OPTIMIZED FUZZY LOGIC CONTROLLED BOOTSTRAP ZVS BASED SVM INVERTER SYSTEM

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Abstract

This work aims on improving the dynamic time response of closed-loop Bootstrap controlled SVM inverter (BSVMI) with PI, FOPID and FLC. In this work the simulink model of FLC based ZVS bootstrap SVM inverter system is discussed. Bootstrap converter is a popular device within the family of power Electronics device. The SVM inverter is used with voltage source inverter (VSI) and the switching pulses are given using FLC controller. The ZVS bootstrap converter is used for reduction of switching losses. The simulation results are presented to find the effect of BSVMI using FLC. The simulation results with PI, FOPID and FLC Controller based BSVMI are compared and the consequent time-domain parameters are presented. The results specify that FLC Controller system has enhanced response than PI and FOPID controlled system.

Keywords: FLC, Bootstrap, SVM, Cloased Loop, Dynamic reponse

I. Introduction

The importance of sinusoidal PWM inverters are reduced and increased different pulse width techniques and it is decreased switching (SW) losses. The SW losses are almost relative to current amplitudes of the mosfet. Almost the amplitudes are the equal; they are relative to number of switching times. The switching currents losses are resolute by loads. Therefore reduction techniques in number of switching times, for case in point, the phase modulation method, be helpful as they produced equivalent PWM waveforms with smaller amount switching times than for the predictable PWM modulation techniques [II, IV, VI, VIII, X, XI, XIII, XIV].

There is a communication commendable fact that the diminution in number of switching epoch and the SW thrashing diminution are more issues level if it is likely to decreased conduction losses by the decline in number of switching times. The controllers are used to improve the response here FLC is done as discussed in Copyright reserved © J. Mech. Cont. & Math. Sci. S. M. Revathi et al
In point of fact phase currents are diverse and no switching model of the prevalent voltage phase reduces the Voltage stress most effectively. SVM has the benefit of inferior harmonics in count to the kind of entire digital execution by a solitary break off microprocessor. Thus, SVM is beneficial in excess of phase control and PWM as given in [VIII], [XIII]. A power inverter can be regarded as into lot of circuit of power electronics device, The Full-bridge inverter and other converter systems. The DC-AC converter is the mainly applicable method because of its amount-problems, plainness, and power electronic circuit’s needs of components. An assortment of zero voltage and zero current switching (ZVZCS) full bridge converters [IV, V, XIV, XVI] based on assisting circles were anticipated. In [I], this includes analyzing low dimensional DC/DC converters with a small signal model or discrete mapping model, and estimating the stability of the system. The most important switch realizes ZVS and the wadding switch realizes ZCS. It widens the soft-switching range and reduces the switching loss of the lagging switch, but the leading switch does not realize the ZCS turn off [XV]. Direct current signals are capable of simply is transferred to alternate current signals by the Full -bridge inverter with the pulse-width-modulation of switching techniques.

In most of the converter and inverter design, a long-established Proportional-Integral controller is adopted and applied with analogue hardware device [XIX]. While the PI controller has been extensively adopted in practice application, the hardware recognition of a PI controller is very difficult to be tuned to have massive performances. Also, uncertainties might be in the different hardware devices of the converter and inverter circuits. For an elaborate structure with uncertainties, an effectual controller might not be practicable using hardware enlargement. For the earlier period of most of systems, if there most of efforts were committed to originate of fuzzy logic controllers for intricate product among the suspicions. To be discussed the step response of control in the fuzzy acquaintance support and implication appliance can be designed. The fuzzy logic method better performance compared with PI and FOPID controller for systems without literal design model. On the other hand, the intricacy of a fuzzy controller be enlarged when the number of fuzzy rules or the number of fuzzy mechanisms applied in the fuzzy controller are superior. The intricacy mounting would be upper and lower limit the applications of fuzzy controllers.

