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# Model Predictive Control of Starting and Running Conditions for Switched Reluctance Motor-A Review

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**ABSTRACT:** Switched reluctance motors require necessary starting for efficient operation. This paper presents a review on different control strategies of estimating the starting and running conditions. The proposed control algorithm is used for the estimation of rotor position angle for starting and running conditions. This followed by selectively reviewing the range of accepted control strategies. The model predictive control showing better performance compared to other control algorithm.

**KEYWORDS:** Model predictive control, Flux linkage, Rotor position angle and Control horizon

## I. INTRODUCTION

Switched reluctance motor gaining confidence in the industry due to simpler converter circuits and rugged construction. Induction motor is work horse of the industry and it will be replaced by switched reluctance motor. This drive may be mainly focussed on electric vehicle because of wider speed control and easier controlling aspects. To operate the drive smoothly, the rotor position is necessary. This can be achieved by providing the resolver detect logically under different running conditions for the switched reluctance machine. The major drawback of using the sensor is inaccurate positioning of rotor during starting. This affects the overall performance of the drive under critical load conditions. In Industry the preference for sensing the positioning the rotor is very meek. The cost and size of the equipment increases and may be unreliable due to increase in temperature. Many developments have done in the area of indirect rotor positioning [1]-[5]. In this paper issued concerning the starting and running conditions of switched reluctance motor is studied and review of different strategies are discussed. Prediction of rotor positioning during starting and running conditions[6]-[9]. Position is estimated using cubic spline method[10]. controller to predict the current and the required location of machine is observed. The simulation of the proposed algorithm is obtained. The initial part of the paper gives brief idea on basic modelling of switched reluctance motor shown in figure1. The review of different position estimation techniques are studied shown in figure 2A new control algorithm is proposed to by model predictive The flow diagram represents the step of the algorithm.

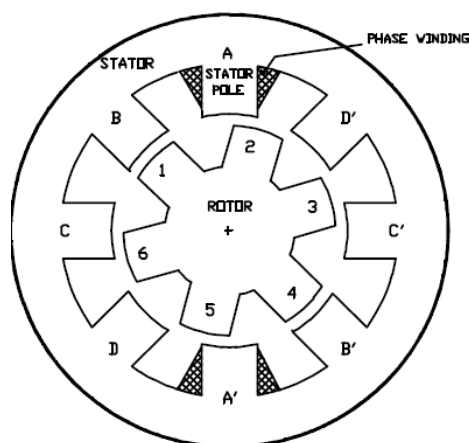


Fig 1.8/6 Switched Reluctance motor

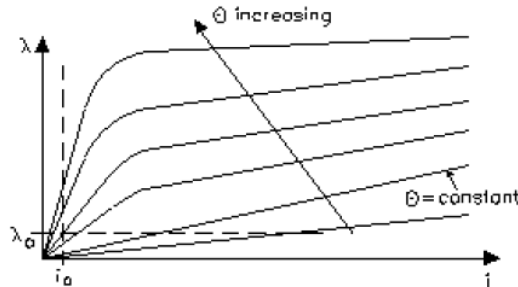


Fig 2. flux-current characteristics

### II. MODELLING OF SRM

The basic equivalent circuit of switched reluctance motor is given in the figure 3.

$$V = iR + \frac{d\psi}{dt} \tag{1}$$

We know that flux linkage is equal to product of inductance with function of theta and current.

