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 PIDcontroller. 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 PIDcontroller 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) motorshave been widely used in many applications, such as industrialapplications, 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 inthree phase mode operation with no brushes, so it needs acontroller which is connected to the three phase stator windings. The controller is useful for changing the function ofcommutator by energizing the stator windings which areproper to the commutation step, so a BLDC motor can operatewell.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 PVmodules and panels. The performance of PVmodules and arrays are generally being ratedaccording to their maximum DC power output inwatts 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 notalways typically the theoretical values, PV modules and arrays operate in the field, where actual performance is usually 85 to 90 percent of the STCrating. 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 iscalled the maximum power point (MPP) and MPPTis 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 isnot always achieved [3]. There exist someimproved 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, ZetaandLuo DC-DC boost converters has been carried out [4] and is observed that the Luo DC-DCconverter is best in terms of transient response inthe among all DC-DC boost converters.The output of this converter is fed to the inverter ofthe 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 samepower output, they are also lighter [5]. BLDCmotors 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 thispaper 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, thatalso completely free of charge. The technology of converting this energy into electricity is calledphotovoltaic. The photovoltaic (PV) panels aremade of semiconductor materials. These modules provide a safe, reliable and maintenance free,environmentally friendly source of power for avery 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 doneusing the below mentioned equations[6]. Solar cellis fundamentally a pp-n junction diode. TheShockley equation is given by:

$$ID=IS[e(q*vD/KT) -1]........(1)$$

ID is the diode current, IS is the diode saturation current, vDis the diode voltage,q is the electron charge(1.6*10-19 C),K is the Boltzmann constant(1.38*10-23 J/K),T is the temperature dependence of IS. 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 Rs(internal resistance of cell) andthe shunt resistance Rsh.
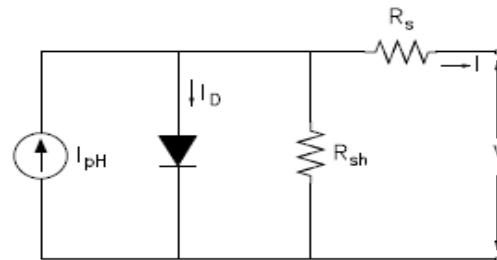

Fig.1.One diode model of pv cell

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

Inorder to produce enough power. The generalized equation for solar array with NP parallel and NSseries cells is:

$$I=NP*IPH-NP*IS[e((V/NS)+(I*RS/NP)/(K*T*A) – 1]...............(2)$$

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

$$V=NS[(K*T*A/q)log[((NP*IPH)-I/(NP*IS))+1]-(I*RS/NP)]$$
$$..................(3)$$

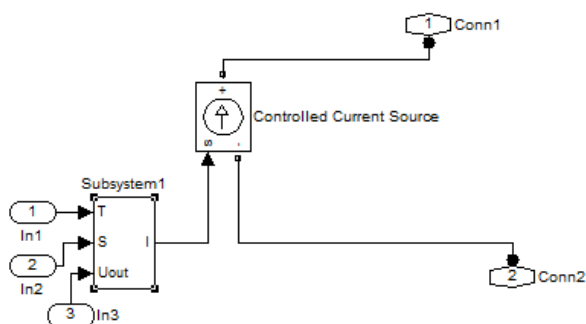The Simulink model of the solar PV array is shownin figure 2 :

Fig 2. Simulink model of a solar panel

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

Parameters	Value
Maximum Power, Pmax	100 W
Voltage at MPP, Vmpp	19.06 V
Current at MPP, Impp	5.25 A
Module Open Circuit Voltage, Voc	22.4 V
Module Short Circuit current, Isc	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].
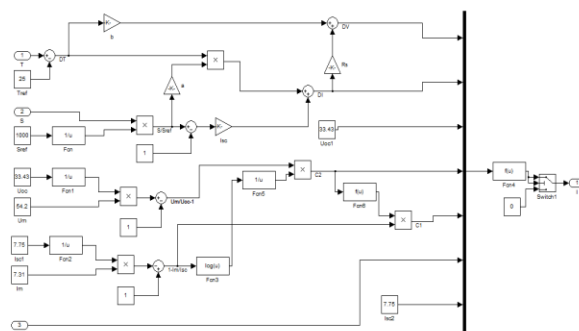

Fig 3.constant voltage mppt

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. Luoconverters have low switching losses and highest efficiency the among the other DC-DCconverters. 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. Thevalues of the elements of the Luo converter isdesigned by considering the ON/OFF switching periods.

