

SOME BASIC PROBLEMS IN THE THYRISTOR CONTROL
OF DIRECT CURRENT MACHINES

by

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To my wife

NEENA BHATIA


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(Chandar Mohan Bhatia)

SUMMARY

The characteristics of a d.c. machine when operated from a pulsed-power-supply are known to differ considerably from those obtained under the d.c. mains operation. These differences are due to the high harmonic-content in the output voltage of the pulsed-power-source which leads to pulsations and often discontinuity in the armature current. Such pulsations affect the machine behaviour in several ways. Firstly, they generate extra losses in the magnetic circuit, in the armature, the interpoles and the frame structure due to the eddy-currents induced in them by the changing armature-reaction-flux. Secondly they lead to increased copper losses for a given motor output due to the fact that the effective value of pulsating direct current is considerably larger than its average value and while losses are proportional to the square of the effective value, the output is proportional to the average value of the armature current. Thirdly they cause more severe commutation difficulties because the current being commutated is the peak value of the pulsating d.c. which is much larger than the average value. Lastly, the pulsations affect the effective values of the armature circuit resistance and inductance leading to drastic modification of the machine torque-speed characteristics.

The basic objectives of the work reported in this thesis are divided into two parts, namely:

- i) Formulation of the analytical expressions for the steady-state behaviour of the d.c. motor under the influence of the pulsed-power-supply and hence accurate ~~and~~ prediction ^{of} the machine torque-speed characteristics.
- ii) Improvement of the operating torque-speed characteristics through the use of energy storage circuits between the solid-state controller and the machine.

The investigations reported in Chapters 2,3 and 4 concentrate on first part as mentioned above. A generalised mathematical model for the separately excited d.c. motor, using constant armature circuit parameters is developed, and it is shown that the machine torque-speed characteristics for any specific case of static Ward-Leonard can be easily predicted from the generalised model. It is observed that there exists considerable qualitative and quantitative difference between the predicted characteristics on different types of pulsed-power-supply; and between the predicted and actual measured behaviour on individual pulsed-power-supply. This shows that the assumption of constant armature-circuit parameters fails to give accurate prediction. Ewing* and Parimelalagan & Rajagopalan** made valient attempts

* Ewing, J.S., "Lumped circuit impedance Representation of D.C. Machine", IEEE Trans. on Power Apparatus & Systems., vol. PAS-87; April, 1968.

**Parimelalagan, R. and Rajagopalan, V., "Steady State Investigations for chopper-fed D.C. Motor with Separate Excitation". IEEE Trans. on Industry and General Applications, Vol. IGA-7; Jan/Feb, 1971.

to predetermine through measurements the required value of these parameters under a given operating condition, but the approximations used by them make it difficult to satisfy the characteristics under all conditions of load, resulting in inaccurate prediction. An attempt has, therefore, been made to predetermine these parameters as a function of the average armature current, frequency of pulsations and the type of pulsed-power-supply used, and hence tabulate them in the form of a matrix which helps in quick estimation of the values under any condition of operation. From the knowledge of the predicted behaviour as mentioned above, the machine parameters are modified with new values chosen from the parameter matrix and the performance is recalculated, and the correction for the extra-losses due to pulsed operation is applied. It is shown that considerable improvement in the accuracy of prediction is brought about by better estimation of the machine parameters and accounting for extra-losses.

Since the harmonic content in the armature current produces pulsating armature-reaction and interpolar fluxes, it is worthwhile to study the effect of the pulsating flux on the machine behaviour. The work of Robinson* and Franklin ** is critically examined and various methods of improvement using external control

* Robinson, C.E., "Redesign of DC motors for applications with thyristor power supplies", IEEE Trans. on Industry and General Applications, Vol. IGA-4; Sept/Oct., 1968.

** Franklin, P.W., "Theory of D.C. Motor controlled by Power-pulses, Part-I- Motor Application; Part-II, Braking methods, commutation and additional losses," IEEE Trans. on PAS, Vol. PAS-91, Jan./Feb., 1972.

circuits are tried and are reported in Chapters 5,6, and 7 of this dissertation. It is experimentally shown that the effect of the interpolar winding on the machine performance becomes detrimental under large delay angle and low duty intervals. The torque-speed characteristic without the interpolar winding is found to be superior to the one obtained with the interpolar winding in the circuit. It is shown that the use of a suitable energy-storage circuit (capacitor bank) across the interpolar winding improves the characteristics appreciably. Further improvement in the machine operating characteristics is possible only through filtering the armature current by the energy-storage circuit between the pulsed-power-supply and the machine. The machine characteristics are measured with different filters namely; (i) a series inductor (ii) a shunt capacitor and (iii) the L-C circuit and are reported in Chapter 6. These filter networks are investigated so as to get optimum improvement with respect to machine torque-speed characteristics, harmonic content in the armature as well as the source current, power-factor as viewed from the a.c. mains side, visible sparking at the commutator surface and noise. It is revealed that the L-C filter is found to be most suitable in every respect and its introduction has produced the expected improvement in the machine torque-speed characteristics making the latter come very close to the characteristics obtained under the d.c. mains operation.

Amato* and many other authors have mentioned that the single-phase TRC causes problems because of the high harmonic content in the armature current, especially at low duty intervals. More significant among these problems are poor source life and efficiency, and poor torque-speed characteristics of the drive motor. However, no systematic attempts appears to have been made to compare the d.c. machine behaviour on single-phase and multi-phase TRC's with the characteristics obtainable with the d.c. mains operation as the standard reference. The theoretical and experimental investigations carried out in Chapter 7 concentrate on the use of the multi-phase choppers. A generalised mathematical model for the multiphase chopper motor system is developed and the validity of the analytical expressions is checked by direct solution for a two-phase chopper case. The test results on a specially designed and fabricated two-phase chopper-motor system show that the machine torque-speed characteristics obtained with this chopper circuit are far superior to those obtained with the single-phase chopper bringing the former very close to those obtainable with the d.c. mains operation. A significant improvement in the harmonic content in the source as well as load current is also observed.

* Amato, C.J., "Latent Losses in Electric Lizzies",
IEEE Trans. on Industry and General Applications; vol.
IGA-5; Sept/Oct., 1969.

To conclude, some basic problems in thyristor control of d.c. motors are examined. Investigation has been carried out in the laboratory to test the validity of theoretical and computer prediction of the machine characteristics. It is shown that experimental evidence in all the cases of pulsed-power-supply is close to the theoretical prediction. The highly drooping torque-speed characteristic obtained with the static Ward-Leonard control is brought back to its usual shape of shunt characteristic through the use of energy-storage circuits. It is hoped that the practical suggestions made in this thesis would eliminate much of the worries of the application engineers while choosing the solid-state control for d.c. motors.

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