

Speed Control of BLDC Motor using Luo Converter based Self Tuned PID with PSO Algorithm

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Abstract: In this paper, a Particle Swarm optimization (PSO) based PID controller is implemented For BLDC motor with Luo Converter. A PSO is designed for PID controller. This study is concerned with employing permanent magnet BLDC motor drive powered from a solar photovoltaic array in which a Luoconverter is used for maximum power point tracking. Amidst the various DC-DC converters, Luoconverters are best suited for solar applications. It has high power density, high efficiency and a simple structure rendering high output voltage with small ripples. Constant Voltage (CV) Algorithm is used as the MPP tracking. The whole system is simulated in MATLAB/SIMULINK environment and the results are presented. The result shows that the PSO based PID controller designed is able to control the speed of BLDC motor properly with the desired response speed. The simulation will be done for Brushless DC motor with PSO using MATLAB/Simulink software the effectiveness of the proposed PSO controller is compared with ANFIS Controller.

Keywords—BLDC motor, bidirectional, PSO, ANFIS controller, voltage source inverter.

I. INTRODUCTION

In recent years, Brushless Direct Current (BLDC) motor have been widely used in many applications, such as industrial applications, electric vehicles, consumer appliances, and so on [1]. BLDC motors have more advantageous than any other types of motor; those are wide speed range, high torque, high-performance, reliable operation, high efficiency, and low maintenance [2]. BLDC motors work similar to conventional DC motor but without brushes, so that makes BLDC motors have high efficiency. A BLDC motor refers to one of types of Permanent Magnet Synchronous Motor (PMSM). PMSM motors are categorized as two types according to the Back-EMF (BEMF) voltage waveform, Brushless AC (BLAC) Motor with sinusoidal BEMF waveform and BLDC motor with trapezoidal BEMF waveform. A BLDC motor is operated in three phase mode operation with no brushes, so it needs a controller which is connected to the three phase stator windings. The controller is useful for changing the function of commutator by energizing the stator windings which are proper to the commutation step, so a BLDC motor can operate well. In many applications, BLDC motor is controlled to get some desired value, such as speed, torque and position [3].

A photovoltaic array is a complete power generating unit that consists of many numbers of PV modules and panels. The performance of PV modules and arrays are generally being rated according to their maximum DC power output in watts under the Standard Test Conditions (STC). The STC are given as:

Table 1: Standard Test Conditions

Parameters	Value
Cell Temperature	25°C
Solar Irradiance	1000W/m ²
Air Mass	1.5 AM

Since these environmental conditions are not always typically the theoretical values, PV modules and arrays operate in the field, where actual performance is usually 85 to 90 percent of the STC rating. The efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and also the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at its highest efficiency[1]. This load characteristic is called the maximum power point (MPP) and MPPT is the process of finding this point and keeping the load characteristic at desired value. The most commonly implemented methods include power matching, perturb-and observe (P&O), incremental conductance (INC), ripple correlation control(RCC), constant voltage and constant current methods [2]. The simplest and fastest methods to achieve maximum power point are the techniques like constant voltage and constant current methods. In these both techniques, a linear dependence between the module current (or voltage) corresponding to maximum power and the module's short-circuit current (or open-circuit voltage) is being assumed. Due to the assumption of constant environmental conditions true MPP is not always achieved [3]. There exist some improved versions that use improved online tracking algorithms to detect short-circuit currents and open-circuit voltages. Luo converters are a series of DC-DC converters that can perform positive to positive DC-DC voltage. This conversion is accompanied with high power density, high efficiency and cheap topology in simple structure. Luo converter gives high output voltage with small amount of ripples. Mathematical and simulation study of PV fed Cuk, Sepic, Zetaand Luo DC-DC boost converters has been carried out [4] and is observed that the Luo DC-DC converter is best in terms of transient response in the among all DC-DC boost converters. The output of this converter is fed to the inverter of the BLDC motor. The recent trend has been to use brushless D.C (BLDC) motors to make the operation more reliable, more efficient, and less noisy. Compared to brushed motors with the same power output, they are also lighter [5]. BLDC motors are being used in most of the modern devices. Efficiency of a BLDC motor is around 85-90%, whereas the conventional brushed motors have only 75% -80% efficiency. BLDC motors are also very suitable for high speed applications, 10000 rpm or above. These motors are also well known for their good speed control. BLDC motors can be used in high-end white goods (like refrigerators, washing machines, dishwashers, etc.), high-end pumps, fans, and other appliances those requiring high reliability and efficiency. In this paper a drive is proposed that is suitable for high-end white goods.

