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# Validation of Dynamic Equivalent Circuit of 4KW Switched Reluctance Motor

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**ABSTRACT**: This paper describes the validation of Equivalent Circuit of SR Motor for dynamic analysis. This paper gives physical interpretation of Dynamic Equivalent Circuit. A mathematical model is presented for analysis of dynamics of SR Motor. Further, Validation of the proposed model is carried out with the help of experimentation on 4KW SR Motor. Finally obtained results are discussed using output waveforms of simulation as well as experimentation.

**KEYWORDS:** Switched Reluctance Motor, Steady state, Dynamic Analysis, SRD, Equivalent Circuit

## I .INTRODUCTION

Switched Reluctance Motor (SRM) gaining popularity day by day in the industry due to its significant advantages over the conventional classical electric motors. It offers not only flexibility in operation but allows four quadrant operations. The recent developed technology lead to reduce the torque ripple, vibrations of SR Motor and audible noise due to flux linkages. The modern industry needs a programmable drive which not only saves the energy but also highly efficient. Switched Reluctance Motor is robust in construction and doesn't having any winding on rotor unlike other classical motors. Hence the speed of rotor can be increased to several times as compare to Induction Motor without any damage. The torque produced by the SR Motor is nonlinear due to its geometrical construction and hence a dynamic model is seems to be challenge [1]. Several papers are published on steady state analysis of SR Motor but less or even negligible attention paid to represent dynamic model using lumped elements with its equivalent circuit. Peter N. Materu and R.krishnan [2] present an approach to the steady-state analysis of the drive including the effects of stator winding resistance, input filter parameters.

## II. LITERATURE SURVEY

The paper by J.K.Chen et.al.[3] presents the investigation of the nonlinear dynamics of an adjustable-speed Switched Reluctance Motor (SRM) drive with pulse width modulation (PWM) technique. Nonlinear iterative mappings based on both nonlinear and approximately linear flux linkage models are derived hence the corresponding sub-harmonic and behavior are analysed. Although both flux linkage models can produce similar results, the nonlinear one offers the merit of accuracy but with the sacrifice of computational time. The paper for SRM [4] describes a fully automated method of measuring magnetization curves (flux linkage versus current and position) of Switched Reluctance (SR) motors. The experimental setup was given, which can be used in other electromechanical devices to obtain the magnetisation characteristics. The measured results of a test SR motor were also presented. J.Mahdavi. et.al.[5] describes the Pspice modeling of a nonlinear dynamics for Switched Reluctance Motor (SRM) and its drive. Yang Yugang, Guo Fengyi and Liu Yongji [6] describe the transient behavior modeling with nonlinear dynamics. The paper also presents simulation of SRD's dynamic performance. K.N. Shrinivas et.al. [7] describes the dynamic characterization by simulation of switched Reluctance Motor. The time varying parameter, namely the inductance of SRM, which solely determine the dynamic response of the machine, is rigorously evaluated using the finite element analysis package. Investigation was carried out on electrical vehicle for dynamics, its modeling and simulation by S. Sadeghi et.al.[8] using MATLAB software. The objective of this paper is to fill the apparent gap in the literature

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using a novel model of dynamic representation using Equivalent Circuit which is capable of analysis of dynamics of Switched Reluctance.

## III. NEED OF DYNAMIC REPRESENTATION OF SR MOTOR

The energy crises on one hand and cost effective production on other hand forces the industry to change their mind set for the economic solutions. The proposed work demonstrates an economical solution using Dynamic Representation of Equivalent Circuit, and hence it is used by consultants/Engineers easily. On the other part, there is limited Software Engineers / Designer available in the industries for special operations on motors. The software also not only costlier but requires license and updating cost. In view of above the proposed work provides a simple and handy solution. Performance parameter may be optimized with integrated approach (Converter and Inverter as whole).

## IV. DYNAMIC REPRESENTATION AND ITS PHYSICAL INTERPRETATION

Dynamic system deals with the change in any of the input parameters results in to change in the output performance parameters. A separate test measurement method is introduced with its physical interpretation.