$$\psi = L(\theta) \times i \tag{2}$$

Hence equation 1 can be represented as

$$V = iR + \frac{d\psi}{d\theta} \times \frac{d\theta}{dt} + \frac{d\psi}{di} \times \frac{di}{dt} \tag{3}$$

$$V = iR + L(\theta, i) \frac{di}{dt} \tag{4}$$

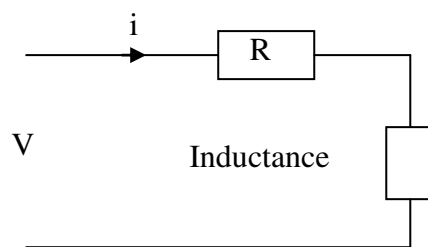


Fig 3. Equivalent circuit of SRM

### III. CONTROL STRATEGIES OF SRM

The main philosophy of rotor positioning is applying the current of certain magnitude to the phases of switched reluctance motor and observe the response corresponding to changes in variation of inductance. The inductance varies directly as the change in current with time is obtained. In unaligned rotor position the inductance is minimum and the inductance is maximum in aligned rotor position. Hence suitable method has to be devised for sensing the rotor position both in starting and running conditions. Prediction of rotor positioning during starting and running conditions is exhibited as follows. The inductance profiles of stator phases depend on rotor position. When the machine is not rotating, the signals are electrified to one particular windings at lesser interval. The excitation has to be changed to another sequence of windings as it affects the performance due to inception value of current. Generally, for the analysis purposes it is assumed that voltage drop due to resistance in the stator is neglected. Hence linear variation of inductance profile is obtained for sensing the rotor position at standstill condition. The drawback of this method is ignoring stator voltage drop and measurement noise [6]. During running conditions, the diagnostic pulse is applied to the unexcited phase. Time T1 is noted when current reaches maximum value and T2 is for maximum to minimum value. At time T1 when current reaches the maximum value the controller should excite next phase. This sequence



continues for computing the rotor position angle. Error usually observed in the final output of triggering pulses for the device and it causes lapsed time for turn-off the device. During starting conditions, the phase current with larger and lesser value of determining the inductance value is not accurate [7]. When the current value is medium and medium inductance value is observed. The positioning of rotor is observed by medium current next to the phase of maximum current. Thus this method is more accurate in determining the rotor position. For running conditions, the optimal phase of larger value of current is chosen [14]. In this methodology the minimum current is not chosen due to the corresponding torque will be minimum and the conduction loss is more. Hence accurate rotor positioning is not done. The phase current with larger value is applied to the unexcited phase of the machine used in this paper. It is shown that as rotating part in machine construction changes from aligned to unaligned position the inductance value reaches minimum. The additional current can be increased by adding external rotor for the machine [8]. Hence the current increases above the threshold value. These characteristics sense the rotor position and the proper sequence will be followed. The starting of the SRM is done by exciting all the phases [9]. By detecting the phases which carry maximum current is chosen as rotor position. The sequence with which the phase next to maximum current is identified for estimating the position for running conditions. Compute the flux linkage due to identified phase add the effect of eddy currents and mutual flux linkages [13]. Generally, the mutual flux linkages will be neglected. Now the characteristics for flux linkages and current is obtained and corresponding rotor position angle is obtained. Rotor position estimation by mathematical models is developed as follows. The rotor position estimation is done by supplying narrow voltage pulse to the phase of switched reluctance motor instantaneously [12]. The peak current in the phase is equivalent to lower inductance. Hence corresponding sequence is formulated in the lookup table depending on the rotation. Peak currents are the function of inductance. The cubic spline function is used because inductance profile is smooth. By knowing the cubic spline constants and the amplitude of current is taken with 2.5 degrees of interval as the location of poles can be estimated easily. Different methodologies of artificial intelligent techniques are illustrated by ANN and fuzzy logic control [10], [11].

Model predictive controller is new control strategy applied effectively to find the location of rotating part of machine. The main feature depicts the importance of foreseeing the variable required for the control in an effective manner and compute the control sequence to lessen the error. The inherent merit of this controller are measured disturbances can be compensated by normal feedforward method and it will be helpful when there are future references are available shown in figure 4. The major demerits are the mathematical formulation is little complex compared to conventional PID algorithm and these algorithms are useful only for slow dynamic systems. In order to use this controller a high speed processor is required like FPGA and DSP. The advantages of MPC shows that in the real system the models are non-linear in nature but it can foresee as a linear model and effectively the performance is executed. The nominal control system has enormous problem of wide set point variations; this leads to changes required for the control parameters. MPC has little variations in the set parameters and hence the control variables changes are less. The performance of the control system is reducing when the constraints are more but in MPC as the models are considered to be as linear, so it emulates any number of constraints but the time required to computation is on the higher side. The demerit of conventional control system is absence of online tuning with foreseeing characteristics. In MPC the online tuning of parameters with foreseeing feature gives enormous flexibility for updating the variables and prescribed output is obtained. [15]

