Gray Wolf Optimization Based Torque Ripple Reduction & Speed Control of SRM Drive for Industrial Applications

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Abstract

In this manuscript, speed as well as current controlling technique for lowering the SRM torque ripple is proposed. The rigorous SRM conduct has been examined over the aspects like torque, speed as well as current. Depending on aspects, the speed of motor has been lowered and regulated the ripples of torque. Later, control-signal has been produced in order to control SRM speed. Therefore, we have projected an augmented speed & controlling the current with the model of PWM for reducing the ripples of torque. The current optimization model depending on torque and current control strategy has been projected in order to control the SRM speed. Moreover, GWO (Gray-wolf-optimization) algorithm relied controller has been used for examining the SRM torque & speed. Ultimately, the projected strategy has been applied in domain of Simulink/MATLAB. Proposed model performance analysis has been contrasted and demonstrated with current strategies like ANFIS & ANN algorithm strategies.

Keywords: SRM, SRMD (switched reluctance motor drive), gray wolf optimization (GWO), torque, current & speed.

1. Introduction

In order flourish productivity EDs (Electrical Drives) estimates critical component in robotization mechanically, the needs of EDs rely on prominent and qualities aimed at new implementations as stated in [1] contribution. Over rapid requirements EDs were considered to be a prominent part utilized mechanically towards such kind of applications. The SRMD has taken more investigation. Single option has been reason behind PMBLMD (Permanent-magnet-brushless-motor-drives), electrically & mechanically more tighter than conventional DC & AC engines such as SM (synchronous-motors) and IM (induction motors) as in [2-5] works. The SRMDs has been used to be mechanical robotization part & utilized in implementations such as electric-vehicles, cross-breed, aeronautical, power-plant applications and many more as stated in [6] contribution.

The fundamental architecture, cheap gathering & unwavering ability quality, maximum freedom level among phases, low dormancy as well as short turn end with capability of working in environment such as coal-mining by an extensive speed were the real situations in the SRMDs as stated in [7-10]. Overall, SRMD runs on variable standard hesitance were been remarkable doubly post-machine as in [11] contribution.

Rotor fondness is to attain the location has been a source signifies for torque generation, where flux and inductance delivered through empowered winding have been a effort as in contribution [12] [13]. Moreover, in the SRMD their inductance phase has been a winding capacity rotor and current [14]. Over ideal phase excitation, the structure of control needs information regarding the position of rotor.
Furthermore, in this manuscript, the significant drawbacks of SRM that has their maximum ripples of torque has been tackled. In this manuscript, the intent is to increase the torque ripples (TR) of SRM by regulating their firing angles of converter. SRM has been non-linear highly and further it has been intricate for using their mathematical-equations in order to relate their performance as well as aspects directly. Hence, independent approaches have been preferred generally for motor controlling. This manuscripts adopts RSM (request surface model) for attaining approximate function, which associates TR of SRM and their firing angles of converter, turn-off & turn-on angles. Moreover, RSM has been a appropriate model for SRM as it utilizes data of system for coming up by polynomial equation, which associates the response of system and aspects, & there has been no requirement aimed at system mathematical approaches for implementing this model effectively as in [17]. Also, achieved equation has been optimized by utilizing an algorithm called GWO for achieving the optimal firing angles of SRM converter combination that assists in attaining the minimal probable motor TRs.

2. Problem Formation

Below aspects have been selected depending on knowledge of the system. Range of angle of turn-on has been [40-60] [θ_{onmin}=40, θ_{onavg}=50, θ_{onmax}=60], θ_{onavg}= (θon_{min}+ θon_{max})/2. Identically, angle range of turn-off has been (77-85) [$\theta_{of\ fmin}$=77, $\theta_{of\ favg}$=81, $\theta_{of\ fmax}$=85], $\theta_{of\ favg}$= ($\theta_{of\ fmin}$+ $\theta_{of\ fmax}$)/2. Entire angles have been measured in terms of degrees. Furthermore, Y has been torque of peak-peak & their has been attained from experimentation ($Y = T_{max} - T_{min}$ over the steady-state). Besides, it has been called to be response of system. Angles of firing were the only modified aspects & other simulation aspect; runs of simulation have been given in below tab 1.

