Bifurcation analysis of single phase half controlled rectifier fed DC series motor drive system

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Investigation for bifurcation and chaos in dc motor drive systems [1]-[2] have mainly presented different nonlinear behaviors in PMDC or shunt motor drive systems. However less research work is dedicated to explore nonlinear behavior of a controlled rectifier fed dc series motor drive system which is extensively used in electric multiple units (EMUs) and has many other industrial applications like elevators, hoists etc. So this paper is intended to present bifurcation phenomenon of a semi-converter fed PWM dc series motor drive system with PI control action. To emphasize the fact that bifurcation behavior exhibited by power electronic and drive systems is mainly caused by change in duty cycle of the gate signal, an attempt is made in this paper to classify pattern of switching pulse or in other words to classify pattern of intersection of the controller output with the synchronized ramp and is based on whether (i) intersection takes place at the top or bottom end ,or with the rising edge of sawtooth waveform,(ii) controller output is more or less than sawtooth at the beginning of a sawtooth cycle and (iii) intersection is once or multiple in a sawtooth cycle. These observations are necessary to identify the cause of bifurcation, which in turn will help to identify boundary of the desired nominal period-1 behavior on the parameter space and thus facilitate to construct useful design rule for avoiding undesirable behavior such as quasiperiodic solution or coexisting attractors. The paper also presents basin of attraction for chaotic and different periodic orbits of the drive system w.r.t controller gain. Matlab simulation and experiment is performed on a 0.5 hp, 1800 rpm, 4amp. dc series motor drive system to explore different interactive patterns. Schematic for voltage mode control of a single phase semi converter fed dc series motor drive system is shown in Fig. 1,where SCRs have been used as the controlled switches with device switching pulse generating circuit being consisting of a comparator, PI controller with limiter and synchronizing ramp generating block. To avoid cycle skipping phenomenon, the controller output is fed to limiter circuit for fixing the lower bound as zero and upper bound less than the peak of sawtooth waveform. Under continuous conduction mode in each half cycle,Ts of supply voltage the SCR semiconverter can have two switch states. Stare1: a particular switch pair

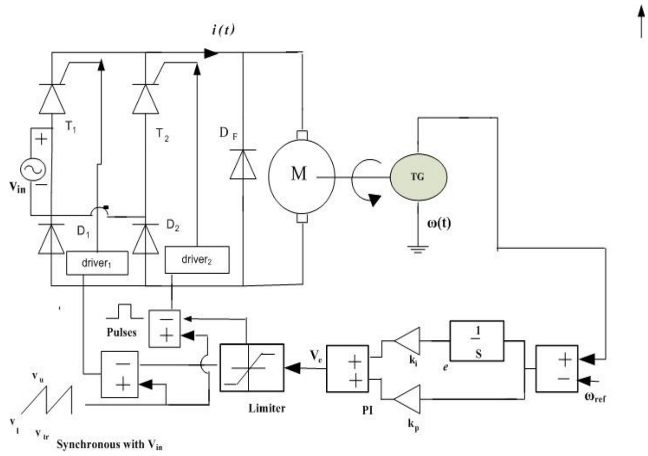

Figure1: Schematic of dc series motor drive system

(T_1-D_2 or T_2-D_1) is on, but D_F is off and connects input voltage to the drive when $V_e < V_{tr}$,. and state 2: freewheeling mode i.e., D_F is on and neither switch pair is in conduction when $V_e > V_{tr}$. Depending upon nature of time evolution of the controlled error signal (V_l) during a cycle of synchronized ramp (time instants x and y as shown in Fig.2) intersection of V_l with the ramp is classified in to TYPE-1 which is for single intersection and TYPE-2,which is for multiple intersections in each cycle of sawtooth waveform.

