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Integral VSC and Preview Control of Efficiency and Speed of a DC Drive

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***Abstract*—A novel integral variable structure control (VSC) system and a preview control system to control the speed of a DC drive and obtain maximum efficiency over the whole control range are proposed in this paper. The reduced dynamic equation of the DC (RDE-DC) drive system is derived based on maximum efficiency. This is done to simplify the complexity of the control system and hence to reduce the execution time of the microprocessor. An integral action is introduced into the VSC to improve the transient response, minimize the steady state tracking error and reduce the rise and settling times of the drive system. An augmented system utilizing a pure integrator (filter) is introduced into the VSC system to mitigate the input chattering problem of the drive system. A preview controller is also synthesized and implemented with the RDE-DC drive system to maximize the efficiency and control the drive speed. This controller utilizes few future values of the desired signal and disturbance signal. The desired signal is the desired drive speed while the load torque is considered as a disturbance signal. The design procedures and comparisons between the different VSC control systems are made. MATLAB® simulation studies are carried-out to investigate the feasibility, tracking performance and robustness of the control system with changing the speed; torque and parameters of the RDE-DC drive system.**

***Index Terms*—VSS, optimal control, preview control, DC drive, RDE.**

I. INTRODUCTION

DUE to the simplicity of controlling of the DC drive in addition to its high performance and fast speed response, many industrial applications including chemical, steel, mining, paper, conveyors and electrical traction utilize this drive. Besides, it is considered as a one of the most controllable drives used in robotic manipulators, flexible manufacturing and position control. Several control applications have been done utilizing modern control techniques. Some of them utilize variable structure control (VSC) [1]-[3], optimal control [4]-[7], optimal PID control [8], adaptive control [9], [10], etc. The drawback of using the VSC is mainly due to the concern of excessive chattering [11], [12]. In practice, chattering is generally undesirable because it involves extremely high frequency chattering control activity during the sliding motion phase. Besides, chattering introduces the possibility of component wear and part damage. These problems will preclude the VSC from using in practical applications. However, VSC is capable of making a control system robust with respect to system parametric or dynamical uncertainties and internal or external disturbances, provided that mitigating the chattering. Therefore, this paper proposes two control systems for speed and efficiency control of a DC drive. The first control system is an integral VSC system with and without augmented system, while the other one is a preview control system. The proposed control systems are designed to control the speed of the RDE-DC drive in the presence of external and internal disturbances. Design of the VSC is based on the plant augmentation method where the RDE-DC drive model is augmented by a pure integrator (filter), which is primarily accountable for reducing the chattering. With this filter, chattering will appear at the augmented system input rather than the input of the DC drive. Further improvements have been done with introducing an integral action in the switching function of the VSC system, which is said here by integral VSC system. The synthesized preview control system depends on solution of the optimal control problem, which is implemented off line and the optimal problem is solved at an arbitrary operating point. The objective of the proposed control systems is to control the drive speed and maximize the efficiency over the whole control range. Different MATLAB® simulation studies are made and showed good speed tracking under different operating conditions, such as load torque variations and/or parameters variation. The synthesize methods of the proposed drive control systems are carried-out and they depend on the reduced dynamic equation (RDE) of the DC drive. This is done to reduce the on-line execution time the microprocessor. Extensive simulation results of these control systems are compared and illustrated coincidental response under different operating conditions. These control systems are designed, implemented and gave considerable performance over the whole control range. The recommendation and conclusion about application of these control systems concerning applicability, robustness and effectiveness are demonstrated.

II. DYNAMIC EQUATION OF A DC DRIVE

The dynamic equation of a separately excited DC drive is given by [4]

$$\begin{aligned}\frac{\mathrm{d}\omega(t)}{\mathrm{d}t} &= -\frac{\omega(t)}{\tau_m} + \frac{k_m i_a(t) i_f(t)}{J} - \frac{T_L}{J}\\ \frac{\mathrm{d}i_a(t)}{\mathrm{d}t} &= -\frac{k_m i_f(t)\omega(t)}{L_a} - \frac{i_a(t)}{\tau_a} + \frac{A_a v_a(t)}{L_a}\\ \frac{\mathrm{d}i_f(t)}{\mathrm{d}t} &= -\frac{i_f(t)}{\tau_f} + \frac{A_f v_f(t)}{L_f}\end{aligned} \quad (1)$$

where

$\omega(t)$: angular speed of DC drive (rad/sec)

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$v_a(t)$, $i_a(t)$: armature voltage and current, respectively
$v_f(t)$, $i_f(t)$: field voltage and current, respectively
L_a, L_f : inductance of armature and field windings, respectively
R_a, R_f : resistances of the armature and field circuits, respectively
$\tau_a = L_a/R_a$, $\tau_f = L_f/R_f$: electrical time constant of armature and field windings, respectively
$\tau_m = J/B$: mechanical time constant
J, B moment of inertia and viscous friction, respectively.
k_m : torque moment of inertia coefficient
$T_L(t)$: mechanical load torque
A_a, A_f : gains of power amplifiers

