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HPSOMPC Control of Bidirectional Series Resonant DC/DC Converter

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Abstract
DC to DC converters are comprehensively applied to several applications in recent subsistence. In this paper hybrid particle swarm optimization tuned model predictive controller (HPSOMPC) is used to attain a better concert of the bidirectional series resonant dc/dc converter while load changes and at starting. The important intention of the proposed controller topology is to improve the steady state stability at output voltage under the variable load conditions. The novel topology has been tested by using simulating tools of MATLAB SIMULINK beneath varying load conditions.

Keywords*: *Series Resonant dc/dc Converter, Particle Swarm Optimization, Converter Response, Model Predictive Control.

1. Introduction

Resonant converters have many positive inherent properties. The advantages are forced to use the resonant converter widely used. The low switching losses in resonant converters are very low so the efficiency is high [1]. Due to the reduced switching losses during switching, soft switching can give the better performance to the converter [2]. When the transient and dynamic performances are improved, then the efficiency and life of the converter will increase.

To get convincing transient and dynamic behavior of system, multiple sliding surface control used [3]. Even though, a voltage recovery time was little large and peak over shoot was also high in dynamic conditions. To get the perfect surface of the switch, many alternative methods are developed like fractional order control (FOC) and also fractional sliding mode control. A better output behavior of the step down converter was achieved by improving the switching surface of sliding mode controller [4]. Nevertheless a ripple voltage was high. To enhance the regulation, efficiency and performance, interleaved discharging (ID) approach was introduced. By using active clamp mechanism the ripple voltage of dual series resonant converter suppressed a lot [5]. But the size and cost was large by reason of inductors. Proceeding with them, to attain a better dynamic response of step down converter, hysteresis with a proportional - integral algorithm was used in current feedback loop [6]. Still the transient output ripple voltage was high. Enduring that, sliding mode voltage controller using PWM was introduced and tested in all basic choppers [7]. PWM signals are pulse trains with variable pulse width and variable frequency [26]-[28]. Yet the recovery time of voltage was large and ripple voltage was also high. To attain the better dynamic performance, capacitor charge balance was used in dc-to-dc converters, [8]. But the recovery time and undershoot voltage during the load change were increased. Later, with the aim of reducing switching losses, by varying the frequency and time period of the pulses were used in converters [9]. But the ripple voltage was not reduced. Many current mode controllers had introduced to curb the ripple voltage [10]. Still the dynamic performance was not improved. Owing to get the superior dynamic performance of synchronous dc to dc buck converter, dynamic evolution control theory was developed [11]. The transient time of the buck chopper was reduced by the use of the linear–nonlinear

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control [12]. Small capacity power rectifier was tested with the mixed signal peak current mode control for transferable appliances. But undershoot, overshoot voltages and recovery time under load change were not yet abridged. By using the adaptive terminal sliding mode control, Hasan Komurcugil tried to get a sensible dynamic behavior [13]. Even though the recovery time was reduced, the undershoot voltage was occurred in voltage waveform beneath load variation. In order to augment the load changing behavior, neural adaptive dynamic surface control was developed [14]. Though the dynamic behavior had enhanced, two special modes were urbanized for input and load variation. To standardize the load voltage of the full bridge converter, some prediction horizon had been explored in model predictive control [15]. While using the sliding mode controller for controlling the buck chopper [16], the transient time was improved but the voltage recovery time while change in load was little high. GA is a computational approach to solve optimization problems using genetic methods and the theory of evolution [25].

To trim down the switching losses, the numbers of switches were reduced in the circuit and achieved bidirectional operation in series resonant converter [17]. In this letter using HPSOMPC the bidirectional series resonant dc/dc converter which was established in [18] has been controlled. The projected controller keeps the voltage as constant with low ripple voltage across the varying load. In this paper, Section 2 deals about the model predictive control and Section 3 illustrates the significance of the optimization technique which is employed in the projected topology. In Section 4 the results which are obtained in simulation are conversed. Finally section 5 concludes.