TABLE 3.DESIGN VALUES OF LUO CONVERTER

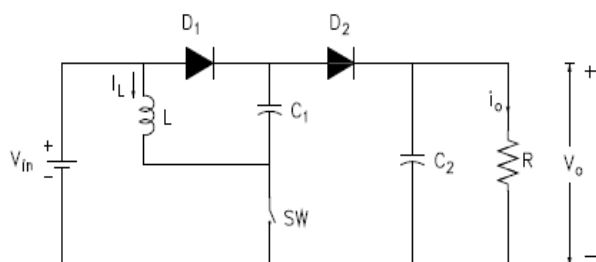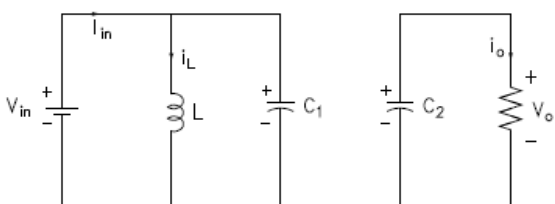| Parameters	Value
Input Voltage,Vin	144 V
Output Voltage,Vo	320 v
Duty Ratio	.18
Inductor, L	8.64mH
Capacitors, C1=C2	524μF
Load resistance	50 Ω
Switching Frequency	10 kHz

Fig 4.classical luo converter
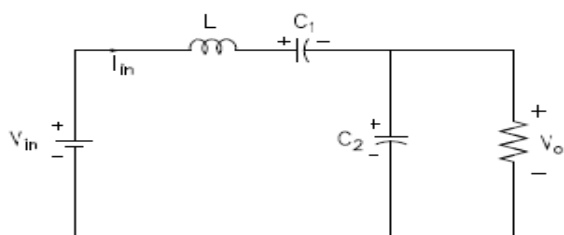

Fig.5.luo converter with switch closed

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 theBLDC motor is expressed as follows[9][10]:

$$Va=R*ia+L(dia/dt)+ea...............(4)$$
$$Vb=R*ib+L(dib/dt)+eb...............(5)$$
$$Vc=R*ic+L(dic/dt)+ec...............(6)$$

L is armature self-inductance (H), R is armature resistance (Ω), Va, V b, V c are terminal phase voltages (V), ia, ib, icaremotor input currents (A) and ea, eb, ecaremotor back -EMFs(V).The back-EMF is related as a function of rotor position [8] and the back-EMF of each phase has120º phase angle difference. Equation of each phase is given as:

$$ea=Kef(\theta e) \omega...........(7)$$
$$ea=Kef(\theta e-2\pi/3) \omega...........(8)$$
$$ea=Kef(\theta e+2\pi/3) \omega ....(9)$$
$$\theta e=P/2* \theta m. ....(10)$$

Keis back EMF constant of one phase (V/rad/s), θeis electrical rotor angle (° el.), ω is rotor speedV(rad/s). θmis mechanical rotor angle (rad) and P isthe number of poles.
Total torque output and torque equation are given:

$$T_e= \frac{e_a*i_a+e_b*i_b+e_c*i_c}{w}$$

(11)

$$T_e\text{-}T_1= J\frac{d\omega}{dt} + B \omega$$

(12)

Teis total torque output (Nm), Tlis 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]:

$$vid = wvid + c1r\ (pid\text{-}xid) + c2\ R\ (pgd\text{-}xid) \quad ……(13)$$

$$xid = xid + vid \quad …………...(14)$$

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, wminis 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 equalto 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 sys- tem 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.
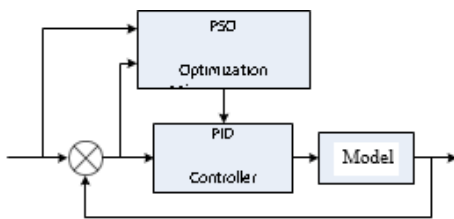