Depending on whether the evolution of controlled error signal during any one or both the switching states saturates at the limiting values as set by the limiter circuit, TYPE-1 can be of four types as shown in Fig. 2(a)-Fig.2(d). **Type 1a** ,where **c**ontrolled error signal never reaches either of the limiting values as shown in Fig. 2(a). For **Type 1b** during freewheeling state V_l reaches the upper limiting value and on state is similar to pattern 1a as shown in Fig. 2(b). . However, for the case of **Type 1c** the output of limiter circuit saturates to upper limiting value during the freewheeling state and to the lower limiting value during conduction period as shown in Fig. 2(c). For case of **Type 1d** the off state is similar to type 1c, but during some initial part of the conduction of a switch pair, V_l reaches lower boundary value and after that the evolution of V_1 remains within both the boundary values as shown in Fig. 2(d). **Type2** can be further classified into type-2a and type-2b. **Type 2a** is characterized by three intersections with the rising edge of ramp. Depending on whether the evolution of V_1 follows the limiting values or not, type-2 can be of four types as type 2ai, type 2aii, type 2aiii, type 2aiv as shown in

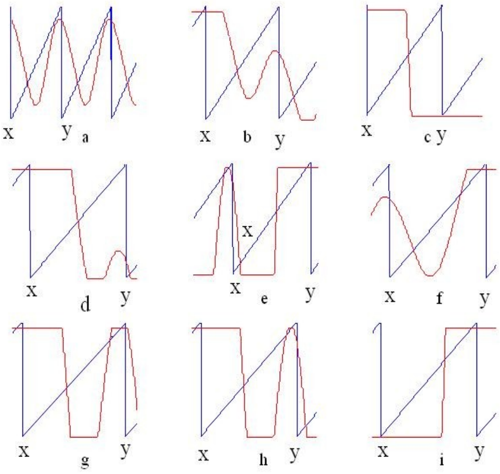

Figure 2: Possible evolution of V_1 in a sawtooth cycle .
*a:*Type1a, *b*Type 1b, *c:* Type 1c *d:* Type 1d, *e:* Type 2ai, *f:* Type 2aii, *g:* Type 2aiii, *h:* Type 2aiv, *i:* Type-2b.

Fig. 2e-2h respectively. In this paper source voltage is kept fixed and bifurcation behaviors are plotted against variation in kp. Simulation is done in MATLAB SIMULINK environment. It is noticed from Fig. 3 that system behavior follows a period doubling route to chaos .To illustrate effect of different interactive patterns with increase in k_p on performance of the drive system corresponding phase plots (ω vs. i) are shown in Fig.4. Before k_p =0.9 (pt. A in Fig. 3) the drive system has period-1 behavior with switching pattern 1a. But with increase in kp drive system bifurcates to period-2 orbit with switching pattern 1b-2aii indicating a border collision type of bifurcation at point A. However with further rise in k_p switching pattern changes from the type 1b-2aii to 1b-2ai and finally to 1d-2ai. Thus it is the increase in k_p which causes V_1 to saturate and .to change pattern *2aii to 2ai* and pattern *1b to 1d*. At point B (kp=2.4), period-2 behavior undergoes again period doubling phenomenon and interactive sequence at the bifurcation point, transits from 1d-2ai to 1d-2ai-1d-2b. Further increase in kp causes saturated V_1 to change period-4 interactive sequence from 1d-2ai-1d-2b to 1d-2ai-1c-2b, then to 2aiv-2ai-1c-2b followed by 2aiii-2ai-1c-2b and finally to2aiii-2aiii-1c-2b. So due to the effect of the limiter circuit, the pattern 1d transits to pattern *1c or 2aiv to 2aiii* and *2ai to 2aiii* with transition from one type of border collision interaction to another type of border collision. As k_p continues to increase the period-4 behavior with interactive sequence 2aiii,2aiii,1c,2b bifurcates to(k_p=5.0, point C) period-8 behavior with the resulting sequence 2aiii,2aiii,1c,2b, 2aiv,2ai,1c,2b . Moving towards right in the bifurcation diagram (Fig 3) the period 8 sequence changes to 2aiii,2aiii,1c,2b, 1d,2ai,1c,2b. With increase in kp(k_p=6.3,point D), period-8 undergoes period doubling

