Analysis and Control of Switched Reluctance Motor Using Tuned Fuzzy Logic Control

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Abstract- *Based on the improvement of management rule base, two modified PI-like symbolic logic controllers with output scaling issue (SF) self-tuning mechanism area unit projected and verified during this paper for application within the switched reluctance motor (SRM) drive system. The motivation of this paper is to change the program complexity of the controller by reducing the amount of fuzzy sets of the membership functions (MFs) while not losing the system performance and stability via the adjustable controller gain. For both kinds of controllers, the output SF of the controller will be tuned incessantly by a gain change issue, whose price is derived from the symbolic logic reasoning, with the plant error and the error amendment magnitude relation because the input variables. This paper presents a study on the management of Switched Reluctance Motor employing a tuned mathematical logic Controller. During this paper, the structure hierarchy and machine complexity of the controller was simplified by reducing the amount of fuzzy sets within the Membership performs while not losing the system performance. The standardisation of mathematical logic Controller is achieved by development of a knowledge/rule base with scaling factors. A complete simulation, applied to the nonlinear model of Switched Reluctance Motor was studied mistreatment MATLAB and also the simulation results shows improved performance.*

Keywords- Fuzzy controller, electrically powered engines, membership function, hierarchy, amendment, mathematical logic Controller.

I. INTRODUCTION

Switched Reluctance Motor (SRM) drives have achieved important attention in high torsion capability applications among researchers throughout recent periods, attributable to advances in high-end management techniques, with powerful digital computation capability. SRMs have options like straightforward construction, flexible control modes, terribly low inertia, a high torque/mass quantitative relation and inexpensive as compared to alternative electronically controlled variable speed drives. However, attributable to the doubly salient structure and magnetic saturation, SRM acquaints with torsion ripples, vibration and noise, that ends up in the limitation SRM application. Conversely, precise management of SRM model isn't simple victimization typical methodology (like PI or PID controls) as its flux linkage, inductance, and torsion possess mutual coupling with rotor position and part current. Hence, analytical or computer-based experimental determinations square measure typically needed to characterize the magnetization curves of the SRM. once the analytical model of the controlled Optimal management of Switched Reluctance Motor victimization Tuned symbolic logic management system is imprecise or tough to model, intelligent management techniques like symbolic logic Controller (FLC) provides higher performance. Basically FLC could be a management strategy higher fitted to non-linear and time varied objects. The advantages of FLC square measure sturdy, in-sensitive to parameters changes, etc., that is applicable to SRM drive management. This paper proposes a tuned symbolic logic speed controller for SRM. The planned FLC uses the speed error and alter in speed error as input and generate constant management term, which improves system performance in steady state. during this paper, section a pair of discusses the previous works in the SRM victimization FLC; section three describes the modelling of SRM, effects of rotor position and therefore the plot of lambda versus current that characterize the machine. The introduction to Fuzzy controller is presented in section four. Section five illustrates the look of generic FLC and calibration the parameters of the membership functions and section half dozen depicts the simulation and analysis of the planned work. The results and therefore the optimum values square measure given and conclusions square measure given within the last section.

The requirements for varying-speed SRM drives embody good dynamic and steady-state responses, minimum ripple, low-speed oscillation, and lustiness. However, due to the serious nonlinearity of the magnetic force property and also the coupling relationships among flux linkage, torque, and rotor position, it's dangerous for Associate in Nursing SRM to urge satisfactory management characteristics. Therefore, new structure styles [3], [4], high performance magnetic cores [5], and accommodative management techniques [6]–[8] within the innovation and improvement of assorted SRMs are conferred increasingly in recent years. At present, the proportional, integral, and/or by-product controllers have a verified management performance for several industrial drives [9]–[11]. Supported the precise mathematical model and system operator's expertise, the PI, PD, or inflammatory disease controller may compensate system variations terribly expeditiously via the acceptable tuning of its dominant parameters. However, the performance may considerably deteriorate once the in operation condition is altered or once the parameters drift. When the precise analytical model of the controlled system is unsure or troublesome to be characterised, intelligent management techniques like formal logic management (FLC), neural network control, or genetic algorithmic program could enable higher performance. Intelligent management approaches attempt to imitate and learn the expertise of the human knowledgeable to urge satisfactory performance for the controlled plant [12]. one in all the foremost powerful tools that can translate linguistic management rules into sensible operation mechanism is that the FLC. The FLC has been found significantly suitable for controller style once the plant is troublesome to model mathematically attributable to its quality, nonlinearity, and/or impreciseness. Hence, the FLC is wide applied in a very considerable type of engineering fields these days owing to its adaptability and effectiveness [11]–[13]. it's been shown that fuzzy management will cut back hardware and value and supply higher performance than the classical PI, PD, or inflammatory disease controllers [2]–[7]. The FLC design approximates the means of knowledgeable operation intuitiveness; this makes it engaging and straightforward to incorporate heuristic rules that mirror the expertise of human experts into the controller [8].

