1)$$
$$V_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + e_b - e_c \quad (2)$$
$$V_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_a) + e_c - e_a \quad (3)$$
$$T_e = kj\omega_m + J\frac{d\omega}{dt} + T_L \quad (4)$$

The back emf and the electrical torque is expressed as

$$E_a = K_e/2(\omega_m * F(\theta_e)) \quad (5)$$
$$E_b = K_e/2(\omega_m * F(\theta_e - 2\pi/3)) \quad .6)$$
$$E_c = K_e/2(\omega_m * F(\theta_e - 4\pi/3)) \quad (.7)$$

$$T_e = K_t/2\{ F(\theta_e)i_a + F(\theta_e - 2\pi/3)i_b + F(\theta_e - 4\pi/3)i_c \} \quad .(.8)$$

Where K_e and K_t are constants of the back emf and torque t. The electrical angle θ_e is equal to the rotor angle times of the no.of pairs of pole i.e.,

$$\theta_e = P/2\ (\theta_m) \quad .(.9)$$

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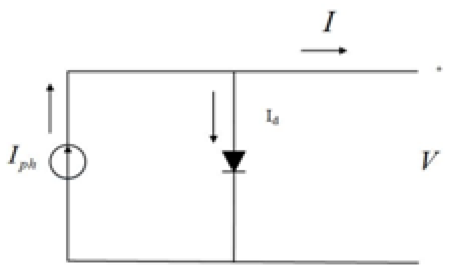
III. MODELING OF PV CELL

A PV system is a system which utiliseseither one or more than one solar panels to convert solar energy into electrical energy. It have electrical and mechanical connections ,photovoltaic modules and mounting and means of regulation for the output which is electrical.

Basically a p-n junction is the building block of PV cellor solar cell. It converts light energy into electricity: the equivalent circuit of simple single solar cell is shown below. It is a simple equivalent circuit of a single solar cell which has a diode and a current source whose connection is in parallel. The current source is generating the photo current I_{ph}, that is directly proportional to, the ambient temperature T_a (^{0}C),the solar irradiance G (W/m^2), and two output parameters: voltage V (V) andcurrent I (A).

In this model, internal losses are not considered. A simple light source and a Diode in anti-parallel connection



Ideal Single diode model

$$I = I_{ph} - I_d \quad (10)$$

$$I_d = I_o\left(exp\ exp\left(\frac{V}{AN_sV_T}\right)\right) - \quad (11)$$

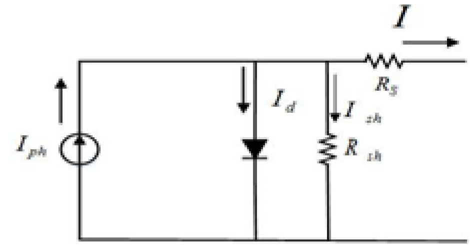
$$V_T = \frac{k.T_C}{q} \quad (12)$$

I_{ph} - Photo Current of solar cell
I_d - Diode Current
V - Voltage that was imposed on the diode
I_o - Leakage current of Diode/Reverse Saturation current
V_T - Thermal voltage (26mv at 300K for selenium cell)
T_c - The actual Temperature of cell
k - Boltzmann Constant (1.368*10^{-23}J/K)
q - The electron charge 1.602 * 10^{-19}in coulombs
N_s - The no of PV cells that are connected in series.
A - Ideality factor

Important to note that 'A', a constant that is depending on PV cell's technology. every term in which V is divided in eq..2 by the exponential function is inversely proportional to temperature of cell and so it varies along with changing conditions. In this paper, this term is designateed as 'a' and it is known as thermal voltage V_T, the ideality factor is assumed to be a constant.

$$a = \frac{N_s.A.k.T_c}{q} = N_s.A.V_T \quad (13)$$

"a" is called modified ideality factor and is considered to be parameter to be determined



Practical model with R_s and R_{sh}

Rs and Rsh are used for representing the intrinsic shunts and series resistance of the cell respectively. normally Rsh has very large value and that of Rs is a very small value. practically, it will be impossible for neglecting the resistance in series R_s and shunt resistance Rsh because of their impact on the efficiency of PV cell.

