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Performance Evaluation of Switched Reluctance Machine Under Varying Switch-on & Switch-off Angle

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***Abstract*— Switched Reluctance machines provides good progress on performance under varying switch-on and switch-off angles environment. In this study switching angles are set to obtain the optimal instantaneous torque in the simulation model. This research is carried out at various rotational speed and varying switching angles. The following waveforms are the outcomes of the simulation model: current, flux-linkage, phase voltage, instantaneous torque and total torque as a function of switching angles. Therefore, for selection of proper switching angles, it is necessary to evaluate the performance of SRM. This research summarizes the method and calculation of the performance of SRM. The findings are achieved by incorporating experimental results.**

***Index Terms* — Optimum Switch-on and Switch-off angles, Current, Phase Voltage, Flux-linkage and Torque.**

I. INTRODUCTION

Switched reluctance motors (SRM) are gaining attention as an excellent drive unit that ranges from advanced electric cars to high-speed aircraft applications due to easy and robust motor structure, relatively minimal manufacturing costs, outstanding torque/speed properties, higher working performance and absolute fault tolerance. Extensive study contributions have been dedicated in recent decades to numerous perspectives of SRM, like as control design, performance analysis of speed regulation, and instrumentation, drive operation, in which exact assessment of an electromagnetic properties of the SRM is a distinguishing feature for each of these instances [1].

Due to its unique and simplistic design, higher torque to inertia ratio, thermal compactness, etc., SR Machine, commonly referred to as a doubly salient varying reluctance machine, having received considerable attention from scientists and industrial sectors over the past decades. The operating strategies of this system are dependent on torque reluctance, that is easy to understand and well known. According to its many benefits, this is commonly seen in variable speed drives [2].

SRM radial arrangement of the rotors and the stators must be symmetrical to prevent magnetic stress only on side. Therefore, the combination of rotors and stators should be even. In order to increase the output performance of the motor, the actual figures of the poles of the rotors and the stators should be identical. The self-starting potential was not possible for the number of SRM stages which were not less than three. The combined systems for stators and rotors should be assigned for working practices requiring four-quadrant operation and self-starting, as follows: three-phase 6/4 pole SRM shown in Fig.1, four-phase 8/6, five-phase 10/8, six-phase 12/10, seven-phase 14/12, etc. Together with the increase of the phases, the phase angle was lessened, that was beneficial for the decline of the impulse of output torque [3].

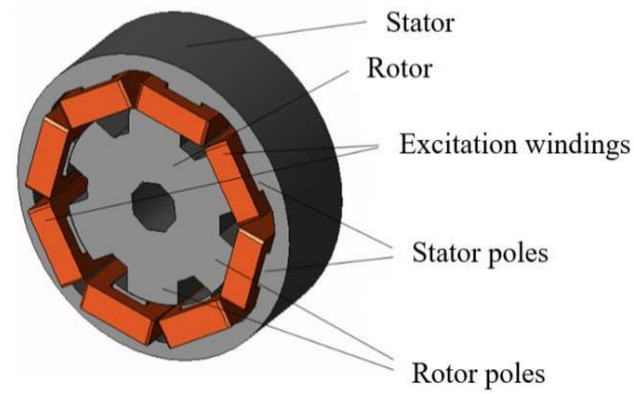

Fig 1. Basic appearance of a 4-phase SR machine

II. LITERATURE REVIEW

Kumar et al. He recommended that in this study addresses the enhancement of performance and the application potential of iron power SMC in the switched reluctance machine. The outcomes of experimental validation and extensive simulation of finite elements suggested manufactured prototype are delineated. The study concludes that, compared to the conventional lamination counterpart, the use of Soft Magnetic Composite as the magnetic core of a SR motor improves its vibration and thermal characteristics [4]. Matin Vatani et al. He proposed that the static and magnetic flux density vectors feature of the FSLSRM are obtained through simulations of FEA. A three-phase asymmetric inverter is used to operate the FSLSRM in order to investigate the dynamic function of the motor. In both single-pulse control (SPC) and current-chopping control (CCC) techniques, the suggested motor output is evaluated. The findings show that there is a substantial increase in performance intensity and efficiency relative to the conventional transverse-flux LSRMs [5]. Ahmad et al. He proposed that the purpose of the study is to address, via advanced simulation analyses, the magnetic features of a SRM of solid-rotor as well as to construct a stator-side structure for the machine which captures its magnetic behavior accurately. Initially, across a broad range of positions of rotor and excitation conditions, the flux-linkage parameters of the SRM of solid-rotor under simulation are calculated. In various excitation constraints, which are required for simulations and performance assessment, the recommended method is helpful for predicting the core loss and winding current. The approach adopted is more precise than the current techniques, but still be easy and quick to adopt [6]. Sovicka et al. He proposed in his study that analyzes and implements a switched reluctance motor drive that features better performance even at low speeds. The combination of an effective specification and current control techniques will result in a significant improvement in performance of the motor drive. After defining the electrical parameters of the assumed motor in terms of stator resistance and inductance, computational simulations and experimental experiments have compared various current control systems illustrating their pros and cons. A new current controller is also being developed, based on a PD controller update [7]. Stefan et al. He recommended that for experimental analysis, the SRM experimental method is defined then utilized. In the experimental methods, the angles of switching are optimized to attain the optimal torque of average. This research is carried out at various speed of axis. The corresponding amplitudes are the outcomes of the experimental analysis: performance here as technique of the speed of rotation, losses, torque ripple and average torque [8]. Xiaodong Sun et al., He recommended that the performance enhancement of a SR Machine of segmented-rotor with 16/10 stator/rotor poles is investigated by this research study. Firstly, the field of implementation, model and theory of operating condition of the SSRM are implemented. Secondly, to obtain the optimal values and some essential factors are assessed. And after that, during performance analysis, the outcomes of simulation are suggested to validate the enhancement of the Segmental SRM and the features of improved fault-tolerant depicted while using the method of finite element. Consequently, tests check the expected static output and the performance under the SSRM's control system of current chopper [9]. Hua et al He suggested that the methodology for designing and simulating the SRM framework is then recommended, based on Simplorer and Maxwell. Finite element model (FEM) of SR motor with various layout dimensions is generated and measured in Maxwell 2D. Based on the power converter, Simplorer and the control circuit is set. Finally, the simulation outcomes are illustrated for analyzing SR motor performance with various parameters of the formation [10].

