A Robust Auto Tuning Speed Control of Permanent Magnet Brushless DC Motor

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Abstract-**Permanent Magnet Brushless DC (PMBLDC) motor exhibits nonlinear behavior due to its friction, inertial variation, saturation and nonlinear coupling between motor current and rotor speed. Such uncertain and time varying system dynamics entitle the auto tuning speed control strategy for PMBLDC motor. The self tuning speed control of PMBLDC motor is subject to stringent problems because the usual controllers are not robust against the inertial and load variations. This paper aims to design and implement a novel auto tuning controller which is robust against load and inertial variations. Tests were performed on the PMBLDC motor simulation model, which provided valuable practical experience to implement the proposed tuning technique.**

Keywords: Auto tuning, robustness, PMBLDC motor, speed control

I. INTRODUCTION

PMBLDC motors and their control drives are penetrating into the market of home appliances, HVAC industry and automotive applications in recent years. They are characterized with high efficiency, silent operation, compact form, reliability and low maintenance. However PMBLDC motors are unstable in their operation. For very slow, medium, fast and accurate speed response, quick recovery of the set speed is important keeping insensitiveness to the parameter variations. In order to achieve high performance, many conventional control schemes are employed [1].However PMBLDC motor control and drives are complex nonlinear, they are still controlled with classical PI/ PI control structures, which are tuned to give good results only around a fixed operating point. Under these circumstances, to obtain the optimal response over the entire operating range, on-line adaptation or auto tuning of the controller is required, and several methods have been proposed in the last decade [2], [3, 4]. This has attracted extensive researches in the field of control engineering, especially in the areas of tuning. In [5], the existent types of adaptive techniques are classified based on the fact that if the process dynamics are varying, then the controller should compensate these variations by adapting its parameters.

It has been found [6] modern concepts like state observer and optimal controllers can furnish significant reduction in speed error, when applied in place of External PI controller in the outer speed loop, in conjunction with internal current loop PI controller, that is very effective for rejection of the considerable load torque ripples. The decisive setback for effective design of speed control of PMBLDC motor is tuning, since the motor along with the drive is a non linear uncertain and time varying, Explicit gain scheduling controller is generally used to accommodate for the predictable nonlinearity, adapting the PI parameters with the inertial load variations. However the unpredictable changes in inertial load variations effect the important change in process dynamics, which require suitable tuning and retuning on the PMBLDC motor drive during its life. Thus this work has been embarked on to devise a new self tuning control method [7,8] with a special attention to the robust speed control of PMBLDC motor [9]. The key idea of this work is to equip the existing PI elements with self-tuning capacity. Since the speed set-point is constant under normal operating conditions, generally there is not sufficient excitation for the closed loop identification of the PMBLDC motor drive. Then the self tuning mode is only activated on purpose by superimposing opportune artificial excitation on speed set points, when tuning or retuning is required.

In traditional control of configuration of Fig.1 the external controller when operating in self tuning mode is defenseless to the controller saturation, because the output variable of the external controller is generally not in saturation simultaneously with the motor current. This is a coordinated control system made from an outer speed control loop and an inner current control loop. The inner current control loop is much faster in response than the outer speed control loop, this pursue from the fact that the inner loop is characterized by the rather small armature circuit time constant (10-50ms), while the outer loop is characterized by the much larger mechanical time constant of the motor (200-1000ms).

In this paper, a new self-tuning method for conventional control configuration of PMBLDC motor is presented which is fully robust to any anomaly affecting the inner loop, in particular can properly work in self tuning mode while the final control variable undergoes saturation conditions for arbitrary time intervals

II. CONVENTIONAL CONTROL SCHEME

The emblematic control scheme of PMBLDC motor with speed and current loop is shown in Fig.2. An alternative control structure is considered in Fig 3 that is capable of making the outer speed loop behavior fully robust against any change in the behavior of the inner current loop $G_{icl}(s)$

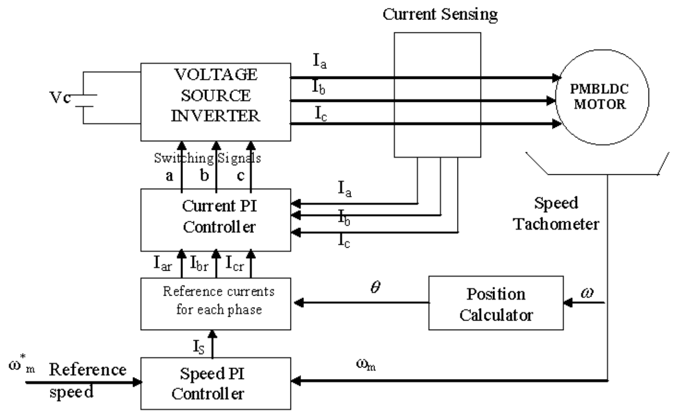

Fig.1. Block diagram of PMBLDC motor drive.