III. RDE of a DC Drive

The RDE of a DC drive is obtained on the basis of maximum efficiency over the whole control range as follows. The controllable losses of a DC drive is,

$$L(t) = k_a i_a(t)^2 + k_f(\omega(t)) i_f(t)^2 \tag{2}$$

where k_a and $k_f(\omega(t))$ are the loss coefficients and the last one depends on the drive speed, such that the optimum current ratio (β) for maximum efficiency is given by

$$\beta = \frac{i_a(t)}{i_f(t)} = \sqrt{\frac{k_f(\omega(t))}{k_a}} \tag{3}$$

Equating the gradient of $L(t)$ to zero and using (1), gives

$$\frac{i_a(t)^2}{\tau_a} + \frac{k_m \omega(t) i_a(t) i_f(t)}{L_a} - \frac{i_a(t) v_a(t)}{L_a} = \beta^2 [-\frac{i_f(t)^2}{\tau_f} + \frac{i_f(t) v_f(t)}{L_f}] \tag{4}$$

which is reduced to

$$v_a(t) = [\frac{R_a}{R_f}\beta + \frac{k_m}{R_f}\omega(t)] v_f(t) \tag{5}$$

Then the RDE of the DC drive, (6), is obtained from (1), (3) and (5).

$$\begin{aligned} \frac{d\omega(t)}{dt} &= -\frac{\omega(t)}{\tau_m} + \frac{k_m i_a(t)^2}{J\beta} - \frac{T_L}{J} \\ \frac{di_a(t)}{dt} &= -\frac{k_m i_a(t)\omega(\omega)}{L_a\beta} - \frac{i_a(t)}{\tau_a} + \frac{v_a(t)}{L_a} \end{aligned} \tag{6}$$

Note that for purpose of simplicity, we have considered $A_a v_a(t) = v_a(t)$ and $A_f v_f(t) = v_f(t)$.

The state space model of the RDE-DC drive, (7), is obtained after linearizing (6), around the operating point (i_{ao}, ω_o) and using Euler's method

$$\dot{\mathbf{x}}(t) = \mathbf{A}'\mathbf{x}(t) + \mathbf{B}'u(t) + \mathbf{C}'d(t) \tag{7}$$

where $\mathbf{x}(t) = [\omega(t) \;\; i_a(t)]^t$, $u(t) = v_a(t), d(t) = T_L(t)$.

Then, the discrete state space model of the RDE-DC drive, (8), is given from (7).

$$\dot{\mathbf{x}}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{B}u(k-1) + \mathbf{C}d(k) \tag{8}$$

where
$\mathbf{x}(k)$: state variable; $u(k)$: input signal
$\omega(k)$: output signal; $d(k)$: disturbance signal
$R(k) = \omega^r(k)$: desired signal

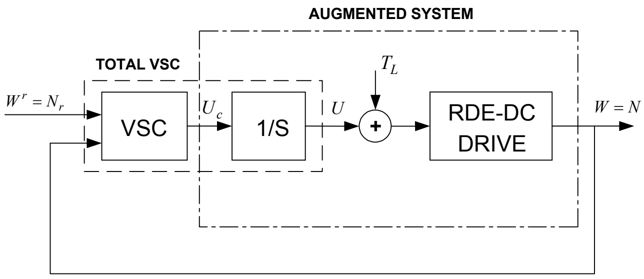

Fig. 1. VSC with augmented system.

The symbol k, means the sampling time kT, and T is the sampling period, while the superscript "t" denotes the transposition It is clear that the armature voltage is delayed by one sampling period to compensate for the micro-processor's execution time. Moreover the optimum current ratio β is obtained at maximum efficiency.

IV. VSC System

The variable structure control (VSC) system is synthesized based on the RDE model in two cases. The first case with using a pure integrator (filter) to eliminate the input chattering, while an integrator is introduced into the switching function to attain zero steady state tracking error, as in the second case.

A. Augmented VSC System

To design the VSC system, first the augmented system is implemented, where a new integrator is introduced as a part of the RDE-DC drive. However, this integrator is considered as a part of the VSC system as shown in Fig. 1. Chattering will now appear at the augmented system input instead of the input of DC drive. Then, the VSC technique is applied to the augmented system, which consists of the RDE-DC drive and a pure integrator. Design of the VSC system is based on the reaching condition method [1]. The general form of the reaching law is

$$\dot{s}(x) = -p\,s(x) - q\,\mathrm{sgn}(s(x)) \tag{9}$$

where the symbols p and q are positive gains, and $\mathrm{sgn}(s(x))$ denotes the signum term of $s(x)$. The robustness of the controlled drive may probably be developed by correctly selecting the gains p and q in (9).

