BLDC Motor Control For EVs Using Cuckoo Search Algorithm In PI Controller Tunning

Arul P[1][a], Ananda M.H[2][b], Dhamodharan Selvaraj[2][c] and Dhanalakshmi R[3][d]

[1] *Electrical and Electronics Engineering Department, Kongunadu College of Engineering and Technology , Tamil Nadu, India.*

[2] *School of Electrical and Electronics Engineering, REVA University, India*

[3] *Department of Electrical and Electronics Engineering, Dayananda sagar college of engineering, Bangalore, India*

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Abstract: electric vehicles (EV) are the present and future technology to overcome the environment problems created by the traditional fossil fuel-based engines. Compact, high torque machines are needed for changing the future of vehicles. The Brushless DC Motors (BLDC) are ones which satisfies the requirement. The BLDC motor speed control is creating more importance in EV industry as it is used in many applications now-a-days. Optimal control of BLDC motor is much need to make the EV more efficient and less consuming ones. DTC control has a PI controller to produce proportional torque reference. If the PI controller parameters like K_P and K_i values are changed arbitrarily the torque ripple and settling time of speed are changing. So, there is numerous combinations of K_p and K_i parameters are available. In this paper the problem is defined with multi-objective. Identification of Kp and Ki parameters is done by minimizing toque ripple and settling time. The objective function is solved by cuckoo search algorithm and results are discussed and compared with manual tuning of PI controller, PSO based PI tuning and CSA based tuning.

1 INTRODUCTION

Many concepts are discussing about torque ripple minimization of Direct Torque Control (DTC) of Brushless DC Motor (BLDC) by changing the switching pattern of pulse width. In 2004, ripple in the torque is identified due to BLDC motor power circuit commutation (Song & Choy, 2004). In 2005 torque ripple is reduced due to implementation of space vector change (Liu et al., 2005). In 2010 stator current improvement and torque ripple reduction is implemented using model predictive control (Li & Cheng, 2010). In 2015, by implementing DTC control to BLDC motor torque ripple is reduced (Mahalingam & Ramji, 2022). In 2012, a new PWM scheme is proposed to eliminated the torque ripple caused due to commutation by using the non-ideal back EMF (Devi et al., 2017) is implemented. Using multilevel inverter and a current controller an attempt made to minimize the torque ripple (Mahalingam & Ramji, 2022) In 2017 repetitivecontrol is used to minimize the torque ripple (Devi et al., 2017) and by using adaptive input-output feedback linearization also a literature is proposed (Fang et al., 2012)

Speed response improvement of BLDC motor is made in many attempts. In 2016, fuzzy PID controller is used to improve the speed response (Varshney et al., 2017). And with only fuzzy implementation also done for improving speed response (Geetha & Thangavel, 2016)

Fig. 1 presents an idea for the control of speed in electric vehicles. The direct torque control (DTC), which was initially created for the control of induction motor drives in which direct control of flux and electromagnetic torque was attempted, evolved as a solution to these challenges. DTC was initially developed for the control of induction motor drives. It made use of the estimated flux and electromagnetic torque to determine optimal inverter switching, which enabled it to acquire quick response times. Because of the non-sinusoidal back-EMF, the DTC of a BLDC motor is different from that of an induction motor and

[a] https://orcid.org/0000-0002-5927-6023
[b] https://orcid.org/0000-0001-6026-3708
[c] https://orcid.org/0000-0001-5946-2427
[d] https://orcid.org/0000-0002-3317-6673

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a PMSM motor. In order to lessen the effects of torque ripple, the hybrid conduction mode was

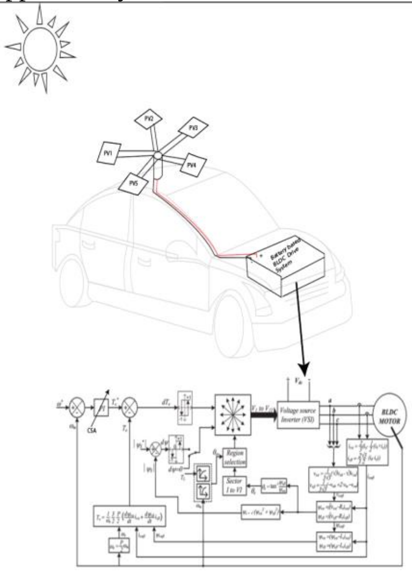

Figure.1 Proposed Block Diagram of the System.

developed on the basis of the features of BLDC. It is essential that the estimated torque be correct in order to achieve direct control of the torque. In this article, we will discuss the direct self-controlled approach for BLDC that makes use of stator flux linkage reference with three phase conduction. The rounding effect in phase back-EMF is one of the causes for the creation of torque ripple, and the back-EMF is derived by making use of shape functions in order to estimate torque.