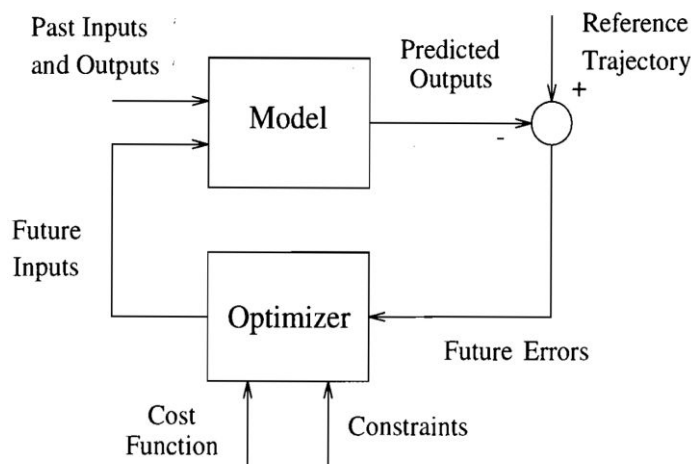


Fig 4. Basic block diagram of MPC



IV. EXPERIMENTAL RESULTS

Assume the input and output of system in the state space model is given as

$$A(M + 1) = XA(M) + YV(M) \tag{5}$$

$$B(M) = ZA(M) + EV(M) \tag{6}$$

V- input variable, B- process output variable, A- state vector variable. E- disturbance vector. The output varies with the available input hence it is assumed that D will be equal to zero. Subtract the vectors between present and future gives

$$A(M + 1) - A(M) = X[A(M) - A(M - 1)] + Y[V(M) - V(M - 1)] \tag{7}$$

$$V(M) - B(M - 1) = Z(A(M + 1) - A(M)) \tag{8}$$

The equation (3) and (4)

$$\Delta A(M + 1) = X \Delta A(M) + Y\Delta V(M) \tag{9}$$

$$\Delta B(M) = \Delta ZA(M + 1) \tag{10}$$

Now the equation (6) can be written from equation (1) in terms of A and B

$$\Delta B(M) = ZX\Delta A(M) + ZY\Delta V(M) \tag{11}$$

Mathematical formulations are obtained and in the next step predictive control of output is obtained by adjusting the future signals. The state variable vector X(K) can be obtained from the measurement and provides the necessary information. The control strategy for future signals can be given as

$$\Delta V(M), \Delta V(M + 1), \dots, \Delta V(M + N_h - 1) \tag{12}$$

N<sub>h</sub>- number of samples in the control horizon used to predict the future control strategy. The future state variables are predicted in the prediction horizon named as N<sub>q</sub>. These can be represented as