II. Circuit Operation of Boostrap Convertor

The route figure of the Bootstrap converter is exposed in Fig. 1. In the circuit, S is the power switch and D is the freewheeling diode. The energy storage submissive rudiments are inductors.
This paper proposes the steady and wrinkle free output voltage from the intend of urbanized DC-DC converter topology.

III. Scope of the Paper

- To model bootstrap converter with reduced switching losses and Voltage-Controlled system in closed loop system with PI controller.
- To model bootstrap converter with reduced switching losses and Voltage-Controlled system in closed loop system with FOPID controller.
- To model bootstrap converter with reduced switching losses and Voltage-Controlled system in closed loop system with FLC controller.
- To develop the hardware setup and test it.

IV. System Description

The block diagram of closed loop system with PI controller is shows in the Fig 1.1. The block diagram of closed loop system with FOPID controller is shown in the Fig 1.2. The Block diagram of closed loop system with FLC controller is shown in Fig 1.3.
Fig 1.2: Block diagram of closed loop system with FOPID controller

Fig 1.3: Block diagram of closed loop system with FLC controller

IV. Discussions

Circuit diagram for bootstrap converter with SVM inverter for source disturbance is appeared in Fig 2.1. Input voltage is appeared in Fig 2.2 and its value is 130V. Circuit diagram for bootstrap converter is appeared in Fig 2.3.

Fig 2.1: Circuit diagram of bootstrap converter with SVM inverter for source disturbance
The output voltage of the bootstrap converter is appeared in Fig 2.4 and its value 415V.

Fig 2.5: Circuit diagram of three phase ZVS- SVM inverter
Circuit diagram for three phase ZVS-SVM inverter is appeared in Fig 2.5. The voltage across R-load is appeared in Fig 2.6 and its value is 415V. The output current through R-load is appeared in Fig 2.7 and its value is 2A. Output power is appeared in Fig 2.8 and its value is 600Watts.

Circuit diagram for bootstrap converter with SVM inverter for closed loop PI controller is shown in Fig 2.9. Input voltage is appeared in Fig 2.10 and its value is 130V. The voltage across the bootstrap converter is appeared in Fig 2.11 and its value 415V.
Fig 2.9: Circuit diagram of bootstrap converter with SVM inverter for closed loop PI controller

Fig 2.10: Input voltage

Fig 2.11: Voltage across bootstrap converter

Fig 2.12: Voltage across R-load

Fig 2.13: Current through R-load
The voltage across R-load is appeared in Fig 2.12 and its value is 415V. The output current through R-load is appeared in Fig 2.13 and its value is 2A. Output power is appeared in Fig 2.14 and its value is 600Watts.

![Output power graph]

**Fig 2.14:** Output power

![Circuit diagram of bootstrap converter with SVM inverter for closed loop FOPID controller]

**Fig 2.15:** Circuit diagram of bootstrap converter with SVM inverter for closed loop FOPID controller

Circuit diagram for bootstrap converter with SVM inverter for closed loop FOPID controller is appeared in Fig 2.15. Input voltage is appeared in Fig 2.16 and its value is 130V. The voltage across the bootstrap converter is appeared in Fig 2.17 and its value 415V.

![Input voltage graph]

**Fig 2.16:** Input voltage
The voltage across R-load is appeared in Fig 2.18 and its value is 415V. The output current through R-load is appeared in Fig 2.19 and its value is 2A. Output power is appeared in Fig 2.20 and its value is 600Watts.
Circuit diagram for bootstrap converter with SVM inverter for closed loop FLC controller is appeared in Fig 2.21. Input voltage is appeared in Fig 2.22 and its value is 130V. The voltage across the bootstrap converter is appeared in Fig 2.23 and its value 415V.

