International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

C-Dump Converter Design and its Dynamic Analysis in Simulink Environment for a Switch Reluctance Machine

Hüseyin ÇALIK, S. Hakan UNDİL, Hasan Hüseyin ÇELİK

Abstract:*It is an analysis of asymmetric converters used to drive switched-reluctance motors (SRM). Usually, two switches per phase exist in these converters, therefore the cost of converter rises up. The energy recovery chopper in a capacitor-dump (C-dump) SRM drive which needs one more additional switch than the number of phases is analyzed, designed and discussed. The converter allows continuous output current operation. The dynamic behavior of the chopper shows that it operates as a boost DC-to-DC converter in a regenerative mode. In this study, A 6/4 SRM for both no motor phase current control applied and controlled at 8A phase current (C.C.), the characteristics of C-dump converter voltage (Vc), current (ig) and phase voltages applied to the motor windings are examined in Matlab-Simulink environment.*

Keywords: *C-Dump Converter, Switched Reluctance Motor, Simulink Dynamic Analysis*

I. INTRODUCTION

The simple structure of SRM (Switched Reluctance Motor), with its low production costs and lower maintenance and repair costs raise the interest to such types of motors [1], [2].

An ideal SRM Converter requires to possess characteristics as being reliable, stable, having less number of switches per phase, highly effective, low noise and torque ripple, low VA ratio, and at the same time controlling the current very rapidly. SRM converters have to regulate the current amplitude and keep the waveform unchanged for the motors and power transistors to operate safely. They have provided the unidirectional current pulses compatible with the rotor position completely. At the same time, in order to minimize the torque fluctuation during the commutation, the current on the phase to be turned off should be decreased to zero as soon as possible, and on the other hand, the current on the phase to be turned on should be raised as soon as possible as well. When the phase inductance of the SRM approaches to its maximum value, the commutation circuit during the turn-off interval should be able to recover this energy that is stored in the inductance. In spite of the fact that the most requirements above are similar to that of AC

and DC converters, many differences in details prevent from using an ordinary converter to drive a SRM. In the literature, it is possible to encounter so many topologies that are used for SRMs [3-10]. These may be mainly given as self-commutated, half-bridge and extra commutated respectively [6]. C-Dump converters have advantages of being able to use one switch per phase and operate without snubber circuits due to Cr recovery capacitor. The phases are also controlled independently. A three phase C-dump converter is designed and analyzed in Matlab-Simulink environment with respect to voltage and current waveforms in this study.

Revised Manuscript Received on October 30, 2019.

* Correspondence Author
Hüseyin ÇALIK*, Istanbul Üniversitesi-Cerrahpaşa , Department of Electric-Electronic Engineering, 34850-Avcılar, Istanbul, Turkey Email: hcalik@bistanbul.edu..tr
S. Hakan Undil**, Nisantasi University, Faculty of Engineering And Architecture, Department of Electric-Electronic Engineering, Istanbul, Turkey is/. Email: hakanundil@yahoo.com
H. Hüseyin ÇELİK***, Marmara University, Faculty Of Technology, Department of Electric-Electronic Engineering, Istanbul, Turkey is/. Email: hcelik@marmara.edu.tr

II. DYNAMICS MODEL OF SRM

The switch reluctance motor has a simple construction, but the solution of its mathematical model is relatively difficult due to its dominant non–linearity behaviour. The flux linkage is a function of two variables, the current (I) and rotor position angle (θ). To investigate the behaviour of SRM, dynamic model is required. The dynamic mathematical model [1], [2], [9] of a SRM is composed of a set of electrical equations for each phase and equations of mechanical system [10-17]. In a typical i phase SRM, the machine's voltage equation can be expressed as:

$$V_i = R_i I_i + \frac{d\psi_i(i,\theta)}{dt} \tag{1}$$

With: $i = 1,2,3$ and $\psi(i,\theta) = i.L(i,\theta)$ it can be written as;

$$V_i = R_i I_i + \frac{d\psi_i(i,\theta)}{di}\frac{di}{dt} + \frac{d\psi_i(i,\theta)}{d\theta}\omega \tag{2}$$

Where; Vi is the terminal voltage of phase i in Volts, Ii is phase current in Amperes, Rj is phase winding resistance in Ohms, λi is the flux linkage in Weber-turns and θj is rotor position in degrees.