II SOLAR PANEL MODELLING AND MPPTRACKING

The sun delivers energy to the earth, that also completely free of charge. The technology of converting this energy into electricity is called photovoltaic. The photovoltaic (PV) panels are made of semiconductor materials. These modules provide a safe, reliable and maintenance free, environmentally friendly source of power for a very long time. Mostly, the PV modules are 5-25square feet in size and weighs about 1.264 to 1.5kg/square metre. The mathematical modelling of a PV array is done using the below mentioned equations[6]. Solar cell is fundamentally a pp-n junction diode. The Shockley equation is given by:

$$I_D = I_S [e^{(q \cdot v_D / K T)} - 1] \dots \dots (1)$$

I_D is the diode current, I_S is the diode saturation current, v_D is the diode voltage, q is the electron charge($1.6 \cdot 10^{-19}$ C), K is the Boltzmann constant($1.38 \cdot 10^{-23}$ J/K), T is the temperature dependence of I_S . The equivalent circuit of the solar cell is given in the Fig.1 which is a one diode model. It consists of a current source, a diode, series resistance R_s (internal resistance of cell) and the shunt resistance R_{sh} .

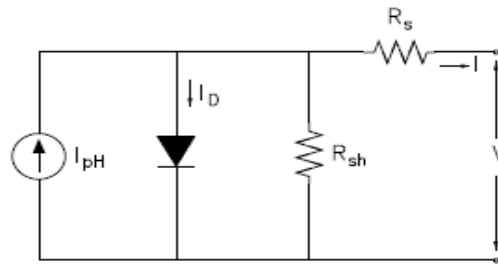


Fig.1.One diode model of pv cell

PV cells produce approximately 2W, the cells should be connected in series-parallel combination

In order to produce enough power. The generalized equation for solar array with NP parallel and NS series cells is:

$$I = NP \cdot I_{pH} - NP \cdot I_S \left[e^{\left(\frac{V}{NS} + \frac{I \cdot R_s}{NP} \right) / (K \cdot T \cdot A)} - 1 \right] \dots \dots \dots (2)$$

A is the ideality factor. The voltage V is given by:

$$V = NS \left[\frac{K \cdot T \cdot A}{q} \right] \log \left[\left(\frac{NP \cdot I_{pH}}{I} - \frac{I}{NP \cdot I_S} \right) + 1 \right] - \left(\frac{I \cdot R_s}{NP} \right) \dots \dots \dots (3)$$

The Simulink model of the solar PV array is shown in figure 2 :

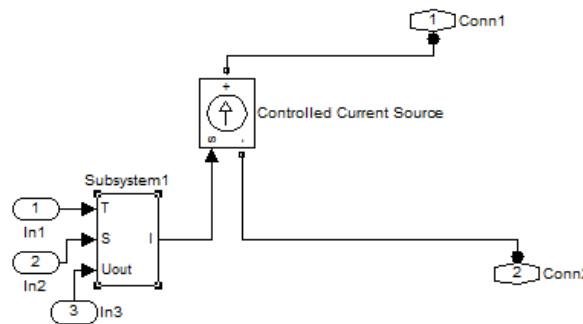


Fig 2. Simulink model of a solar panel

TABLE 2: RATINGS OF SOLAR PANEL, KAVONE SOLAR KS-10

Parameters	Value
Maximum Power, P _{max}	100 W
Voltage at MPP, V _{mpp}	19.06 V
Current at MPP, I _{mpp}	5.25 A
Module Open Circuit Voltage, V _{oc}	22.4 V
Module Short Circuit current, I _{sc}	5.83 A
Standard Test Conditions	1.5 AM, 1000 W/sq.m, 25 °C

The principle of constant voltage MPPT is that the maximum power is assumed to be at a certain fixed percentage of the open circuit voltage [6]. The current of the PV panel is momentarily set to zero and allows the measurement of the open circuit voltage of the panel. The reference voltage is set at almost 80% of the open circuit voltage and is compared with the PV voltage. If the PV

voltage is lower than the reference voltage then the duty cycle of the converter is decreased and vice-versa if the reference voltage is higher [6]. This method is very simple and low cost [7].