Table I. Simulation Table

Runs	x_1 (θ_{on})	x_2 (θ_{off})	Y
1	θ_{onmin}=40	θ_{offmin}=77	3.15
2	θ_{onavg}=50	θ_{offmin}=77	3.40
3	θ_{onmax}=60	θ_{offmin}=77	4.09
4	θ_{onmin}=40	θ_{offavg}=81	1.79
5	θ_{onavg}=50	θ_{offavg}=81	1.91
6	θ_{onmax}=60	θ_{offavg}=81	3.72
7	θ_{onmin}=40	θ_{offmax}=85	1.22
8	θ_{onavg}=50	θ_{offmax}=85	1.15
9	θ_{onmax}=60	θ_{offmax}=85	3.47

Table of simulation would be utilized for generating the predicted regression equation system. Corresponding equation would be utilized to be objective function aimed at optimization issue.

3. SRM Modeling & Control

Utilization of irregular or uneven bridge converter has been common model to regulate SRM. In the fig1, it exhibits the circuit of asymmetric converter of half-bridge. Moreover, this converter is having 2 semi-conductor switches generally IGBT (insulated-gate bipolar-transistor) in series by every phase winding for energizing them.

Current has been circulated in every winding phase when 2 switches have been closed. RSM for 2 variables has been utilized in this manuscript, where turn-off & turn-on angles were 2 variables. Corresponding regression equation has been a function that would be simplified as in [11]. Moreover, the process of projected model is in the following way:

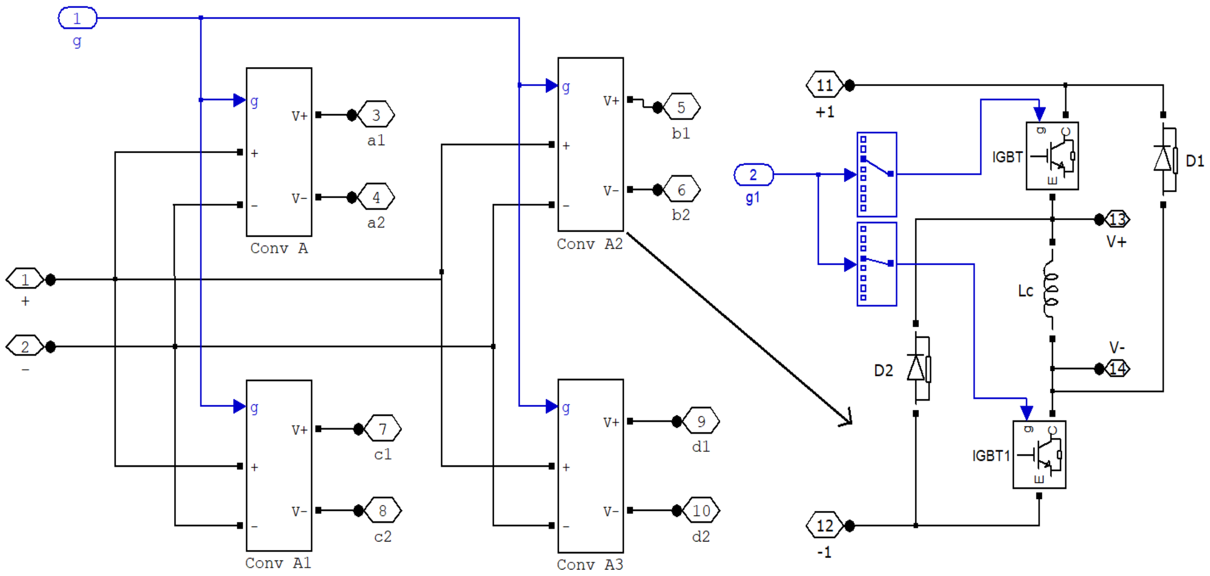

Fig. 1; Asymmetric Half Bridge Converter

1. Determine the issue & range of firing angles.
2. Construct simulation table depending on diversified firing angles mixture & record the outcomes of torque ripples.
3. Apply RMS aimed at simulation table & attain the system method or objective-function.
4. Implement optimization model on method & utilize the corresponding firing-angles for attaining minimal torque ripples of SRM. Optimization has been done offline in environment of simulation & then angles of firing have been fed into controller in real-time. Moreover, fixed current-control & conditions of no-load have been followed in experimentation.

