ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 07, Issue, 11, pp.16617-16622, November, 2017

ORIGINAL RESEARCH ARTICLE

OPEN ACCESS

TORQUE RIPPLE MINIMIZATION OF SWITCHED RELUCTANCE MOTOR USING MODEL PREDICTIVE CONTROLLER TECHNIQUE

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ARTICLE INFO

Article History:
Received 14th August 2017
Received in revised form
26th September, 2017
Accepted 11th October, 2017
Published online 12th November, 2017

Key Words:
Model predictive Control,
Switched Reluctance Motor,
PID controller, Torque Ripple.

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ABSTRACT

In recent years many control characteristics were implemented to improve the performance of machines in the field of power electronics. Some of the controllers give very good performance to achieve the premeditated value; out of these controllers the model predictive controller (MPC) gives good results in power electronics drive control. This paper presents application of model predictive controller for switched reluctance motor is done and performance characteristics are compared with the PID controller. The advantage of MPC is that it allows the easy inclusion of system constraints, thus different control objectives can be flexibly taken in account in different applications. Another remarkable merit of MPC is the inclusion of nonlinearities, such as harmonic spectrum control and switching frequency reduction. A key important factor for applying the controller in switched reluctance motor is to regulate the torque and avoid torque ripple, which considered as a very major drawback in SRM.

Citation: Muruganantham, S. and Ashokkumar, R. 2017. "Torque ripple minimization of switched reluctance motor using model predictive controller technique", *International Journal of Development Research*, 7, (11), 16617-16622.

INTRODUCTION

Usage of power converters in drives, energy conversion, traction, and distributed generation were increased in the recent trends, apart from the usage the control of power converters became very necessary. In the recent trends many controllers were introduced to control various characteristics of power converters. Some of the control scheme are given in fig.1. From these, hysteresis and linear controls with pulse width modulation (PWM) are the most established in the literature. The development of faster and more powerful microprocessors, the implementation of new and more complex control schemes is possible nowadays. Some of these new control schemes for power converters include fuzzy logic, sliding mode control, and predictive control. Fuzzy logic is suitable for applications where the controlled system having some of its parameters is unknown. Sliding mode presents robustness and the switching nature of the power converters. Other control schemes found in the literature include neural networks, neuro–fuzzy, and other advanced control techniques. Predictive controller has very special features when compared with the other controllers. Some of the features are: (i) concepts are perceptive and easy to understand, (ii) it can be applied to a variety of systems, (iii) constraints and nonlinearities can be easily included, (iv) multivariable case can be considered. Predictive controller has a high volume of calculations then a classic controller but implementation became possible by fast running microprocessors available nowadays (Jiefeng Hu *et al*, 2017). The main characteristic of predictive control is the use of the model of the system for the prediction of the future behavior of the controlled variables. Different classification of predictive controllers are shown in fig.2 In deadbeat control, the optimal actuation is the one that makes the error equal to zero in the next sampling instant. A more flexible criterion is used in MPC, expressed as a cost function to be minimized (Blaabjerg, F *et al.*, 2012; Patricio Cortes M.P *et al*,.2009). The optimization criterion in the hysteresis-based predictive control is to keep the controlled variable within the boundaries of a hysteresis area, while in the trajectory based, the variables are forced to follow a predefined trajectory. The principle of trajectory-based predictive control strategies is to force the system's variables onto precalculated trajectories. Control algorithms according to this strategy are direct self control or direct mean torque control. Deadbeat control and model predictive control always need a modulator for generating reference voltage, but the advantage of predictive control is that concepts are very simple and spontaneous (Patricio Cortes M.P *et al*,.2009). Depending on the type of predictive control, implementation can also be simple.