The hybrid PSO-IC algorithm for grid connected PV power system with EV battery is introduced for charging the EV vehicle (Ahmed et al., 2020). And for roof top photovoltaic controlled with new hybrid optimization technique also proposed for battery charging purposes (Selvaraj & Rangasamy, 2022),.

This paper made an attempt to reduce the torque ripple and minimization of speed settling time. Multi-objective problem is formulated in this paper and the PI controller output is controlled by changing the K_p and K_i parameter. Here cuckoo search algorithm is used to compare the performance after and before optimization.

2 PROBLEM IDENTIFICATION

In order to manage the torque that the motor produces, the DTC control utilizes a speed control loop that is equipped with a PI controller. This loop produces a proportional torque value that is used as an electromagnetic torque reference. It can be understood by considering the following:

$$N_{error} = N^* - N \quad (1)$$

When applied to PI controller it can be defined as

$$T_e = (K_p + \int_{T_{e,min}}^{T_{e,max}} K_i) * N_{error} \quad (2)$$

Therefore, the outcomes of the torque measurements are entirely dependent on the Kp and Ki values that the PI controller uses. The ripples in the torque can be adjusted by making adjustments to the values of the PI controller. Therefore, it is formulated as an equation for discrete optimization, with settling time functioning as an additional target. Therefore, the problem is stated as the minimizing of torque and settling time of speed of the DTC control, and this is accomplished by taking into consideration an arbitrary limit for the values of Kp and Ki.

3 OBJECTIVE FUNCTION

Torque ripple is a key factor that can easily be the cause of vibration in permanent magnet motors as well as mechanical noise. Torque ripple has a negative impact on the control precision of BLDC speed control systems since it is a big factor. The dependability of the motor may be jeopardized as a direct outcome of the situation, particularly in the event that the issue is severe. Continuous application of the motor torque is required in virtually every circumstance. Suppressing ripple in the torque output is a necessary step in the development of a high-precision permanent magnet motor, which is why this step is included in the design process. The oscillations in the motor's torque, as well as the amount of time it takes for those oscillations to settle, are shown as,

$$F = \min \left\{ \sum_{t=0}^{N} \left(\frac{T_e(t)}{N} \right) \alpha + T_s \beta \right\} \ldots . (3)$$

$T_e(t) - electromechanical\ torque\ at\ sample\ t$

$N - total\ number\ of\ sample$

$T_s - speed\ settling\ time\ in\ sec$

$\alpha, \beta - weight\ values\ for\ multi\ objective\ function$

Constraints:

$$K_{p,min} < K_p < K_{p,max} \quad \ldots .(4)$$

$$K_{i,min} < K_i < K_{i,max} \quad \ldots . (5)$$

4 CUCKOO SEARCH ALGORITHM BASED PI TUNING

Xin-She Yang is responsible for the development of the mathematical model of the cuckoo algorithm (CS). There is a class of algorithms known as "nature inspired algorithms," and the cuckoo method is a member of that class. The approach was devised as a result of the observation of the cuckoo's mating behavior, which served as its inspiration.

Here the host nests are the Kp and Ki parameters. The objective is the torque ripple and speed settling time.

Procedure of CSA is given below

Step 1. Initialize N host nests (K_P & K_i) Xi (i= 1, 2,..n) and maximum number of iteration.

Step 2. (minimization of eq(3)) or cost function (Fi) is evaluated. Cuckoo is selected random basis with levy flights algorithm.

Step 3. Choose a nest among N nests and name it as (j).

Step 4. Check old solution is less than new one and replace j by new solution.

Step 5. Best nest(solutions) are saved.

Step 6. Rank the solutions and find the current best.

Step 7. Do this for all the iterations

Step 8. Display the results.

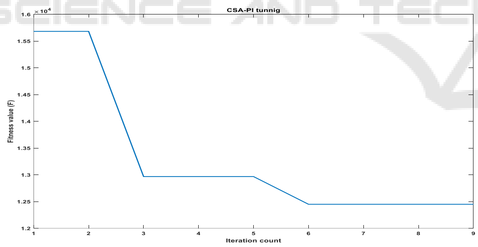

Figure.2 Cuckoo search algorithm convergence graph

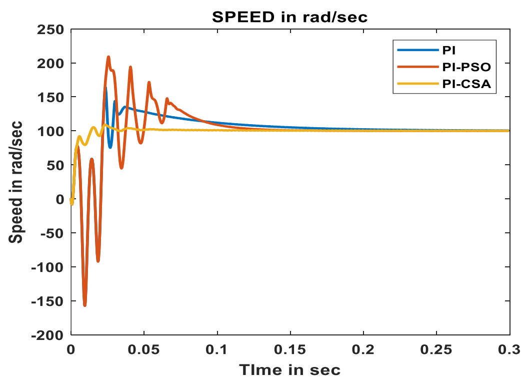

Figure.3 Speed graph of PSO-PI, CSA-PI and manual tuned PI controller (PSO settling time is .12 sec; CSA settling time is 0.0454sec; PI setting time is .25 sec)