4. Mathematical Model of Wolf Pack Hunting

The mathematical model of the GWO algorithm was developed on the basis of the observation of hunting techniques used by wolfs. Wolves can hunt alone, in pairs or in packs. In case of hunting in pack, the group of wolves uses various tactics to confuse their victim [6].

In the numerical implementation of the wolves pack behavior, the discrete positions of all individuals are determined in successive time step (iterations). The vector of position for the i-th wolf in the k-th time step is determined in the algorithm according to formulae:

$$\mathbf{X}_k^i = \mathbf{X}_{k-1}^p - A_k \left| C_k \mathbf{X}_{k-1}^p - \mathbf{X}_{k-1}^i \right| \qquad (1)$$

where A^k and C^k are the coefficients of the GWO algorithm, $X^p{}_{k-1}$ is the position of the prey (optimal point). The parameters A^k and C^k are calculated as follows [7]:

$$A_k = 2a_k r_1,\ C_k = 2r_2 \qquad (2)$$

where r_1 and r_2 is random numbers from range (0, 1), a_k is the coefficient which determine the ability of wolves to migration in the area of optimization task. In successive iterations coefficient a_k is decrease. On the basis of hunting techniques used by wolves, it is assumed that the optimal point is located between the best individuals (α, β and δ) in the pack. Therefore, to determine the vector of position for each i-th individual in k-th time step, the following formula1 is used:

$$\mathbf{X}_k^i = \frac{\mathbf{X}_1 + \mathbf{X}_2 + \mathbf{X}_3}{3} \qquad (3)$$

Where

$$\begin{cases} \mathbf{X}_1 = \mathbf{X}_{k-1}^{\alpha} - A_k^{\alpha} \left| C_1 \mathbf{X}_{k-1}^{\alpha} - \mathbf{X}_{k-1}^i \right| \\ \mathbf{X}_2 = \mathbf{X}_{k-1}^{\beta} - A_k^{\beta} \left| C_2 \mathbf{X}_{k-1}^{\beta} - \mathbf{X}_{k-1}^i \right| \\ \mathbf{X}_3 = \mathbf{X}_{k-1}^{\delta} - A_k^{\delta} \left| C_3 \mathbf{X}_{k-1}^{\delta} - \mathbf{X}_{k-1}^i \right| \end{cases} \qquad (4)$$

in which: $X^{\alpha}{}_{k-1}$, $X^{\beta}{}_{k-1}$ and $X^{\delta}{}_{k-1}$ are the vectors of positions of the individuals α, β and δ gamma in previous time step.

5. Introduction to GWO Control System

Furthermore, in this segment, inspiration of projected model has been primarily explored. Later, mathematical approach has been given.

GW (Grey-Wolf) belongs for candidate-family. GW have been considered to be apex predators, meaning, which they were at food chain top. Mainly, GW suitably for living in pack. Also, the size of group has been an average of 5-12. In fig-2, they are having crucial social dominant architecture as exhibited.