There are various type of controllers are implemented for controlling torque ripple: Conventional PI, PD, PID Controllers, SRM Drive System with consists of Hysteresis/PWM Current Controller and Torque Controller,

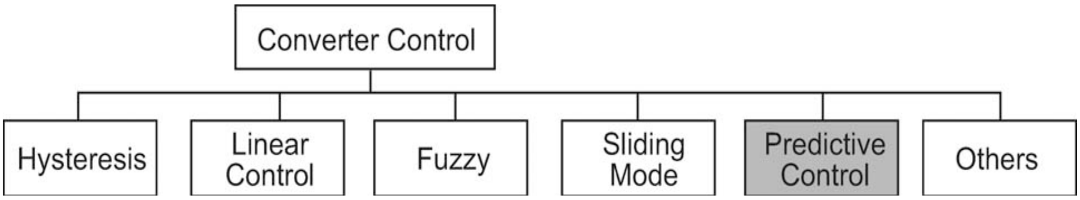

Fig. 1. Different control scheme for converters

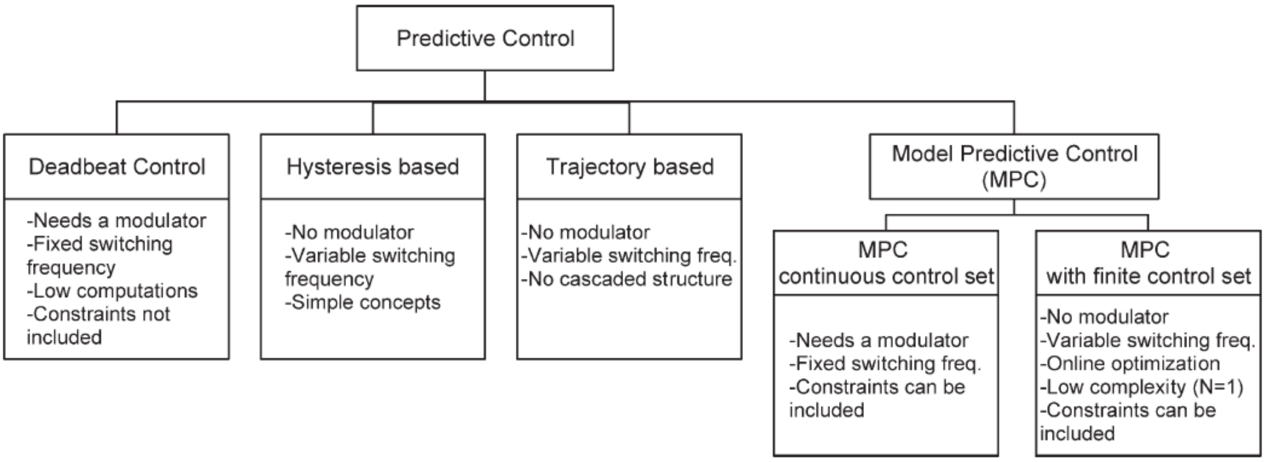

Fig. 2. Classification of predictive controllers

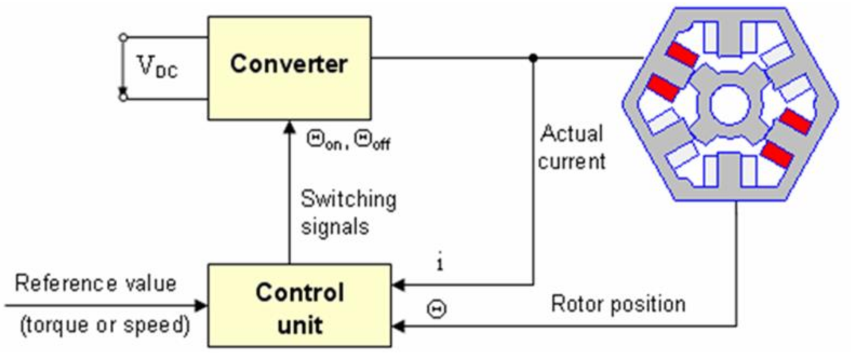

Fig. 3. General functional diagram of SRM

Switched Reluctance Motor

The switched reluctance motor (SRM) is a variable reluctance motor that is designed to convert energy efficiently. SRM is a very simple structure: its rotor is brushless and has no winding of any kind. The motor is singly excited from stator windings which are concentric coils wound in series on diagonally opposite stator poles; both rotor and stator are made of laminated iron. In spite of the simple structure of the motor, because of the highly saturated operating condition and the doubly salient structure of the motor, an accurate analysis of the SR motor is very difficult and conserving(R. Krishnan.2001). The main drawback of SRM motor is torque ripple and vibration, these problems are due to nonlinearity of the electromagnetic property and winding current General diagram of SRM using controllers is shown in Fig.3.