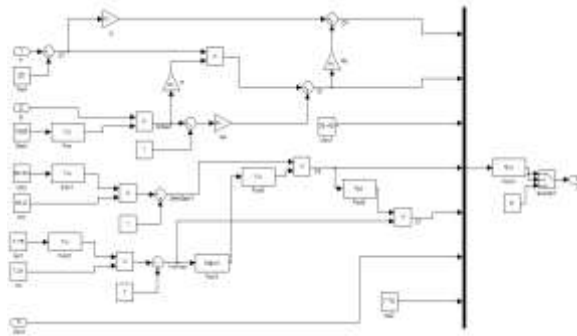


Fig 3.constant voltage mppt

III LUO CONVERTER MODELLING

The positive output Luo converter converts positive input voltage to positive output voltage. There are various types of Luo converters viz, self-lift, re-lift, triple-lift, quadruple-lift and super-lift, all of this being derived from the elementary circuit. Luo converters have low switching losses and highest efficiency the among the other DC-DC converters. Voltage lift technique has been employed to design high voltage gain converters. It reduces the value of duty ratio and also the effect of parasitic elements. Luo converters provide improved output current characteristics due to the inductor in the output stage which make this configuration effective for MPP tracking. The values of the elements of the Luo converter is designed by considering the ON/OFF switching periods.

TABLE 3.DESIGN VALUES OF LUO CONVERTER

Parameters	Value
Input Voltage, V_{in}	144 V
Output Voltage, V_o	320 v
Duty Ratio	.18
Inductor, L	8.64mH
Capacitors, $C_1=C_2$	524 μ F
Load resistance	50 Ω
Switching Frequency	10 kHz

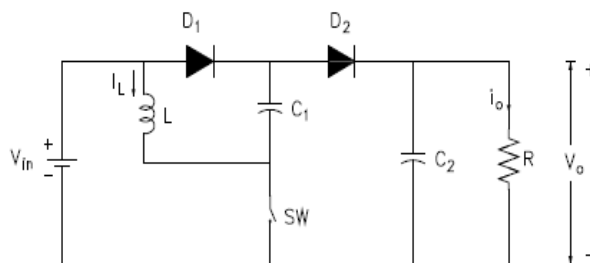


Fig 4.classical luo converter

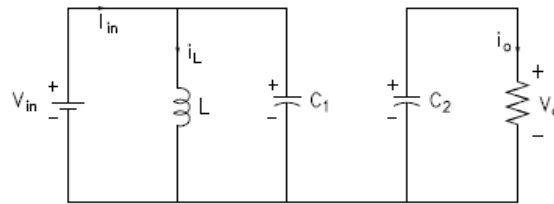


Fig.5.luo converter with switch closed

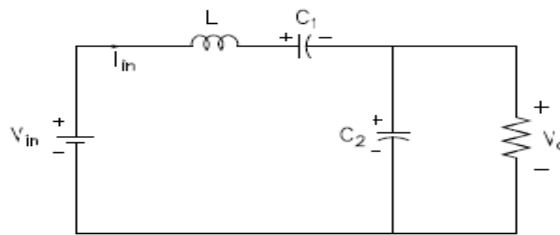


Fig.6.luo converter with switch open

IV MODELLING OF BLDC MOTOR

BLDC motor is fed from a three-phase voltage source..The model of the armature winding for the BLDC motor is expressed as follows[9][10]:

$$V_a = R \cdot i_a + L \cdot (di_a/dt) + e_a \dots \dots \dots (4)$$

$$V_b = R \cdot i_b + L \cdot (di_b/dt) + e_b \dots \dots \dots (5)$$

$$V_c = R \cdot i_c + L \cdot (di_c/dt) + e_c \dots \dots \dots (6)$$

L is armature self-inductance (H), R is armature resistance (Ω), V_a, V_b, V_c are terminal phase voltages (V), i_a, i_b, i_c are motor input currents (A) and e_a, e_b, e_c are motor back -EMFs(V).The back-EMF is related as a function of rotor position [8] and the back-EMF of each phase has 120° phase angle difference. Equation of each phase is given as:

$$e_a = K_e f(\theta_e) \omega \dots \dots \dots (7)$$

$$e_b = K_e f(\theta_e - 2\pi/3) \omega \dots \dots \dots (8)$$

$$e_c = K_e f(\theta_e + 2\pi/3) \omega \dots \dots \dots (9)$$

$$\theta_e = P/2 \cdot \theta_m \dots \dots \dots (10)$$

K_e is back EMF constant of one phase (V/rad/s), θ_e is electrical rotor angle (° el.), ω is rotor speed V(rad/s). θ_m is mechanical rotor angle (rad) and P is the number of poles.

Total torque output and torque equation are given:

$$T_e = \frac{e_a \cdot i_a + e_b \cdot i_b + e_c \cdot i_c}{\omega} \dots \dots \dots (11)$$

$$T_e - T_1 = J \frac{d\omega}{dt} + B \omega \dots \dots \dots (12)$$

Te is total torque output (Nm), Tl is load torque(Nm), J is inertia of rotor and coupled shaft(kgm²), B is friction constant(Nm/rad/s).

TABLE 5. BLDC MOTOR SPECIFICATIONS

Parameters	Value
Rated Power	1 kW
Rated Voltage	320 V
Rated Speed	1800 rpm
Phase Resistance	4.35 Ω
Phase Inductance	12.4 mH
Inertia	.002505 kgm ²
Damping Ratio	.0003035
No. Of Poles	8

V SELF TUNED PID USING PSOALGORITHM

PSO is a method for optimizing hard numerical functions on metaphor of social behavior of flocks of birds and schools of fish. The original PSO algorithm is discovered through simplified social model simulation. It was first designed to simulate birds seeking food which is defined as a cornfield vector. The bird would find food through social cooperation with other birds around it (within its neighborhood). It was then expanded to multidimensional search. In PSO each particle in swarm represents a solution to the problem and it is defined with its position and velocity. In D-dimensional search space, the position of the ith particle can be represented by a D- dimensional vector, xi = (xi1,..., xid, ..., xiD). The velocity of the particle vi can be represented by another D- dimensional vector vi = (vi1,..., vid, ..., viD). The best position previously visited by the ith particle is de- noted as pi=(pi1,...pid,...piD), and pg as the index of the particle visited the best position in the swarm, then pg becomes the best solution found so far, and the velocity of the particle and its new position will be determined according to the following two equa- tions, which a inertia weight w is added to [3]:

$$vid = wvid + c1r (pid-xid) + c2 R (pgd-xid) \quad \dots\dots(13)$$

$$xid = xid + vid \quad \dots\dots\dots\dots\dots(14)$$

Where c1 and c2 are positive constants, and r and R are two random functions in the range [0,1]; xi = (xi1, xi2,... , xiD) represents location of the ith particle; pi =(pi1, pi2, ..., piD) represents the best previous position (the position giving the best fitness value) of the ith particle; the symbol g represents the index of the best particle among all the particles in the population; vi = (vi1, vi2, ... , viD) represents the rate of the position change (velocity) for the ith particle [7]. The parameter w in formula (1) is inertia weight that increases the overall performance of PSO. It is reported that a larger value of w can favor higher ability for global search while lower value of w implies a higher ability for local research. To achieve a higher performance, we linearly decrease the value of inertia weight w over the generations to favor global research in initial generations and local research in the later generations. The linearly deceased value of inertia is according the following formula.

$$w = w_{max} - iter \cdot \frac{w_{max} - w_{min}}{iter_{max}} \quad (15)$$

Where intermix is the maximum of iteration in evolution process, wmax is maximum value of inertia weight, wmin is the minimum value of inertia weight, and iter is cur- rent value of iteration.