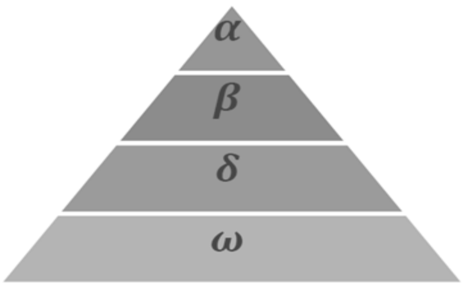

Fig. 2; Hierarchy of Grey Wolf (Dominance Decreases from Top Down)

Leaders have been female & male known as Alphas. Also, it has been responsible mainly to make decisions regarding place of sleeping, wake time, hunting etc. Decisions of alpha have been dictated for packing. Nevertheless, some democratic conduct type has been noticed, where alpha follows pack wolves. Overall alpha acknowledges the pack by holding down tails. Wolf alpha has been known as wolf-dominant as her orders need to be succeeded through pack as in [6]. Furthermore, wolves of alpha have been enabled. Alpha has been not required the robust pack member however effective pack managing. It exhibits that, pack discipline and organization has been more prominent than their robustness.

Beta has been considered as next phase in grey wolves architecture. Betas have been wolves of subordinate, which assist alpha in activities of pack or making decision. The wolf of beta has been either girl or boy and she or he has been possibly the effective candidate as alpha in instance 1 of wolves of alpha passes becomes or away.

Omega has been minimal ranking of GW. Omega acts as scapegoat role. The wolves of omega always posses for submitting overall other prominent wolves. Also, they were final wolves, which have been enabled for eating. It might notice omega has been not prominent individual in pack however it is not noticed that entire pack face inside issues & fights in instance of omega losing. Furthermore, it has been because of frustration & violence of entire wolves through omega. Further, this helps in estimating the overall pack & handling framework dominance.

Also, in some instances, omega has been baby-sitters. When wolf has been not omega, beta, alpha she of he is known to be subordinate. Also, delta wolves is to submit for betas & alphas, however, omega has been dominated. Elders, caretakers, hunters, sentinels belong for this class. Scouts have been reasonable for noticing territory & warming boundaries the pack in instance of danger. Furthermore, sentinels assure & protect the pack safety. Elders have experienced wolves, that have been utilized as beta or alpha. Hunters assist betas & alphas while prey is been hunted & offering pack food. Ultimately, caretakers have been reasonable to care wounded, ill & weak wolves in pack.

Additionally, wolves social architecture, cluster hunting has been other interesting social conduct. As per [7], prominent grey-wolf levels hunting have been in the following:

1. Prey has been approached, tracked & chased.
2. Harassing, encircling & pursuing prey till it halts moving
3. Prey attack.

These steps have been exhibited in fig. 3

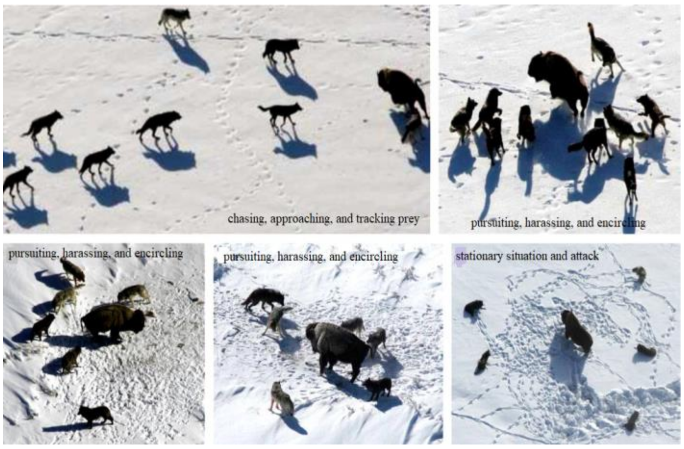

Fig. 3; Hunting behaviour of Grey Wolves

This hunting model & grey wolves social framework have been modelled mathematically for designing GWO & optimization has been performed.

6. Results & Discussions

Experimentation test has been carried in this manuscript for exhibiting projected model effectiveness. Simulink/MATLAB software has been utilized for studying the performance of SRM & GWO application. Later, implementing algorithm of GWO has been explored in fig-3 towards objective-function that has been attained by utilizing RSM, θ values on θ off level=1, and θ on level=0.78377 that relates towards 42.16230 & 850 have been attained. Objective function optimum value identified through GWO has been 0.98167. Moreover, firing angles would be implemented towards converter of SRM for attaining minimal operation of torque ripples. Further, optimum GWO algorithm settings incorporate grey-wolves of 10 & 10 repetitions.