III MATHEMATICAL MODELLING OF SRM

The Fig.1 illustrates a typical cross-sectional outlook of SR machine of 8/6 pole, 4-phase. Through rotor angle, the reluctance of a phase changes due to its double salience formation of machine, and performs as a system of non-linear and is lying in associated side for saturation. To attain the flux-linkage characteristics by phase current and rotor place, it is fundamental requirement for machine modelling. Fig. 2 illustrates the flux-linkage waveform of SRM [11].

The following SR Machine equation is as under:

$$v = i * r + \frac{d\Psi}{d\theta} \qquad (1)$$

Where, r is resistance of phase winding, i is the current, θ is the angle of rotor, v is the voltage of applied and Ψ is the phase winding flux-linkage. The phase current can be achieved by utilizing Eq. (1) and the waveform of flux linkage of motor. The motor instantaneous torque can be termed as:

$$T_{d}= \frac{dW'}{d\theta}\Big|_{i=constant} \qquad (2)$$

the co-energy is depicted by W' and equation given below:

$$W' = \int_0^i \Psi \, di \,\Big|_{\theta=constant} \qquad (3)$$

The machine instantaneous torque can be acquired by utilizing Eq. (2) and Eq. (3). Fig. 6 shows the instantaneous torque of SRM. The speed of rotor can be attained from resulting equation:

$$T_d = T_L + B * \omega + J * \frac{d\omega}{dt} \qquad (4)$$

IV. SIMULATION MODEL

We have used to develop a simulation model of Switched Reluctance machine as shown in Fig. 2 to calculate the performance and created the model in MATLAB for evaluating the performance under varying switch-on and switch-off angles, current and flux-linkage, phase voltage waveforms in order to calculate the instantaneous torque as well as total torque and finally found the analysis of results.

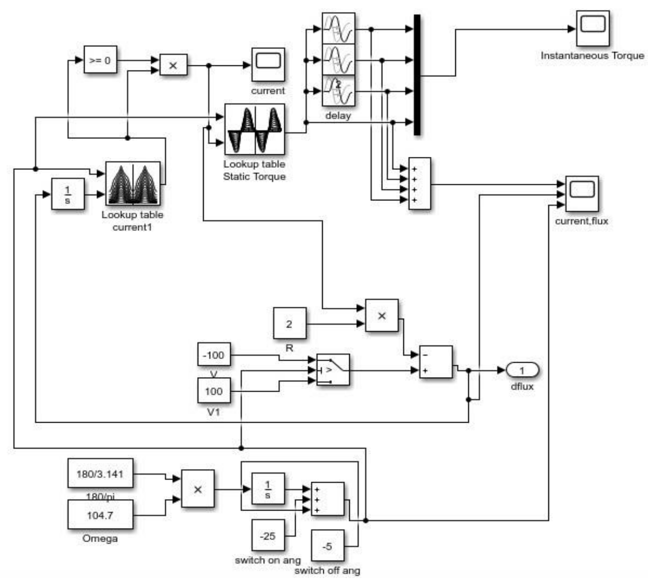

Fig. 2 Simulation Model

One of the few effective approaches for switching of angles and/or optimization against operating conditions, including flux-linkage, current, phase voltage, high speeds, instantaneous torque and total torque to evaluate the performance of SRM. The purpose of this simulation model is to evaluate the SR Machine performance characteristics, through simulation results to build a model of simulation for the system that measures its performance behavior accurately. First, by switching angles, the characteristics of the SRM through simulation are calculated under varying angles of rotor and excitation conditions. The obtained current of winding is extracted by switch-on and switch-off angles to establish a simulation model by performing a simplified analysis method on each collection of experimental results.

The simulation recommended model is beneficial to predict the current, phase voltage and total torque under varying angles of switch-on and switch-off, in performance calculation and simulation. The recommended model is more sophisticated than the existing methodologies, and being easy and quick to execute.

V SIMULATION RESULTS AND DISCUSSIONS

Results based on four cases to evaluate the performance of SRM:

In first case, the experimental data taken from simulation model to calculate the performance of SR machine under varying switch on and switch off angles through current, flux linkage, phase voltage, instantaneous torque and total torque which is shown in fig.2.