The process of optimization utilizing PSO is depicted as following:

1. Initialize a population of particles with random positions and velocities on D-dimensions in the problem space.

2. For each particle, evaluate the desired optimization fitness function in D variables.
3. Compare particle's fitness evaluation with its pbest. If current value is better than pbest, then set pbest equal to the current value, and pi equals to the current location xi in D-dimensional space.
4. Identify the particle in the neighborhood with the best success so far, and assign its index to the variable g. Change the velocity and position of the particle according to Equation (1) and (2).
5. Loop to step 2) until a criterion is met, usually a sufficiently good fitness or a maximum number of iterations.

(A) Online Self-Tuning of PID Controller

The framework of online parameter self-tuning system is depicted as Figure 1. In this framework the PSO optimization module complete the self-tuning of PID parameters with a microprocessor that achieves the optimum of PID parameters. These parameters are used to retune the PID controller in PID controller module.

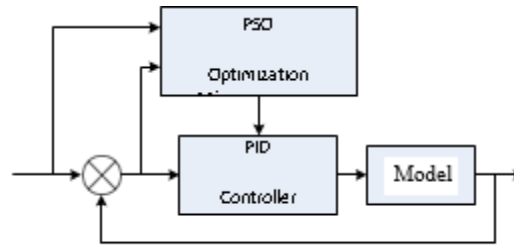


Figure 4. The framework of online self-tuning system

To seek the optimum parameters (K_p, K_i, K_d) of PID controller, PSO program should search in D-dimensional search space. The function optimization problem can be viewed as a 3-dimensional space in this project. That is tuning of PID controller parameters is to search optimization value in $K_p, K_i, K_d, the 3$ dimensions search spaces as shown in formula (4). With the optimized parameters based on PSO algorithm, the PID controller can achieve optimal properties.

$$X = \begin{bmatrix} K_1^0 & K_1^1 & K_1^2 \\ K_2^0 & K_2^1 & K_2^2 \\ \dots & \dots & \dots \\ K_3^0 & K_3^1 & K_3^2 \end{bmatrix} \quad (16)$$

There are two necessary problems to be tackled in the PSO parameters optimization: one is particle coding, namely particle expression, the other is fitness function choosing. Since the original PSO algorithm is designed for real-value problem, so PID parameters optimize problem is easily solved. As for fitness function choosing, there are several fitness function has been widely used in parameters optimization of PID controller. Suitable fitness function can be chosen according to the demand of the project. The much simpler one is shown as the following formula, and this one is used in Va run Agawam's re- search[6]. The feature of response will be discussed in next section of this paper.

$$J = \int_0^{\infty} e^2(t) dt \quad (17)$$

Another fitness function is time integration of square error as follow

$$J = \int_0^{\infty} te^2(t)dt \tag{18}$$

It seems simpler, yet it is hard to get the ideal time response too.

Another widely used fitness function is as,

$$J = \int_0^{\infty} (w_1 |e(t)| + w_2 u^2(t))dt \tag{19}$$

Where $e(t)$ is system error, $u(t)$ is the output of controller, the utilization of this item is to limited energy. While we find that the item has no dramatically effect on the performance compared to the case without this item. Coming next a new item is added to objective function, such as

$$J = \int_0^{\infty} [w_1 |e(t)|]dt + w_3 t_s \tag{20}$$

Where t_s is settling time of response, Using this item can decrease the settling time of response, and coefficient w_3 is also important for the smooth of the response curve.

To avoid overshoot of response, punishment of overshoot method is adopted. The punishment item is added to the fitness function.

$$\text{if } (e(t) > 0)$$

$$J = \int_0^{\infty} [w_1 |e(t)| + w_4 |e(t)|]dt + w_3 t_s \tag{21}$$

Where w_4 is much larger than w_1 ($w_4 \gg w_1$), the parameters choosing of w_1, w_3, w_4 is very important for the performance of optimization. Our experiment shows that carefully choosing w_3 and w_4 is very importing in engineering.

V PROPOSED SYSTEM

The proposed system consists of a solar PV array, a Luo converter and a BLDC motor. This is a drive that is suitable for high end white goods system. A schematic diagram is shown that depicts the overview of the system.