Convergence of objective function utilizing GWO has been compared towards other optimization approach that has ANFIS & ANNN [20] & the fig-4 exhibits convergence curve of fitness function. ANFIS & ANN aspects have been present in appendix.

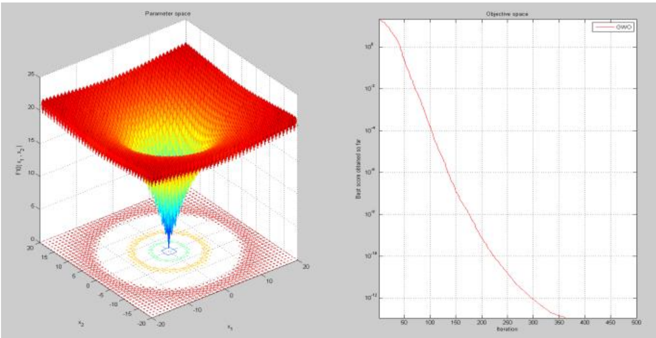

Fig. 4; The Optimization Fitness Function Convergence

It could be noted from convergence curve of fitness function above which GWO is having maximal convergence speed towards value of optimum fitness. Hence, GWO has been competitive towards ANFIS & ANN that has standard algorithm of optimization.

7. Appendix

The best solution obtained by GWO is : 2.9686e-014 2.4602e-014 -2.5034e-014 1.9399e-014 -2.466e-014 2.8115e-014 -4.2258e-014 2.4027e-014 2.7615e-014 1.5778e-014 -3.0816e-014 2.2721e-014 -2.8189e-014 -1.4455e-014 -2.505e-014 2.2569e-014 -3.6548e-014 -3.5761e-014 2.6273e-014 -1.7823e-014 1.9959e-014 3.0448e-014 3.9185e-014 3.0614e-014 2.7735e-014 -2.8993e-014 -2.3489e-014 1.6077e-014 -2.7423e-014 -3.3372e-014

The best optimal value of the objective funciton found by GWO is: 1.1102e-013

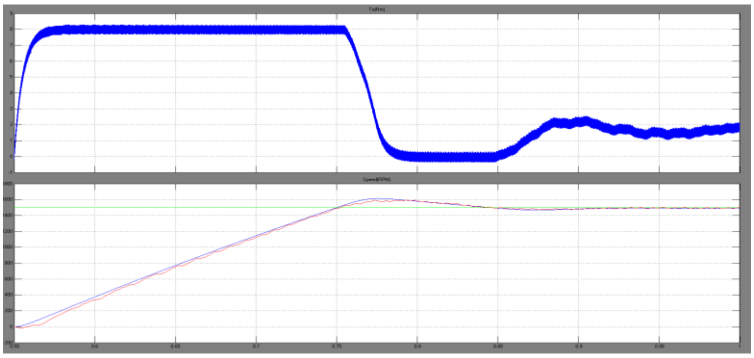

Fig. 5; ANFIS Based SRM Drive with Speed 4000RPM (Conventional System)

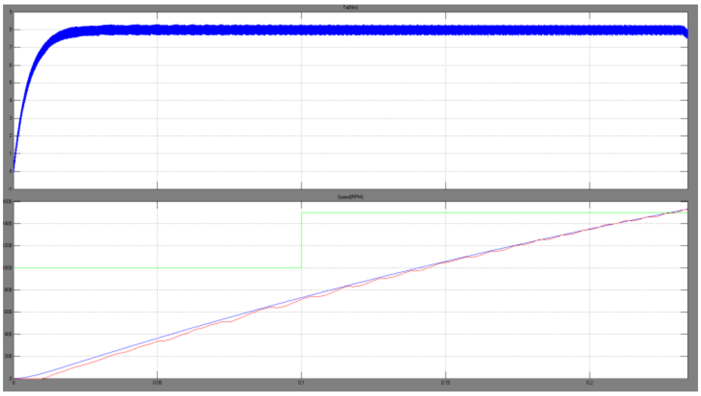

Fig. 6; GWO Based SRM Drive with Speed 4000RPM (Proposed System)