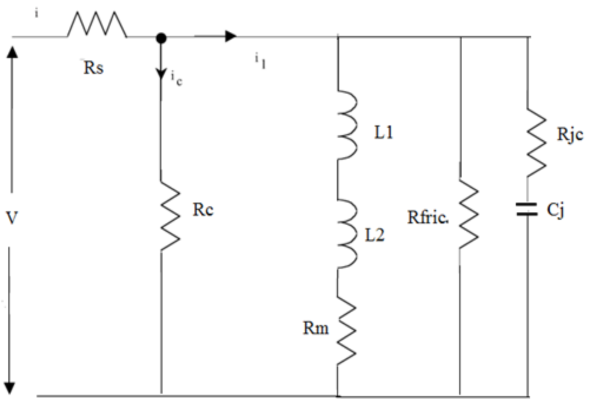


Fig. 1 Dynamic Representation of Equivalent Circuit

[In above Equivalent Circuit, Rc – Represents copper loss, L1 – Represents Self Inductance, R'm – Represents Conversion of Mechanical Energy, Rfric – Friction Coefficient and Cj – Representing Moment of inertia]
The physical interpretation is correlated with the new circuit which includes new term Ceq to represent a mechanical term representing torque due to rotor movement and inertia of the rotor and equivalent speed. From the dynamic equivalent circuit, the total circuit is an electric network representing components such as resistance, inductor, and capacitor. The Transducer and their connected mechanical systems are separated by electric-circuit element and sources. A frictional coefficient is represented by a resistive element. The parameters of Dynamic Equivalent Circuit are measurable. The Dynamic Equivalent Circuit consists of energy conversion components and can be determined by characteristics of the electrical and mechanical systems connected to its input and output terminals.

## V. THE MATHEMATICAL MODELLING

Transducer and their connected mechanical systems are separated by electric-circuit element and sources. Hence total network is an electrical network. The electromechanical equivalence is seems to be the differential equations of the systems and of the equivalent circuit. The mechanical torque or force in represented by T and its electrical equivalent is represented by i, similarly moment of inertia J is represented by its electrical equivalent C as capacitor. The dynamic modelling can be implemented using following equations

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$$J\frac{d^2\theta}{dt^2} = T_{Total} \tag{1}$$

Where total torque is given by,

$$T_{Total} = T_e - T_L \tag{2}$$

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}T_{Total} \tag{3}$$

$$\frac{d\theta}{dt} = \omega \tag{4}$$

The rotor speed is given by,

$$\frac{d\theta}{dt} = \frac{1}{J}\int T_e - T_L \tag{5}$$

$$V = R\,i + L(\theta,i)\frac{di}{dt} + \frac{dL(\theta,i)}{d\theta}\,.\,i.\,\frac{1}{J}\int (T_e(\theta,i) - T_L) \tag{6}$$

Hence, the dynamic current is given by,

$$\frac{di}{dt} = \frac{1}{L(\theta,i)}\{[\,V - (R + \omega\frac{dL(\theta,i)}{d\theta}]\,i\} \tag{7}$$

The equation (7) is useful to calculate the dynamic current of one phase of Switched Reluctance Motor. To calculate the dynamic current, a separate Matlab program is developed. For dynamic calculations, there is need to solve the equation (6) and (7) simultaneously and the data need to process using Matlab software.

## VI. SIMULATION RESULTS

A simple but yet useful hardware and software is developed and effectively implemented for measurement and data recording. In the experimentation, there is use of actual circuits which are used in the SRM Drives. Therefore results recorded are very useful for performance analysis of SRM. The modules are developed for one phase of Switched Reluctance Motor. The figure (2) shows torque verses speed with applied load.

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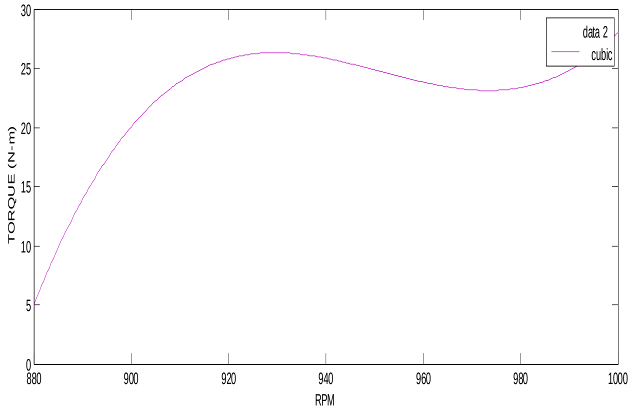


Fig.2 Torque Vs Speed Characteristics

The figure (3) shows instantaneous Torque verses Time of SR Motor. The controller has been programmed for constant torque at 1500 RPM or 1800 RPM or 3000 RPM and the input is 380V or 415V. The entire speed ranges in available for rated torque of the SR Motor. The accelerating torque is permanently available up to 150% of rated torque between 0 to 80% rated speed during the measurement.