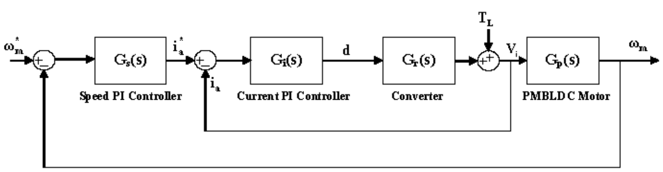

Fig.2. Conventional cascaded control diagram of PMBLDC motor drive

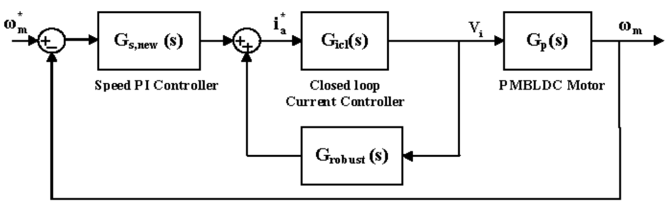

Fig.3.Block diagram of robust scheme

The structure Fig.3 is a novel alternative to the conventional control scheme as shown in Fig.2 provided that

$$G_{s,new}(s) = \frac{G_{\omega cl,ideal}(s)}{G_p(s)} \tag{1}$$

$$G_{robust}(s) = G_{\omega cl,ideal}(s)$$

Where $G_{\omega cl}(s)$ is the designed closed loop transfer function from ω_m* to ω_m with the inner loop transfer function $G_{icl}(s) = 1$. It is easy to show that, when the inner closed loop transfer function from ω_m* to ω_m takes a generic value

$$G_{icl}(s) = \frac{G_i(s)G_r(s)}{(1+G_i(s)G_r(s))} \tag{2}$$

Then the scheme of Fig.3 determines the following input output relationship for the outer loop

$$\omega_m = G_{\omega cl}(s)G_{icl}(s)\omega_m^* + (1 - G_{\omega cl}(s)G_{icl}(s)) \tag{3}$$

Where it appears that the only consequence of $G_{icl}(s) \neq 1$ is that the closed loop transfer function of the outer loop is simply multiplied by $G_{icl}(s)$

These results have been proved by an analytic study of the equations that describe the control action in terms of the input variables. It is well known that, PI controller for conventional control scheme can be simple to implement in practice. To satisfy the demand for easy to use the PMBLDC motor drive system, auto-tuning technology has been applied from a practical point of view

III. SELF TUNING SPEED CONTROLLERS

The manual tuning of controllers in cascade loops is a time-consuming task. Many kinds of auto-tuning technology have been proposed so far [10]. To meet the standardization requirements for tuning of speed controllers are designed based on the fixed-structure process models. PI controllers can satisfactorily be tuned based on the following process model:

$$G_m(s) = \frac{1}{m_0 s^2 + m_1 s + m_2} \tag{4}$$

Where $G_m(s)$ denotes the model of the PMBLDC motor and m_0, m_1 m_2 are the model parameters to be estimated from the input output data. An effective self tuning strategy for PI controller has been developed using time delayed identification technique(TDIT) [12] and simple synthesis criteria essentially based on the cancellation of the poles of the standard model can be done with reference to the speed control scheme shown in Fig.2.To enhance standardization, the self tuning strategy based on $G_m(s)$ is associated to any individual PI algorithm, independently of the role played by the controller itself. The only data asked to the user for the synthesis are the phase margin and the maximum control bandwidth.

The self-tuning PI controller has widely been tested in different inertial load variations, showing very good performances even for processes with a dynamic response significantly different from (1). In the configuration of Fig.4 the parameter estimator TDIT of the external PI controller considers $\Delta\omega_m/\Delta I_a$ to identify the speed response. This works properly when the internal loop control variable is not in saturation otherwise set point to the current controller may continue to vary. However its variations can not determine any response of the process variable ω_m so that the estimator TDIT receives contradictory information and produces totally wrong parameters estimation. Avoiding this kind of parameter divergence, a logical signal can be used that stops parameters estimation that when V_i is in saturation and may cause relevant information to be lost in transient conditions. On the contrary the cascade control scheme of Fig.3 can be equipped with self tuning capacity without any particular problem with regard to saturation and without any additional logical function.

