A Review on Speed Control of BLDC Motor fed from Solar PV Array using Particle Swarm Optimization

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Abstract - **Recently, Brushless DC Motors are finding numerous usages in industrial application due to its added advantages over other AC motors. This paper basically talks about the speed control of BLDC motor fed from a standalone Solar PV system with perturb and observe MPPT method to extract the maximum efficiency. Particle Swarm Optimization technique has been used to find the optimized result for the PI controller. The end result shows the PSO controller controls the speed of the BLDC motor quite well.**

***keywords* - Solar PV Array, P&O, MPPT, PSO, BLDC motor, PI Controller**

I. INTRODUCTION

An Electronically Commutated Motor (ECM) or simply a Brushless DC Motor are synchronous motors whose AC supply is given through a Inverter or a Switching Power Supply to drive each phase of the motor. The BLDC motor are permanent magnet motors in which solid state switches are used to work as brushes or commutator.

Nowadays BLDC motor are the most commonly and widely used motors. It has numerous industrial and commercial application which includes aero modeling, positioning system, electric vehicles, peripheral devices etc. Its advantages include flat torque over wide range of speed, long operational lives, less bulky, comparatively quiet, required less raw material to build so is also better for the environment.

There is always been discussion about which controller is good and controls the system most effectively. There are number of controllers including Fuzzy logic, PID controller, PI controller,

Artificial Neural Network etc. PID controller are most widely used one in industries, it has a closed loop system with a feedback path. P denotes the Proportional Gain which can be achieved by multiplying the error by a constant K_p. We notice a large change in the output when K_p is high for the same error.

- The system will become unstable when the value of K_p is too high.
- The system will become less responsive or less sensitive when the value of K_p is too small.

I denote the Integral Gain which is achieved by multiplying the error with the constant K_i and adds to the controller output. It helps the system to move towards a particular setpoint and eliminates the residual steady state error. D denotes the Derivative Gain which can be calculated by analyzing the slope of the error over time and multiplying the rate of change with constant K_d. It determines the system behavior and improves settling time and stability of system.

Optimization algorithms are generally used to find the optimized parameters for the controller. Some of them are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant-Bee algorithm, Bacterial Forging Optimization (BFO) etc. GA and PSO are very popular optimization techniques but nowadays many new techniques has also been analyzing for their feasibility. In this paper, we give a brief description about Particle Swarm Optimization technique. It was first presented by Eberhert, Kennedy and Shi, based on the social behavior of the animals such as flock of birds and birds etc.

Renewable energy is more preferred nowadays due to environmental conditions. Solar is one of the best renewable energy sources among others. So Solar PV Array with Perturb and Observe type of maximum power point tracking has been used to extract the maximum efficiency from the solar array.

II. REVIEW OF METHODOLOGY

The review of the paper shows the controlling of the BLDC motor using the methodology given as below:

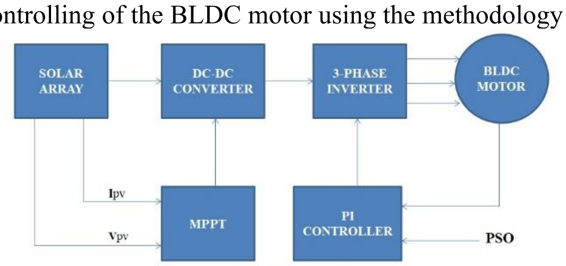


Fig 1. Block diagram of proposed work

A. Solar PV Array

A solar cell works on the principle of photoelectric effect i.e., when solar radiations falls on the semiconductor plate it produces electrical current. Solar Array mainly defines the combination of two or more solar cells connected either in series or in parallel to fulfil the energy requirement. Solar cells are usually connected in series to produce higher voltage and in parallel to produce higher current than the system.

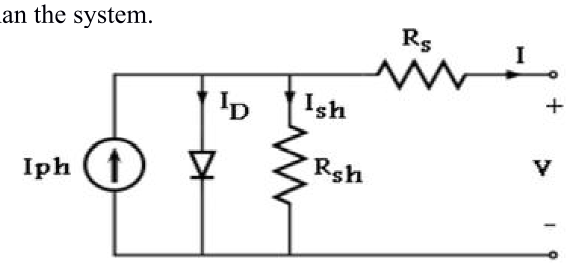


Fig 2. PV cell equivalent circuit

It shows a basic equivalent circuit diagram of a Solar cell.
The equation can be developed to calculate the output current with the inputs of solar array i.e. voltage, solar irradiation and temperature.

$$I = I_{ph} - I_o\,(e^{\frac{q(V+IR_s)}{\alpha kT}} - 1) - \frac{V+IR_s}{R_{sh}} \quad (1)$$

where;
I_{ph} = Phase current
I_D = Diode current
R_s = Series resistance
R_{sh} = Shunt resistance

Series resistance are taken into account due to combined resistances of contacts, metal grips and p and n layers. Shunt resistance are considered due to leakage current through p-n junction.