Figure 4. The framework of online self-tuning system

Toseektheoptimumparameters(Kp,Ki,Kd)o fPID 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 parametersistosearchoptimizationvaluein$K$

p, *Ki*,*Kd,the3* dimensions search spaces as shown in formula (4).With the optimized parameters based on PSO algorithm, the PID controller can achieve optimal properties.

$$X = \begin{bmatrix} K_1^0 & K_1^1 & K_1^2 \\ K_2^0 & K_2^1 & K_2^2 \\ ... & ... & ... \\ K_3^0 & K_3^1 & K_3^2 \end{bmatrix}$$ (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 functionchoosing.SincetheoriginalPS Oalgorithmis designed for real-value problem, so PID parameters optimize problem is easily solved. As for fitness functionchoosing,thereareseveralfitne ssfunctionhasbeen widely used in parameters optimization of PID controller. Suitable fitness function can be chosen ac- cording to the demand of the project. The much simpler one is shown as the following formula, and this one is used in Varun Agawam's re-search[6].Thefeatureofresponsewillbe discussedin next section of thispaper.

$$J = \int_0^\infty e^2\left(t\right)dt$$ (17)

Another fitness function is time integration of square error as follow

$$J = \int_0^\infty te^2\left(t\right)dt$$ (18)

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

Another widely used fitness function is as,

$$J = \int_0^\infty \left(w_1 |e(t)| + w_2 u^2(t) \right) dt$$

(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

$$J = \int_0^\infty \left[w_1 |e(t)| \right] dt + w_3 t_s$$

(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.

$$if \ (e(t) > 0)$$

$$J = \int_0^\infty \left[w_1 |e(t)| + w_4 |e(t)| \right] dt + w_3 t_s$$

(21)

Where w_4 is much larger than w_1 ($w_4 >> w_1$), 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, aLuo converter and a BLDC motor. This is a drive that is suitable for high end white goods system. Aschematic diagram is shown that depicts the overview of the system.
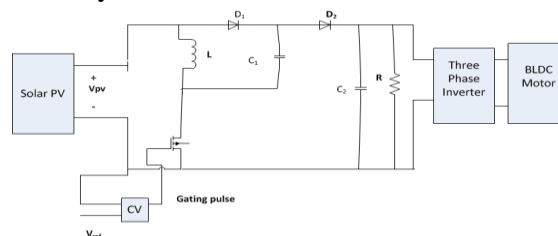

Fig.5. schematic diagram of proposed system

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 Luoconverter where the voltage lifting takes place tothe required rating of the BLDC motor. Since theatmospheric 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 totheLuo 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 ANDDISCUSSION

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 mechanismcan improve the present system.Fig.6 represents theMATLAB/SIMULINK model of the proposed BLDC motor with Luo Converter. In Fig. 7, the voltage output of the Luoconverter shows an initial overshoot but settling fast response. The output current shows a peak valueof 2.5 A and then settles at 1.6A(Fig.9).The gating pulses provided by working out the CVMPPT is shown in Fig.11 at 1000 W/m2 solarirradiation.The duty ratio is set at 0.18 and the switching frequency is 10kHz.The simulation results are shown in the followingfigures.
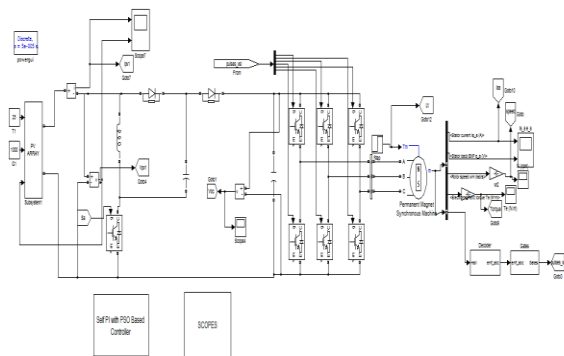