The flux linkage is a function of current and rotor position. The mechanical dynamic equations can be expressed as θ.

$$T_e = \frac{1}{2}\frac{dL(i,\theta)}{d\theta} i^2 \quad (3)$$

The average toque can be written as the super position of the torque of the individual motor phase.

$$T_{ei} = \sum_{i=1}^{i} T_e \quad (4)$$

In which: $i = 1,2,3$

The motion equation is:

$$J\frac{d\omega}{dt} = T_e - T_l - B\omega \quad (5)$$

where; Ti is the phase torque in Nm, Tl is the load torque in Nm and ω is angular speed in radians per second. J and B represent the Torque of Inertia in kg.m2 and coefficient of friction in Nm/rad/s respectively.

III. C-DUMP CONVERTER DESIGN WITH SIMULINK

Three phases C-Dump converter circuit topology is given in Fig.1.a. In this circuit, the voltage of Cr (Vc) is controlled by the duty cycle of the chopper circuit switch. Therefore, the peak voltages on the phase switches are prevented that is a considerable advantage. The winding currents can be independently controlled in this converter and the accumulated energy during the turn-off is transferred to the C-Dump capacitor. The recovered energy is delivered to the power supply by using a chopper. This approach increases the efficiency of converter and reduces the turn-off interval. The capacitor voltage is remained at 2Vs during (d=0.5) turn-on interval, in order to apply –Vs to the phase switch that is turned off. This part of the circuit works as a chopper in accordance with buck principle to discharge the capacitor. A simplified one phase equivalent circuit of three phase C-dump converter which describes the operation is presented in Fig.1.b.

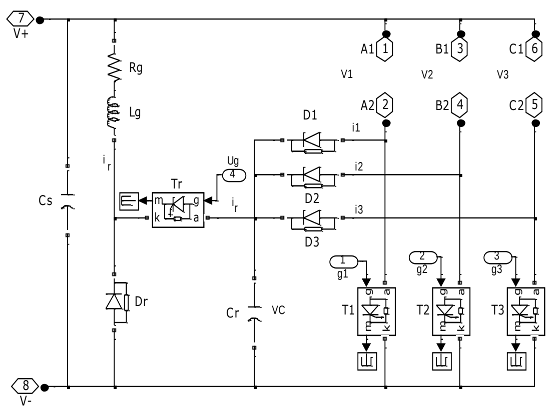

Fig. 1.a 3 Phase C-Dump Converter for a SRM

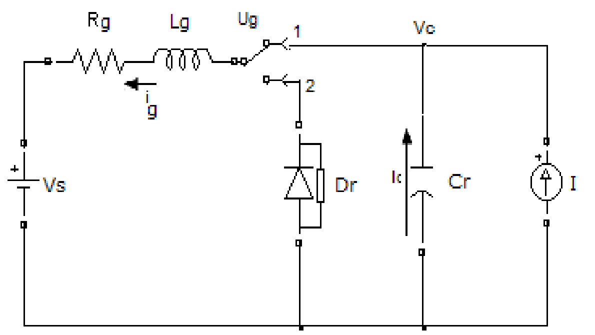

Fig. 1.b. C-Dump Converter Equivalent Circuit [9]

In the figure, (I), (Tr), (Ig) and (Vs) represent the sum of the currents of the phase windings during the discharge, the transistor of recovery circuit, the recovery inductance current and the power supply voltage respectively. Cr, Lg and Rg also represent C-dump capacitor, Lg inductance that stores energy during the recovery and total equivalent resistance respectively. The operating frequency of Tr switch is 1/T and it remains at '1' position for the time of (dT). The switch is reversely at the position of '2' for (1-d). T(0<d <1). In both position of the switch, the each one can be considered as two separate linear circuits. The circuit equations when the switch is at '1' position;

$$c_r\frac{dV_c}{dt} = I - i_g \quad (6)$$

$$R_g.i_g + L_g\frac{di_g}{dt} = V_c - V_s \quad (7)$$

The circuit equations when the switch is at '2' position;

$$c_r\frac{dV_c}{dt} = I \quad (8)$$

$$R_g.i_g + L_g\frac{di_g}{dt} = -V_s \quad (9)$$

can be written.