Performance Optimization in SRM Drives with Online Commutation angle control, Sliding Mode Control, Adaptive Speed and current control of SRM based on generalized Minimum Variance Controller, Fuzzy Logic and Neural Networks, Model Predictive Control (E. I. Silva *et al.*,2007). Due to nonlinearity of the electromagnetic property it is difficult to get satisfactory control Characteristics. PI, PD, or PID controller is compensating system variations efficiently by appropriate tuning. However, the performance may significantly deteriorate when the operating condition is altered or when the parameters drift. Model Predictive Control (MPC) is receding in horizon control which results in advanced control techniques in practical applications in recent decades. Comparison of PID controller and MPC was done to prove the effectiveness of MPC.

PID controller

A Proportional + Integral + Derivative controller is implemented for torque ripple reduction in switched reluctance motor. Where P = Kp, I = Ki, D = Kd. The torque control systems was built and tested to evaluate the performance of discrete PID control algorithms from the experimental actual speed, torque and measured phase voltage, phase current in PID control modes during steady state/transient operation under soft chopping operation. In all the cases the dwell angle is kept constant at 30 degrees. In the PID control mode, results have shown that, the steady state error(e) becomes less after 0.2 secs in loaded conditions(Patricio Cortes M.P *et al*,.2009).

- Its response is lagging during large disturbances.
- It has difficulties in the presence of Nonlinearities

Because of the saliency of the stator and rotor, the torque ripple is produced when the former phase is being excited opposite voltage and the latter phase has been excited. The point of intersection between the two excited phases must be advanced to a higher value to minimize the torque ripple. To attenuate the torque ripple, the addition of a compensating current signal is proposed. This signal is dependent of the rotor position and the reference current which in turn depends on the motor speed and the torque load value. The output compensating current signal produced by the controllers, Ic is