Fig 2.21: Circuit diagram of bootstrap converter with SVM inverter for closed loop FLC controller

Fig 2.22: Input voltage

Fig 2.23: Voltage across bootstrap converter
The voltage across R-load is appeared in Fig 2.24 and its value is 415V. The output current through R-load is appeared in Fig 2.25 and its value is 2A. Output power is appeared in Fig 2.26 and its value is 600Watts.
Fig 2.27: Bootstrap converter switching pulse S1, without controller Vds1 & with controller Vds1

The switching pulse given to the bootstrap converter for the switch S1, without controller Vds1 & with controller Vds1 is shown in the Fig 2.27. The switching pulse given to the inverter for the switch M1, without controller Vds1 & with controller Vds1 is shown in the Fig 2.28.

Fig 2.28: Three phase inverter switching pulse M1, without controller Vds1 & with controller Vds1
Fig 2.29: Comparison of bootstrap converter output voltage with regulated without controller, With PI, FOPID, FLC controller

The voltage regulation of the bootstrap converter output voltage is compared with without controller and with PI, FOPID, and FLC controller and it is shown in the Fig 2.29.

Table 1: Comparison of Time domain parameters for voltage (Vref = 425V)

| Controllers | Rise time (s) | Peak time (s) | Settling time (s) | Steady state error (V) |
|-------------|---------------|---------------|-------------------|------------------------|
| PI          | 0.35          | 0.51          | 0.58              | 3.9                    |
| FOPID       | 0.24          | 0.37          | 0.41              | 3.4                    |
| FLC         | 0.19          | 0.20          | 0.28              | 1.6                    |

The comparison of time domain analysis for voltage (Vref = 425V) is given in the Table 1. The rise time in PI controller is reduced from 0.35 sec to 0.19 sec in FLC controller; the peak-time in PI controller is reduced from 0.51 sec to 0.20 sec in FLC controller; the Settling-time in PI controller is reduced from 0.58 sec to 0.28 sec in FLC controller and steady-state-error in PI controller is reduced from 3.9 V to 1.6V in FLC controller by replacing PI controller with FLC controller. FLC controller has better response compared to PI and FOPID controllers. Dynamic-response is also improved by using FLC controller.

Table 2: Comparison of Time domain parameters for voltage (Vref = 415V)

| Controllers | Rise time (s) | Peak time (s) | Settling time (s) | Steady state error (V) |
|-------------|---------------|---------------|-------------------|------------------------|
| PI          | 0.29          | 0.45          | 0.50              | 3.3                    |
| FOPID       | 0.19          | 0.30          | 0.35              | 2.8                    |
| FLC         | 0.13          | 0.16          | 0.23              | 1.2                    |

The comparison of time domain system for voltage (Vref = 415V) is given in the Table 2. The rise time in PI controller is reduced from 0.29 sec to 0.13 sec in FLC controller; the peak-time in PI controller is reduced from 0.45 sec to 0.16 sec in FLC controller; the Settling-time in PI controller is reduced from 0.50 sec to 0.23 sec in FLC controller.
FLC controller and steady-state-error in PI controller is reduced from 3.3 V to 1.2V in FLC controller by replacing PI controller with FLC controller. FLC controller has better response compared to PI and FOPID controllers. Dynamic-response is also improved by using FLC controller.

**Table 3: Simulation parameters**

| Parameter      | Value     |
|----------------|-----------|
| Vin            | 130V      |
| C1             | 500μF     |
| L1             | 1mH       |
| L2             | 2mH       |
| C2,C3          | 100mF     |
| L3,L4,L5       | 2mH       |
| C4,C5,C6,C7,C8,C9 | 0.5μF   |
| L01,L02,L03    | 100mH     |
| C01,C02,C03    | 100μF     |
| R01,R02,R03    | 125Ω      |
| MOSFET(IRF840) | 200V/8A   |
| DIODE          | 230V/1A   |
| Vo             | 415V      |
| Kp             | 0.018     |
| Ki             | 0.8       |
| Kd             | 0.07      |
| Kf             | 0.5       |

**Fig 2.30: Hardware snap shot**

The hardware snap shot is appeared in the Fig 2.30. The input voltage is exposed in the Fig 2.31.
The switching pulse given to the bootstrap converter for the S1 and V_{ds} is shown in the Fig 2.32. The output voltage across bootstrap converter is appeared in the Fig 2.33.