$$A(M + 1 | m), A(M + 2 | m), \dots, A(M + N_q | m) \tag{13}$$

The regulator perspective generally taken lesser than the forecast prospect. The main reason is depending on the prediction of input the output can have modified. The figure 5 depicts different sampling instants both during the past and future control. The value of m shown in the figure is depicted as present condition operation. The latest measured output, b<sub>k</sub>, and previous measurements, b<sub>k-1</sub>, b<sub>k-2</sub>... are known and are the filled circles in Figure 5. If there is a measured disturbance, its current and past values would be known. The part 3(b) shows the controller's previous moves, a<sub>k-4</sub>... a<sub>k-1</sub>, as filled circles. As is usually the case, a zero-order hold receives each move from the controller and holds it until the next sampling instant, causing the step-wise variations. In Optimization [15] the values of set points, measured disturbances, and constraints are specified over a finite horizon of future sampling instants, m+1, m+2... m+Q, where Q (a finite integer ≥1) is the prediction horizon. The controller computes K moves v<sub>k</sub>, v<sub>k+1</sub>... v<sub>k+N<sub>c</sub>-1</sub>, where N<sub>h</sub> (≥1, ≤Q) is the control horizon. The moves are the solution of a constrained optimization problem. The optimal moves are the four open circles in Figure 5, and the controller predicts that the resulting output values will be the nine open circles in Figure 5. It also maintains both the values within their constraints, v<sub>min</sub> ≤ v<sub>k+j</sub> ≤ v<sub>max</sub> and b<sub>min</sub> ≤ b<sub>k+1</sub> ≤ b<sub>max</sub>. When it's finished calculating, the controller sends move v<sub>k</sub> to the system. The system operates with this constant input until the next sampling instant, Δt time units later. The controller then obtains new measurements and totally revises its plan shown in figure 5. The regulator is acted on the system and the operation is continued until the desired set point is reached. The sampling instant has to be regrouped for the enhancement of effective governor mechanism is achieved [15]. Desired output is observed with future prospect has some short fall. Suitable training is required for different values under test is required so that the regulator is more efficient to minimize the mistakes and regulator acts under unprecedented turbulences in the system.

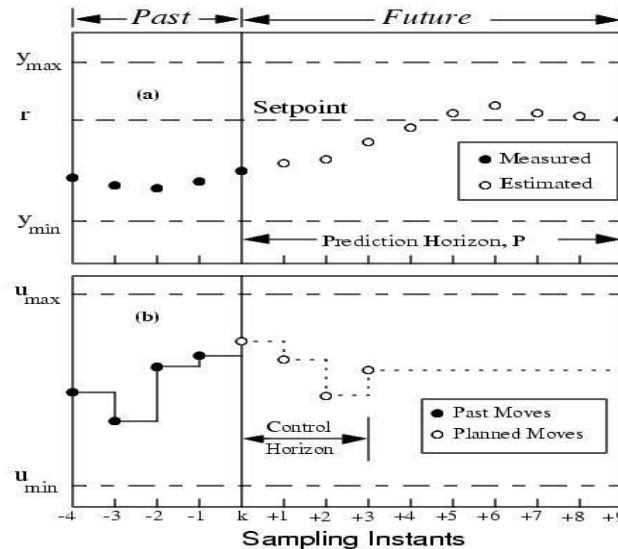


Fig.5 Working of Model Predictive Controller

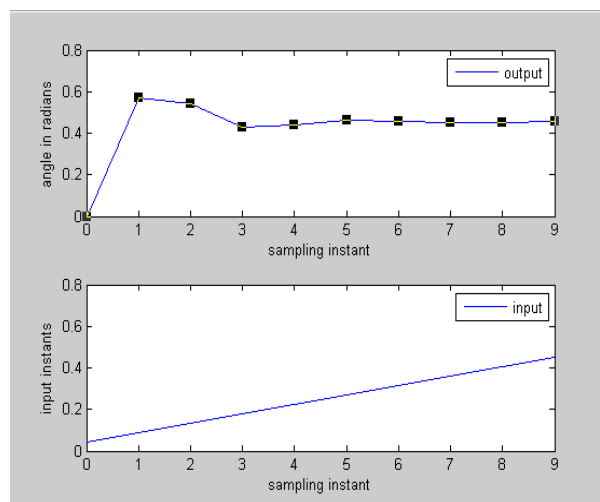


Figure 6 Prediction of input and output instants

## V. CONCLUSION

The different control strategies have been analyzed for the effective starting and running conditions of switched reluctance motor. The other methods have some shortfall in solving the problem. This can be averted by the new methodology such that future control horizon also predicted for effective operation. It is found that this methodology has to be improved by suitable training. Hence from this review of different control strategies and in future model predictive controller can be verified with hardware for practical realization.

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