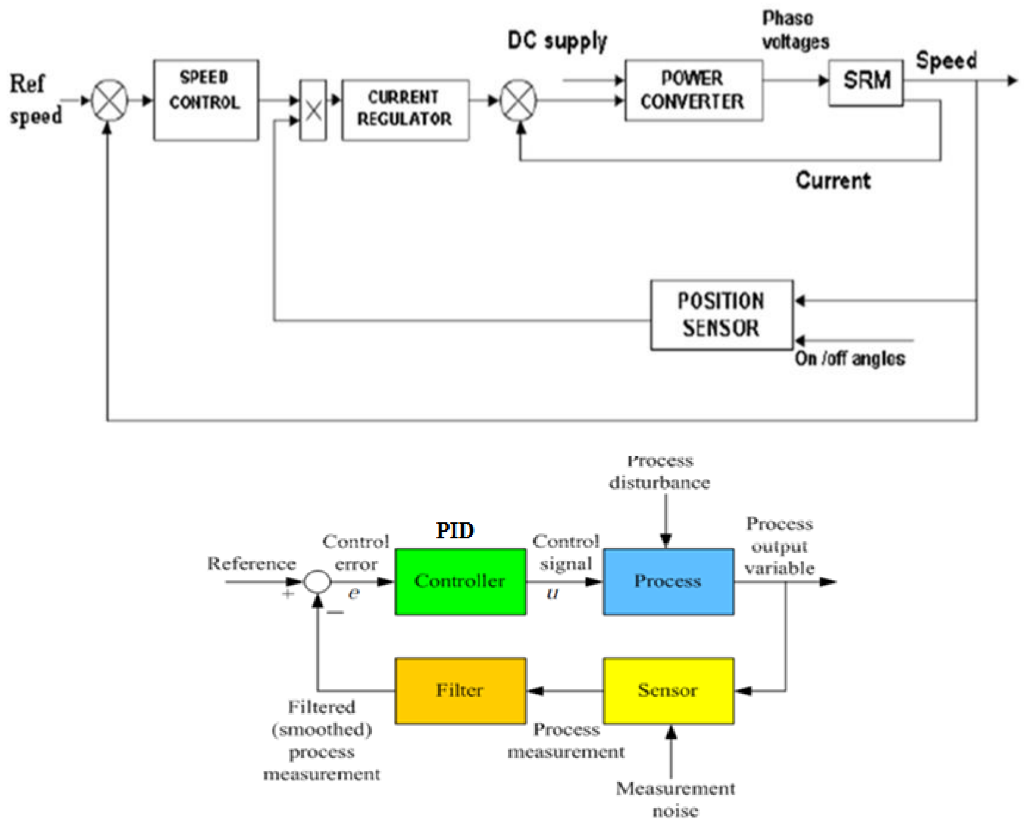

Fig. 4. Block diagrams of PID controller with SRM

Kp-Proportional Gain=19.21, Ki- Integral Gain=0.3 and Kd-Derivative Gain=0.1

$$u = u_0 + \underbrace{K_p e}_{u_p} + \underbrace{\frac{K_p}{T_i}\int_0^t e\,d\tau}_{u_i} + \underbrace{K_p T_d \frac{de}{dt}}_{u_d} \quad (1)$$

Where e is steady state error and u is the control signal from PID controller and it is given in equ.1. PID controller is implemented in 6X4 SRM motor with three phase classic bridge converter circuit.fig.4 and fig.5 shows the block diagram of PID with SRM and simulation results of PID controller respectively.

From the simulation result it is concluded that

- PID controller has maximum overshoot
- It does not provide optimal control.

added to the reference current signal, which ideally, should be constant in steady state, but producing significant ripple. The compensating signal should then be adjusted in order to produce a ripple free output torque (T. J. E. Miller. 1993). In fact, it is a function that possesses high mathematical complexity and therefore the production of this signal is quite complicated so there is a need of easy compensation for the above problems. The model predictive control is applied to reimburse the process.

The advantage of MPC is that it allows the easy inclusion of system constraints, thus different control objectives can be flexibly taken in account in different applications. Another remarkable merit of MPC is the inclusion of nonlinearities, such as harmonic spectrum control and switching frequency reduction. The key is to choose the appropriate weighting factors to get a satisfactory tradeoff between the control objectives (Shun-Chung Wang *et al.*, 2011).

To regulate and keep its torque close to a reference value

- Further, minimization of the winding currents and the operation within the rated values
- Finite switching frequency make it impossible to regulate the torque
- Every switch transition causes a heat loss in the converter, hence switching frequency should minimize.
- Finally, to achieve low torque ripple and operating at a low switching frequency.
- Minimizing an objective function at each time step
- The major advantage of MPC is its straightforward design procedure.
- Given a model of the system, including constraints, one only needs to set up an objective function that incorporates the control objectives.
- By putting different weights on the control objectives, to balance torque ripple, winding currents, and switching frequency

time horizon (usually equal to 1)called finite state predictive control take $N = 1$, the system behavior at $k + 1$ instant can be predicted with the measured value $y(tk)$ and n possible voltage vectors, resulting in n possible values $yp1$, $yp2$, …, ypn, as depicted in fig.7. Finite state predictive control method is the simplest method for model prediction control(A. Linder *et al.,2005).*

Next, a cost function will be formulated to evaluate the effectiveness of all the possible voltage vectors on the system performance. The voltage vector that minimizes the cost function will be chosen for the next sampling period. For example, if $yp3$ is closest to y^*, the voltage vector producing $yp3$ will be selected to control the converter between k and $k + 1$ instants. In this way different values are interacted and the right value is predicted in model predictive control which is close to reference value. Fig.8 shows the magnetization curve of SRM.