As it is known, in recent years, switched reluctance motors (SRMs) have gained more attention in various applications requiring high performance due to the advancement in high speed processors and advancement in power electronics. Switched reluctance motors (SRMs) have been used more as alternatives to induction and permanent magnet synchronous machines in electric and hybrid electric vehicle (HEV) applications. However, rotor position sensor requirement and torque ripple are mentioned as the main disadvantages of SRM [1].

A.Guettaf in [2] proposed that the fuzzy logic control technique can be used to minimize the torque ripple in switched reluctance motor converters. It was employed with the asymmetric half bridge converter. R. Zhong in [3] described a neural network based position estimator which largely decreases the computational burden and relatively high accuracy can be achieved. And also the proposed NN works well in higher speed which exceeds more than 1000 r/min. A. Rajendran in [4] employed the H-infinity robust control technique. Controlling the speed of the motor without using any control technique was more difficult and the time to achieve stability was comparatively high. Controlling the speed of the SRM by PI controller was better, but the accuracy and the stability were affected. The performance of fuzzy based PI-controller was low when compared to H-infinity controller. Shun-Chung Wang described two rule bases to simplify the complexity of the controller by reducing the membership functions without losing stability and system performance. Both the rule bases are developed based on the practical understanding of the SRM basic behaviour, operating mode and experimental results.

L. Jessi Sahaya Shanthi in [6] discussed a novel Artificial Neural Network based rotor position estimation for the SRM motor to minimize the number of sensors used in the application. In this technique, the error is reduced by a factor of 2 when compared to others converter topologies. S. Paramasivam in [7] discusses a approach for estimation of rotor position using Artificial Neural Network and two AI techniques are used to implement various operating conditions such as motor start up, transient and steady state. S.-Y. Wang on [8] presents a novel adaptive fizzy cerebellar model articulation controller to regulate the speed of the SRM. The simulation result shows that the adaptive controller performs well in tracking ability, load disturbance rejection capability and parameter variation capacity. Shun-Yuan Wang in [9] proposed an adaptive TSK-fuzzy controller for the SRM drive system. The control schemes such as ATSKFC, fuzzy control, and PI speed control were compared and it is concluded that the ASKTFC better speed tracking capability under single quadrant, four-quadrant, and full-load operations

II. SWITCHED RELUCTANCE MOTOR

In SRM, the torsion is generated thanks to the push–pull between reluctance forces. The made magnetic force torsion is related to the variation of the machine co energy, and the co energy varies with the flux linkage, excitation current, and rotor position. The flux linkage, inductance, and torsion are highly coupled and nonlinear with the variation of rotor position and section current, and hence, its magnetization characteristics and operational behaviour are tough to decouple and model mathematically. Fig. 1(a) and (b) shows the cross-sectional profile of a four-phase 8/6-pole SRM and therefore the equivalent circuit of one section winding, severally The per section equivalent circuit of the SRM (neglecting mutual inductances) was given as

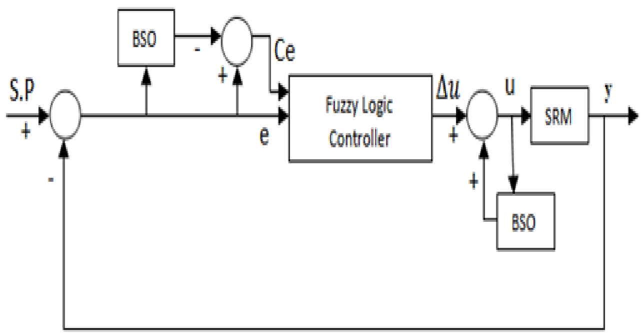

Figure 1. Block diagram of the tuned fuzzy logic controller for SRM

$$v_j = R_j i_j + d\frac{\lambda_j(\theta_r, i_j)}{dt}, j = a, b, c, d \quad (1)$$

Wherev_j, i_j and R_j are the voltage, current and resistance of phase j, respectively. cj and Lj are flux-linkage and inductance of phase j.