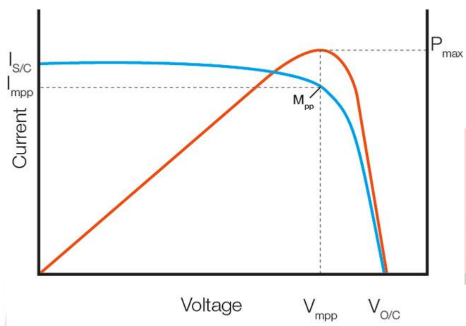


Fig 3. I-V and P-V characteristic of solar array

The fig 2. is short-circuited making the output voltage, V=0 and current is maximum, I=$I_{S/C}$ hence V-I characteristic can be plotted. When fig 2. is open circuited then output voltage is maximum, V=$V_{O/C}$ and current, I=0 hence P-V characteristic is plotted.

B. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking / Power Point Tracking can be used to maximize the output power of the solar cell under all conditions. MPPT mainly regulates the output obtained from the solar pv array and provide that output to the DC-DC converter or the inverter circuit. The maximum power (P_{mpp}) can be calculated by multiplying MPP voltage (V_{mpp}) and MPP current (I_{mpp}).

$$P_{mpp} = V_{mpp} * I_{mpp} \quad (2)$$

MPPT have several strategies which can be used to optimize the output power of the solar pv array. One may implement different algorithms and switch among those based on operating condition of the solar array. Some of them includes Perturb and Observe, Incremental Conductance, Current Sweep, Constant Voltage, Temperature Method etc. Among them perturb and observe and incremental conductance methods are the most commonly used ones. However, this paper deals with the perturb and observe method to extract the maximum efficiency from the solar array.
In this technique, a minor perturbation is in introduced in voltage to cause the power variation of the PV module. Then PV output power is periodically measured and compared with the previous power. Now, if output power increases same process is continued else the perturbation is reversed. So mainly, the PV module voltage is increased or decreased to check the power variation.

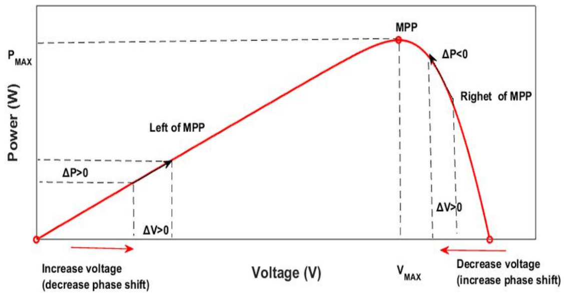


Fig 4. Perturb and Observe on P-V curve

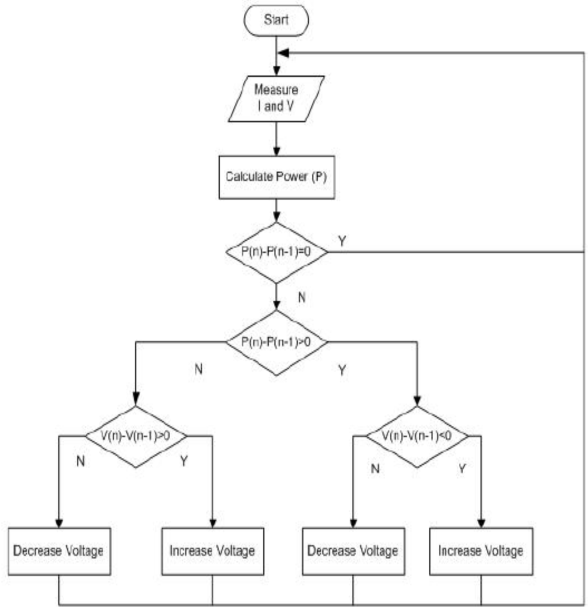


Fig 5. Perturb and Observe flowchart

On the basis of the above P-V curve we can determine the MPP as follows:

- When an increase in voltage leads to increase in power, this means that the operating point of the PV module is on the left of MPP. Hence, further perturbation is required in the right to reach the mpp.
- When an increase in voltage leads to decrease in power, this means that the operating point of the PV module is on the right of MPP. Hence, further perturbation is required towards the left to reach the mpp.

Hence PWM duty cycle is increased or decreased to extract the maximum power.