The data taken from simulation model in which the switch-on angle is -30°, switch-off angle is 0°, winding resistance 2Ω, the phase voltage 50V and speed 500 rpm as shown in table 1.

TABLE 1. operating parameters of SR Machine for modelling.

System Parameter	Values
Switch-on angle	-30
Switch-off angle	0
Winding Resistance	2 Ω
Phase Voltage	50 V
Speed	500 rpm
No: of phases	04
No: of diodes	08
No: of transistors	08

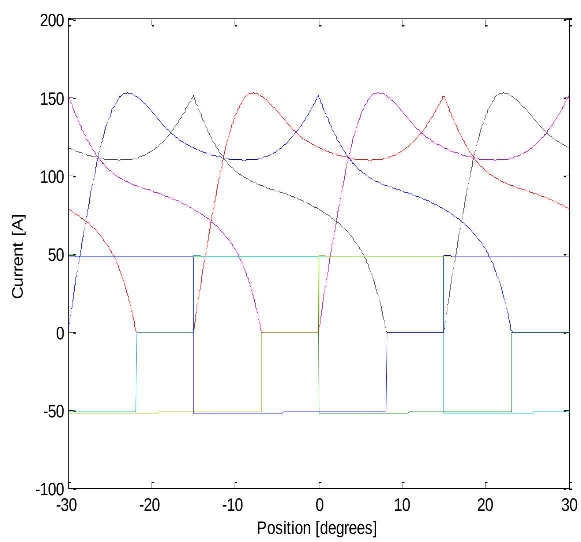

Fig.3. Current waveform

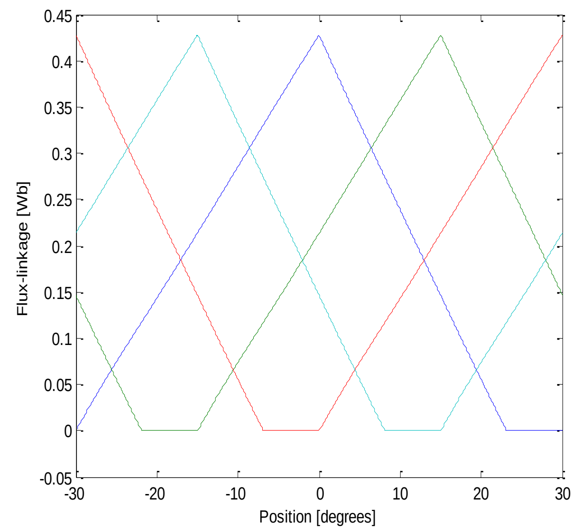

Fig.4. Flux-linkage waveform

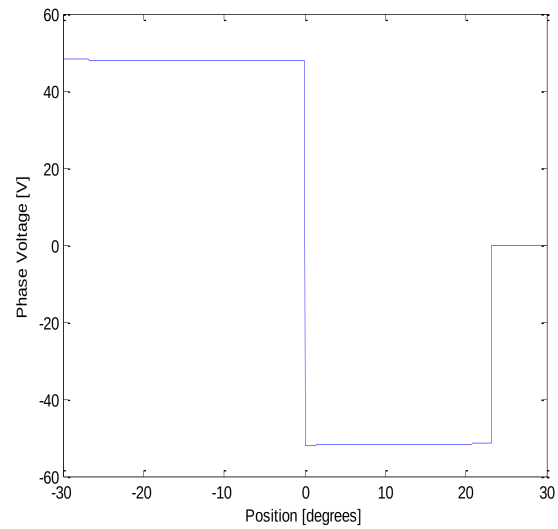

Fig.5. Phase voltage waveform

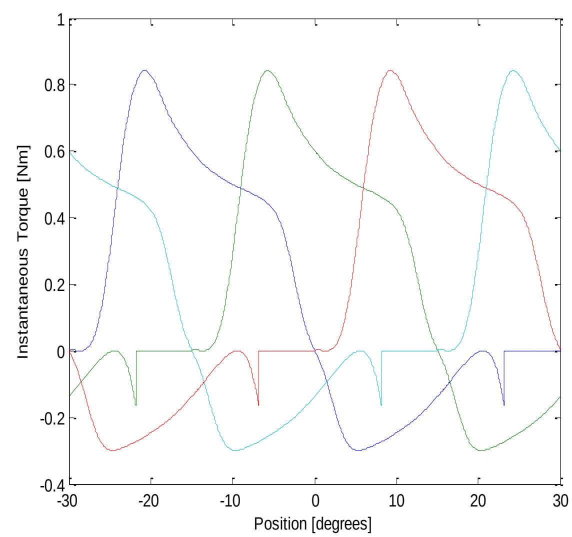

Fig.6. Instantaneous torque waveform