The dynamic equation of the RDE-DC drive model of (7), is rewritten in (10).

$$\begin{aligned} \dot{x}_1 &= a_{11}x_1 + a_{12}x_2 + b_{11}u + c_{11}d \\ \dot{x}_2 &= a_{21}x_1 + a_{22}x_2 + b_{21}u + c_{21}d \\ v_f &= [\frac{R_a}{R_f}\beta + \frac{k_m}{R_f}x_1]^{-1}u \\ i_f &= \beta^{-1}x_2 \end{aligned} \tag{10}$$

where $x_1 = \omega$, $x_2 = i_a$, $u = v_a$, $d = T_L$; and a_{ij}, b_{i1}, c_{i1}, $i = 1,2$, $j = 1,2$ are the elements of the matrices $\mathbf{A}', \mathbf{B}, \mathbf{C}'$ in (7).

The VSC technique has the form

$$\begin{aligned} u(x) &= u^+(x) \quad \text{if} \quad s(x) > 0 \\ u(x) &= u^-(x) \quad \text{if} \quad s(x) < 0 \end{aligned}. \tag{11}$$

The switching function of the augmented VSC system is defined as

$$s(x) = c_1 e + c_2 x_2 + \dot{x}_2 \,, \tag{12}$$

where $e = x_1 - \omega^r$ is the output error. The symbol ω^r denotes the desired drive speed. The constants c_1 and c_2, are obtained off-line according the required performance, and u^+ and u^- are illustrate the maximum and minimum allowable control voltage, respectively.

The condition under which the system state will move toward and reach the switching surface is called a reaching condition. Such that the pair of inequalities:

$$\lim_{s(x)\to 0^+} \dot{s}(x) < 0 \quad \text{and} \quad \lim_{s(x)\to 0^-} \dot{s}(x) > 0 \tag{13}$$

give sufficient conditions for sliding modes to exist.

The design procedure of the VSC system is derived as follows, let

$$x_3 = \dot{x}_2 \tag{14}$$

then from (10), considering $u_c = \dot{u}$

$$\dot{x}_3 = \ddot{x}_2 = a_{21}\dot{x}_1 + a_{22}\dot{x}_2 + b_{21}u_c + c_{21}\dot{d} \tag{15}$$

the substitution from (10) into (15) gives

$$\dot{x}_3 = f_1 x_1 + f_2 x_2 + f_3 u + f_4 d + b_{21}u_c + c_{21}\dot{d} \tag{16}$$

where

$$\begin{aligned} f_1 &= a_{11}a_{21} + a_{21}a_{22}, \; f_2 = a_{12}a_{21} + a_{22}a_{22} \\ f_3 &= a_{21}b_{11} + a_{22}b_{21}, \; f_4 = a_{21}c_{11} + a_{22}c_{21} \end{aligned}.$$

Now the augmented system comprises, the first equation in (10), (14) and (16). Then substitution of the variables of these augmented system into the first derivative of (12) with respect to time, gives

$$\begin{aligned} \dot{s}(x) &= g_1 x_1 + g_2 x_2 + c_2 x_3 + g_3 u + g_4 d \\ &\quad + b_{12}u_c + c_{21}\dot{d} - c_1\dot{\omega}^r \end{aligned} \tag{17}$$

where

$$\begin{aligned} g_1 &= c_1 a_{11} + f_1, \;\; g_2 = c_1 a_{12} + f_2 \\ g_3 &= c_1 b_{12} + f_3, \;\; g_4 = c_1 c_{12} + f_4 \end{aligned}.$$

The VSC of the augmented system (18), is obtained by equating (9) by (17), and solving for u_c.

$$\begin{aligned} u_c = -\frac{1}{b_{12}}[& g_1 x_1 + g_2 x_2 + c_2 x_3 + g_3 u + g_4 d \\ & + c_{21}\dot{d} - c_1\dot{\omega}^r + k\, s(x) + q\,\mathrm{sgn}(s(x))] \end{aligned} \tag{18}$$

The constants c_1 and c_2 are obtained according to the assignment of the eigenvalues of the original system (RDE-DC drive), or by trial and error basis.

The block diagram of the VSC system of the RDE-DC drive is constructed from (18), as illustrated in Fig. 1.

B. Integral VSC System

Different from using the augmented system with a pure integrator (filter) of the original system as in the previous sub-Section, an integral VSC system is synthesized as indicated in the following steps. The concept of this system relies on introducing an integrator into the switching function, and then applying the reaching condition method. Then, let the switching function of (12) to be

$$s(x) = c_1 e + c_2 \int e dt + x_2 \,. \tag{19}$$

The same procedures as the previous sub-Section, will be repeated, without using the augmented system, to obtain the following integral VSC system.

$$\begin{aligned} u_c = -\frac{1}{a_0}[& a_1 x_1 + a_2 x_2 + a_3 d - c_2\omega^r \\ & - c_2\dot{\omega}^r + k\, s(x) + q\,\mathrm{sgn}(s(x))] \end{aligned} \tag{20}$$

where

$$\begin{aligned} a_0 &= c_1 b_{11} + b_{21}, \;\; a_1 = c_1 a_{11} + a_{21} + c_2 \\ a_2 &= c_1 a_{12} + a_{22}, \;\; a_3 = c_1 c_{11} + c_{21} \end{aligned}.$$