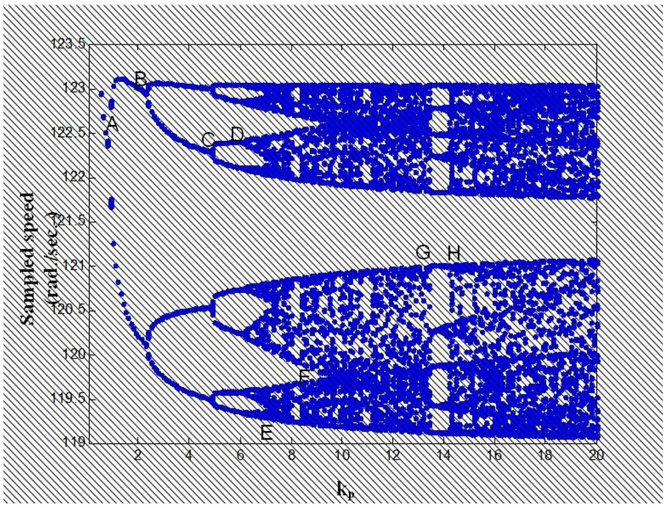

Figure 3: Bifurcation behavior of speed at T_L=0.8Nm, ω_{ref}=120 rad./sec. and K_i=0.01 against variation in k_p

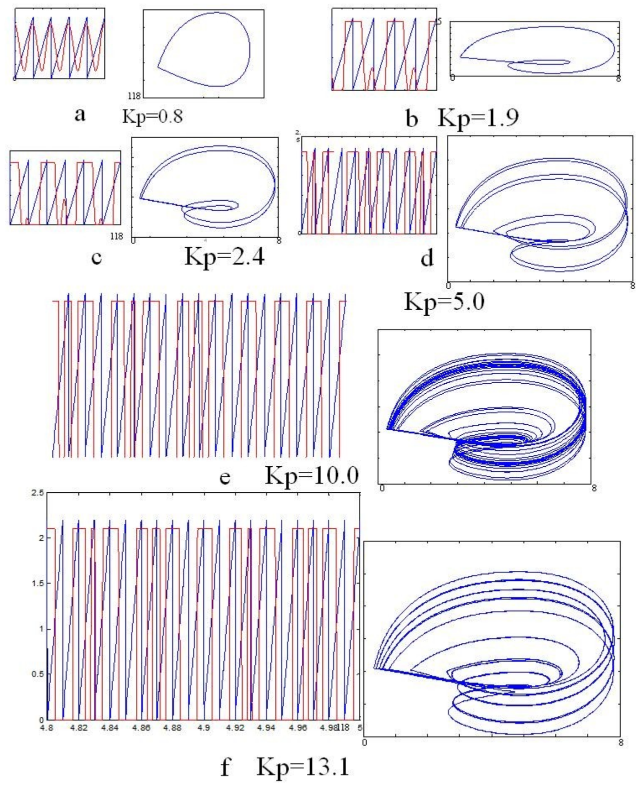

Fig.ure 4: Phase plot (ω vs. i) and corresponding interactive patterns between V_{tr} and V_l for different k_ps

operation .This period-16 zone is a narrow band. At k_p=7.0, (point E), this period-16 zone transform to chaotic orbit zone ,initially with 4 distinct dense chaotic zones and then two distinct chaotic zones(k_p=9.4,point F) .Creation of chaotic attractor from a higher periodic orbit is through bc_C type bifurcation. To be noted that, a narrow zone of period -5 orbit is observed in both chaotic zones region between point ‘G’(k_p=13.1) and ‘H’(k_p=14.2).

References

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