Assume that the process part $G_p(s)$ be modeled by (4).Then the closed loop response $G_{\omega cl}(s)$ is naturally assumed as the time delay second order system:

$$G_{\omega cl}(s) = \frac{e^{s\tau}}{b_0 + b_1 s + b_2} \tag{5}$$

Where b_2 is the inverse of the gain of the speed measurement system, i.e. Tachogenerator T_g. Since $G_m(s)$ is a model of $G_p(s)$ its identification will be performed by considering the signals ω_m* and ω_m of Fig.4 as the input and output signals. The parameters b_0/b_2 and b_1/b_2 of $G_{\omega cl}(s)$ are easily chosen with the following criteria. The damping ξ_ω of $G_{\omega cl}(s)$ should be the maximum between the lower bound ξ and the estimated ratio ξ_ω of $G_m(s)$. The natural frequency of $G_{\omega cl}(s)$ will be proportional to the one of $G_m(s)$ through a user defined speed-up factor $\alpha_s > 1$

IV. Self tuning robust speed controller

In the arrangement of Fig.4, the model to be estimated corresponds to the PMBLDC motor response from the actual input current i_a to the corresponding speed ω_m of the outer loop. Thus the saturation of inner loop control variable does not affect in anyway the estimate $G_m(s)$ the only effect of the saturation could eventually be that of blocking input excitation of the process under estimation. Observe that the control concept expressed is quiet general being its application allowed for all asymptotically stable process model $G_m(s)$.

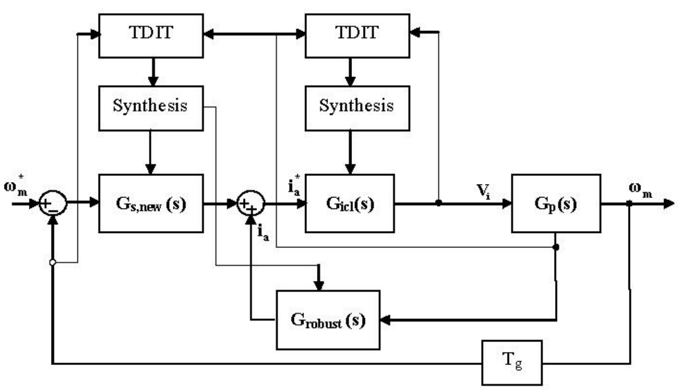

Fig.4.Auto tuning robust speed control scheme

V. Results and Discussion

The PMBLDC drive system with the conventional and the proposed robust control schemes have been simulated with MATLAB. Speed response to the step change of reference value of 2000rpm for various inertial loads $J=J_n$, $J=0.5J_n$ and $J=2J_n$ are shown in Fig.5 and Fig.6. To make the comparison more objective the PI/PI control and the robust cascade control

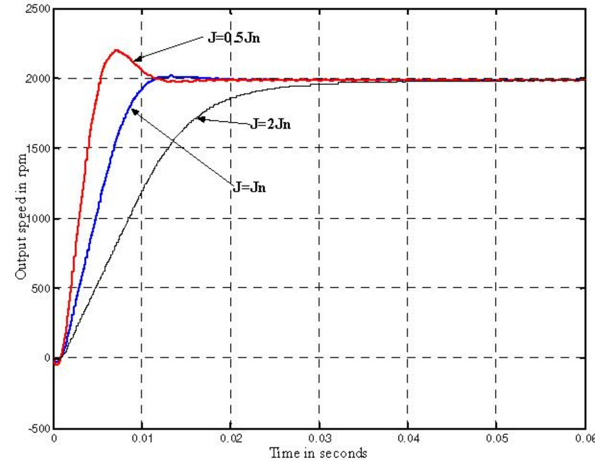

Fig.5 Simulated speed responses for a step change in input and moment of inertia change in the drive for conventional scheme.