But with using the augmented system, the switching function of (12) becomes

$$s(x) = c_1 e + c_2 \int e.\mathrm{d}t + c_3 x_2 + x_3 \,. \tag{21}$$

Then follow the previous procedures to obtain the integral VSC system with the augmented system as given by

$$\begin{aligned} u_c = -\frac{1}{b_{21}}[& b_1 x_1 + b_2 x_2 + c_3 x_3 + b_3 u + b_4 d + \\ & c_{21}\dot{d} - c_2\omega^r - c_2\dot{\omega}^r + k\, s(x) + q\,\mathrm{sgn}(s(x))] \end{aligned} \tag{22}$$

where the variable x_3 is given from (14), and the constants c_1, c_2 and c_3, are obtained off-line according to the desired performance. The constants b_1, b_2, b_3, and b_4 are given by

$$\begin{aligned} b_0 &= c_1 + a_{21} \\ b_1 &= b_0 a_{11} + a_{11}a_{21} + c_2, \;\; b_2 = b_0 a_{12} + a_{22}a_{22} \\ b_3 &= b_0 b_{11} + a_{22}b_{21}, \qquad b_4 = b_0 c_{11} + a_{22}c_{21} \end{aligned}$$

V. Preview Control System

The real time optimal preview control law (23), for the RDE-DC drive is synthesized using (8) as given in [5].

$$\begin{aligned} u(k) = {} & g_1 \sum_{i=0}^{k} e(i) + (g_2 - g_1)e(k) + g_3 x(k) + \\ & g_4 u(k\text{-}1) + \sum_{j=1}^{M} \{F_{rj}[\Delta R(k+j) - \Delta R(j)] \\ & + F_{dj}[\Delta d(k+j-1) - \Delta d(j-1)]\} \end{aligned} \tag{23}$$

where

$$\mathbf{G} = [g_1 \; g_2 \; g_3 \; g_4]$$

$$F_{rj} = G_j G_r, F_{dj} = G_j G_d, j = 1,2,\ldots,M$$

Feedback Gain : $\mathbf{G} = -\boldsymbol{\gamma}\boldsymbol{\Theta}^{\mathrm{t}}\,\mathbf{K}\boldsymbol{\Phi}$

Feedforward Gain : $\mathbf{G_1} = -\boldsymbol{\gamma}\,\boldsymbol{\Theta}^{\mathrm{t}}\,\mathbf{K}$

$\mathbf{G_2} = -\boldsymbol{\gamma}\,\boldsymbol{\Theta}^{\mathrm{t}}\,\boldsymbol{\Phi}^{\mathrm{t}}\boldsymbol{\lambda}$

$\mathbf{G}_j = \mathbf{G}_{j-1}\,\mathbf{K_1}$; $j = 3,4,\ldots,M$

$\mathbf{K_1} = \mathbf{K}^{-1}\boldsymbol{\varphi}^{\mathrm{t}}\boldsymbol{\lambda}$, $\mathbf{K}, \boldsymbol{\gamma}$ and $\boldsymbol{\lambda}$ are the steady state solution of the following Riccati equation

$$\mathbf{K}(i) = \mathbf{Q} + \boldsymbol{\Phi}^{\mathrm{t}}\boldsymbol{\lambda}(i+1)\boldsymbol{\Phi}$$

$$\boldsymbol{\lambda}(i+1) = \mathbf{K}(i+1)[\mathbf{I}_5 - \boldsymbol{\theta}\boldsymbol{\gamma}(i+1)\boldsymbol{\theta}^{\mathrm{t}}\mathbf{K}(i+1)]$$

$$\boldsymbol{\gamma}(i+1) = [\mathbf{R} + \boldsymbol{\theta}^{\mathrm{t}}\mathbf{K}(i+1)\boldsymbol{\theta}]^{-1}$$

where $W(k) = G_r\, \Delta z(k) + G_d\, \Delta d(k-1)$,
$\Delta z(k) = [\Delta\Delta R(k - \Delta R(k-1)]$; $\Delta = (1 - q^{-1})$.