C. BLDC Motor

BLDC motors are permanent magnet motors which uses solid state switches in place of commutators and brushes. The bldc motors are not only distinguished from other motors by high efficiency but also due to low maintenance.

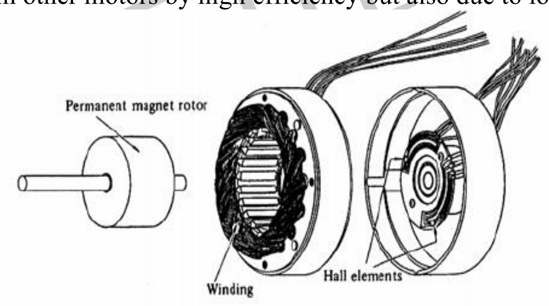


Fig 6. Disassembled view of BLDC motor

The construction of BLDC motor is similar to that of AC motors, hance also known as permanent magnet synchronous motor. The stator winding is similar to those in a polyphase AC motor, and rotor consist of one or more permanent magnets. BLDC motor incorporates some means to detect the rotor position and produce signals to control the electronic switches. Hall sensors are hence most commonly used, while some also use optical sensors.

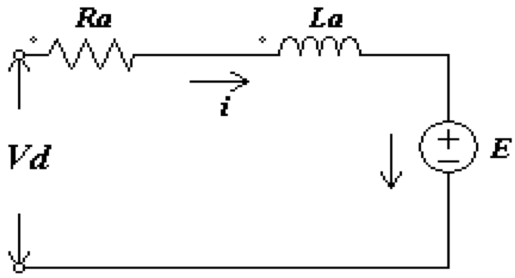


Fig 7. Per Phase equivalent of BLDC motor

Now the equation of the phase current for the above model can be obtained as:

$$\frac{di_a}{dt} = \frac{1}{L-M}(V_a - E_a - Ri_a) \tag{3}$$

$$\frac{di_b}{dt} = \frac{1}{L-M}(V_b - E_b - Ri_b) \tag{4}$$

$$\frac{di_c}{dt} = \frac{1}{L-M}(V_c - E_c - Ri_c) \tag{5}$$

Now voltage can be obtained by used Kirchhoff's voltage law:

$$V_d = R_a i + L_a\frac{di}{dt} + E \tag{6}$$

The electromagnetic torque, T_e can be stated as follows:

$$T_e = \frac{P}{\omega} \tag{7}$$

and,

$$P = Ei \tag{8}$$

We get,

$$T_e = \frac{E_a i_a + E_b i_b + E_c i_c}{\omega} \tag{9}$$

D. Particle Swarm Optimization (PSO)

The main function of an optimization algorithm is to find the best result for the controller circuit. Lately, there has been discussion about the effectiveness and usage of optimization techniques. Although the result of all the algorithms depend upon the size of the particles. But among the many Genetic Algorithm (GA) and PSO proves to be better. Also, PSO proves to be more efficient and fast as compared to GA for smaller number of particles. It happens due to the differences in the algorithm in both the optimization techniques.

PSO is an intelligent optimization algorithm which belongs to the meta-heuristic class of optimization algorithm. It is mainly inspired by the social behaviour of the animals such as birds and fishes. It uses some intelligent agent called particles which is used to reach another level of intelligence.

Now every particle has a position (X_i) in the search space denoted by;

$$X_i^t = (x_{i1}x_{i2}x_{i3}\ldots x_{in})^T \tag{10}$$

And the velocity (V_i) which describes the movement in the sense of direction and distance denoted by;

$$V_i^t = (v_{i1}v_{i2}v_{i3}\ldots v_{in})^T \tag{11}$$

Every particle has a memory of its best position in the respect of position and velocity which is known as local best or personal best denoted as P_{best}. The common best experience among the whole swarm is known as global best denoted as G_{best}. These vectors are also updated for the dimension i.e. j, according to the given equation.

So, the velocity can be updated by the given equation:

$$V_{ij}^{t+1} = \omega V_{ij}^t + c_1 r_1^t(pbest_{ij} - X_{ij}^t) + c_2 r_2^t(gbest_j - X_{ij}^t) \tag{12}$$

And, the position can be updated by the given equation:

$$X_{ij}^{t+1} = X_{ij}^t + V_{ij}^{t+1} \tag{13}$$

where, i=1,2,…,P j=1,2,…,n.