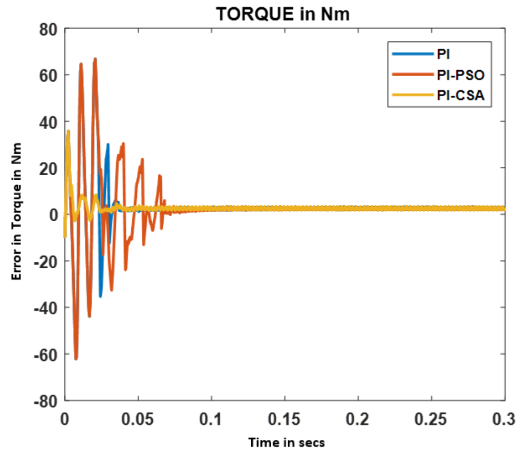

Figure.4 Error torque of PSO-PI, CSA-PI and Manual tuned PI controller (PSO-PI maximum torque ripple is 68 Nm; CSA-PI maximum torque ripple is 35Nm; PI maximum torque ripple is 68Nm)

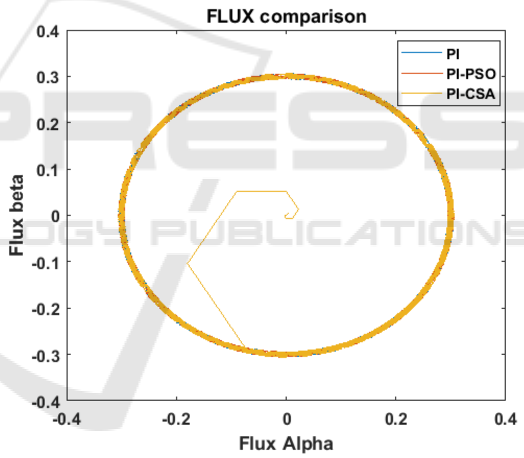

Figure.5 Flux wave of PSO-PI, CSA-PI and manual tuned PI (saffron is PI controller and blue is CSA-PI – where saffron is visible and Blue is less visible)

5 DISCUSSIONS

Fig.2 shows the Cuckoo search algorithm convergence graph where the fitness function is reducing n every iteration. Fig.3 shows Speed graph of PSO-PI, CSA-PI and manual tuned PI controller. Here PSO settling time reaches 0.12 sec. CSA settling time is 0.0454sec; PI setting time is .25 sec. Fig.4 shows Torque of PSO-PI, CSA-PI and Manual tuned PI controller. Here PSO-PI maximum torque ripple is 65 Nm. CSA-PI maximum torque ripple is 35Nm; PI maximum torque ripple is 68Nm. Fig.5 shows Flux wave of PSO-PI, CSA-PI and manual tuned PI. Here also saffron is PI controller and blue is CSA-PI – where yellow is visible and Blue (PI) magenta (PSO-PI) is less visible. The identified in PSO is Kp=18 and Ki = 49. CSA is $K_p = 2$ and $K_i = 17$.

Table 2: Comparison table

	Torque Ripple in Nm	**Setting time in sec**
PSO-PI	65	0.12
CSA-PI	35	0.0454
Manual tuning of PI	68	0.25
% of improved	48.52	81.84

Table 2: BLDC motor parameters

Parameters	**Values**
Stator phase resistance Rs (ohms)	1.3
Armature inductance (H)	0.00085
Flux linkage (V.s)	0.175
Inertia (J(Kg.m^2)	0.0008
Viscous damping F(N.m.s)	$1.349X10^{-5}$
Pole pairs	4
Torque in Nm	60
Speed in rad/sec	150rad/sec

6 CONCLUSIONS

The BLDC motor is modeled and the DTC control is applied to control the speed and torque. Then the PI controller parameters like K_P and K_i are optimized by multi-objective for minimization of torque ripple and settling time. Solution algorithm proves the better results. It is tabulated in table I. The CSA based PI controller performs better in both speed settling time and torque ripple minimization.

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