Fig 6 Matlab/Simulink model for proposed Luo converter based BLDC motor using self-tuned PID with PSO
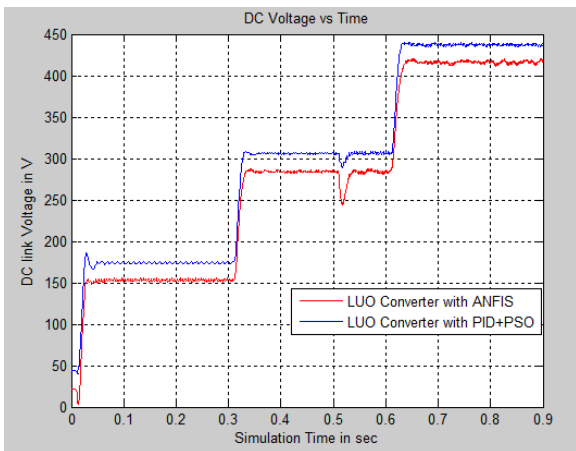

Fig 7 simulation waveform of the Luo

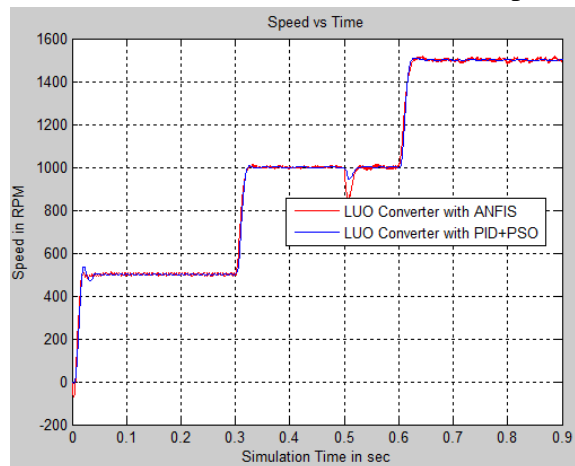Converter Output Voltage with Speed Variations from 500,1000 and 1500 rpm.

Fig 8 simulation waveform of BLDC motor Speed with Speed Variations from 500,1000 and 1500 rpm.
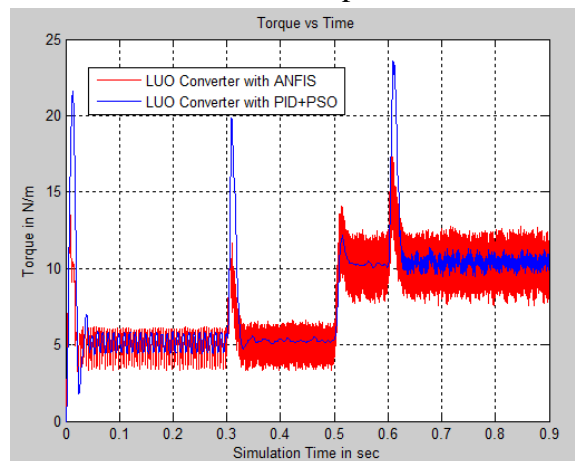
Fig 9 simulation waveform of BLDC motor Torque with Speed Variations from 500,1000 and 1500 rpm.

VII CONCLUSION

In this paper, PSO-based speed controller of BLDC Motor with Luo Converter has been developed, wherePSO algorithm is used to find the appropriate PIDcontroller parameters with considering the response speed of BLDCmotor. 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 inspeed 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 BLDCMotor Drive for Solar PV Array Based Water Pumping‖IEEEInternational Conference on Power Electronics DrivesandEnergy System (PEDES).

[3]. ArulmozhiyalR.,"Design and implementation of fuzzyPID controller for BLDC motor using FPGA." Power ElectronicsDrives and Energy Systems (PEDES), 2012 IEEEInternationalConference on. IEEE, 2012.

[4]. Gupta, Gaurav, and PrernaGaur,"Fuzzy logic controlledpowerfactor corrected bridgeless buck boost converter-fedbrushlessDC motor drive"Computer, Communication and Control(IC4),2015 International Conference on. IEEE, 2015

[5]. Atul Kumar, Dr. Prerna Gaur, ―Bidirectional DC/DC ConverterforHybrid Electric Vehicle‖ IEEE Transactions on AdvancesinComputing, Communications and Informatics (ICACCI),P.P839-843,sep 2014

[6]. JyhShing Roger Jang, ―ANFIS: Adaptive Network Based Fuzzy Inference System‖, IEEE Transactions on System, Man, AndCybernetics, 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 andDataCommunication, ISSN: 2320-2084.