The switching pulse for inverter M1 & V_{ds} is shown in the Fig 2.34.
The switching pulse given to the inverter foe M1 and $V_{ds}$ is shown in the Fig 2.34. The switching pulse given to the inverter foe M1 and M2 is shown in the Fig 2.35.

**Fig 2.35:** Switching pulse for inverter (M1,M2)

The switching pulse given to the inverter foe M4 and M6 is shown in the Fig 2.36.

**Fig 2.36:** Switching pulse for inverter (M4, M6)

The output voltage across RL load is appeared in the Fig 2.37. The output current across RL load is appeared in the Fig 2.38.

**Fig 2.37:** Output voltage across RL load

**Fig 2.38:** Output current through RL load
Table 4. Hardware parameters

| Parameter | Value   |
|-----------|---------|
| C1        | 2200μF  |
| L1        | 1.5mH   |
| L2        | 3mH     |
| C2        | 1000μF  |
| C3        | 100μF   |
| L3, L4, L5| 2mH     |
| C4, C5, C6, C7, C8, C9 | 104μF |
| L01, L02, L03 | 50mH |
| C01, C02, C03 | 100μF |
| R01, R02, R03 | 125Ω |
| MOSFET (IRF840) | 200V/8A |
| DIODE     | 230V/1A |

V. Conclusions

The bootstrap converter with SVM inverter with closed loop is simulated and the results with PI, FOPID and FLC converters are presented. At voltage (Vref=425V), the steady state error is reduced from 3.9 V to 1.6 V. At voltage (Vref=415V), the steady state error is reduced from 3.3 V to 1.2 V. Therefore FLC based active filter may be a viable alternative to the existing system. The reduction in settling time and the steady-state error is high in the case of FLC controller system. At voltage (Vref=425V), the settling time is reduced from 0.58 sec to 0.28 sec. At voltage (Vref=415V), 0.50 sec to 0.23 sec. The advantages of the proposed system are the reduction in losses, line drop, steady state error and settling time.

The present work deals with the investigation of PI, FOPID, and FLC controlled bootstrap converter with SVM inverter system. The improvement with FLC controller is done. The future work will be done in application of induction motor drive with closed loop system.

References

I. Ayyanar R and Mohan N “Novel soft-switching DC-DC converter with full ZVS-range and reduced filter requirement. I: Regulated-output applications,” IEEE Trans. Power Electron., Vol. 16, No. 2, pp. 184-192, Mar. 2001.
II. Cavalcanti M.C., E.R.C. da Silva, A.M.N Lima, C.B. Jacobina, R.N.C. Alves; “Reducing losses in three-phase PWM pulsed DC-link voltagetype inverter systems,” IEEE Transactions on Industry Applications, Vol. 38, No. 4, pp. 1114 - 1122, 2002.

III. Celanovic N. and D. Boroyevich, “A fast space vector modulation algorithm for multilevel three phase converters,” IEEE Trans. Ind. Appl., Vol. 37, No. 2, pp. 637 - 641, Feb. 2001.

IV. Chu E. H., X. T. Hou, H. G. Zhang, M. Y. Wu, and X. C. Liu, “Novel zero-voltage and zero-current switching (ZVZCS) PWM three-level DC/DC converter using output coupled inductor,” IEEE Trans. Power Electron., Vol. 29, No. 3, pp. 1082-1093, Mar. 2014.

V. Chen T. F and S. Cheng, “A novel zero-voltage zero-current switching full-bridge PWM converter using improved secondary active clamp,” IEEE International Symposium on Industrial Electronics, Montreal, pp. 1681-1687, 2006.

VI. Govindaraj T and B. Gokulakrishnan, “Simulation of PWM based AC/DC Converter control to improve Power Quality,” International Journal of Advanced and Innovative Research. ISSN: 2278-7844, Dec-2012, pp 524-533.

