A REVIEW: CONTROL STRATEGIES IN BI-DIRECTIONAL DC-DC CONVERTER TOPOLOGIES

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Abstract- Bidirectional DC-DC power converters are increasingly finding their way into a wide array of applications where the need for power to flow in both forward and reverse directions is crucial. These applications span across various fields such as energy storage systems, uninterruptible power supplies, electric vehicles, and renewable energy systems, among others, showcasing the versatility and importance of these converters. The primary objective of this article is to delve into the control strategies employed in these converters. When looking at the overall design, these converters can be categorized into two main groups: non-isolated and isolated configurations, each with its specific characteristics and applications. Furthermore, the prevalent control methods and switching techniques used in these converters are thoroughly examined to provide a comprehensive understanding of their operation. While some control strategies like PID, sliding mode, fuzzy logic, and model predictive control are commonly utilized across all DC-DC converters for enhancing their efficiency and performance. The paper delves into the distinct features of converter topology and control scheme, offering insights into their typical uses and advantages, thereby serving as a valuable resource for comparing existing configurations or selecting the most suitable converter for a specific application. By shedding light on these aspects, it opens up avenues for exploring new configurations and optimizing converter selection based on specific needs and requirements in various scenarios.

Keywords: Bidirectional DC-DC Converter, PID, Sliding Mode, Dynamic Evolution, Model Predictive, Fuzzy, Digital Control, Boundary Control.

1. INTRODUCTION

Selecting an appropriate method of control for bidirectional converters is a crucial decision that heavily relies on the specific topologies at play and the control challenges that manifest in practical scenarios [3]. This necessitates a thorough exploration into the concrete control tactics employed in both non-isolated and isolated configurations. In scenarios where isolation is not a prerequisite, opting for non-isolated setups can prove to be not only more cost-effective but also less intricate due to the absence of a transformer, thus facilitating a transformer-less execution [6]. Nevertheless, in instances demanding high power output where isolation between sources and loads becomes imperative, opting for isolated topologies emerges as the more favourable choice, offering perks like electrical isolation, heightened dependability, simplified implementation of soft switching controls, bidirectional energy flow, and ensuring the safety of equipment and personnel. These advantages are predominantly derived from the utilization of transformers that predominantly function at elevated frequencies [44]. Beyond merely the selection of topology for bidirectional DC-DC converters, a highly efficient and integrated control approach is indispensable for the optimal functioning of these converters [45]. To address diverse control issues that surface in non-isolated and isolated bidirectional DC-DC converters, a series of control strategies have been proposed for different applications.

2. CONTROL TECHNIQUES USED IN BI-DIRECTIONAL DC-DC CONVERTERS

Real-time applications involving bidirectional converters require careful selection of appropriate control techniques [2-6]. This section delves into the strategies associated with both isolated and non-isolated bidirectional DC-DC converter topologies. Non-isolated configurations are favoured for medium-power applications due to their cost-effectiveness and simplicity, stemming from the absence of transformers [46-49]. Conversely, in high-power scenarios, isolated topologies are preferred to ensure necessary isolation between high-power sources and low-power loads. Isolated converters, operating at high frequencies and utilizing transformers, offer benefits such as Zero Voltage Switching (ZVS), Zero Current Switching (ZCS), electrical isolation, and enhanced reliability. Controlling power converters like DC-DC converters to achieve high efficiency and superior dynamic response poses a significant challenge. Various control algorithms, such as genetic algorithms (GA), improved GA, partial swarm optimization (PSO), evolutionary programming (EP), hybrid evolutionary strategies, seeker optimization algorithm (SOA), bacterial-foraging optimization (BFO), gravitational search algorithm (GSA), differential evolution (DE), and artificial bee colony algorithm (ABC) have been developed to address these challenges. Recent advancements include more sophisticated algorithms like whale optimization algorithm, enhanced red wolf optimization, improved social spider optimization (ISSO), antlion optimization algorithm (AOA), JAYA algorithms, PSO extended algorithms such as R-PSO, L-PSO, PSO-CFA, improved PSO based on success rate

(IPSO-SR), fruit fly optimization algorithm (FFOA), and modified fruit fly optimization algorithm (MFFOA), which are combined with fundamental control laws like PID and SMC for power converter control.