[8]. Kamal, Md Mustafa, Lini Mathew, and S.Chatterji,"Speedcontrolof 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 motorinMATLAB/SIMULINK." Computational IntelligenceandCommunication Networks (CICN), 2013 5thInternationalConference on. IEEE, 2013

[10]. Sreekala, P., and A. Sivasubramanian,"Speed control ofbrushless DC motor with PI and fuzzy logic controller using resonantpoleinverter."Innovative Smart Grid Technologies-India (ISGT India),2011 IEEE PES. IEEE, 2011

[11]. Sriram, J., and K. Sureshkumar,"Speed control of BLDCmotorusing 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 controllingOf BLDC motor based fuzzy logic." Information CommunicationandEmbedded Systems (ICICES), 2014 InternationalConferenceon.IEEE, 2014.

[13]. Ananthababu.B. Dr Ganesh C. Pavithrac.v. ―Fuzzy Based SpeedControl 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 andDriveSystem"Chennai and Dr.MGRUniversity Second International Conference on Sustainable Energy and IntelligentSystem (SEISCON 2011).

References

[15] Bhim Singh, RajanKumar,"Solarphotovoltaic array fedwater pump driven by brushless DC motor usingL landsman converter,".IET Renewable Power Generation ,Volume: 10, Issue: 4, 4 2016

[16]   Ali   F.Murtaza,   Hadeed   Ahmed
        Sher,MarcelloChiaberge,DiegoBoero,Mirko   De
        Giuseppe, Khaled E. Addoweesh,"Comparative
        Analysis   of   Maximum   Power   Point
        TrackingTechniques   for   PV   applications,".16th
        International MultiTopic Conference (INMIC), 2013

[17] QiuxiaYang , Qi Wang ,"An Improving Control
     Method ofCTV +P&O on Photovoltaic Power
     Generation MaximumPower Point Tracking," Fifth
     International Conference onIntelligent Human-
     Machine Systems andCybernetics,IEEE,2013

[18]   Deepak,   Rupendra   Kumar   Pachauri,
        YogeshK.Chauhan,"Modeling   and   simulation
        analysis of PV fed Cuk,Sepic, Zeta and Luo DC-DC
        converter,"   InternationalConference   on   Power
        Electronics, Intelligent Control andEnergy Systems
        (ICPEICES),IEEE .2016

[19] Rutuja A Bhat, Pallavi S. Jadhav,"Modeling and
     simulationof 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. Braciník, M.
     Höger,"Modellingof a dynamic cooperation between
     a PV array and DC boostconverter", 5th International
     Youth Conference on Energy(IYCE), IEEE, 2015

[21] Abhishek Kumar Gupta, Ravi Saxena, "Review on
     widelyusedMPPT Techniques for PV Applications,"
     InternationalConference   on   Innovation   and
     Challenges in Cyber Security(ICICCS-INBUSH),
     IEEE,2016.

[22]A.   Tashakori,   ,   M.   Ektesabi,   and   N.
     Hosseinzadeh,"Modelingof BLDC Motor with Ideal
     Back-EMF   for   AutomotiveApplications,"
     Proceedings of the World Congress onEngineering
     Vol II WCE 2011,, London, U.K., 2011

[23] Ming-Fa Tsai, Tran PhuQuy, Bo-Feng Wu, Chung-Shi
     Tseng ,"Model Construction and Verification of a
     BLDC MotorUsing MATLAB/SIMULINK and
     FPGA Control," 6th IEEEConference on Industrial
     Electronics and Applications (ICIEA),2011

[24]   BaloghTibor;   ViliamFedák;
     FrantišekDurovský,"Modeling and Simulation of the
     BLDC Motor in MATLABGUI," IEEE International
     Symposium   on   IndustrialElectronics,2011IEEE
     International Conference on Power, Control, Signals
     and   Instrumentation   Engineering   (ICPCSI
     2017)1035.