VII. Govindaraj T, Rasila R, “Development of Fuzzy Logic Controller for DC – DC Buck Converters”, International Journal of Engineering Techsci. Vol 2(2), 192-198, 2010.

VIII. Gupta A. K., and A. M. Khambadkone, “A space vector PWM scheme for multilevel inverters based on two-level space vector PWM,” IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1631–1639, Oct. 2006.

IX. Halasz S, B.T. Huu, A. Zakharov; “Two-phase modulation technique for three-level inverter-fed AC drives,” IEEE Transactions on Industrial Electronics, Vol. 47, No. 6, pp. 1200 - 1211, 2000.

X. Hideaki Fujita, Ryo Suzuki: “A three-phase solar power conditioner using a single-phase PWM control method,” IEEJ Trans. IA, Vol. 130, No. 2, pp. 173-180, 2010.

XI. Haifeng Lu, Wenlong Qu, Xiaomeng Cheng, Yang Fan, Xing Zhang: “A Novel PWM Technique With Two-Phase Modulation,” IEEE Trans. On Power Electronics, Vol. 22, No. 6, pp. 2403-2409, 2007.

XII. Jin K., X. Ruan, and F. Liu, “An improved ZVS PWM three-level converter,” IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 319–329, Feb. 2007.

XIII. LingaSwamy. R and Satish Kumar. P (2008), ‘Speed control of space vectored modulated inverter driven induction motor’, proceedings of the International Multi conference of engineers and computer scientist, vol.2.
XIV. MousaviA and G. Moschopoulos, “A new ZCS-PWM fullbridge DC–DC converter with simple auxiliary circuits,” IEEE Trans. Power Electron., Vol. 29, No. 3, pp. 1321-1330, Mar. 2014.

XV. Ruan X. and Y. Yan, “A novel zero-voltage and zero current- switching PWM full-bridge converter using two diodes in series with the lagging leg,” IEEE Trans. Ind. Electron., Vol. 48, No. 4, pp. 777-785, Aug. 2001.

XVI. Szychta E., “ZVS operation region of multi resonant DC/DC boost converter”, Journal of Advances in Electrical and Electronic Engineering, Vol.6, No.2, 2007, Zilina University, pp. 60-62.

XVII. Sefa I., N. Altin, S. Ozdemi, and O. Kaplan, “Fuzzy PI controlled inverter for grid interactive renewable energy systems,” IET Renewable Power Generation, vol. 9, no. 7, pp. 729-738, 2015.

XVIII. Tabisz W.A., Lee F.C., "DC analysis and design of zero-voltage switched multi-resonant converters", IEEE 20th Annual Power Electronics Specialists Conference, PESC '89, vol. 1, 1989, p. 243 – 251.

XIX. Tattiwong K. and C. Bunlaksananusorn, “Analysis design and experimental verification of a quadratic boost converter,” in TENCON 2014 - 2014 IEEE Region 10 Conference, Oct 2014, pp. 1–6.

XX. Taniguchi K., H. Irie ; “Trapezoidal modulating signal for three-phase pwn inverter,” IEEE Transactions on Industrial Electronics, Vol. 33 , No. 2, 193 - 200, 1986.

XXI. Tao C.W. and J.-H. Taur, “Design of fuzzy controllers with adaptive rule insertion,” IEEE Trans. Syst., Man, and Cyber., Part B: Cyber., vol. 29, no. 3, pp. 389-397, 1999.

XXII. Wai R.-J., M.-W. Chen, and Y.-K. Liu, “Design of adaptive control and fuzzy neural network control for single-stage boost inverter,” IEEE Trans. Ind. Electron., vol. 62, no. 9, pp. 5434-5445, 2015.

XXIII. Zhou K, D. Wang,(2002),‘Relationship between Space Vector Modulation and three phase carrier-based PWM: A comprehensive analysis’, IEEE Trans. Ind. Elec. Vol. 49,pp 186-196.