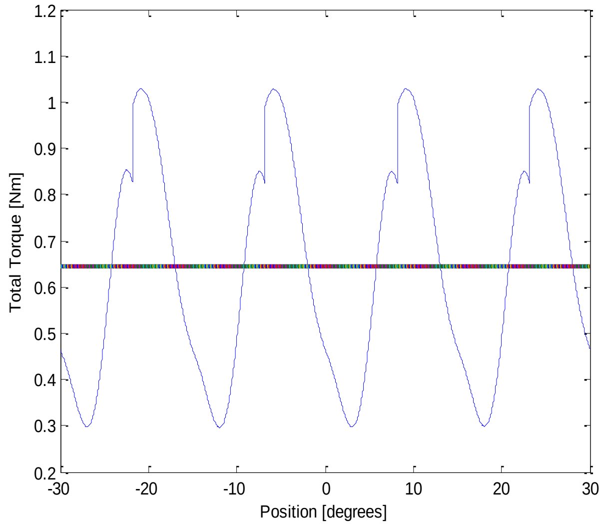

Fig.7. Total torque waveform

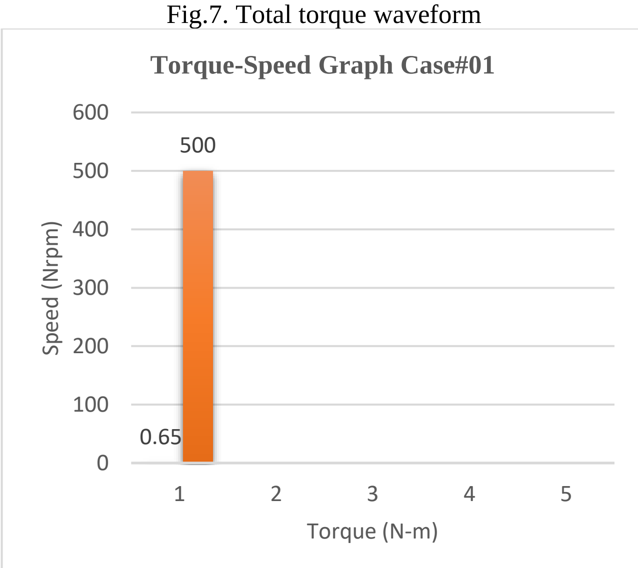

Fig.8. Graph between speed and torque

In second case, we only change the angle of the switch-on then see how impact on performance of SRM. The operating parameters of SRM model in second case is taken as, the switch-on angle is -25°, switch-off angle is 0°, winding resistance 2Ω, the phase voltage 50V and speed 500 rpm as shown in table 2.

TABLE 2. operating parameters of SR Machine for modelling.

System Parameter	Values
Switch-on angle	-25
Switch-off angle	0
Winding Resistance	2 Ω
Phase Voltage	50 V
Speed	500 rpm
No: of phases	04
No: of diodes	08
No: of transistors	08

