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PI Based Speed Control of Induction Motors Employing Model Predictive Flux Control

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ABSTRACT
Model-based predictive torque control is a new kind of MPC for AC motor drives that has drawn a lot of interest from the research community lately. When compared to conventional induction motor drive control strategies like Direct Torque Control and Field-Oriented Control, Maximum Power Take-off offers many benefits, including simpler implementation, the ability to incorporate multiple objectives into a single cost function, an optimization-based solution, and the ability to account for system constraints and nonlinearities. The torque and stator-flux magnitude reference values and their future values at the next sampling instant are where the cost-function errors lie. On the other hand, the cost-function might potentially include other goals. Using all of the permitted switching states, the induction motor drive mathematical model predicts the future values. This work also discusses about a novel approach Dynamic Speed Control of Induction Motors Employing Model Predictive Flux Control (MPFC) and Volts by Frequency (V/f) Techniques. The gate pulse control for two-level-three-phase inverter at the AC side is controlled using proportional integral controller.

Keywords – Model-based predictive torque control (MPTC), induction motor drive, Model Predictive Flux Control (MPFC), Volts by Frequency (V/f) Techniques, proportional integral (PI) controller, pulse width modulation.

I. INTRODUCTION

In industry, more than half of the total electrical energy produced is consumed by electric motors [1]. Among several types of electric motors, three-phase induction machines (IMs) occupy a prominent place. But, dynamic behaviour of the machine is often very complex particularly in context to torque and speed [2, 3]. Numerous control techniques have been developed by the researchers to make. The earliest method for controlling electrical devices was scalar control, which involves maintaining a constant V/f ratio to maintain a constant flux within the machine [4]. It is distinguished by its straightforward structure, which is based on the stator flux-control, and ease of installation [5]. On the other hand, the flux oscillates vigorously and with significant amplitudes during the transient states, either at machine startup or when the machine's rotation direction changes [6]. The torque and speed quality will be affected by these oscillations, which will lower the transient-state performances. As a result, this kind of control is limited to uses like ventilation and pumping where there is little speed variation.

As the time passes, control gets more mature and Field Oriented Control (FOC) method was developed to control transient torque [5]. Another one Direct Torque Control (DTC) was introduced which has remarkable dynamic performance as well as good robustness with respect to the variations of the parameters of the machine.

Model-based predictive torque control, or MPTC, is a new kind of MPC for AC motor drives that has drawn a lot of interest from the research community lately [7]. When compared to conventional induction motor drive (IMD) control strategies like Direct Torque Control (DTC) and Field-Oriented Control (FOC), Maximum Power Take-off (MPTC) offers many benefits, including simpler implementation, the ability to incorporate multiple objectives into a single cost function, an optimization-based solution, and the ability to account for system constraints and nonlinearities. The torque and stator-flux magnitude reference values and their future values at the next sampling instant are where the cost-function errors lie. On the other hand, the cost-function might potentially include other goals. Using all of the permitted switching states, the IMD mathematical model predicts the future values. This work also discusses about a novel approach Dynamic Speed Control of Induction Motors Employing Model Predictive Flux Control (MPFC) and Volts by Frequency (V/f) Techniques.

It explores the integration of MPFC with V/F control to enhance dynamic response and efficiency. The V/F control method maintains a constant voltage-to-frequency ratio, ensuring stable motor operation across various speeds. This work also presents the comparison of MPFC based on PI and hysteresis controllers.

II. MODEL PREDICTIVE FLUX CONTROL (MPFC)

This is an advanced mastery technique improves the efficiency of induction motors by anticipating future states and optimizing control actions in real-time. The MPFC utilizes a mathematical representation motor analyses the functioning of the system current condition to forecast future behavior, including rotor flux, stator current, and torque [8]. These variables are predicted by MPFC, which then sets up the best switching signals for the inverter as shown in figure 1. This makes sure that the motor works well even when the load changes. Improved dynamic responsiveness of induction motors [9]. Traditional control methods such as PID controllers do not offer this advantage. frequently face difficulties in adjusting to rapidly changing operating conditions, resulting in inefficiencies. MPFC consistently modifies control inputs to ensure peak performance. This approach improves both the speed and torque response while reducing harmonic distortion and energy losses linked to motor performance.