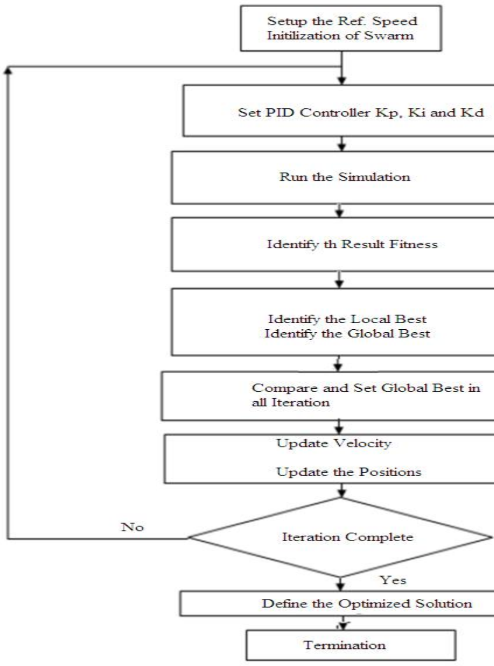


Fig 8. PSO Algorithm for tuning of BLDC Motor Controller

The equation 12 consist of three components i.e., Inertia term, Cognitive component and Social component. All the three components help in updating the velocity for PSO.

III. RESULT AND CONCLUSION

This paper deals with the speed control of BLDC motor fed from a solar PV array using Particle Swarm Optimization technique. So, a comparison has been made between the two model i.e., model of a bldc motor with solar array and model of bldc motor with solar array and pso.

A. Model of BLDC motor with solar Array

In this model the system is powered by solar pv array. A PSO has not been used in this model to find the parameters for the PI controller, hence some values of the PI controller parameters are taken at random.

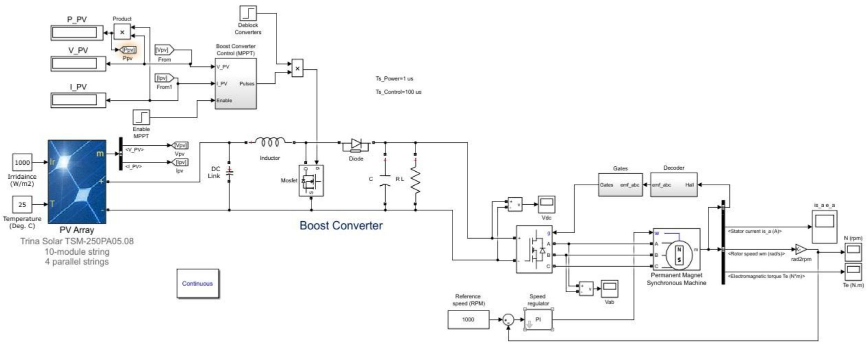


Fig 9. Model of BLDC motor with solar PV array

The parameters for the simulation can be stated as follows;

BLDC motor parameters		PSO parameters	
R	0.7Ω	w	1
L	2.72e-3H	c_1	2
J	0.8e-3kg.m^2	c_2	2.2
F	1e-3N.m. s	Number of particles	40
P	3	Maximum iteration	40

Table 1. Simulation Parameters

These parameters can be changed according to the requirement and usage. The parameter for the optimization technique can be increased to get the better results.

K_p	K_i	Rise Time (t_r)
0.0002	0.3	3 sec
	0.5	2.1 sec

	0.7	1.7 sec
0.0004	0.3	3.2 sec
	0.5	2.1 sec
	0.7	1.8 sec
0.0006	0.3	2.7 sec
	0.5	2 sec
	0.7	1.6 sec

Table 2. Comparison of Rotor Speed at different K_p and K_i

The above table shows the rise time of the rotor speed at different PI controller parameters i.e. K_p and K_i. Since random number of values for the PI controller has been checked to analyse the best output, which is then compared with the output of the model having PSO, to find the values of PI controller.

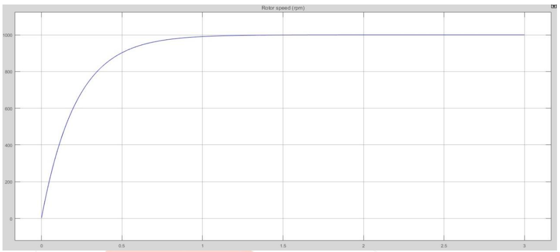


Fig 10. Rotor speed for BLDC motor with solar array

Now, this is the graph of rotor speed for the best output amongst the different values of the PI controller, K_p and K_i.

B. Model of BLDC motor with Solar Array and PSO

In this model the system is again powered by a solar pv array. This model also contains a PSO, which is used to get the optimized result for the PI controller parameters.