The weight matrices of the performance index are

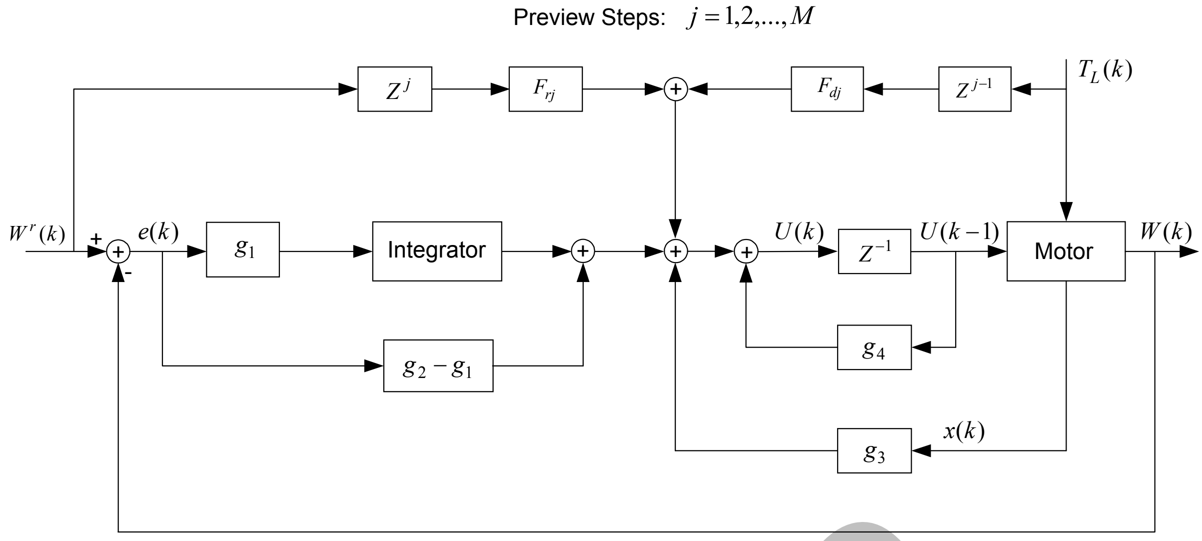

Fig. 2. Preview control system.

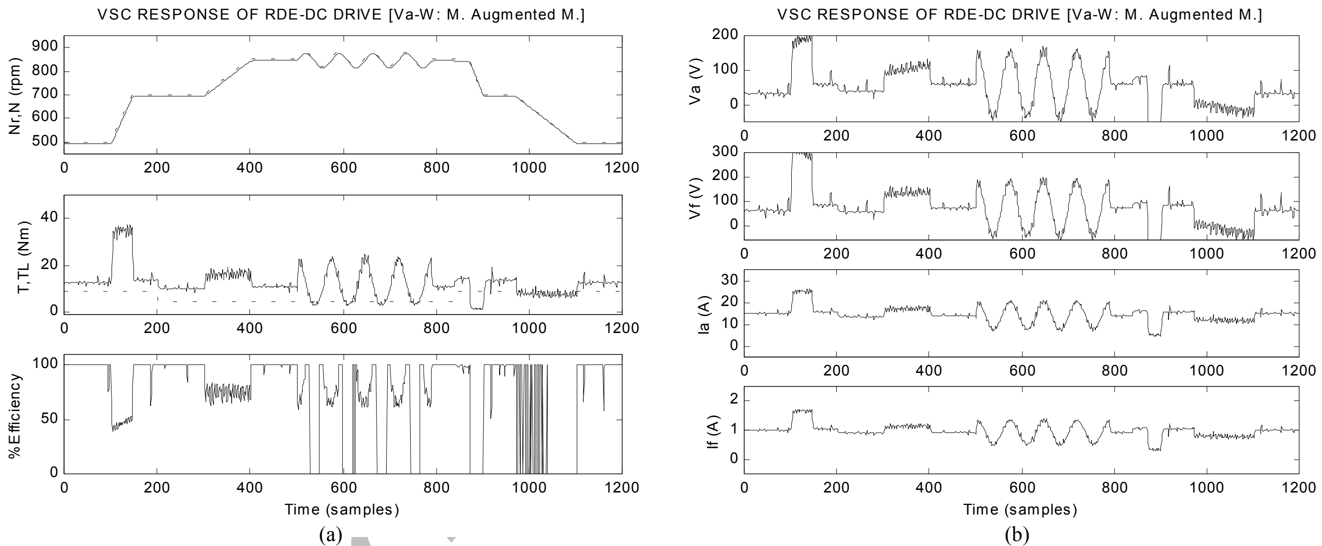

Fig. 3. Results of VSC with augmented system (see (18)), $c_1=550$, $c_2=20$, $p=17275$, $q=825$.

$$\mathbf{Q}=\begin{bmatrix} q & q & \\ q & q & \\ & & 0 \end{bmatrix}\ (5\times 5),\ R=r\ (1\times 1)$$

The output error is $e(k)=\omega^r(k)-x_1(k)$.

All the parameters of the optimal preview control law (23), are defined straight forward as in [5] and utilizing (8). The symbol $M\geq 1$ denotes the preview steps.

The preview control system structure is implemented from (23), as indicated in Fig. 2. In this figure the load torque, which represents the disturbance signal, is directly measured or can be estimated on line during operation.

VI. Simulation Results and Comments

The proposed VSC systems and the optimal preview controller are used in this paper to maximize the efficiency and to control speed of the RDE-DC drive. This drive is a 2-pole, 1.5 kW, 100 V, 18.5 A, 1000 rpm DC shunt motor which has the following parameters. J =0.652 Nm.sec^2; L_a =0.0117 H; L_f =11.3 H, τ_a =0.0186 sec; τ_f =0.113 sec; τ_m =11.1 sec, K_m =0.839 Nm/A; K_e =5.27 Nm/A; T_L =8.91 Nm, β = 15.05 at rotor speed N =1000 rpm.