When $R_s$is considered , eq.3.2 should have the next form as follows.

$$I_d = I_o\left[exp\left(\frac{V+IR_S}{a}\right) - 1\right] \quad (13)$$

Practically by using Kirchhoff's law current will be obtained by eqn.:

$$I = I_{ph} - I_d - I_{sh} \quad (14)$$

I_{sh} is current through shunt resistor

$$I = I_{ph} - I_o\left[exp\left(\frac{V}{a_{ref}}\right) - 1\right] - \frac{V+R_SI}{R_{sh}} \quad (15)$$

It is not easy for determinimg this transcendental equations parameters, but this model provides the best performance with experimental values.

Determination ofI_{ph}:
the output current at STC is

$$I = I_{ph,ref} - I_{o,ref}\left[exp\left(\frac{V}{a_{ref}}\right) - 1\right] \quad (16)$$

This equation allows quantifying $I_{ph,ref}$ which cannot be obtained when PV cell is short circuited.

$$I_{sc,ref} = I_{ph,ref} - I_{o,ref}\left[exp\left(\frac{0}{a_{ref}}\right) - 1\right] = I_{ph,ref}$$
(17)

But this equation will be valid only in the ideal case. So, then equality is incorrect

$$I_{ph,ref} \approx I_{sc,ref} \quad (18)$$

The photo current depends mainly on both irradiance and temperature.

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{ph,ref} + \mu_{sc}\Delta T\right) \quad (19)$$

$$\Delta T = T_c - T_{c,ref} \quad (20)$$

G - Irradiance (W/m^2)
G_{ref} - Irradiance at STC (1000W/m^2)
$T_{c,ref}$ - Temperature at STC (298K)
μ_{sc} - Temperature coefficient (A/k)
$I_{ph,ref}$ - Photo current at ST

Determination of I_o

The shunt resistance R_{sh} is regarded as high value, so the last term of the equation can be removed from the next approximation.

$$I = I_{ph,ref} - I_{0,ref}[exp\ exp\left(\frac{V}{a_{ref}}\right)] \quad (21)$$

At three of the most important points at STC. The open circuit voltage $(I = 0, V = V_{oc,ref})$.The short circuit currnt $(V = 0, I = I_{sc,ref})$and the voltage $(V_{mp,ref})$ and current$(I_{mp,ref})$at maximum power, the following equation can be written

$$I_{sc} = I_{ph,ref} - I_{0,ref}[exp\ exp\left(\frac{I_{sc,ref}R_s}{a_{ref}}\right)] \quad (22)$$

$$0 = I_{ph,ref} - I_{0,ref}[exp(\frac{I_{sc,ref}R_s}{a_{ref}})] \quad (23)$$

$$I_{pm,ref} = I_{ph,ref} - I_{0,ref}[exp\ exp\left(\frac{V_{ph,ref}+I_{pm,ref}R_s}{a_{ref}}\right) - 1] \quad (24)$$

One term is neglected due to it is smaller than that of the exponential term..

$$0 = I_{sc,ref} - I_{0,ref}exp\left(\frac{V_{oc,ref}}{a_{ref}}\right) \quad (25)$$

$$I_{0,ref} = I_{sc,ref}exp\left(\frac{-V_{oc,ref}}{a}\right) \quad (26)$$

The reverse saturation current is given by

$$I_0 = DT_c^3 \exp\left(\frac{-q\varepsilon_G}{A.k}\right) \quad (27)$$

For eliminating diode diffusion factor equation 27 is computed twice: at T_c and $T_{c,ref}$.Then, the ratio of two equations is written a

$$I_o = I_{o,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3 exp\left[\left(\frac{q\varepsilon_G}{Ak}\right)\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right] \quad (28)$$

$$I_o = I_{sc,ref}exp\left(\frac{-V_{oc,ref}}{a}\right)\left(\frac{T_c}{T_{c,ref}}\right)^3 exp\left[\left(\frac{q\varepsilon_G}{A.k}\right)\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right] \quad (29)$$

IV. PID TUNED FUZZY CONTROLLE

The important aspect of the PID controller is the ability of using the three control terminologies of integral ,proportional and derivative influences on the output of controller for applying accurate control. The block diagram given below shows the principles on which these terms are being generate and applied. It describes a PID controller, that continuously calculating an error value which is the difference of a set value and a measured value a corrections applied based on integral, derivative, and proportional terms. The controller tries for minimizing the error every time by adjusting the controlling variable u(t), like the opening of a control valve, to a new value calculated by a weighted sum of the control terms.