In order to define 1 and 2 positions, a u_g control signal coefficient may be set

as $u_g = 1$ and $u_g = 0$ as in Eq. 9.

$$u_g = 0.5\left(1 + sign\left(u_t + Sin\omega_g t\right)\right), \quad \omega_g = 2\pi f_g \text{ rad/s} \quad (10)$$

(1) and (2) positions can be combined in one equation.

$$c_r\frac{dV_c}{dt} = I - u_g.i_g \quad (11)$$

$$L_g\frac{di_g}{dt} = u_g.V_c - V_s - R_g.i_g \quad (12)$$

The state equations of this system can be given as follows;

$$\frac{dV_c}{dt} = \frac{I - u_g . i_g}{c_r} \quad (13)$$

$$\frac{di_g}{dt} = \frac{u_g . V_c - V_s - R_g . i_g}{L_g} \quad (14)$$

V_c and i_g waveforms can be examined by numerically integrating in Matlab-Simulink environment using the state equations in Eq. 11 and 12

C-Dump inductance voltage (V_g) may be obtained as follows;

$$V_g = u_g . V_c - V_s + V_s (1 - u_g)(1 - Z_g) \quad (15)$$

$$Z_g = 0.5(1 + sign(i_g)) \quad (16)$$

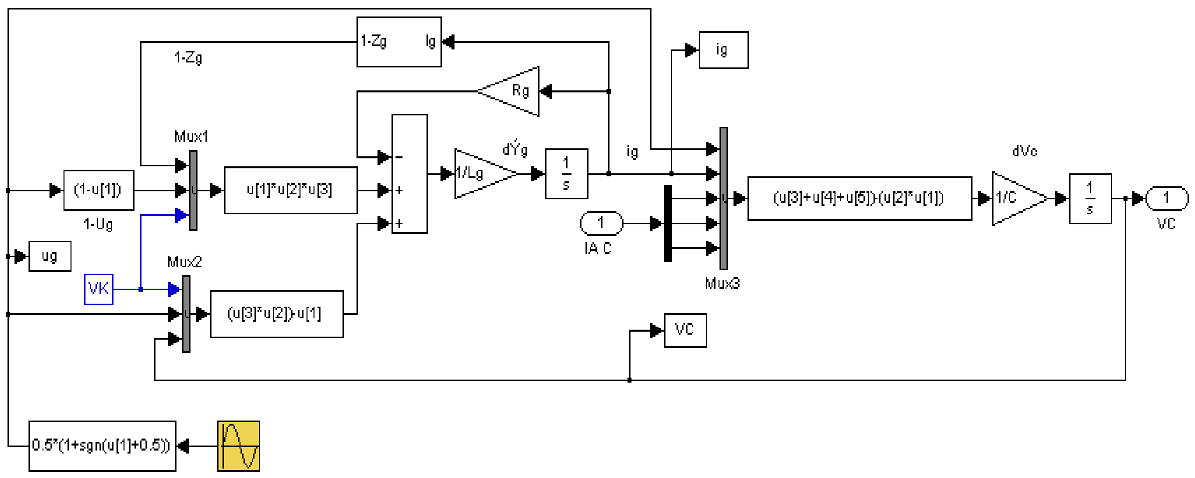

Fig. 2 C-Dump converter Simulink model

Here, Zg is 1 when the current in the C-dump circuit is existing and positive, otherwise is 0. In Eq.9, ut changes the duty-cycle of the energy that is transferred to the power supply. In this study, C-Dump switching frequency and power supply are selected as fg=17kHz and Vs=24V respectively.

In this control system, Phase voltage equation is given as in the following;

$$V_i = V_s - V_c (1 - u_n) - (V_s - V_c)(1 - u_n)(1 - Z_g) \quad (17)$$

In Eq.17, the positions of the phase switches are determined by un. In this study, the amplitudes of the phase currents are defined by hysteresis control strategy. un equals (1) for and otherwise is 0. Therefore, the effects of freewheeling diodes are included to define the phase voltages. The C-dump driver circuit obtained by means of Eqs.11 -17 is shown in Fig.2.

Dynamic characteristics of the SRM belonging to the first phase are shown in Fig.3.