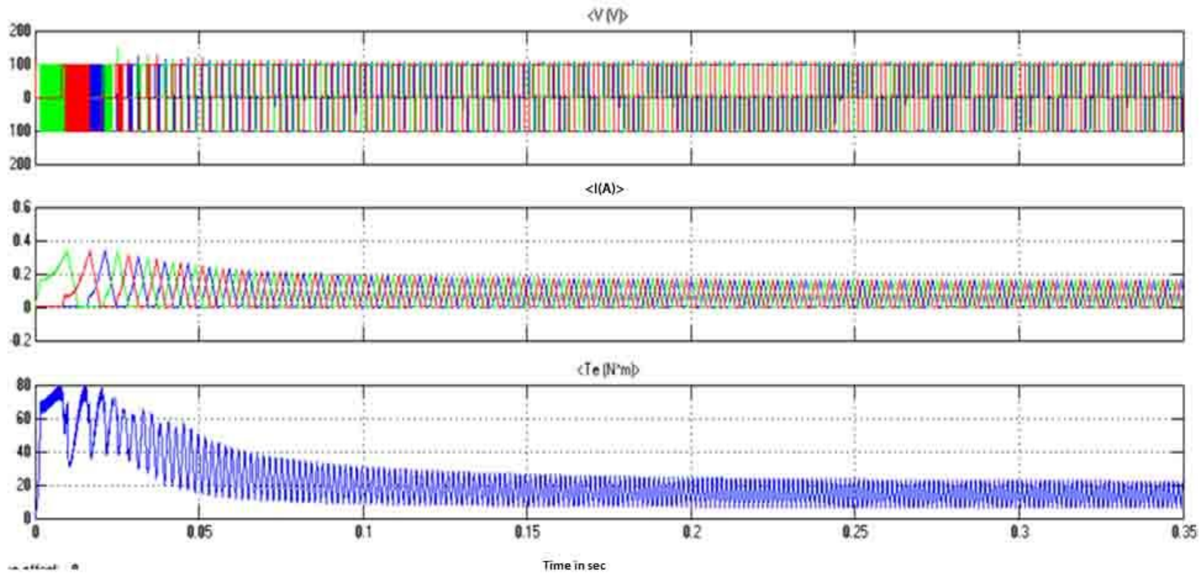

Fig. 5. Simulation result of PID controller

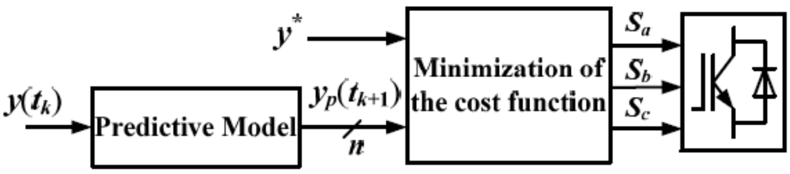

Fig. 6. Control scheme of Model Predictive Control

Model Predictive Controller

In MPC, the behavior of the variable is predicted by a system model over a certain time horizon, and a cost function as the criterion is used to select the optimal switching states [11]. The principle of this control scheme is illustrated in fig.6. All the possible system transitions $yp(tk+1)$ can be predicted using the measured value $y(tk)$ at the control actions according to a prediction model $\{y(tk), N\}$. This prediction model is directly derived from the discrete-time model of the system which depending on the control objectives. By considering a short

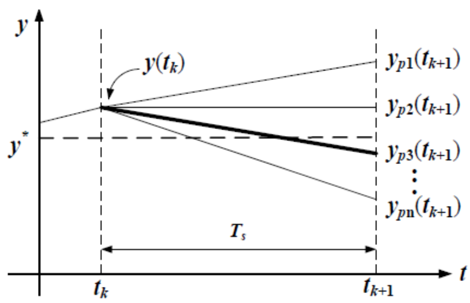

Fig 7. n possible voltage vectors at (N=1)