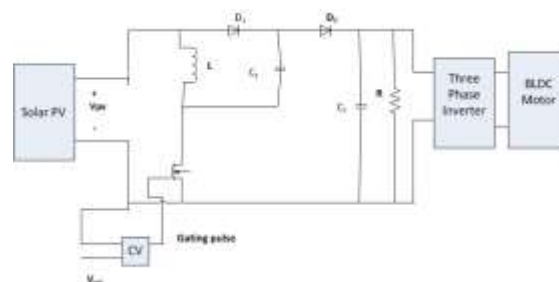


Fig.5. schematic diagram of proposed system

The solar PV array captures sunlight and converts it into electrical energy through photovoltaic. The output voltage of solar PV array is fed to the Luo converter where the voltage lifting takes place to the required rating of the BLDC motor. Since the atmospheric conditions are not the same all through the day, we need to use the maximum power point tracking. Constant Voltage method. Due to its simplicity and low cost, is used in which the reference voltage is compared with the PV output voltage to yield the duty ratio. The gating pulses to the Luo converter have this duty ratio.

The output voltage of the converter is fed to the BLDC motor. The output speed of the motor is used for the earlier stated applications.

VI SIMULATION RESULTS AND DISCUSSION

The system outputs the speed of 1500 rpm when simulated for which the design was done. The converter output voltage has been obtained at the required value. Output power is also obtained. The implementation of an online tracking mechanism can improve the present system. Fig.6 represents the MATLAB/SIMULINK model of the proposed BLDC motor with Luo Converter. In Fig. 7, the voltage output of the Luo converter shows an initial overshoot but settling fast response. The output current shows a peak value of 2.5 A and then settles at 1.6 A (Fig.9). The gating pulses provided by working out the CVMPPPT is shown in Fig.11 at 1000 W/m² solar irradiation. The duty ratio is set at 0.18 and the switching frequency is 10kHz. The simulation results are shown in the following figures.

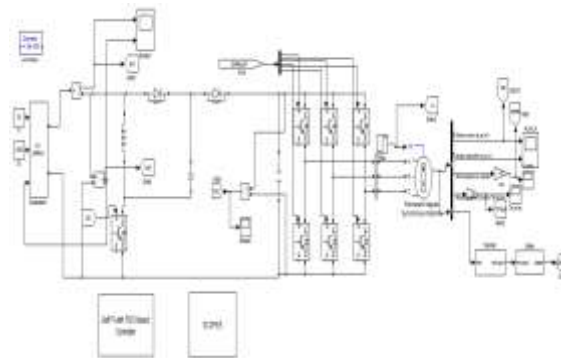


Fig 6 Matlab/Simulink model for proposed Luo converter based BLDC motor using self-tuned PID with PSO

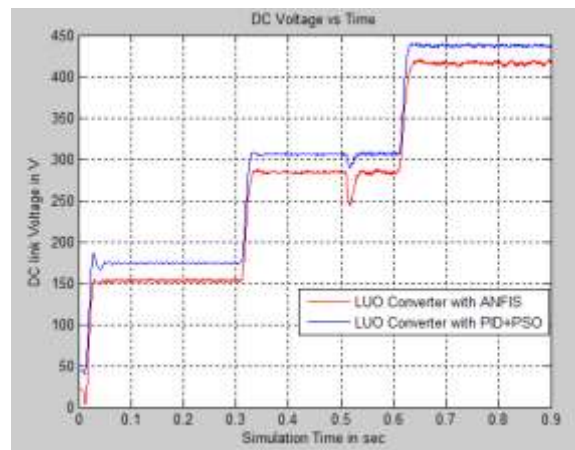


Fig 7 simulation waveform of the Luo Converter Output Voltage with Speed Variations from 500,1000 and 1500 rpm.

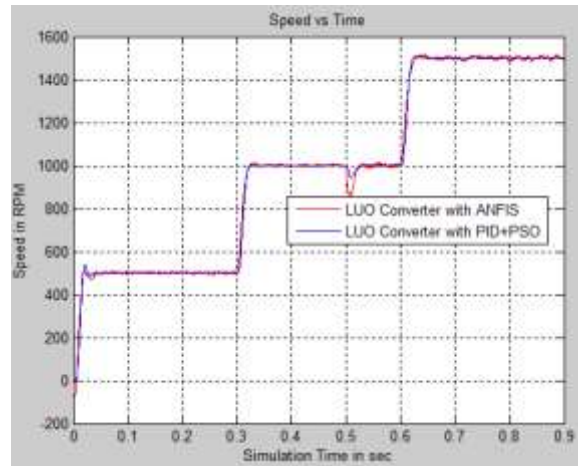


Fig 8 simulation waveform of BLDC motor Speed with Speed Variations from 500,1000 and 1500 rpm.