Figs. 3 to 7, indicate the MATLAB® simulation results of the synthesized VSC systems and the optimal preview controller with T=10 msec. In these figures the horizontal lines denote the time in samples. The vertical lines in Figs. 3(a), 4, 5 and 6(a), depict from up to down the desired drive speed N_r (rpm), in dotted line, and its response N (rpm) in solid line, and the load torque T_L (Nm) in dotted line and the developed torque T_D (Nm) in solid line. The %efficiency of the RDE-DC drive is also indicated in the last block of these figures. While in Figs. 3(b) and 6(b), the vertical lines demonstrate from up to down the armature voltage V_a (V), field voltage V_f (V), armature current I_a (A) and field current I_f (A), respectively. An enlarged part of Fig. 6(a) is shown in Fig. 6(c). In this part, effect of the preview steps (M =0,2) on the transient response of the drive when the desired speed is changed from 500 rpm to 700 rpm and the load torque is changed from 100% to 50%, is illustrated. Effect of changing the load torque (from 100% to 50% and back to 100%), mechanical time constant (from 100% to 50%), and rotor resistance (from 100% to 150%) to the regulated speed is depicted in Fig. 7. Fig. 3, illustrates the response of the VSC (18), with augmenting the RDE-DC drive system, while Fig. 4 depicts the system response of the integral VSC (20), where an integrator is introduced into the switching function, without augmenting the RDE-DC drive system. The response of the

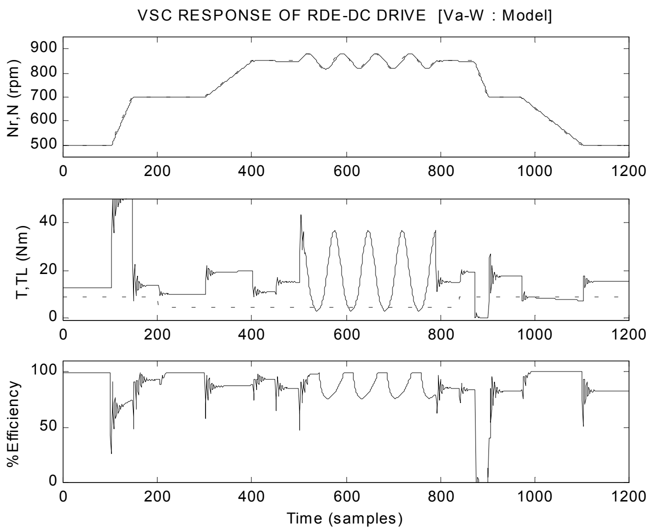

Fig. 4. Results of integral VSC without augmented system (see (20)), $c_1 = 0.25$, $c_2 = 20$, $p = 0.46$, $q = 1$.

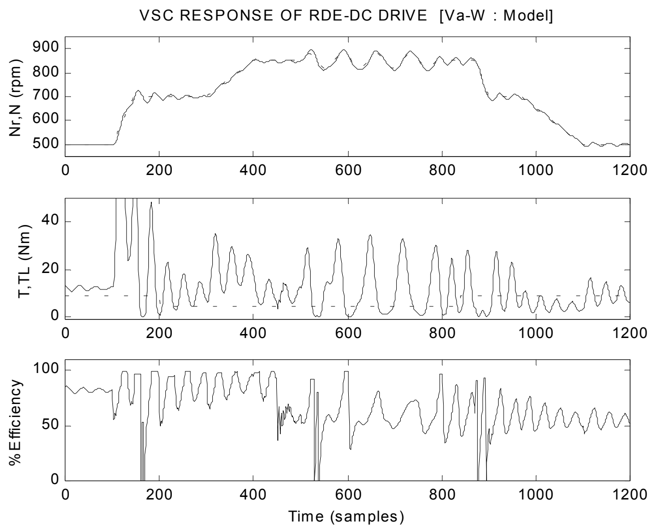

Fig. 5. Results of integral VSC with augmented system (see (22)), $c_1 = 0.5$, $c_2 = 150$, $c_3 = 0.85$, $p = 0.1$, $q = 1$.