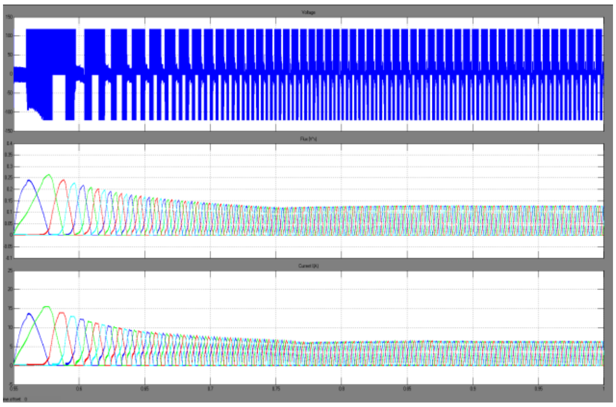

Fig. 7; ANFIS based Voltage, Flux, & Current (Conventional System)

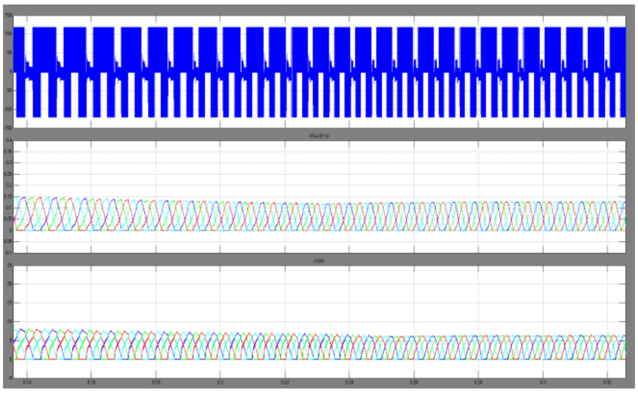

Fig. 8; GWO based Voltage, Flux, & Current (Proposed System)

Table II. Gain Parameters

Parameters	ANN		ANFIS		GWO	
Tuned	Speed controller	Current controller	Speed controller	Current controller	Speed controller	Current controller
K_p	3.85	4.26	5.38	5.24	4.75	3.24
K_i	7.25	6.58	5.79	4.39	5.85	5.25
K_d	8.382	5.27	4.89	6.17	2.39	1.98
λ	0.78	0.64	0.40	0.28	0.31	0.54
μ	0.27	0.42	0.24	0.71	0.52	0.83

Table III. The Performance Analysis of FL, ANN and ANFIS & GWO Controllers with Speed Command 4000 rpm

Controllers	Settling Time	Rise Time	Peak Overshoot	Peak Time
Fuzzy Logic	0.2967	0.1229	1.39%	0.8049
ANN Control	0.2866	0.1	0.85%	0.7605
ANFIS Control	0.118	0.0962	0.20%	0.7308
GWO Control	0.08	0.0122	0.10%	0.2890

8. Conclusion

GWO controller has been projected in this manuscript for controlling the current & speed and SRM torque ripple driven system. Also, projected controller has been dependent on strategy of hunting algorithm & it has been applied in platform of Simulink or MATLAB. Furthermore, gain aspects have been tuned by utilizing projected strategy that offers optimum signal control that SRM has been driven. Furthermore, current, torque, inductance & speed performance has been utilized. GWO controller performance has been compared by ANN, ANFIS algorithm. Projected GWO controller effectiveness has been examined from settling-time, rise-time, median, mean, analysis as well as speed has been examined. TR have been defined by utilizing GWO & contemporary model depending on ANFIS & ANN controllers in respective order. From analysis of performance, projected approach simulation result exhibits effective performance than traditional models.

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