2.1 PID Control

The proportional integral derivative (PID) controller's overall design is showcased in Fig. 1. This particular form of control is melded with alternative control strategies to create hybrid approaches geared towards optimizing system operation in terms of efficiency. It is harnessed across various control challenges emerging from distinct converter setups. Dealing with control in bidirectional DC-DC converters poses a notable challenge, leading to two primary controller transitions due to the converters. In scenarios involving battery charging through traditional means utilizing V_L and V_H , significant transients arise during the shift from V_L to V_H control. To circumvent such substantial transitions, the PID controller is paired with a pulse width modulation (PWM) scheme. This integration not only diminishes the capacitor size at the DC bus side of the converter but also curtails the transition period [1]. In situations where inverters are linked with bidirectional converters, active and reactive currents must be managed sequentially to independently regulate powers, subsequently allowing inverters to govern active and reactive powers on the AC sides. Eventually, the inverter can be managed using PWM with reference values [2]. An additional challenge tied to bidirectional power flow involving bidirectional converters is the delay occurring during mode transitions. This setback can be tackled by incorporating an auxiliary switch alongside the main switch, typically featuring a fixed turn-on time [3]. Despite control problems being tackled through digital signal processing (DSP), issues like substantial power loss stem from discrete current sampling. Furthermore, the traditional control method falls short in controlling the switching time of the auxiliary switch due to the resonant current sensing issue, thus prompting the utilization of a PID controller with discrete voltage sampling to achieve superior outcomes. Within bidirectional DC-DC converters, the dead time of switches can impact system performance. This dead time factor is factored in to address the nonlinear dependency effects of current on duty cycle [4]. In circumstances where the PID controller may not be the optimal choice to regulate current across the entire spectrum, a control strategy is devised based on either continuous current or discontinuous current. Discontinuous current, characterized by positive dead time in inductor current, necessitates a swift and steady transition between continuous conduction mode (CCM) and discontinuous conduction mode (DCM) if both modes are active [5]. As a result, the PID controller oversees current regulation in DCM, while requiring a pre-set with a control algorithm in CCM. In order to achieve optimal power conversion efficiency and cost-effectiveness in systems such as multiple converters with multiple inputs and outputs (MIMO), the implementation of a well-crafted control strategy holds great significance when dealing with bidirectional DC-DC converters. The capacitor situated at the DC bus or battery source end ensures voltage regulation through a sophisticated voltage controller logic driven by a PI control algorithm, while the current control algorithm, in conjunction with a PI controller, governs the electronic flow within the magnetic devices. Additionally, the duty cycle is meticulously defined for the switches in the converters [6]. To safeguard the switching devices against overcurrent, the inductor current is regulated effectively, thereby ensuring the protection of the load from any abnormal current influx. The evaluation of bidirectional DC-DC converters, characterized as nonlinear systems, warrants the employment of a closed-loop control scheme that is linearized around its equilibrium point, notwithstanding that the stability analysis remains consistent for both step-up and step-down operations. Leveraging the Bode plot as a linear method serves as a valuable tool to scrutinize the stability during the transition of bidirectional power flow [7-9]. Consequently, the formulation of a mathematical model becomes imperative, paving the way for the design of a suitable control scheme based on the stability conditions derived from the bode plot analysis.