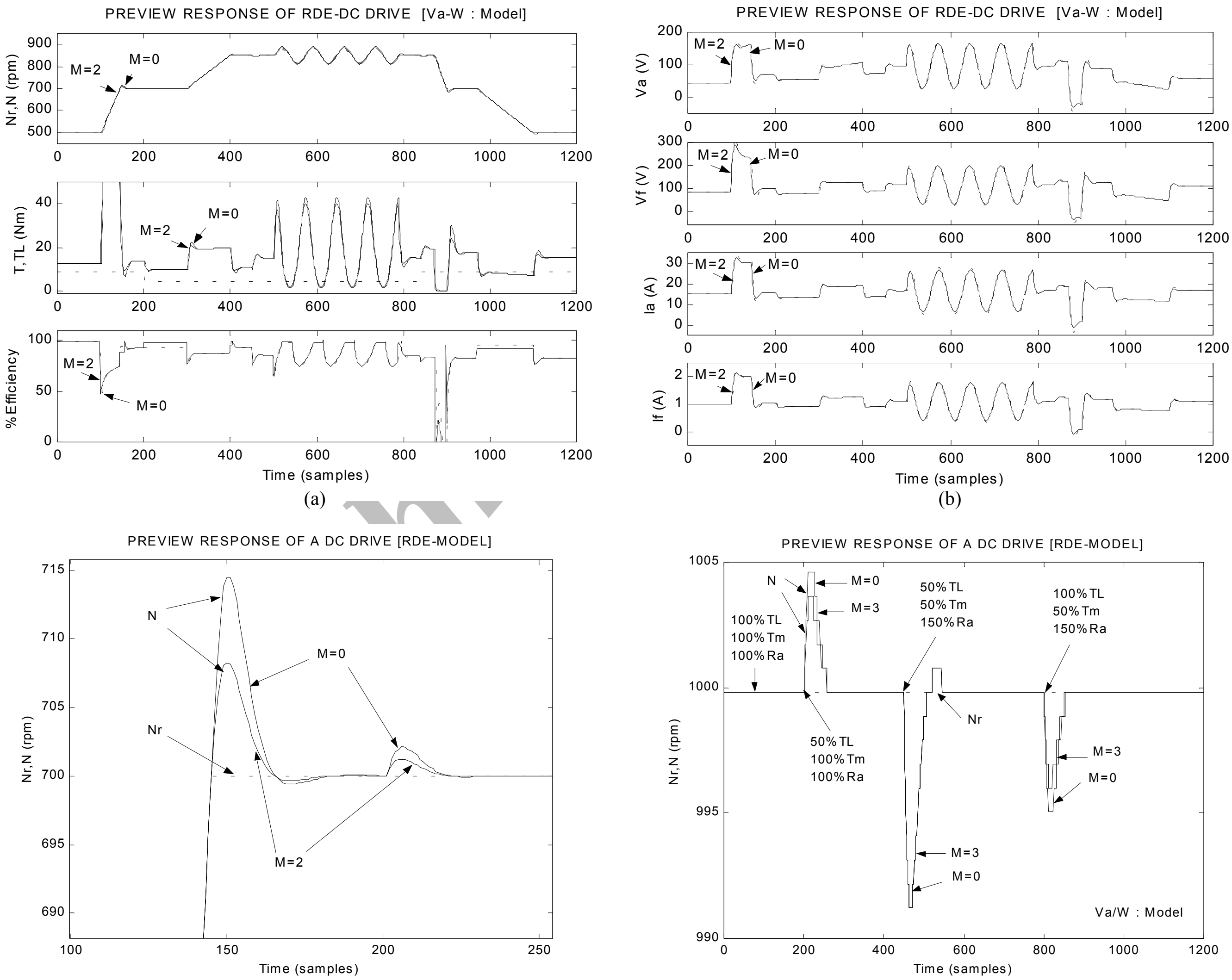

Fig. 6. Results of preview control (see (23)), $r = 1$, $q = 100$, $M = 0{,}2$.

integral VSC (22), with augmenting the RDE-DC drive system is indicated in Fig. 5. Furthermore, Figs. 6 and 7, indicate the response of the preview control (23), without augmenting the RDE-DC drive system. The gains of the VSC of (18) are c_1=550, c_2=20, p=17275 and q=825, and for the integral VSC of (20) the gains are c_1=0.25, c_2=20, p=0.46 and q=1.0, while for the integral VSC of (22) are c_1=0.5, c_2=150, c_3=0.85, p=0.1 and q=1.0. For the preview control law of (23), the weighting factors and preview steps are r=1.0, q=100 and M=0,2 for the response of Fig. 6, and r=1.0, q=1.0 and M=0,3 for the response of Fig. 7. In these figures the dotted lines denote the desired speed Nr in rpm, and the desired load torque TL in Nm, as in Figs. 3(a), 4, 5, 6(a), and 7. As indicated in Figs. 6(c) and 7, the preview steps $M=2$ or $M=3$, improve the transient response of the RDE-DC drive system in comparison with preview steps $M=0$, where this represents the transient response of the system with the ordinary optimal control law. In Figs. 3 to 6, the desired speed N_r is selected to change abruptly, ramp and a sinusoidal shape, while the load torque T_L is selected to change abruptly from full load to half load and back to full load. These changes are made to investigate the tracking performance and the robustness of the proposed controllers with external disturbances. The desired motor speed is taken constant at 1000 rpm as in Fig. 7. Finally, in all these figures, the mechanical time constant $\tau_m = T_m$ is changed from 100% to 50% while the rotor resistance R_a is changed from 100% to 150% at the sample instant 450, to investigate the robustness of the proposed controllers with parameters variation. Under these operating conditions the preview controller with minimum preview steps has the superior performance over the performance of all the proposed VSC systems. Also, the integral VSC without augmented system gives good transient response with respect to the response of the VSC with augmented system. It can be seen that a remarkable improvement in the overall system performance is achieved by applying these controllers. Finally, the robustness of the preview controller can cope with the saturation or the armature reaction effects, where the design is carried out to deal with the uncertainty or un-modeled dynamics.