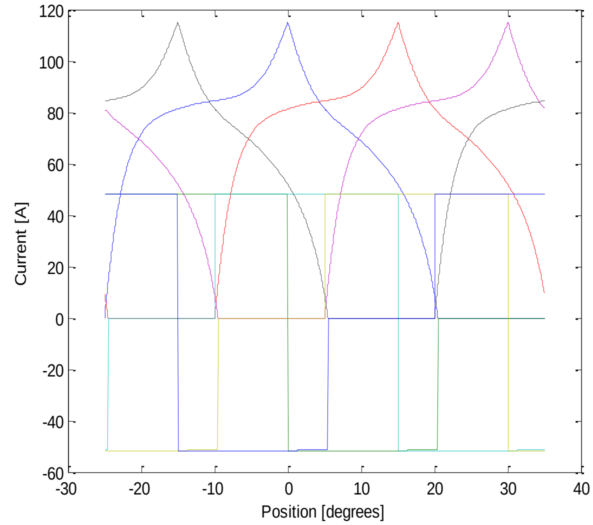

Fig.9. Current waveform

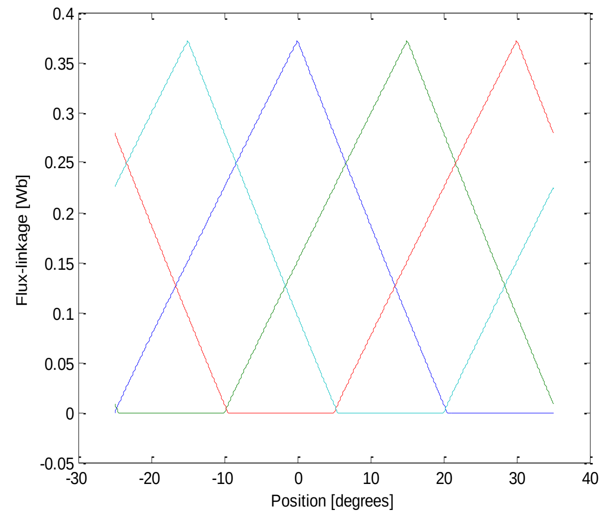

Fig.10. Flux-linkage waveform

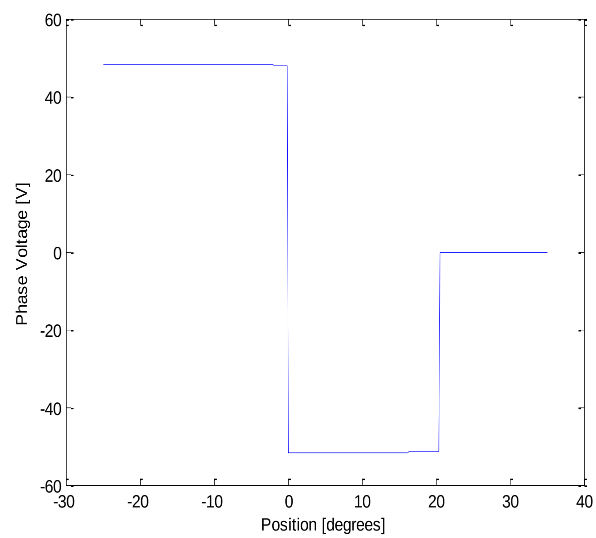

Fig.11. Phase voltage waveform

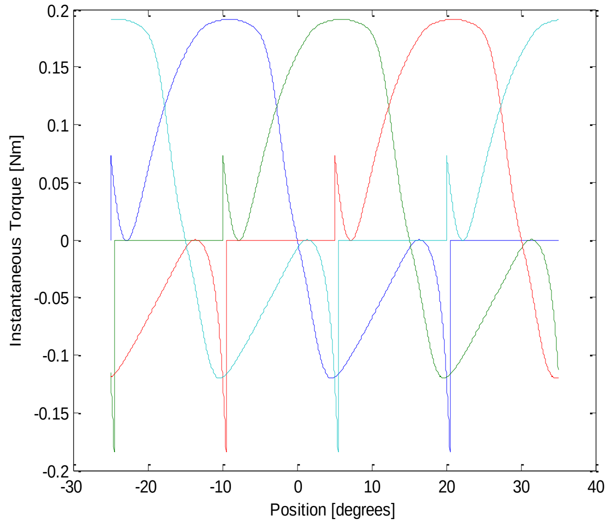

Fig.12. Instantaneous torque waveform

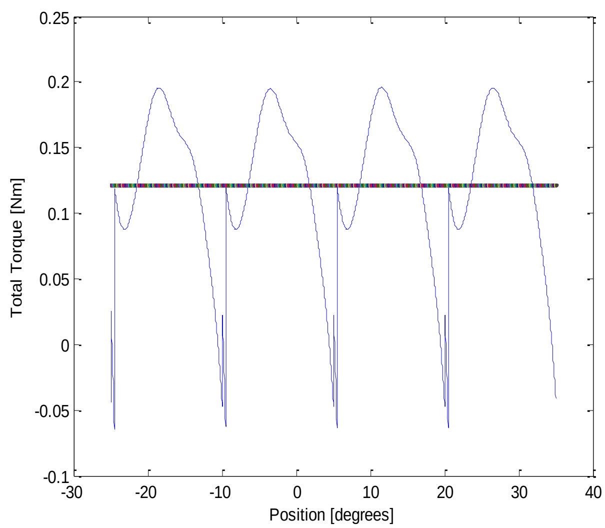

Fig.13. Total torque waveform

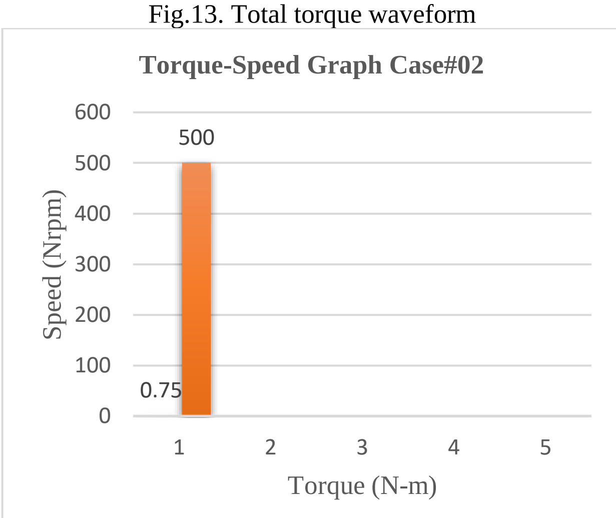

Fig.14. Graph between speed and torque

In third case, we change the both angles, switch-on and switch-off angles then see how impact on performance of SRM. On that impact of performance of SRM can be improved. The operating parameters of SRM model in third case is taken as, the switch-on angle is -35°, switch-off angle is -5°, winding resistance 2Ω, the phase voltage 50V and speed 500 rpm as shown in table 3. The Simulation results of current, flux-linkage, phase voltage, instantaneous torque and total torque are shown below.

TABLE 3. operating parameters of SR Machine for modelling.

System Parameter	Values
Switch-on angle	-35
Switch-off angle	-5
Winding Resistance	2 Ω
Phase Voltage	50 V
Speed	500 rpm
No: of phases	04
No: of diodes	08
No: of transistors	08