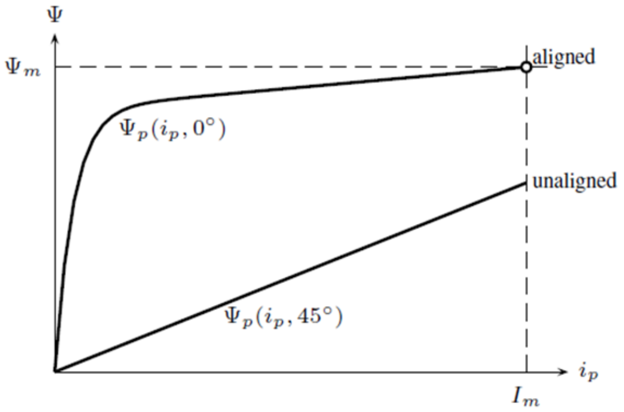

Fig. 8. Magnetization curve of SRM

The Magnetization Characteristics of the 6/4 SRM are described by the equ.2, 3 and 4 .Equ.2 gives the magnetization characteristic of motor at unaligned position and equ.4 gives the magnetization characteristic of motor at aligned position.

$$\Psi_p(i_p, 45°) = L_q i_p \tag{2}$$

$$\Psi_p(i_p, 0°) = L_{dsat} i_p + A(1 - e^{-Bi_p}), \tag{3}$$

$$\Psi_p = L_q i_p + \left[L_{dsat} i_p + A(1 - e^{-Bi_p}) - L_q i_p\right] f(\theta_p). \tag{4}$$

Torque expression of SRM

The electromagnetic torque [Te] which is given by the Equ.7 generated by a phase p is given by the derivative of the machine co energy which is given by

$$W'_p(i_p, \theta_p) = \int_0^{i_p} \Psi_p(i_p, \theta_p)\, di_p \tag{5}$$

$$T_{e,p} = \left[\frac{L_{dsat} - L_q}{2} i_p^2 + A i_p - \frac{A}{B}(1 - e^{-Bi_p})\right] f'(\theta_p). \tag{6}$$

$$T_e = \sum_p T_{e,p} \tag{7}$$

Controller objectives

Model predictive control problem is expressed by appropriate cost term for the cost function and it is given by Equ8 and 9. The main objective of MPC is to keep the torque close to the reference value which is achived by putting the quadatic penalty.

Where weight of the torque is greater than zero.

$q_T > 0$, q_T – weight on the torqe.

Next is to minimize the ohmic loses in the winding current where weight on the current is greater than zero.

$q_I > 0$, q_I – weight o the current

$$\epsilon_T(\ell) = q_T\,(T_e(\ell) - T_{e,ref})^2 \tag{8}$$

$$\epsilon_I(\ell) = q_I \sum_{p=1}^{3} i_p(\ell)^2, \tag{9}$$

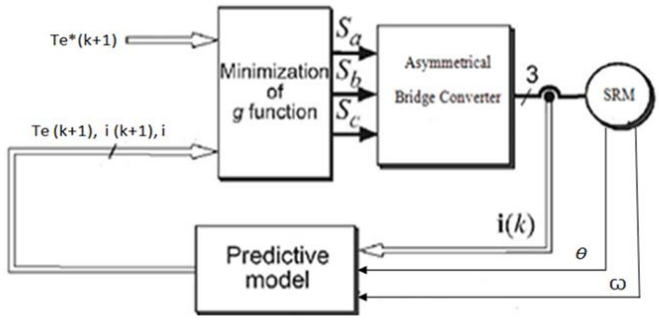

Fig. 9. Block diagram of model predictive torque controller

In this model MPC torque control give effective result on bringing the torque value close to the reference value and minimizes the ohmic loses in winding current. The above property reduces the torque ripple and acoustic noise to the