VII. Conclusion

In this paper a novel integral variable structure control system and a preview control system to maximize the efficiency over the whole control range and to control the speed of the DC drive system are synthesized and implemented. The RDE-DC drive is derived based on maximum efficiency. This is done to simplify the complexity of the control system and hence to reduce the execution time of the microprocessor. An integral action is introduced into the VSC system to improve the transient response, minimize the steady state output tracking error and reduce the input chattering. An augmented system utilizing a pure integrator is introduced into the VSC system to mitigate the input chattering problem of the drive system. The preview controller utilizes minimum preview steps of desired motor speed and load torque to improve the transient response of the RDE-DC drive system. The proposed controllers are sustained to cope with large range of parameters, disturbances or reference variations.

Therefore, these controllers are useful to control systems utilizing repeatedly operating points or variable loads over the whole control range. Minimum overshoot, minimum rise and settling times, zero steady state tracking error, good robustness and less input chattering are achieved by using the integral VSC system and preview controller with minimum number of preview steps. The experimental work will be done to investigate the applicability of the proposed controllers considering effects of the saturation and armature reaction of the DC drive.

References

[1] T. M. Nasab and M. M. Negm, "Robust performance for induction motor using VSC systems with free chattering," in *Proc. of the IFAC-IFIP-IMACS Int. Conf. on Control of Industrial Systems*, pp. 223-229, 1997.

[2] T. M. Nasab and W. L. Green, "A practical method for suppressing VSS chattering," *AMSE Journal on Simulation and Control*, vol. 49, no. 3, pp. 37-60, 1995.

[3] T. M. Nasab and M. M .M. Negm, "A new technique to suppress chattering in variable structure systems," in *Proc. of the ISCA 10th Int. Conf. on Computer Applications in Industry and Engineering, ICCAIE'97*, pp. 40-43, Texas, USA, Dec. 10-12, 1997.

[4] M. M. M. Negm and A. F. Kheireldin, "Efficiency optimized speed control of reduced dynamic equation of DC motor based on robust preview control system theory," *Journal of Modeling, Simulation and Control, A, AMSE Periodicals*, vol. 33, no. 2, pp. 39-52, 1991.

[5] M. M. M. Negm, "Torque optimized speed control of a 3-phase induction motor," in *Proc. of the IEEE-PES/CSEE International conference on Power System Technology, PowerCon'2000*, vol. 1, pp. 67-72, Australia, 2000.

[6] E. A. Mohamed, M. M. M. Negm, A. I. Said, and A. S. Awad, "Speed control of a DC drive based on optimal performance," in *Proc. IEEE Africon 4th Int. Conf.,* vol. 2, pp. 638-653, South Africa, Sep. 24-25, 1996.

[7] S. Awad, E. A. Mohamed, M. M. M. Negm, and A.I. Said, "Speed control of DC motor drives based on efficient utilization of energy and optimal performance," in *Proc. CIRED, 14th Int. Conf. and Exhibition on Control*, UK, IEE Conf. Pub. No. 438, vol. 5, pp. 5.22.1-5.22.5, 1997.

[8] M. M. M. Negm, F. N. Al-Ghnnam, T. M. Nasab, and S.A.Leithy, "Experimental investigation of speed control of DC motor based on optimal PID-controller," in *Proc. of the Sixth Annual IEEE-TEM, KFUPM, Saudi-Arabia*, pp.136-141, 1999.

[9] M. M. M. Negm and A. F. Kheireldin, "Efficiency optimized speed control of RDE of DC motor based on robust preview control and adaptive controlm" in *Proc. of the IMACS-IFAC Symposium, Co-sponsorship of AFCET, IMACS-MCTS'91*, vol. 1, pp. 1-9, France, 1991.

[10] M. M. M. Negm, "Adaptive vector control for a three-phase induction motor," in *Proc. IEEE ICIT'96 Inter. Confer. On Industrial Technology,* pp. 762-766, Shanghai, China, Dec. 1996.

[11] T. M. Nasab and M. M. M. Negm, "Designing of switching surfaces with variable parameters for chatting free variable structure Systems," in *Proc. of the First IEEE International Energy Conference, IEC'2000*, pp .1-5, UAE, May 7-9, 2000.

[12] E. Ho and P. C. Sen, "Control dynamics of speed drive systems using sliding mode controllers with integral compensation," *IAS Annual Meeting, 1989, Conference record of the 1989 IEEE*, vol. 1, pp. 639-648, 1989.

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