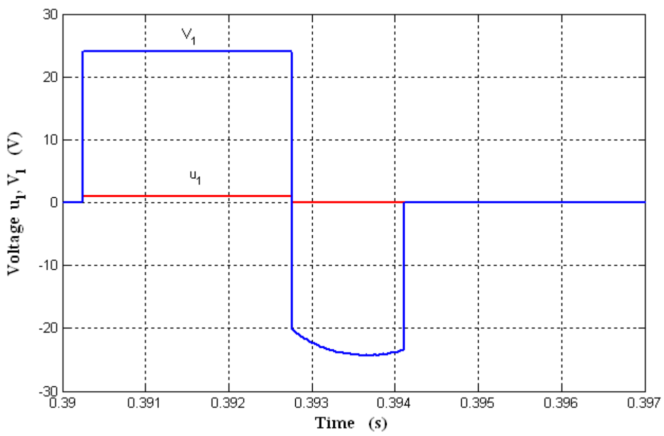

Fig. 3 a. First Phase drive and winding voltage waveforms

The first phase voltage waveform of the SRM is given in Fig.3.a. As can be seen in Fig.3.a, Vi=24V is applied to the phase windings during the conduction of the power transistor of the first phase (0,3914-0,3940s). At the end of the turning-on time, in order to turn on the other phase, the phase current to be turned off has to be brought to zero quickly.

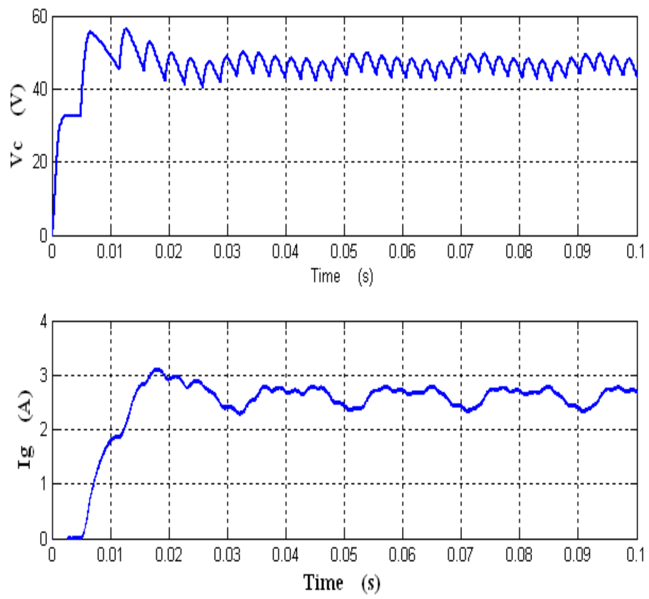

Fig. 3 b. C-Dump voltage and current waveform

Therefore, at the end of the conduction time, Vi=-24V in reverse polarity is applied to the phase winding to be turned off during the time (0,394-0,3954s) interval.

As shown in Fig.3.b, T1 switch that drives the first phase winding remains closed until the end of the conduction time for uncontrolled current operation in C-Dump circuit. C-dump capacitor is charged for once during the conduction time and then retains its charge the same up to the end of the conduction time.

In Fig.4.a, when 8A current control is applied to the SRM, the control signal voltage of the switch (u1) for one phase of the motor and winding voltage V1 are presented. As may be seen in the same figure, Vs=24V is applied to the phase windings for 0,3921s when it is turned on. The current control is applied to the SRM up to the time (0,3958s) that is the end of the conduction interval. The C-dump capacitor voltage (Vc) and the inductor current (ig) waveforms in time domain are given in Fig.4.b. The voltage of C-Dump circuit reaches at 63,5V at the beginning and then drops to the approximate average value (48V).