From the nonlinear equation (1), the driving torsion are often obtained only the part current is switched on throughout the rising amount of part inductance. From the Fig.1 it's discovered that, the saturation effects area unit most at m = 0º and minimum at higher angles as rotor approaches unaligned position.

A. Effect of Rotor Position

Rotor position data is fed back to the controller to work out the section commutation sequence, which is employed to attain optimum speed and torsion management. To implement this, FLC is meant with non-linear SRM sculptured as automotive vehicle Regressive Moving Average (ARMA

The SRM model is represented as

$$X_n = \varphi_1 X_{n-1} + \varphi_2 X_{n-2} + \cdots\ldots + \varphi_p X_{n-p} + a_1 X_{n-1} + \theta_q X_{n-1} + \cdots..+\theta_q a_{n-q} \quad (2)$$

The terms 1xn-1 through 〖 X〗 _(n-p) are the autoregressive portion of the filter. The terms associate through a_(n-q) are the moving average of the noise input method.

III. DESIGN OF FUZZY LOGIC CONTROLLER

In this section, the fuzzy management fundamentals are printed first, and then, the key purpose of self-tuning PI-like fuzzy controller (STFC) are in short reviewed. Afterward, the modified style of the projected STFC is delineated in detail.

Atlast, an improved compensating control strategy is developed in order to improve the proposed control scheme. The control scheme is discussed below[12].

A. Fuzzy management Philosophy :

A basic FLC system structure that consists of the information base, the logical thinking mechanism, the fuzzification interface, and the defuzzification interface is shown in Fig. 3. primarily, the fuzzy controller will be viewed as a man-made call maker that operates during a closed loop in real time. It grabs plant output y(t), compares it to the required input r(t), and then decides what the plant input (or controller output) u(t) ought to be to assure the requested performance. The inputs and outputs are “crisp.” The fuzzification block converts the crisp inputs to fuzzy sets, and also the defuzzification block returns these fuzzy conclusions into the crisp outputs.

B. Designing of FLC:

The PI-like fuzzy controller (PIFC) is driven by a collection of control rules instead of constant proportional and integral gains. The block diagrams of a standard PIFC Associate in Unsigned an STFC are shown in Figs. 4 and 5, severally. the most distinction between each managements is that the STFC includes another control rule base for the gain change issue α [22]. Ability is necessary for fuzzy managements to make sure acceptable control performance over a good vary of load variations regardless of inaccurate operational information or plant dynamic behaviour. There are 3 ordinarily used strategies to form a fuzzy controller adaptive: input or output SF standardization, radio frequency definition or shifting, and management rule modification. During a classical fuzzy controller, the UOD standardization of the MFs of the input or output variables will be won’t to overcome the steady-state error.

Here, a discrete-time controller with 2 inputs and one output is taken into account. From Fig. 5, the error e and alter of error Δe are used because the input variables, that are outlined as

$$e(k) = (k) - y(k) \quad (3)$$

$$\Delta e(k) e(k) - e(k-1)$$

$$= y(k-1) - y(k)$$

$$, if\ r(k) = r(k-1) \quad (4)$$

where r and y denote the reference command and plant output, respectively. Indices k and k-1 represent the present and former states of the system, severally. The management output is the progressive modification of the management signal Δu(k). The control signal is obtained by

$$u(k) = u(k-1) + \Delta u(k) \quad (5)$$

The UOD altogether membership functions of the controller inputs, i.e., e andΔe, and also the output, i.e.,Δu, ar outlined on the normalized domain [−1, 1], as shown in Fig. 6. The linguistic values NB, NM, NS, ZE, PS, PM, and atomic number 82 represent negative huge, negative medium, negative tiny, zero, positive tiny, positive medium, and positive huge, severally. On the opposite hand, the UOD for the gain change issue α (which is used to fine-tune the output SF) is normalized over the interval [0, 1], as shown in Fig. 7. The linguistic values ZE, VS, S, SB, MB, B, and VB represent zero, very small, small, small big, medium big, big, and extremely huge, severally. Here, aside from the 2 fuzzy sets at the outermost ends (trapezoidal MFs are considered), symmetric triangles with equal bases and five hundredth overlap with adjacent MFs are chosen.