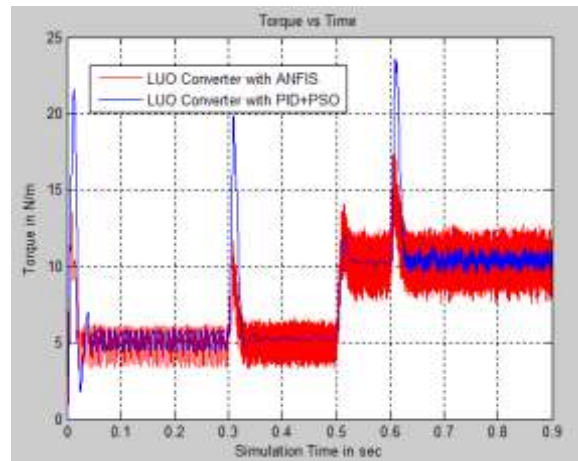


Fig 9 simulation waveform of BLDC motor Torque with Speed Variations from 500,1000 and 1500 rpm.

VII CONCLUSION

In this paper, PSO-based speed controller of BLDC Motor with Luo Converter has been developed, where PSO algorithm is used to find the appropriate PID controller parameters with considering the response speed of BLDC motor. According to the simulation result, it can be concluded that PSO algorithm can be used to find the PI parameters appropriate to the response speed designed and gives a good performance to control BLDC motor speed by reaching the reference speed with constant response speed having been designed. ANFIS control scheme is used for the speed control of Brushless motor. In braking modes of operation, instead of wasting kinetic energy it can be stored in a battery. The excess energy is effectively stored in the battery based on the mode of operation of the bidirectional converter. Simulation studies were conducted to evaluate the performance of ANFIS and PSO Controller logic based speed control method. The advantages of this proposed method are excellent in speed control, reduction of torque ripples and THD values. The proposed method results give better performance as compared with ANFIS.

REFERENCES

[1]. Lin, Chang-Hua, Hom-Wei Liu, and Chien-Ming Wang. "Design and implementation of a bi-directional power converter for electric bike with charging feature." Industrial Electronics and Applications(ICIEA), 2010 the 5th IEEE Conference on IEEE, 2010