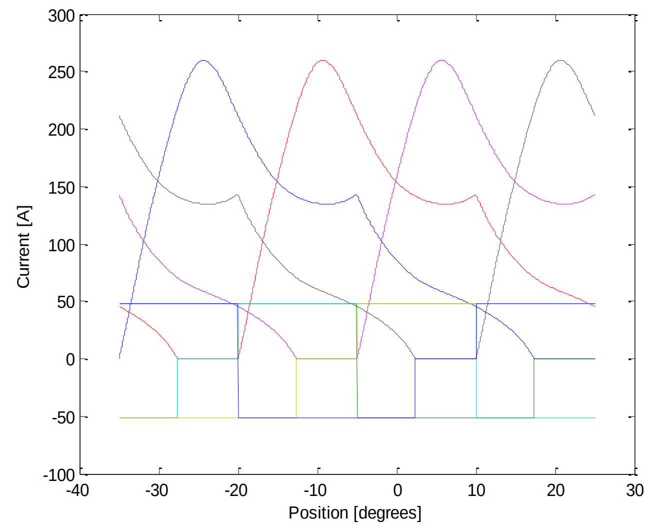

Fig.15. Current Waveform

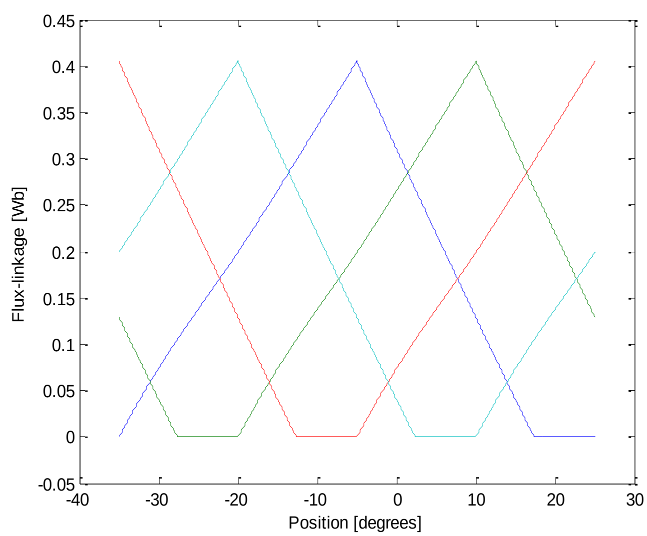

Fig.16. Flux-linkage Waveform

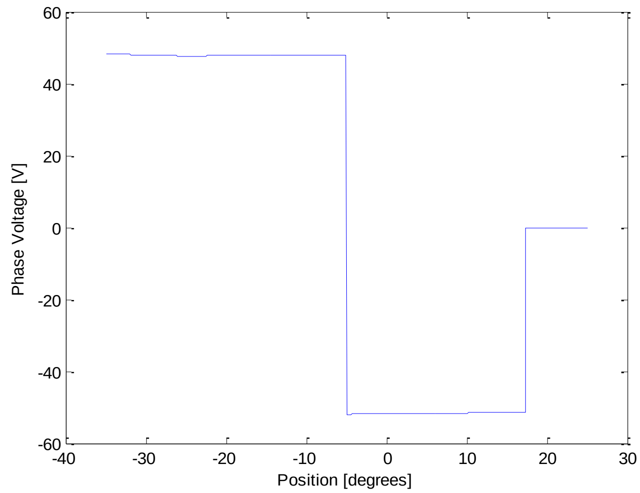

Fig.17. Phase voltage Waveform

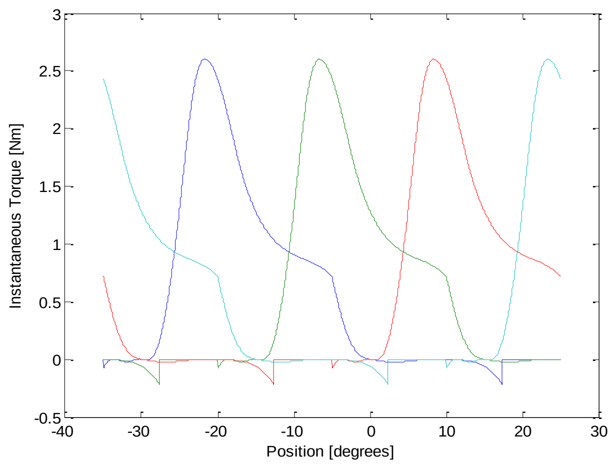

Fig.18. Instantaneous torque waveform

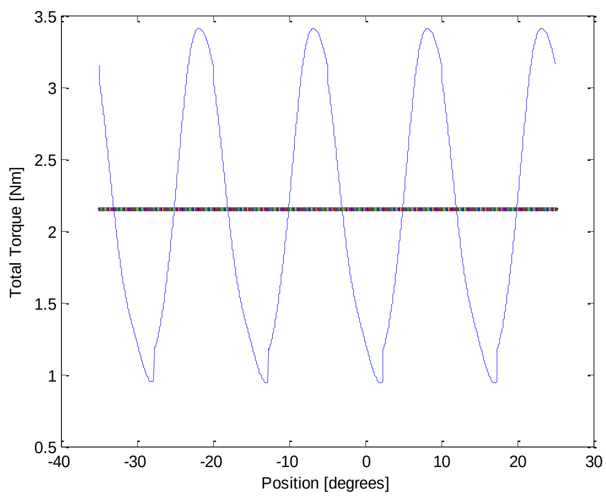

Fig.19. Total torque waveform

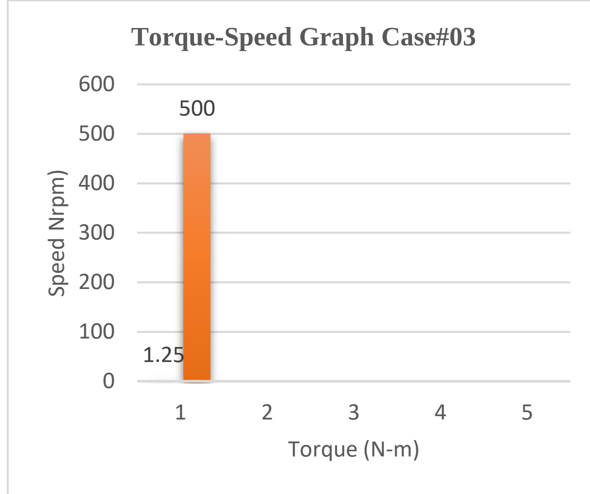

Fig.20. Graph between speed and torque

In fourth case, we change the both angles, switch-on and switch-off angles as well as change phase voltage then see how impact on performance of SRM. On that impact of performance of SRM can be improved. The operating parameters of SRM model in fourth case is taken as, the switch-on angle is -30°, switch-off angle is 0°, the phase voltage 100V, winding resistance 2Ω, and speed 500 rpm as shown in table 4.