The output equation of PID controller is

$$\mathbf{u(t)=k_p*e(t)+k_i}\int_0^t e(t)dt+\mathbf{k_d}\frac{de(t)}{dt}$$

where k_p= proportional gain
k_i= intergral gain
k_d= derivative gain
In this model:

Term Proportional (P) is proportional to the value of current of the actually-obtained i.e. error e(t). If the value of error is large and positive, the output of control is proportionately large and positive, considering the gain factor "K". Using proportional control alone will be resulting an error among the actual and the obtained value, as it is requiring an error for generating the proportional response. If it has no error, then there is no correction response required..

Term **I**con siders previous values of the actually-obtained (error) and then integrates them over time for producing the I term. If there is any residual error after the application of proportional control, the integral termtries for eliminating the residual error by adding a control effect because of the historic cumulative values of the errors. When the error is diminished, the integral term will stop growing.

Integral (I) control is integrating of the error signal. In reality, this means that the value of the manipulated variable varies by a rate proportional to the error. This controller eliminates the steady state error of the system.

Term Derivative (D) is a best estimation for the future trend of the actually-obtained error, based on its current rate of change. It ia also known "anticipatory control", as it is effectively seeking for reducing the effect on the error by exerting a control influence generated at the rate of change in error. Derivative action is used for making the control fast. Its change in output is proportional to the rate of change of the deviation.

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Tuning – The balance for these effects are being achieved by the loop tuning for producing the optimal controlling function. The constants for tuning are shown below as "K" and are derived for each of the control application, as they are depending on the response characteristics of the complete loop outside to the controller. These depend on the behavior of the any control signal delays measuring sensor, the final control element (such as a control valve) and the process itself.

The combined action is having the advantages of the three individual control actions:

Parameter	Speed of Response	Stability	Accuracy
increasing k	Increases	Deteriorate	Improve
increasing ki	Decreases	Deteriorate	Improve
increasing kd	Increases	Improve	No change

Comparasion of Gain Response of P, PI and PID Controllers

Parameter	P Controller	PI Controller	PID Controller
Rise time	Decreases	Decreases	small Decreases
Overshoot	Increases	Increases	Small Decreases
Settling time	Minor change	Increases	Small Decreases
Steady state error	Decreases	Significant change	No change
Stability	Worse	Worse	If Kd Small Better

Effects On Various Output Parameter Of P, PI And PID Controller W.R.T To Variation In Rise Time

V. SIMULATION RESULTS

The specification of BLDC motor used in this work is as follows

Power, P	930W
Speed, N	3000 rpm
DC voltage	310 V
No. of poles	4
Moment of inertia	8 Kg.cm^2
Voltage constant, K_e	78 V/k rpm
Torque Constant	0.74 Nm/A
Phase inductor, L_s	9.13mH
Phase Resistance, R_s	3.58Ω

Specifications of BLDC motor

Design of solar PV array and PV module

For a PV Module	
Parameters	*Value*
Maximum power, P_M (W)	*48.45*
Voltage at maximum power point, V_{MPP} (V)	*17*
Current at maximum power, I_{MPP} (A)	*2.85*
Open circuit voltage, V_{oc}(V)	*21*
Short circuit current, I_{sc}(A)	*3.11*
For a PV array	
Maximum power, P_M (W)	*1360*
Voltage at maximum power point, V_{MPP} (V)	*82*
Current at maximum power, I_{MPP} (A)	*16.58*
Open circuit voltage, V_{oc}(V)	*105*
Short circuit current, I_{sc}(A)	*18.66*
Number of modules in series, N_s	*182*
Number of modules in parallel, N_p	*6*

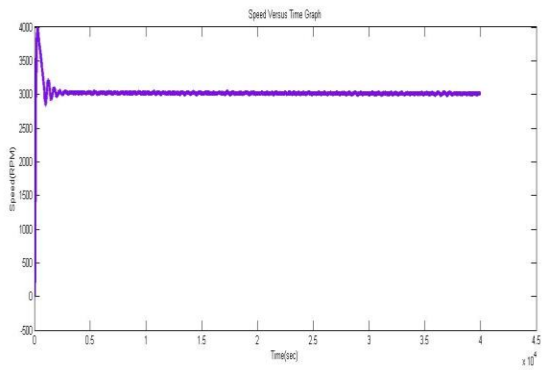
Design of Boost converter:

S. No.	Parameter expression	Selected value
1	$L_1 = \frac{DV_{pv}}{f_s \Delta I_{L1}}$	6mH
2	$L_2 = \frac{(1-D)V_{pv}}{f_s \Delta I_{L1}}$	6mH
3	$C_1 = \frac{DI_{dc}}{f_s \Delta V_{C1}}$	22µF

Where
f_s is switching frequency,
D is duty cycle,
which is obtained from below formula
$D = \frac{Vdc-Vpv}{Vdc}$
V_{pv} is voltage of PV array.
$I_{dc} = \frac{Pmpp}{Vdc}$

- Torque α (speed)^2
- Power α (speed)^3
- Power = k_t* (speed)^3
- Where k_t = torque constant, it can be calculated as
- Torque constant(k_t)= (Power)/(Speed)^3
- $K_t = p/\omega^3$
- Torque = $k_t*\omega^2$
- Torque constant = Torque/ Rated current
- Voltage constant = Voltage-peak (L-L)/ (K* speed)
- Back EMF flat area (degrees)=120

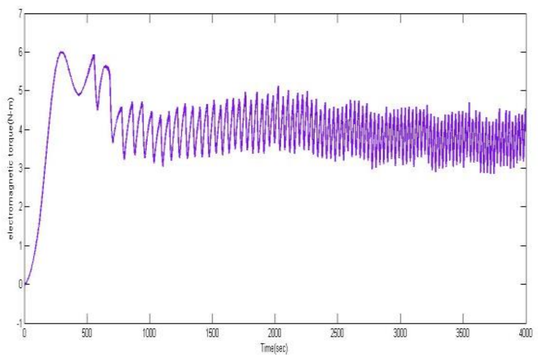
Speed vs time



Speed versus Time

The speed of the motor with respect to time varies as above.intially the peak overshoot reaches upto 4000 RPM and reaches to steady state with a settling time of 0.3 seconds.

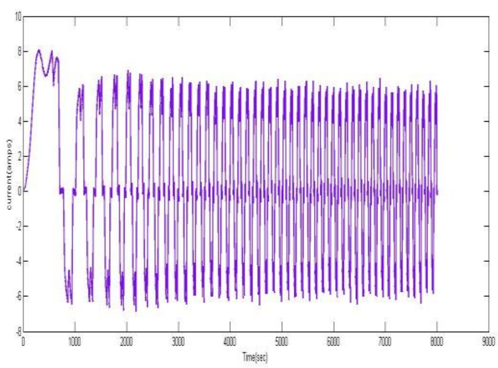
Electromagnetic torque vs time



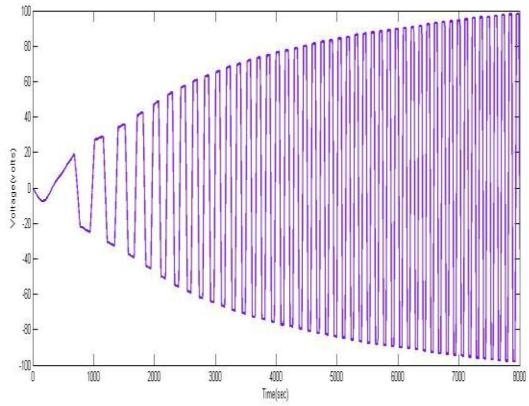
Here the torque varies w.r.t time which is initially rise to peak and settles down at 3.20 seconds as shown in the below figure.

Current and Voltage graphs

The current& voltage fluctuates as shown in below figure as the parallel to the load variation



Stator Current Vs Time



Stator Voltage Vs Time

VI. CONCLUSIONS

The proposed solar power fed boost converter fed BLDC motor was designed, modeled and simulated in the MATLAB/Simulink. The performance of proposed drive was observed from BLDC motor starting current, speed and torque curves. It has found that starting inrush current of the drive is low compared with conventional DC-DC converter. The performance of the motor speed and torque was found satisfactorily for constant temperature and irradiance condition and also for variable temperature and irradiance condition. The DC voltage and phase current sensing elements are eliminated, resulting in a simple and cost effective drive. Low starting inrush current results soft starting of motor pump. Based on the simulation results, BLDC motor with boost converter is suitable and compatible combination for solar PV based BLDC Drive at variable weather conditions .Hence for the desired speed of the motor is achieved by the proper adjustments of gains of PID based fuzzy controller for different variation of load.

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