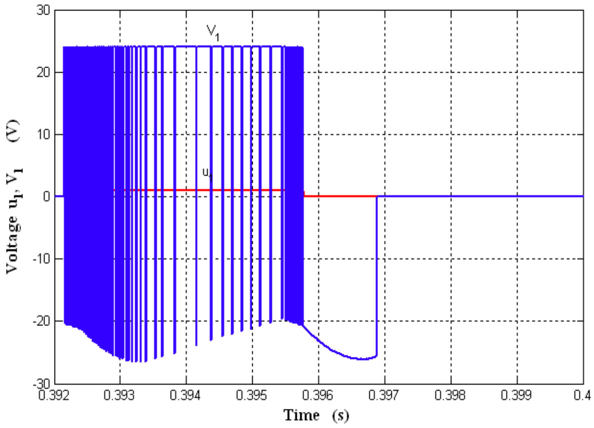

Fig. 4 a First phase winding and T1 drive voltage waveforms (C.C)

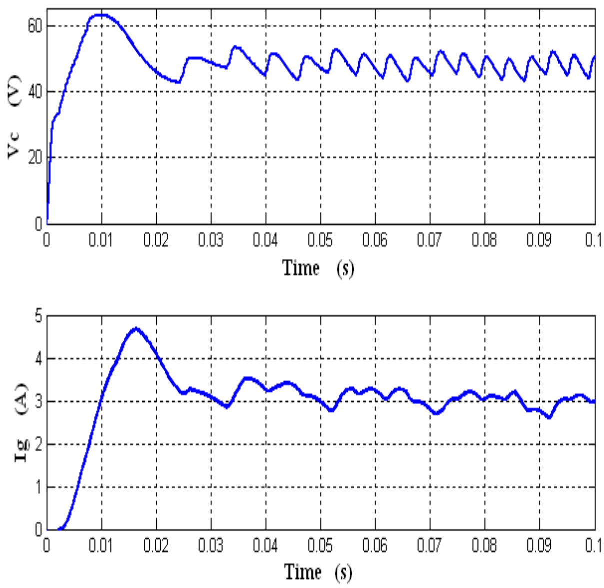

Fig. 4 b. C-Dump voltage Vc and Ig current waveform (C.C)

The C-dump capacitor voltage has a ripple at the average value of Vc=2Vs=48V as seen from Fig. 4.b. The amplitude of Vc voltage is adjusted by the duty-cycle of T1 switch which is described in section I. C-Dump current ig reaches at 4.7A at the beginning and then drops to the approximate average value (2.89A). T1 switch that drives the first phase winding turns on and off continuously according to the reference current value. Therefore, it is observed that ig current has ripple due to charging or discharging of C-dump capacitor (Cr) and the transient response of the phase inductor (Lg). The C-dump current ripple, for the controlled operation, is more explicit than that of the uncontrolled working.

Drivers of SRMs have many differences from that of AC Machines due to they produce torque by using currents in one direction. Although each phase of a SRM is individually driven, two phases are simultaneously driven during the commutation. Because of the fact that SRM drivers does not have any standardization so far, the model of asymmetric converter only exists and commonly used in simulation software packages such as Matlab-Simulink and lack of this model has been considerable for a long time. In this study, to compensate for this shortage, a C-dump converter model is composed by means of circuit equations and the dynamic behaviour of the converter is simulated, analyzed in Matlab-Simulink and shown that it is applicable to all SRMs. It is also presented that the proposed C-Dump converter model can be adaptable for any SRM model that might be produced by any other model developers in Matlab-Simulik.