Furthermore, MPFC facilitates accurate flux regulation, guaranteeing that the motor operates within its designated parameters while achieving the necessary performance levels. This renders it exceptionally appropriate for applications that necessitate dynamic motor control, including industrial drives and renewable energy systems.

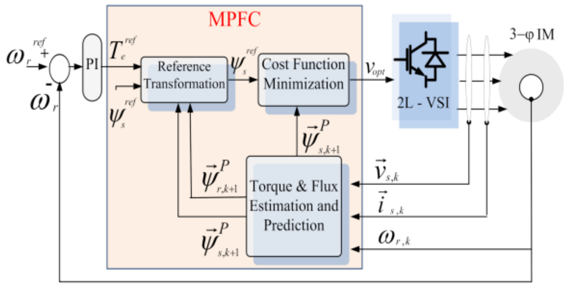

Fig. 1 Schematic of model predictive flux control of IM

III. PROPOSED WORK

Induction Machine are widely used as single-phase Induction Motor (SPIM) and three-phase Induction Motor (TPIM) [10]. The SPIM are widely adopted for domestic purposes like pumping, mixer, vacuum, fans, and now a days it is also used in two-wheel as well as four wheels electric vehicles. The TPIM is widely used in commercial as well as industrial applications such as conveyors, lifts, cranes, pump house, lathe machine, crushers, mills, exhaust fans etc. The reason behind is wide spread application is its design simplicity, high efficiency, low or minimum maintenance, construction id rugged and is very cheap also [11]. However, the advantages mentioned also have some inconvenience since, IM suffers from very fragile dynamic behaviour [12]. The reason behind this is, the mathematical modelling of IM comprises of a system of nonlinear equations, having multivariable which are strongly coupled. The variation in one parameter effects the other directly or indirectly. Also, some of its variables, are not measurable like flux [13]. To obtain a robust and precise control of IM more advanced algorithms are required which can control the torque and flux of the IM. Earlier, voltage-frequency control was used as static control technique which keeps the stator flux constant. This technique is simple in design but for the direction change of current, flux oscillates strongly. Hence it has poor dynamic behaviour [14]. Field oriented control technique is developed for transient control of stator torque. This is an indirect type of control which provides a decoupling between stator flux and rotor torque. In early 1980, a very robust and effective direct control method was developed which is Direct Torque Control (DTC) [15]. This is a very popular IM control method which is capable of control static as well as dynamic behaviour of IM.

But control is very complicated and response is slow. This work also discusses about a novel approach Dynamic Speed Control of Induction Motors Employing Model Predictive Flux Control (MPFC) and Volts by Frequency (V/f) Techniques.

It explores the integration of MPFC with V/F control to enhance dynamic response and efficiency. The V/F control method maintains a constant voltage-to-frequency ratio, ensuring stable motor operation across various speeds. MPFC employs a dynamic model to forecast the motor's future state. The system enhances control actions in real-time, allowing the motor to swiftly adapt to load fluctuations and uphold stability amidst changing operating conditions. This guarantees accurate regulation of the motor's flux.

The V/F control technique ensures a consistent ratio between voltage and frequency, which promotes stable motor operation at different speeds. This method effectively avoids magnetic saturation in the motor, enhancing its performance across various operational conditions. V/F control helps in generating gate signals of the VSI by accurately tracking the reference signals and feeding them to PI-controller. In place of PI controller, hysteresis controller can also be used [16]. But hysteresis controller has high ripples in torque and stator side AC-current a comparative analysis between PI and hysteresis controller is presented in table-1.