TABLE 4. operating parameters of SR Machine for modelling.

System Parameter	Values
Switch-on angle	-30
Switch-off angle	0
Winding Resistance	2 Ω
Phase Voltage	100 V
Speed	500 rpm
No: of phases	04
No: of diodes	08
No: of transistors	08

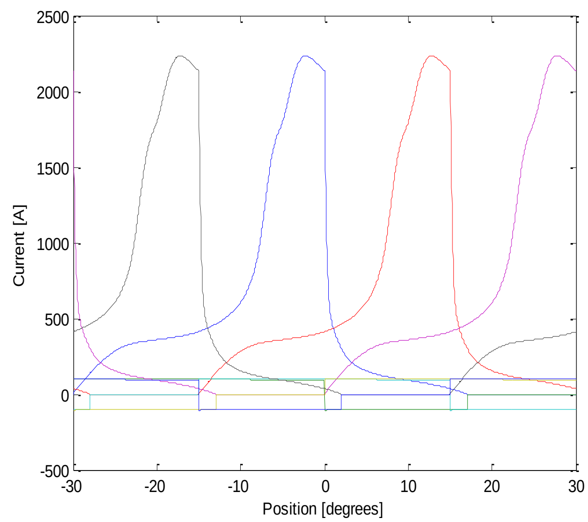

Fig.21. Current waveform

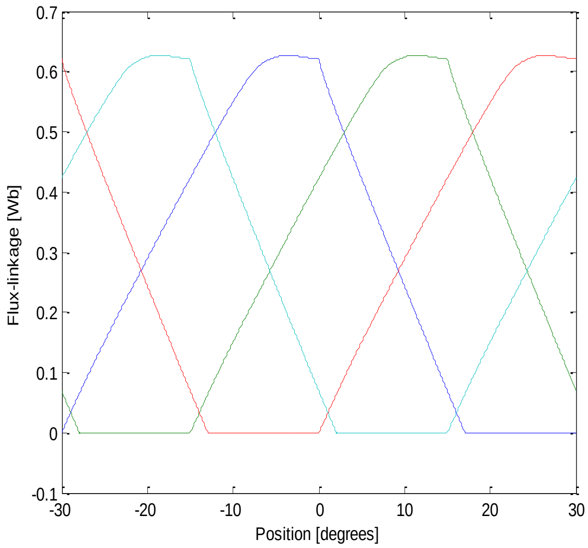

Fig.22. Flux-linkage waveform

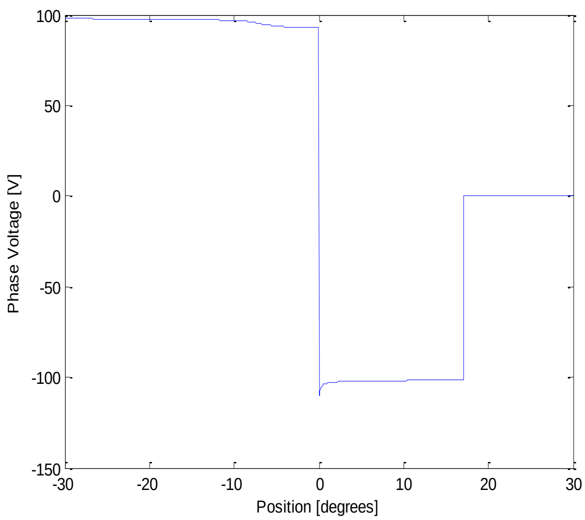

Fig.23. Phase voltage waveform

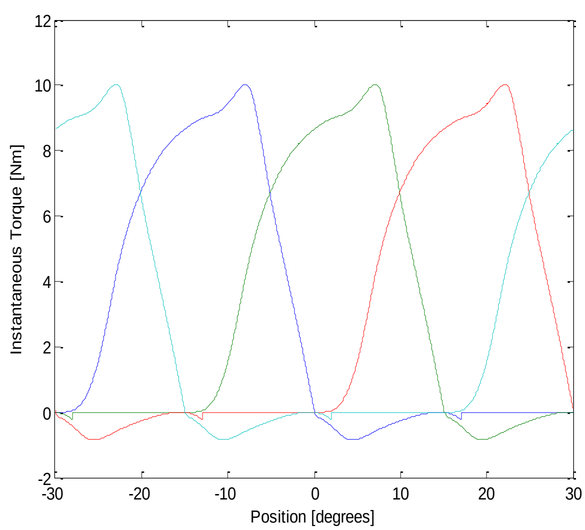

Fig.24. Instantaneous torque waveform

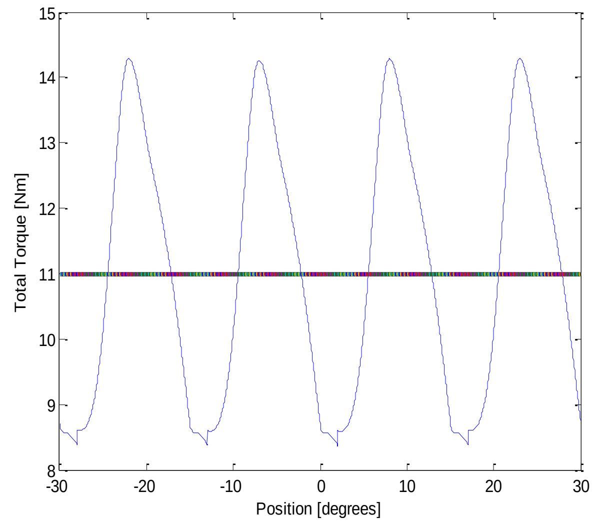

Fig.25. Total torque waveform

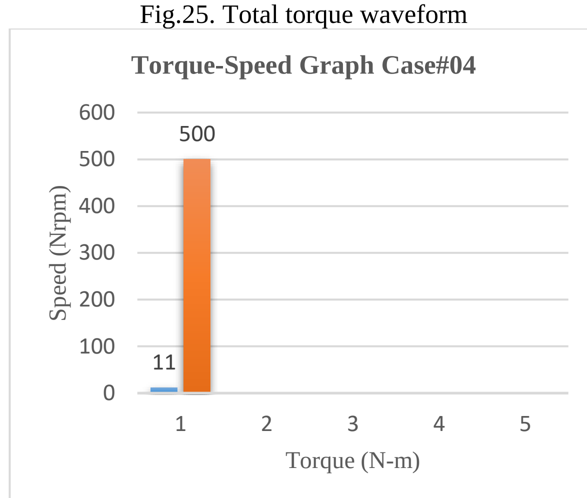

Fig.26. Graph between speed and torque

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VI CONCLUSION

This is verified from analysis of results that under varying switch-on and switch-off angles of SRM to evaluate or improve the performance of machine. We can easily find out the performance of machine through switching angles to calculate the current, flux-linkage, phase voltage, instantaneous torque and total torque of SRM.

For the performance evaluation of SRMs, precise simulation modelling is very important for the analysis of machine performance predicated on air gap inductance varying with rotor position, switching angles and current. It is very important to acquire the data of flux linkage and instantaneous torque. The results of the analysis revealed that the optimal advanced data model offers better performance than the model with less data. Owing to an error that reasons for accuracy in measurement results when nearest performance is calculated. The results of this study can be adapted under various operating conditions, such as switching angles, current, flux-linkage, phase voltage, instantaneous torque, total torque and SRM transient performance to further calculations.

REFERENCES

[1] Ling, Xiao, Liang Gong, Bingchu Li, and Chengling Liu. "Precise in-situ characterization and cross-validation of the electromagnetic properties of a switched reluctance motor." *Artificial Intelligence in Agriculture* (2020).