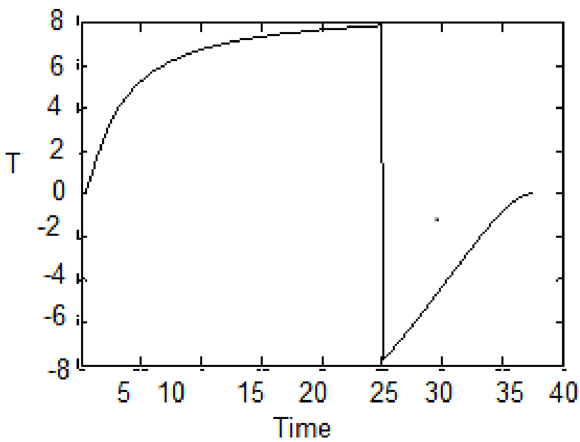


Fig. 3 Instantaneous Torque Characteristics

Figure (4) shows Speed verses Time which is gradually increasing one with the applied electrical load. The experiment is carried out for measurement of actual torque and a MATLAB program is used to plot the same. The waveforms can also be captured using digital storage oscilloscope. The motor is continuously running with applied variable load.

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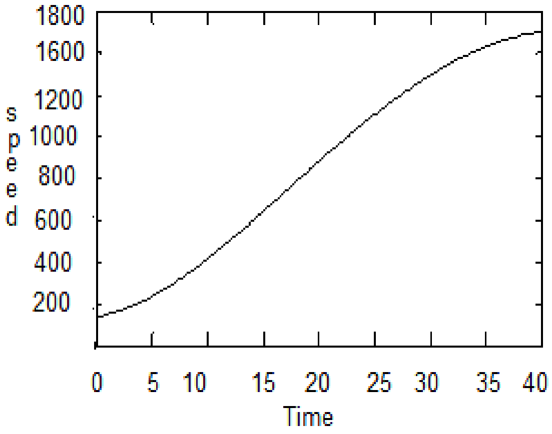


Fig. 4 Speed Vs Time Characteristics

The figure (5) shows the flux linkages characteristics of 4 KW SR Motor

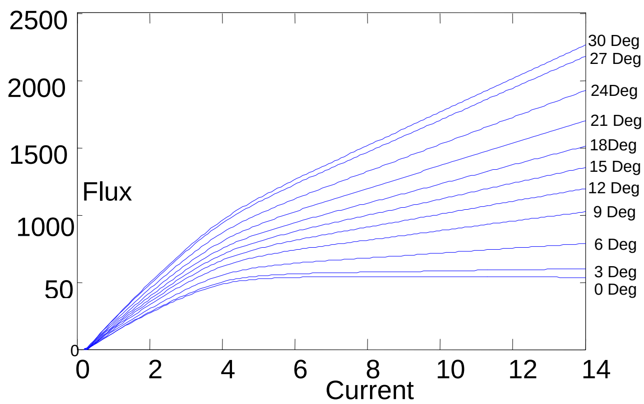


Fig.5 Flux - linkages Characteristics

The iterative readings are processed by the Matlab (using Simpson's 1/3ed rule) which calculates the flux linkage. The flux linage characteristics are plotted for various rotor positions and currents. In the figure (5) the flux linage characteristics are plotted from 0 to 30 degree rotor positions.

## VI. CONCLUSION

The dynamic equivalent circuit of SR Motor can be used for calculating the performance parameters. The dynamic characteristics are verified theoretically and experimentally. In the dynamic condition, the speed of SR Motor is varying one and torque-speed characteristics are plotted in this condition. In overall, a new innovative method is developed for performance measurement of SR Motor using Equivalent Circuit.

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