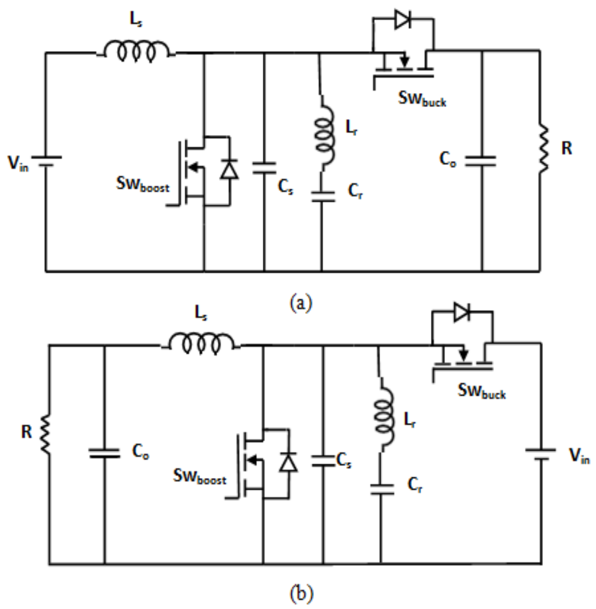

Figure 1: Bidirectional dc/dc series converter (a) Step-up Mode (b) Step-down mode

2. Model Predictive Control

The bidirectional series converter is given in fig 1. The resonance created by inductor L_r and capacitor C_r which are connected in series [18]. This converter can increase the voltage which was fed and decrease the load voltage according to the connection. The condition for achieving the Zero voltage switching is the resonant inductor value should be greater than the value of main inductor. When considering the step-up mode of bidirectional converter, $S_w$boost is active. $S_w$boost has two states, due to ZVS condition $S_w$boost turn to off. Here the state variables are current in main inductor (L), current in resonant circuit, output capacitor voltage and the resonant capacitor voltage. Consider 'D' as Duty cycle and 'u' as switching state. With all the promising way of modes of operation, the state space equation can be given as,

$$\frac{dx(t)}{dt} = (DA_1 + (1-D)A_2)x(t) + (DB_1 + (1 -$$
$$DB2u\,(t)$$

$$y(t) = Cx(t) \qquad \textbf{(1)}$$

Here,

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{L_r} \\ 0 & 0 & \frac{-1}{R_{c_o}} & 0 \\ 0 & 0 & 0 & \frac{-1}{Z_{c_r}} \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 0 & 0 & \frac{1}{LL_r} & -\left[1+\frac{1}{L_r}\right] \\ 0 & 0 & -\frac{1}{L_r} & \frac{1}{L_r} \\ 0 & 0 & \frac{-1}{R_{c_o}} & 0 \\ 0 & 0 & 0 & \frac{-1}{Z_{c_r}} \end{bmatrix}$$

$$B_1 = \begin{bmatrix} \frac{1}{L} \\ \frac{1}{L} \\ 0 \\ 0 \end{bmatrix}$$

$$B_2 = \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix} \qquad \textbf{(2)}$$

The objective function is preferred as [19],

$$J(k) = \sum_{m=k}^{k+N-1} \left(\left| v_{op,e}(m+1) \right| + w \left| \Delta u(m|k) \right| \right) \qquad \textbf{(3)}$$

This gives the variation between the voltage at output

V_{op} and the reference value V_{ref} of corresponding prediction horizon N with the control weight 'w'.

Where,

$$v_{op,e}(k) = v_{ref} - v_{op} \quad \textbf{(4)}$$

$$\Delta u(k) = u(k) - u(k-1) \quad \textbf{(5)}$$

3. Significance of Hybrid PSO

The basic aim of model predictive control (MPC) is to minimize the objective function (3) under the dynamics of the model of the converter (2).

$$U(k) = arg\, min\, J(k) \quad \textbf{(6)}$$

This work focuses on the optimization of the important parameters of the MPC hybrid particle swarm optimization (HPSO). In (3), to tune the weight factor 'w' HPSO is applied. Eberhart introduced the optimization method called as Particle Swarm Optimization (PSO). Normally its steps forward to the growing motion. The principle of working is like a group of birds searching food [20]. The consecutive factors are the important factors of PSO technique. They are, (a) The procedure is held in examine on collection like fish grouping (ii) The important producers of this optimization method contains particle rapidity and place finding. Therefore, work out instant will be too low. [21].