C. Tuning of FLC:

The reference signal was generated employing a signum perform and this signum performing of ±10% variation akin to the desired variation in speed. The Mean Absolute Error (MAE) of the system calculated mistreatment eqn.

$$Mean\ Absolue\ Error = \sum_{k=1}^{N} \frac{|(ref-output)|}{N} \quad (6)$$

is employed because the performance lives.

The mechanical equation for SRM drive can be written as,

$$T_e = J_{m\omega_r^{\cdot}} + B_m \omega_r + T_L \quad (7)$$

Where vr is the rotor speed, is the command current of the SRM, as ¼ 2Bm/Jm, Bs ¼ Kt/Jm and Cs ¼ 1/Jm are composed of parameters of SRM. In real time ap The complete formula consists of 2 stages. Stage1 illustrates a formal logic primarily based current compensation theme and stage2 options the management formula that limits the speed of rise and fall of the voltages to suppress the ripples caused throughout the section commutation interval. within the stage1, an incremental price is other to the antecedent obtained reference speed. The correction term is obtained by a fuzzy rule base. The rule base relates the rotor position and therefore the normalized error between the desired and therefore the actual voltage.

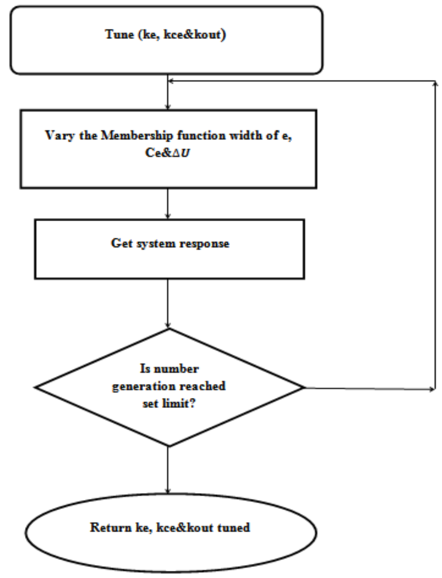

Figure 2. Tuning of coefficients – Flow Chart

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D. Gain Tuning Strategy

The FLC while not scaling gain calibration mechanism includes a drawback, i.e., because the controller style is finished, the outlined domain of the input and output variables is mounted. This may result in long subsidence time and oscillation round the planned speed once the system approaches the steady state. This is caused by low controller resolution once the speed error is small. so as to get satisfactory performance, the Universe of Discourse(UOD) of the controller ought to be adjusted in keeping with the operative point. Therefore, the fuzzy controller, which might modification UOD by calibration scaling gains through an eternal and nonlinear variation of the change issue, is developed. Here, the eye is focused on the calibration of output scaling gain as a result of it is appreciate the controller gain, and output-gain regulation plays a dominant role because of its robust impact on the performance of the controller. The self-adjusting mechanism of the planned fuzzy controllers is delineating as follows.

As the said exploration for the step response of the SRM is shown in Fig. 11, integration the 2 rule bases into a union rule base to alter the system is possible. The basic principles and therefore the style tips area unit explained as follows:

1) a special linguistic price of the controller output ought to be outlined for every distinct combination of linguistic values for Δu and α, as shown in Tables I and II. For example, once e is metal and Δe is NS, then Δu is PM (Table I) and α is VS (Table II), that the combine (PM, VS) forms a definite combination. From the linguistic combine (PM, VS), we have a tendency to deduce that the trend of controller output should be positive little, i.e., a sway rule are often outlined as follows: If e is metal and Δe is NS, then the combined output Δuαi is notation. Exploitation a similar principle, the rule bases of Δu and α are often integrated into a changed combined rule base.
2) Variation impact of Input and Output SFs: SF modulation is one in every of the foremost used solutions to boost the performance of a fuzzy controller. The look of the SFs, significantly the output SF, is extremely crucial in Associate in Nursing FLC due to their influences on the performance. Take the STFC shown in Fig. 5 as Associate in nursing example. Its relationships between the SFs and therefore the input and output variables of the controller square measure shown in (15)–(17). Converting e, Δe, and Δu into linear unit, ΔeN, and ΔuN by the scaling gains, severally, means they're transferred from the actual UOD into the interval [−1, 1] (normalization). The effect of SF adjustment is reminiscent of extending or shrinking the actual UOD of the input and output variables.
3) Self-Tuning Mechanism: nowadays, there square measure still no well-defined and general ways for gain standardisation to get the optimum response as a result of the determination of the optimum values of the adjustable parameters needs the information of a precise model of the plant. Moreover, the sensible testing results show that the impact of input SF standardisation has lesser impact on system performance than output SF standardisation, and both types of SF standardisation can increase the system quality any. Therefore, solely output SF standardisation is adopted within the planned two changed STFCs.