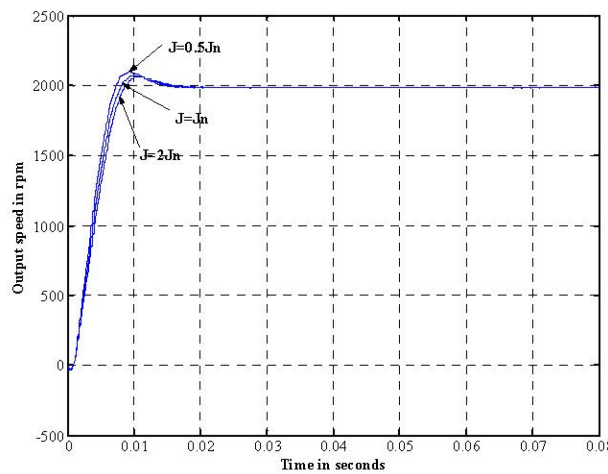

Fig.6 Simulated responses for a step change in input and moment of inertia change in the drive for robust scheme

were tuned so as to have the same performance in nominal conditions. In both cases excitation of the self tuning controls was provided by applying a step change in input to the speed. The superiority of the proposed method is improved robustness against inertial load variations, evident from the Fig.5 and Fig.6. This is attained imposing that the Bode diagram magnitude of the closed loop transfer functions take the identical value at an appropriate frequency. If there is any resonance condition, then the appropriate frequency is Resonance frequency, otherwise, cut-off frequency. The performance of the robust auto tuning controller is even better demonstrated in Fig.7 and 8.where the estimated process models in frequency domain are obtained for conventional PI controller and robust auto tuning controller respectively.

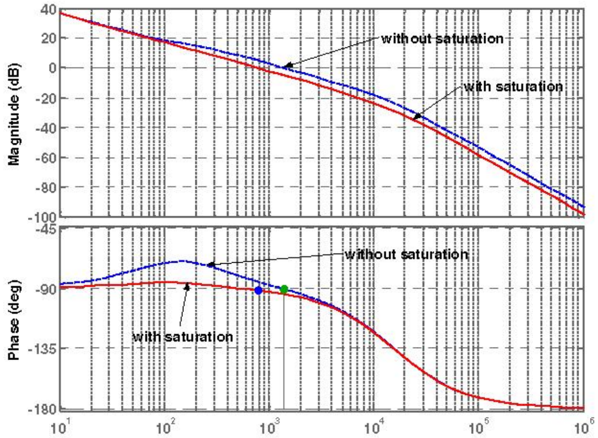

Fig.7 PMBLDC motor model estimates with and without saturation using conventional PI control

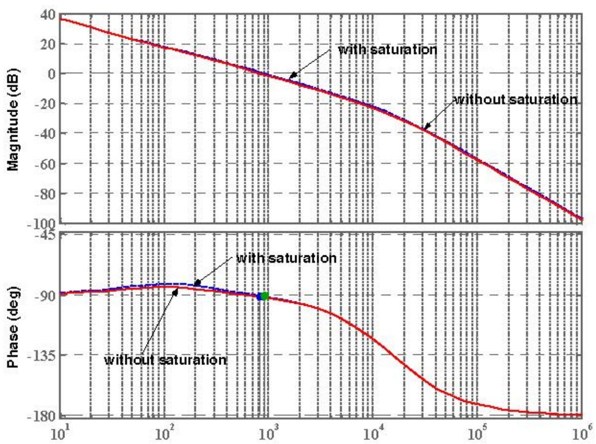

Fig.8 PMBLDC motor model estimates with and without saturation using auto tuning robust PI control

VI. CONCLUSIONS

Departing from the traditional approach towards tuning of speed control of PMBLDC motor drive systems where the outer speed and inner current loops are tuned in strict sequence, the proposed approach is to carry out the entire tuning process in one experiment. The new concept of auto tuning robust control really opens the way to the application of speed control of PMBLDC motor drive, very important from economical point of view. The features of the new control concept have been demonstrated on nonlinear modeling and simulation using MATLAB. Simulations are provided the applicability and effectiveness of the auto tuning approach and the new robust speed controller design.

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Appendix:

The PMBLDC motor parameters are

Number of turns per phase = 100

Resistance per phase = 1.4 ohm

Self inductance per phase = 2.44mH

Mutual inductance per phase = 1.5mH

Maximum value of flux density = 60 Wb/m^2

Rotor length = 0.03 m

Rotor radius = 0.02m

Value of viscous friction = 0.002

Moment of Inertia = 0.0002 $Kg\text{-}m^2$

Total number of phases = 4