According to [22],

$$\mathrm{v_{ij,new}} = \mathrm{w.v_{ij}} + \mathrm{c_1 rand_1}\left(\mathrm{pbest_{ij}} - \mathrm{d_1.particle_{ij}}\right) + \mathrm{c_2 rand2}(\mathrm{gbest_{ij}} - \mathrm{d_2.particle_{ij}}) \quad \textbf{(9)}$$

$$particle_{ij,new} = particle_{ij} + v_{ij,new} \quad \textbf{(10)}$$

Where,

c_1, c_2 - cognitive coefficients

$rand_1, rand_2$- random real numbers. Range will be 0 to 1

v_{ij} = velocity

$particle_{ij}$ = position vector

$pbest_{ij}$ = best personal vector

$gbest_{ij}$ = best swarm vector

Most of the times searching may begin before local optima reached. So the computation time may be reduced. In order to avoid this crisis, the hill climbing heuristic is used in between the exploration and exploitation. According to the Algorithm of Hybrid PSO mentioned in [22-29] the simulation has carried out.

4. Simulation Results and Analysis

The Matlab Simulink is used to check the dynamic behaviour of Bidirectional series resonant converter using HPSOMPC. Table 1 gives the constraints of the circuit which are applied in simulation.

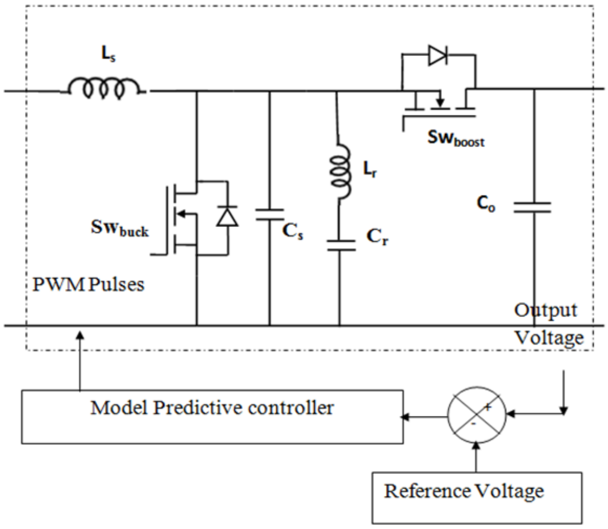

Figure 2: Block diagram used in simulation of the Bidirectional series resonant converter using HPSOMPC

Table 1: Components of Bidirectional dc/dc converter

Parameter	Value
Inductor (Ls)	.007µh
Capacitor (Cs)	33 nf
Inductor (Lr)	489µh
Capacitor (Cr)	2µf
Capacitor (Co)	52mf
Switching Frequency	5 KHz

Initially bidirectional series resonant converter is acting as a step up converter. Input voltage will be fed as 200 V and the load voltage will be higher when compared to the voltage which was fed. The anticipated output of step up chopper is 400 V. This is achieved by use of HPSOMPC. At 0.1 sec the load varied from 50 Ω to 33 Ω. Even though current varied, the voltage is in invariable as shown in fig 3.

When bidirectional series resonant converter act as a step down converter, 400 V had given as input voltage, then the anticipated output voltage is 200 V. The step-down chopper has tuned through HPSOMPC. The weight factor in the controller is tuned by using HPSO. At 0.1 sec, the load varied from 100 Ω to 50 Ω. The output voltage has been kept as unvarying by using HPSO tuned MPC during changing load condition. This condition has shown in fig 4.

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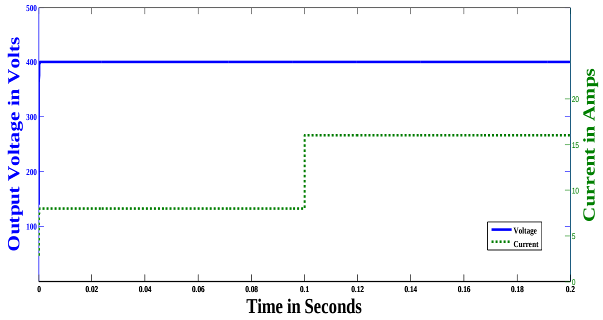

Figure 3: Output current and voltage graphs of step-up chopper at cargo change of 50 Ω to 33Ω