REFRENCE

1. Y.G. Dessouky, B.W. WIllIams and J. E. Fletcher, 1998, "A Novel Power Converter With Voltage-Boosting Capacitors For a Four-Phase SRM Drive", EEE Trans. Ind. Electron., Vol. 45, pp. 815–823
2. DIRK A.P., 1990, "Switched Reluctance Drives: New Aspects", IEEE T-PE, Vol. 5, No. 4, pp. 454-458
3. YADLA PALI, NAVEEN, 1999, "Implementation of a Novel Soft – Switching Topology for Switch Reluctance Motor Drives", Phd. Thesis, Virginya Politechinic Enst., Virginya
4. DAVIS R. M., RAY W. F., BLAKE R. J., 1981, "Inverter Drive for Switched Reluctance Motor: Circuits and Components", Proc. IEE, Elec. Power Appl., Vol. 128, No. 2, pp.126-136
5. S.VukosavIc and V. R. StefanovIc, 1990, "SRM Inverter Topologies: A Comparative Evaluation", IEEE IAS Conf., pp. 946-958
6. VUKOSAVIC S. and STEFANOVI. R., 1991, "Switched Reluctance Motor Inverter Topologies", I.E.E.E. Trans. On Industry Applications, Vol. 27, No. 6, pp.1034-1047
7. Ramu KrIshnan and Peter N. Materu, 1990, "Design of a Single-Switch-per-Phase Converter for Switched Reluctance Motor Drives", IEEE Trans. on Industrial Electronics, Vol. 37, No. 6, pp. 469-476
8. R.KrIshnan and S. Lee, 1994, "Analysis and Design of a Single Switch per Phase Converter for Switched Reluctance Motor Drives", IEEE PESC Conf., pp. 485-492.
9. [9] R.Krishnan and P. Materu, 1993, "Analysis and Design of a Low Cost Converter for Switched Reluctance Motor Drives", IEEE Trans. on Industry Applications, Vol. 29, No. 2, pp. 320-327
10. R.KrIshnan, S. Lee and R. Monajemy, 1996, "Modeling, Dynamic Simulation and Analysis of a C-dump Brushless DC Motor Drive," IEEE APEC Conf., pp. 745-750
11. HAVA A.M., BLASKO V. and LIPO T.A., 1992, "A Modified C-Dump Converter For Variable-Reluctance Machines", I.E.E.E. Trans. On Industry Applications, Vol. 28, No. 5, pp. 1017-1022
12. [Kyu-Dong Kim, Doo-Jin shin ; Uk-Youl Huh, ‘’Application modified C-dump converter for industrial low voltage SRM’’ ISIE 2001. 2001 IEEE International Symposium on Industrial Electronics Proceedings (Cat. No.01TH8570)
13. Tae-Won Lee, Yong-Ho Yoon, Yuen-Chung Kim, Byoung-Kuk Lee, Chung-Yuen Won, Control of c-dump converters fed switched reluctance motor on an automotive application, , Electric Power Systems Research Volume 77, Issue 7, May 2007, Pages 804-812

14. Tomczewski K., Wrobel K, Improved C-dump converter for switched reluctance motor drives,., IET, Power Electronics, vol. 7, no. 10, pp. 2628-2635 2014,
15. Farzad Faradjizadeh, Mohammad reza Tavakoli, Ebrahim Afjei,''C-Dump converter for Switched Reluctance Generator'' The 5th Annual International Power Electronics, Drive Systems and Technologies Conference PEDSTC 2014
16. Rakesh D. Zalke, A. G. Thosar ''C-Dump Converter for Switched Reluctance Motor'',2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), May 2017
17. Souvik Ganguli, ''Analysis of A C-Dump Converter for Switched Reluctance Motor Drive Using PSPICE'' *International Journal of Advanced Engineering Technology E-ISSN 0976-3945 IJAET/Vol.II/ Issue IV/October-December, 2011 p 331-335,

AUTHORS PROFILE

Hüseyin CALIK He received the B.Sc, M.Sc.and degrees in Electrical Engineer from Marmara University, Turkey, in 1999 and 2005. He is working at the Dept. of Elec. Program in Tech. Sciences Vocational College of Istanbul University-Cerrahpasa Ass. Prof. His research interests are in the areas of Industrial automation systems, computer aided design, adjustable-speed drives, fuzzy logic and neural network applications.

S. Hakan UNDIL He received both B. Sc. and M.Sc. degrees in Electronics and Telecommunication Engineering from Faculty of Electrical and Electronics Engineering in Istanbul Technical University. He received his Ph.D. degree in Electrical Engineering from the Institute of Science and Technology in Yıldız Technical University in 1994. He is currently professor, Nisantasi University, Faculty Of Engineering And Architecture, Department of Electric-Electronic Engineering, Istanbul, Turkey. His research interests include modeling and simulation, power electronics, control of electrical machines .

Hasan Hüseyin Çelik Technology Faculty, Department of ,Electrical-Electronics Engineering Marmara University, Istanbul, He was born in Aydin, Turkey, in 1965. He received the B.S. and M.S. degrees in electronics and communication engineering from Yildiz Technical University, Esenler, Turkey, in 1987, and the Ph.D. degree in electronics and computer education from Marmara University, Istanbul, Turkey, in 1999. Since then, he has been a member of the Technology Faculty, Marmara University. He participated the second industrial education program of the World Bank at Ferris State University, MI, for nine months in 1991. His research interests include intelligent systems, embedded systems, and control.