Table-1 Comparison of PI and Hysteresis controller

Parameters	Controllers	
	PI	Hysteresis
Oscillations in Torque	1	3
Settling time for speed	0.1 sec	0.12 sec
Ripples in stator current	Low	High

IV. SIMULATION RESULTS

This paper presents a simulation model for the control of an induction motor using Model Predictive Flux Control (MPFC) and Volts per Frequency (V/f) techniques implemented in MATLAB/Simulink as shown in figure 2. This model offers a thorough depiction of the dynamic control system, facilitating precise testing and evaluation of the control strategies across different operational scenarios. The model incorporates multiple subsystems, such as the induction motor model, the MPFC and V/F control blocks, a proportional-integral (PI) controller, and a 2-level voltage source inverter (VSI). The simulation model provides a reliable framework for evaluating the performance of the MPFC-based V/F control system used in induction motors. The system achieves efficient and precise motor control by incorporating dynamic real-time adjustments via MPFC and maintaining a constant voltage-to-frequency ratio. The simulation outcomes confirm the system's efficacy in industrial settings where dynamic speed and torque regulation are essential. The simulation parameters are fed in the form of m.code which is given below;

```
%Supply DC Voltage
Vdc=220;
%Machine Parameters
 J=0.02; (Inertia constant)
 Rs=0.813; (Stator resistance)
 Rr=0.531; (Rotor resistance)
 Lr=0.1088; (Rotor inductance)
 Ls=0.1063; (Stator inductance)
 Lm=0.1024; (mutual inductance)
 P=2; (pole pairs)
 %Electrical Time Constants
 ts=Ls/Rs;
 tr=Lr/Rr;
 %Constants in equation
 sigma=(1-(Lm^2)/(Ls*Lr));
 kr=(Lm/Lr);
 ks=(Lm/Ls);
 r_sigma=Rs+Rr*(kr^2);
 t_sigma=(sigma*Ls)/(r_sigma);
 delta=1/((Ls*Lr)-Lm^2);
 set_speed=500; % in rad/s
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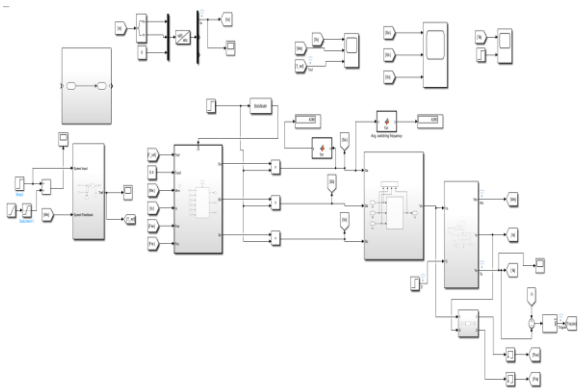

Fig. 2 MATLAB simulation model of proposed MPFC based IM

Proportional-Integral Controller (PI) block regulates the speed by reducing the discrepancy between the reference speed (Tref) and the actual speed (Wm). The PI controller generates a control signal that guides the V/F control, enabling the motor to adjust its input voltage and frequency. The PI-controller block is shown in figure 3. Error Calculation determines the discrepancy between the target speed and the actual motor speed, enabling the PI controller to make real-time adjustments to the control inputs.

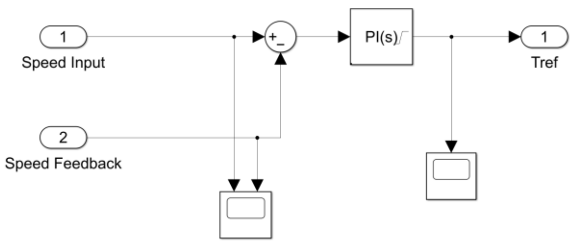

Fig. 3 Simulated Design Logic for PI Based Speed Controller

The Voltage Source Inverter (VSI) produces switching pulses across three phases as shown in figure 4 (red, blue, and green) to regulate the operation of the induction motor. These pulses are generated using pulse width modulation (PWM) techniques, effectively transforming the DC input into an AC output while maintaining both voltage and frequency parameters. The differing widths of the pulses signify the modulated signals that regulate the motor's speed by preserving a consistent voltage-to-frequency ratio (V/f control).