- [2]. RajanKumar, Bhim Sing,—Buck Boost Converter Fed BLDC Motor Drive for Solar PV Array Based Water Pumping|IEEE International Conference on Power Electronics Drives and Energy System (PEDES).
- [3]. ArulmozhiyalR., "Design and implementation of fuzzyPID controller for BLDC motor using FPGA." Power Electronics Drives and Energy Systems (PEDES), 2012 IEEE International Conference on. IEEE, 2012.
- [4]. Gupta, Gaurav, and Prerna Gaur, "Fuzzy logic controlled power factor corrected bridgeless buck boost converter-fed brushless DC motor drive" Computer, Communication and Control(IC4),2015 International Conference on. IEEE, 2015
- [5]. Atul Kumar, Dr. Prerna Gaur, —Bidirectional DC/DC Converter for Hybrid Electric Vehicle| IEEE Transactions on Advances in Computing, Communications and Informatics (ICACCI),P.839-843,sep 2014
- [6]. JyhShing Roger Jang, —ANFIS: Adaptive Network Based Fuzzy Inference System|, IEEE Transactions on System, Man, And Cybernetics, Vol.23, No.3, Pp.665-685, 1993.
- [7]. Joice, C. Sheeba, and P. Nivedhitha, "Simulation of speed control of brushless dc motor, with fuzzy logic controller."2016 Online International Conference on Green Engineering and Technologies(IC-GET) International Journal of Electrical, Electronics and Data Communication, ISSN: 2320-2084.
- [8]. Kamal, Md Mustafa, Lini Mathew, and S.Chatterji, "Speed control of Brushless DC Motor using fuzzy based controllers."Electrical, Electronics and Computer Science (SCEECS), 2014IEEE Students' Conference on. IEEE, 2014.
- [9]. Awaze, Sneha K. "Four quadrant operation of BLDC motor in MATLAB/SIMULINK." Computational Intelligence and Communication Networks (CICN), 2013 5th International Conference on. IEEE, 2013
- [10]. Sreekala, P., and A. Sivasubramanian, "Speed control of brushless DC motor with PI and fuzzy logic controller using resonant pole inverter." Innovative Smart Grid Technologies-India (ISGT India), 2011 IEEE PES. IEEE, 2011
- [11]. Sriram, J., and K. Suresh kumar, "Speed control of BLDC motor using fuzzy logic controller based on senseless technique." Green Computing Communication and Electrical Engineering(ICGCCEE), International Conference on. IEEE, 2014.
- [12]. Blessy, M. S., and M. Murugan, "Modeling and controlling Of BLDC motor based fuzzy logic." Information Communication and Embedded Systems (ICICES), 2014 International Conference on. IEEE, 2014.
- [13]. Ananthababu.B. Dr Ganesh C. Pavithrac.v. —Fuzzy Based Speed Control Of BLDC Motor With Bidirectional DC-DC Converter|2016 online international conference on Green Engineering and Technologies (IC-GET)
- [14]. V.M.Varatharaju, B.L.Mathur, K.U.Udhayakumar —ANFIS Based Controllers and Modelling simulation of PMBLDC Motor and Drive System” Chennai and Dr.MGR University Second International Conference on Sustainable Energy and Intelligent System (SEISCON 2011).

References

- [15] Bhim Singh, Rajan Kumar, "Solar photovoltaic array fed water pump driven by brushless DC motor using L landsman converter," .IET Renewable Power Generation ,Volume: 10, Issue: 4, 4 2016
- [16] Ali F.Murtaza, Hadeed Ahmed Sher, Marcello Chiaberge, Diego Boero, Mirko De Giuseppe, Khaled E. Addoweesh, "Comparative Analysis of Maximum Power Point Tracking Techniques for PV applications," .16th International Multi Topic Conference (INMIC), 2013
- [17] Qiuxia Yang , Qi Wang , "An Improving Control Method of CTV +P&O on Photovoltaic Power Generation Maximum Power Point Tracking," Fifth International Conference on Intelligent Human-Machine Systems and Cybernetics, IEEE, 2013

- [18] Deepak, Rupendra Kumar Pachauri, Yogesh K.Chauhan,"Modeling and simulation analysis of PV fed Cuk, Sepic, Zeta and Luo DC-DC converter," International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), IEEE .2016
- [19] Rutuja A Bhat, Pallavi S. Jadhav,"Modeling and simulation of BLDC motor in electric power steering by using MATLAB," International Conference on Intelligent Systems and Control (ISCO), IEEE, 2016
- [20] M. Látková, M. Baherník, P. Bracíník, M. Höger,"Modelling of a dynamic cooperation between a PV array and DC boost converter", 5th International Youth Conference on Energy (IYCE), IEEE, 2015
- [21] Abhishek Kumar Gupta, Ravi Saxena, "Review on widely used MPPT Techniques for PV Applications," International Conference on Innovation and Challenges in Cyber Security (ICICCS-INBUSH), IEEE, 2016.
- [22] A. Tashakori, M. Ektesabi, and N. Hosseinzadeh, "Modeling of BLDC Motor with Ideal Back-EMF for Automotive Applications," Proceedings of the World Congress on Engineering Vol II WCE 2011,, London, U.K., 2011
- [23] Ming-Fa Tsai, Tran Phu Quy, Bo-Feng Wu, Chung-Shi Tseng, "Model Construction and Verification of a BLDC Motor Using MATLAB/SIMULINK and FPGA Control," 6th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2011
- [24] Balogh Tibor; Viliam Fedák; František Durovský, "Modeling and Simulation of the BLDC Motor in MATLAB GUI," IEEE International Symposium on Industrial Electronics, 2011 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI 2017) 1035.