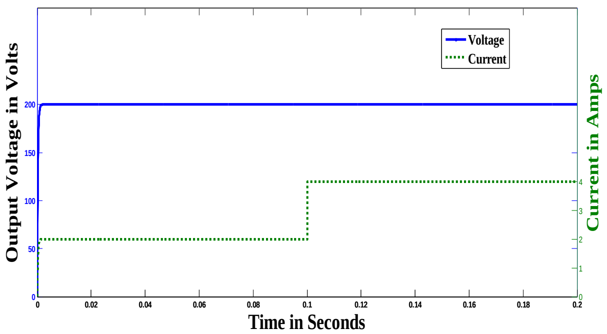

Figure 4: Output current and voltage graphs of step-down topology at load change of fifty Ω to 33Ω

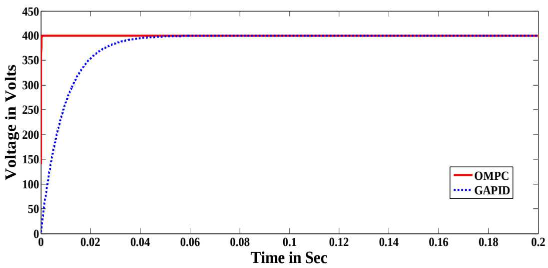

Figure 5 (a) Comparison of boost converter output voltage between HPSOMPC and GAPID

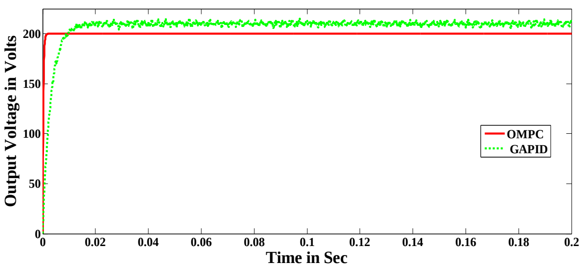

Figure 5 (b) Comparison of buck converter output voltages between HPSOMPC and GAPID

Figure 5 Gives the comparison of ripple voltage of projected controller and GAPID controller. The simulation of same converter using GAPID has done by the use of simulink. The gains of the PID controller has been optimized by genetic algorithm. The genetic algorithm parameters which are used in this paper are, initial population of 160, no. of generations 110, reproduction, stochastic uniform selection through 8 best individuals, Gaussian mutation with shrinking and scattered crossover.

Table 2: Comparison of transient and steady state period between proposed controller and other controllers

Controller Type	Time taken for Recovery	Transient Period
Discretized sliding mode control (DSMC) [21]	3 m sec	-
ATSMC [11]	1.66 msec	0.04 sec
Sliding mode control [11]	38 m Sec	0.06 Sec
Firefly tuned model predictive Controller [23]	0.3 m sec	0.01 sec
GA PID	1.2 m sec	Step down converter = 0.017 sec Stepup Converter =0.062 sec
HPSO tuned model predictive Controller	0.4 m sec	Step down converter = 0.0015 sec Stepup Converter = 0.0006 sec

Table 3: Comparison of voltage ripple between proposed controller and other controllers

Controller Type	Voltage Ripple
Sliding Mode VC. [7]	840mV
Interleaved Discharging Method [5]	24 mV
Firefly tuned Fuzzy Sliding Mode Controller [22]	10 mV
Bidirectional power flow control strategy [23]	5000 to 10000 mV
GA PID	Buck converter = 9000 m V Boost Converter = 35 m V
HPSO tuned model predictive Controller	Buck converter = 7 m V Boost Converter = 7 mV

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Table 2 and table 3 are clearly indicates the strength of proposed controller. The improvement of transient period and ripple reduction ensures the reliability of the controller.

5. Conclusion

In this paper, a novel controller called hybrid PSO tuned model predictive control has been presented for controlling bidirectional series resonant converter and investigated by MATLAB simulation. The transient response of converter has been improved and the same is proved in table 2. The proposed configuration is compared with existing DC to DC converter configuration. The projected controller is entirely capable of shielding the system while dynamic load occurs in circuit. All the given comparisons give the rigid of proposed controller than other controllers are presented in this paper. Because of the HPSO, the transient period has been reduced quickly. The simulation results confirm that the recovery time and ripple voltage while step load change condition and transient time have been awfully improved.

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