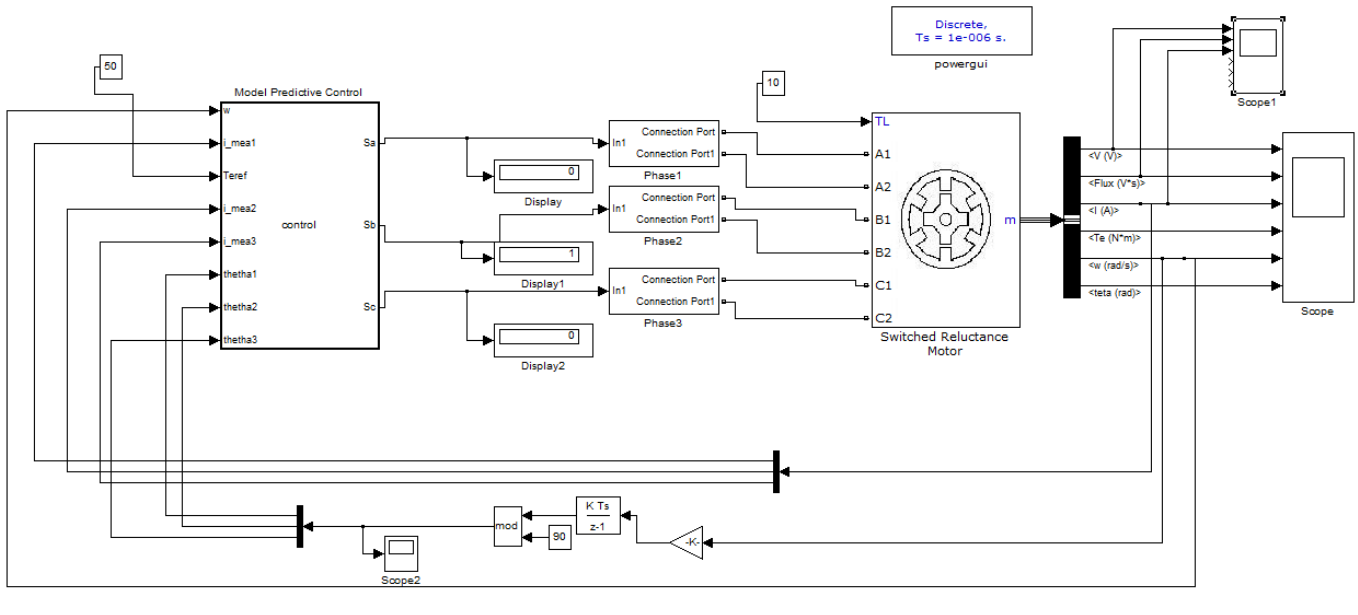

Fig. 10. Simulation diagram of SRM with Model Predictive Controller

SIMULATION RESULTS

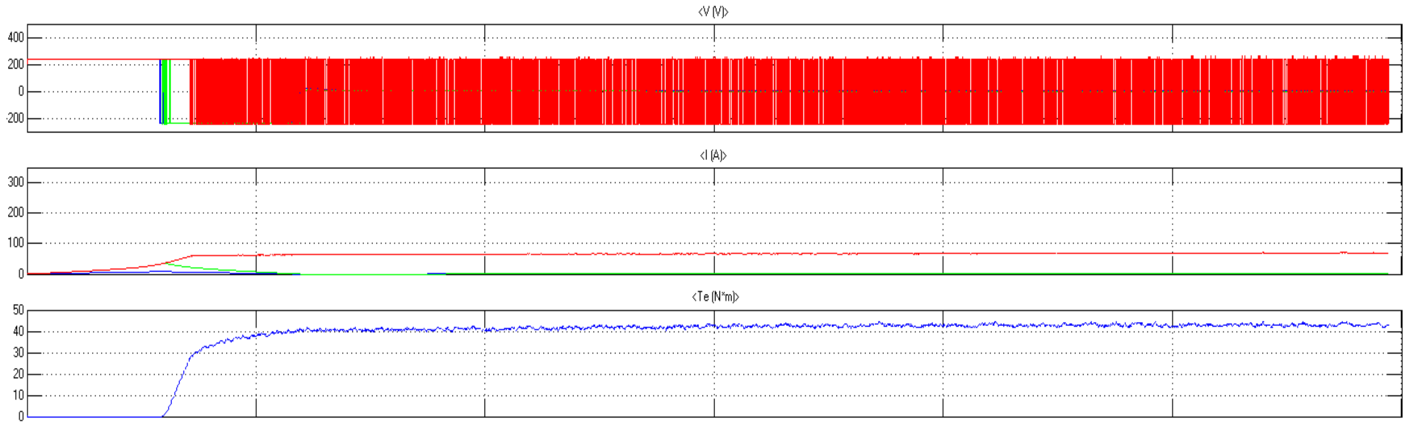

Fig. 11. Simulation results of Model Predictive Controller

Conclusion

In this paper, torque ripple and acoustic noise which is caused due to nonlinearity in electromagnetic property and winding current is reduced to the concern level by model predictive control method. When comparing the simulation results of PID Controller and MPC controller it is found that MPC controller has minimum overshoot and provide optimal control on torque ripple and winding current. PID controller response is lagging during large disturbance in magnetic nonlinearities but MPC uses predicted value which produces response close to the reference value even in nonlinearities. Model predictive controller is suitable for torque ripple reduction and acoustic noise control in SR motors.

Acknowledgement

I convey my sincere thanks to my beloved guide Dr. R. Ashokkumar.

REFERENCE

Abu-Rub, H., J. Guzinski, Z. Krzeminski, and H. A. Toliyat. 2004. "Predictive current control of voltage source inverters," IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 585–593,

Blaabjerg, F. Liserre, M , Ma, K. 2012. "Power electronics converters for wind turbine systems". IEEE Trans. Ind. Appl. 48, pp708–719.

Cortés, P., J. Rodríguez, D. E. Quevedo, and C. Silva. 2008. "Predictive current control strategy with imposed load current spectrum," *IEEE Trans. Power Electron.*, vol. 23, no. 2, pp. 612–618.