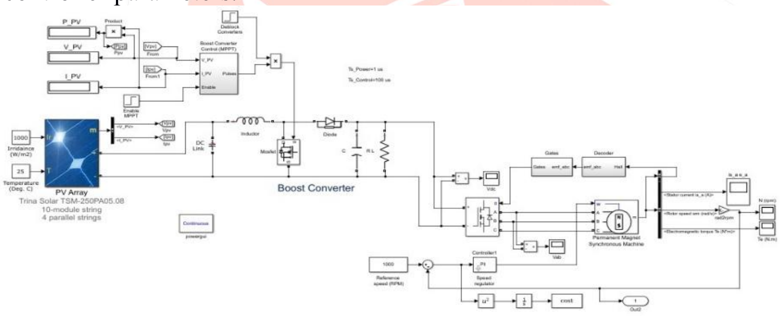
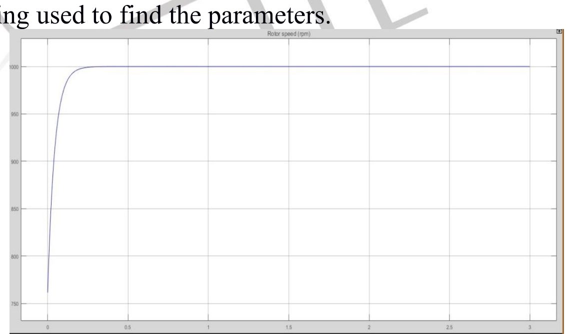


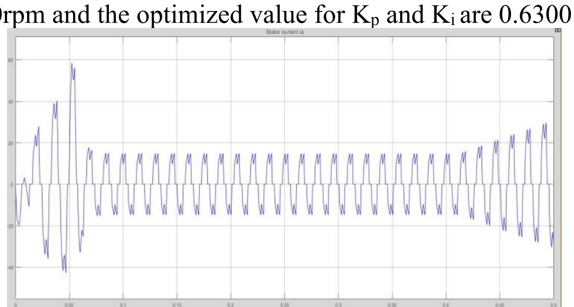
Fig 11. Model of BLDC motor with solar array and pso

All the parameters are kept same at the time of simulation. Except that in the former model random values of K_p and K_i is used whereas in the latter PSO is being used to find the parameters.

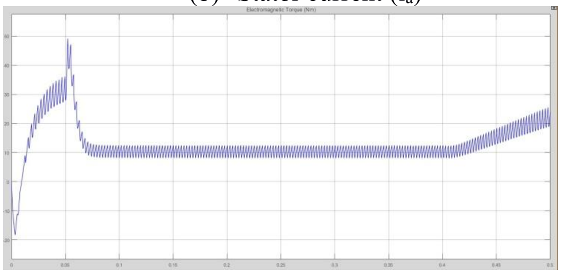


(a) Rotor Speed

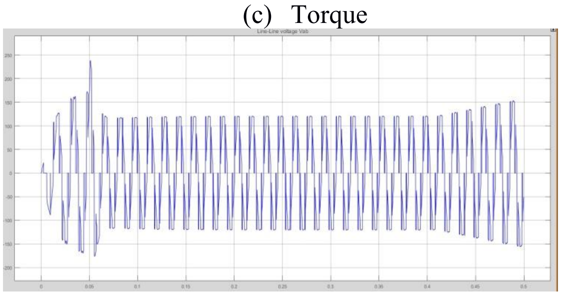
The reference speed is taken as 1000rpm and the optimized value for K_p and K_i are 0.6300 and 0.0504.



(b) Stator current (i_a)



(c) Torque



(d) Output Voltage (V_{ab})

Fig 12. Graphs of BLDC motor with solar array and PSO

Fig 12(a) shows the rotor speed for BLDC motor with a rise time as low as 0.25sec. Fig 12(b) shows stator current with a peak value of 60A. Fig 12(c) shows torque and Fig 12(d) is output voltage with a value of 120V.

Reference Speed (n_{ref})	Without PSO Rise time (t_r)	With PSO Rise time (t_r)
750 rpm	1.7 sec	0.3 sec
1000 rpm	1.5 sec	0.25 sec
1500 rpm	1.6 sec	0.34 sec
2000 rpm	1.7 sec	0.32 sec
3000 rpm	1.9 sec	0.35 sec

Table 3. Comparison of both the models at different speeds

Above table shows the comparison of rise time of rotor speed for both the models at different speed.

C. Conclusion

In this paper, a comparison has been shown between model of BLDC motor with solar array and model of BLDC motor with solar PV array and PSO. The rotor speed of the BLDC motor of both the models has been compared. The graphs show that the rotor speed of BLDC motor with solar array and pso has a good speed response with no overshoot and less rise time when compared with the other model.

Hence, the result shows that the Solar fed controller based on PSO can control the BLDC motor speed quite well.

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