IV. EXPERIMENTAL RESULTS

A. Simulation Results

Simulation was applied on MATLAB/Simulink to verify the practical implementation of the planned

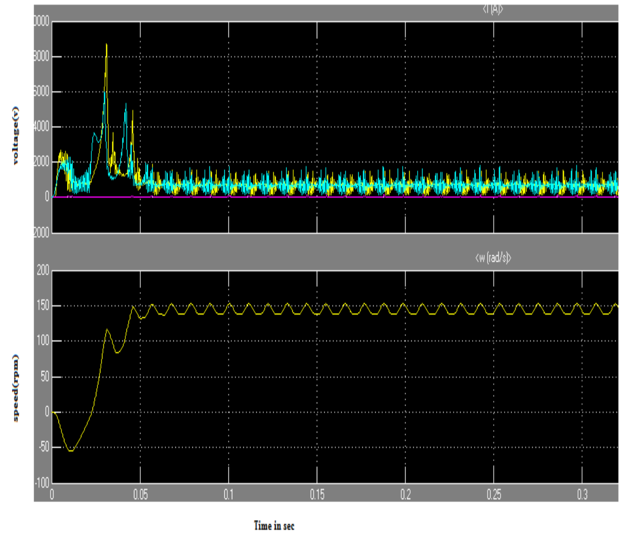

Figure 3. Simulation result of FLC

fuzzy controller for the single-phase electrical converter. Fig. ten presents the reference signal for the SEPIC's output, wherever it tracks the maximum power. The results introduced in Fig. twelve belong to voltage and current signals of the traditional PI controller. The PI controller is chosen for comparison due to its severe use in business applications [36]–[38]. The convertor conditions utilized in the PI controller area unit identical as that used in the FLC. The PI controller is intended well wherever it's optimized to provide minimum error signal. However, it clearly appears that the signal cannot follow the reference signal in Fig. 10 fast. what is more, the output voltage doesn't lie on the maximum power curve. Moreover, great deal of power can be lost thanks to the PI controller. the explanation behind this that the PI controller addresses 2 main issues: the steady state error and also the most overshoot. If one want specialize in time, the by-product controller should be value-added to become the PI–derivative (PID) controller, however this causes instability within the steady state. Therefore, the PI controller cannot follow correct changes in reference signal effectively.

B. Experimental Results

A model was designed to analyze the performance of the proposed FLC-based control theme for the convertor and electrical converter for period PV applications. The ability electronic switches utilized in this paper are insulated-gate bipolar semiconductor device (IGBT) modules GT50J325. The controllers of the dc–dc power converter and therefore the dc–ac electrical converter are enforced victimisation the DSP of TMS320F28335. The PV module's ratings, whereas the foremost parameters of the example.

V. CONCLUSION

In this paper, two changed fuzzy PI-like controllers with gain self-tuning mechanism by neutering a gain change issue has been devised and tested through an experiment for the SRM drive system. 2 changed rule bases area unit designed to alter the program quality of the controller by reducing the quantity of fuzzy sets of the membership functions while not losing the system performance and stability victimisation the adjusting strategy of the controller gain. each rule bases area unit designed supported the fuzzy management rules, that area unit derived from the sensible understanding and information of the SRM's basic behaviour, operating mode, and experimental expertise. Here, attention is focused on the adjustment of the output SF as a result of output-gain regulation has higher impact on the performance and stability of the system. Additionally, the projected controller also can simplify the quality of the system attributable to its additional concise design.

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