[2] Sah, Gyanendra Kumar, Shefali Jagwani, and L. Venkatesha. "A new simplified control strategy for switched reluctance motor." In *2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE)*, pp. 241-244. IEEE, 2017.

[3] Liu, Songyong, Guojun Tan, Chenxu Luo, Xulong Zhang, and Zhenglan Ma. "Magnetic performance of shearer switched reluctance motors drive." *Procedia Earth and Planetary Science* 2 (2011): 98-103.

[4] Vijayakumar, K., A. Joseph Basanth, R. Karthikeyan, V. Sivakumar, N. Balamurugan, and C. Shanmuga Sundaram. "Influence of iron powder core on the switched reluctance motor performance enhancement." *Materials Today: Proceedings* (2020).

[5] Vatani, Matin, Saman Ahmadi, Mojtaba Mirsalim, and Amir Khorsandi. "Performance Analysis of a Novel Linear Switched Reluctance Motor with Transverse-Flux and Four-Sided Structure." In *2020 11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)*, pp. 1-5. IEEE, 2020.

[6] Ahmad, Syed Shahjahan, and G. Narayanan. "Experimental Investigations on Flux Linkage Characteristics and Stator-Side Modeling of a Solid-Rotor Switched Reluctance Machine." *IEEE Transactions on Industrial Electronics* (2019).

[7] Sovicka, Pavel, Pavol Rafajdus, and Vladimir Vavrus. "Switched reluctance motor drive with low-speed performance improvement." *Electrical Engineering* (2019): 1-15. presentation

[8] Kocan, Stefan, and Pavol Rafajdus. "Dynamic Model of High Speed Switched Reluctance Motor for Automotive Applications." *Transportation Research Procedia* 40 (2019): 302-309

[9] Sun, Xiaodong, Kaikai Diao, and Zebin Yang. "Performance improvement of a switched reluctance machine with segmental rotors for hybrid electric vehicles." *Computers & Electrical Engineering* 77 (2019): 244-259.

[10] Hua, Chengchao, Ping Xu, Qishuang Ma, and Wei Ye. "Performance analysis of switched reluctance motor based on Maxwell and Simplorer." In *2017 Chinese Automation Congress (CAC)*, pp. 6510-6515. IEEE, 2017.

[11] Sah, Gyanendra Kumar, Shefali Jagwani, and L. Venkatesha. "A new simplified control strategy for switched reluctance motor." In *2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE)*, pp. 241-244. IEEE, 2017.