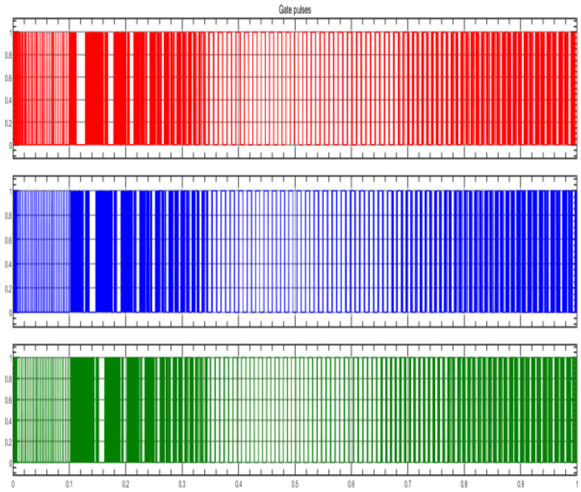

Fig. 4. Switching Pulses for VSI

The figure 5 depicts torque variations as the motor responds to changes in load and speed. The torque curve illustrates an initial transient phase characterised by a rapid increase in torque to meet the load requirements, subsequently leading to a stabilisation period. As the speed varies and the motor transitions to a steady-state condition, we observe a minor reduction in torque. The middle graph depicts the motor's speed, showing a gradual increase until it attains the desired operational point. The gradual increase in speed aligns with the control system's capacity to adaptively modify the voltage and frequency according to the motor's requirements. The speed curve illustrates the system's capability to facilitate an efficient ramp-up of the motor while preserving stability. At the bottom, the control system presents the reference torque (Tref) as a constant, serving as its target. The upper graph illustrates the measured torque and evaluates it against this reference point. The strong correlation between the actual torque and Tref demonstrates that the control system is successfully managing the motor’s performance to meet the intended output.

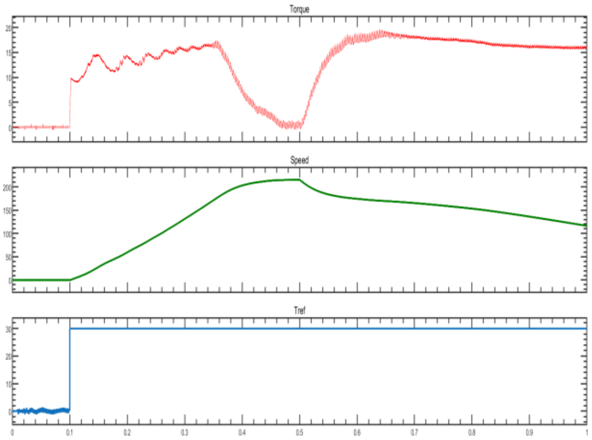

Fig. 5 Torque, Speed, and Reference Torque Comparison

Figure 6 shows how the stator current changes over time, showing changes in frequency and amplitude caused by the Model Predictive Flux Control (MPFC) and V/F methods that were used. At first, the current exhibits temporary oscillations as the motor responds to variations in speed and load, subsequently transitioning to a more stable sinusoidal pattern. The central segment emphasises a decrease in current amplitude, suggesting fluctuations in load or variations in speed. With the adjustments made to the control system, the stator current returns to a stable state, ensuring smooth operation while minimising harmonic distortion.

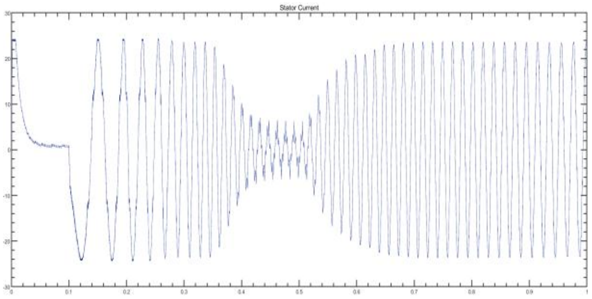

Fig. 6. Current Waveform of the Stator

V. CONCLUSION

The investigation into dynamic speed control of induction motors using a PI-based V/F control method combined with a voltage source inverter (VSI) demonstrated significant improvements in motor performance and operational efficiency. The integration of Model Predictive Flux Control (MPFC) and Volts per Frequency (V/f) control techniques for the dynamic speed control of induction motors has demonstrated significant improvements in motor performance and operational efficiency. Throughout the research, the focus was on addressing the limitations of traditional control methods by introducing an approach that not only maintains a stable voltage-to-frequency ratio but also optimizes motor response to dynamic load variations. By predicting future motor states, the MPFC method enhances the motor's dynamic responsiveness, while the V/f technique ensures a consistent flux in the motor, preventing magnetic saturation and ensuring reliable performance.

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