Jiefeng Hu and KaWai Eric Cheng. 2017. "Predictive Control of Power Electronics Converters in Renewable Energy Systems" vol.10,pp515

Krishnan, R. 2001. "Switched Reluctance Motor Drives: Modeling, Simulation, Analysis, Design, and Applications", Boca Raton, FL: CRC Press

Linder, A. and R. Kennel. 2005. "Direct model predictive control—A new direct predictive control strategy for electrical drives," in *Proc. Eur. Conf. Power Electron. Appl.*

Miller. T. J. E., 1993. "Switched Reluctance Motors and Their Control" Magna Physics Publishing and Clarendon Press, Oxford.

Nelder, J.A. and R.Mead. 1965. "A simplex method for function minimization,"Comput. J., vol. 7, no. 4, pp. 308–313.

Patricio Cortes M.P, Kazmierkowski , Ralph M. Kennel, Daniel Quevedo, and Jose Rodriguez. 2009. "Predictive Control in Power Electronics and Drives", IEEE trans on *Ind Elec.*10 pp4312-4324

Patricio Cortés, Marian P. Kazmierkowski Fel, Ralph M. Kennel, Daniel E. Quevedo, and José odríguez. 2008. "Predictive Control in Power Electronics and Drives" IEEE Trans. Ind. Electronics, Vol. 55, No. 12.

Reluctance Motor Drives" IEEE Trans. Ind. Electronics, Vol. 58, No. 5.

Shun-Chung Wang and Yi-Hwa Liu. 2011. "A Modified PI-Like Fuzzy Logic Controller for Switched

Silva, E. I., B. P. McGrath, D. E. Quevedo, and G. C. Goodwin. 2007. "Predictive control of a flying capacitor converter," in *Proc. Amer. Control Conf.*, New York, pp. 3763–3768.

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