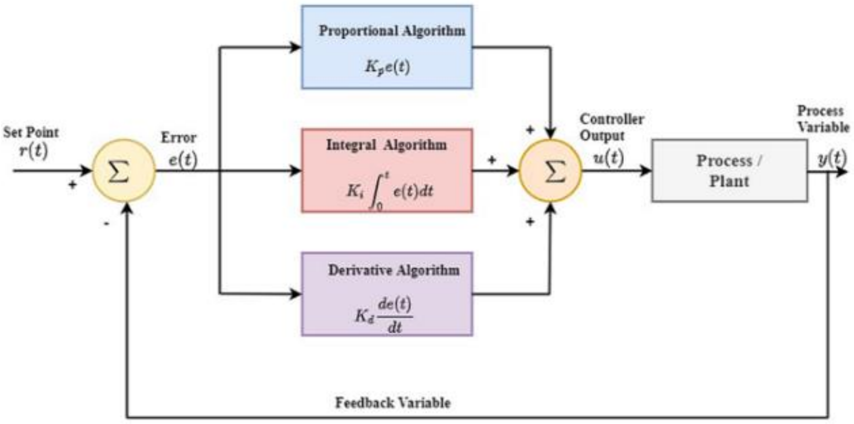

Fig. 2.1 Basic structure of PID Controller

2.2 Sliding Mode Control

Sliding mode control, as depicted in Fig. 2, emerges as a noteworthy alternative to the conventional PID controller for specific reasons. The presence of bidirectional DC-DC converters introduces nonlinear elements, causing the dynamic equations of the system to become nonlinear. The typical linear methods utilized for stabilization may overlook dynamic variations and fail to fully characterize the system. In contrast, sliding mode control, a nonlinear control strategy, excels in providing precise control by accommodating perturbations and disturbances effectively [10]. The conventional methods may struggle to handle large signals and external perturbances in a bidirectional converter's control loop. State-space averaging models might not capture the regulator's behaviour accurately under such conditions. In contrast, sliding mode control, known for its adaptability to dynamic changes, proves to be a suitable solution, albeit a more intricate one requiring precise calibration [11]. Exploring the realm of bidirectional Cuk converters reveals insights into three distinct switching states governed by three unique sliding surfaces. The analysis indicates the system's robustness against output voltage variations in steady-state scenarios, particularly when negative inductor magnetic coupling and linear power parameter sets are in play. When dealing with a bidirectional converter connected to a nonlinear load like BBBC, traditional control techniques falter due to the system's in deterministic operational states [12]. On the contrary, sliding mode control offers a solution by ensuring robustness against parameter fluctuations, thereby enhancing transient response and stabilizing DC bus voltage amidst nonlinear load variations. Challenges arise when dealing with converters featuring poles and zeros in the right half plane, affecting stability analysis during large signal behaviours. To overcome such hurdles, innovative configurations have been proposed. Leveraging the capabilities of sliding mode control, a tailored controller is devised through numerical analysis for BBBC applications such as power backup systems. Assumptions are made regarding the rapid dynamics of inductor current and capacitor voltages compared to super capacitor dynamics. This control strategy showcases remarkable insensitivity to structural disturbances, proving advantageous in applications like micro-grid systems that demand stable voltage regulation amidst nonlinear elements and time-dependent dynamics [13]. At times, blending two or more control strategies becomes necessary to tackle challenges that a single technique cannot handle alone. Take, for example, the cascade control approach that employs two PI controllers [14]. While one PI controller can stabilize all functions, it may fall short when faced with extreme fluctuations in load and line conditions. This is where PID steps in as a controller to enhance overall performance. Another scenario involves integrating sliding mode with a fuzzy logic controller to eliminate the chattering phenomenon that occurs when using sliding mode control in isolation [15-16]. For specific tasks like recharging an ultra-capacitor, a combination of fuzzy logic and sliding mode controllers is preferred due to their collective ability to adapt effectively to changes and minimize deviations from the desired outcome [17].

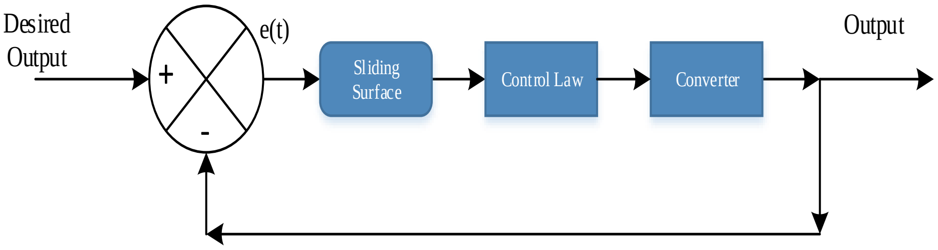

Fig. 2.2 Basic structure of SMC Controller

2.3 Partial Swarm Optimization (PSO) with Sliding Mode Control (SMC)

The utilization of PSO is possible in a bidirectional DC-DC converter incorporating established control strategies such as SMC, illustrated in Fig. 3. In this context, we have delved into the application concerning electric vehicles for efficient and closely regulated battery charging. The selection of SMC control parameters is facilitated through the utilization of PSO. By combining PSO with SMC, the aim is to optimize control actions. PSO functions to minimize an objective function that encompasses errors in inductor current, DC bus, and battery voltage. At each iteration, PSO assesses the objective function, saving the best particle value for comparison to obtain the ultimate global optimum among the best values within the SMC framework [24].

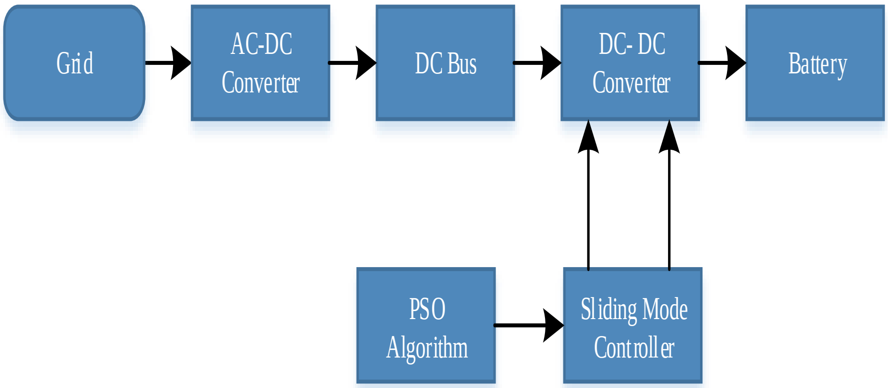

Fig. 2.3 Basic structure of PSO-SMC

2.4 Dynamic Evolution Control (DEC)

The illustration of the Fig. 2.4 unveils the innovative evolution controller. Tailored for nonlinear systems, this controller operates on the premise of tracing the evolution path regardless of disturbances, thereby reducing dynamic state error over time. Noteworthy is the remarkable performance enhancement it offers to the system without the need for precise parameter values.

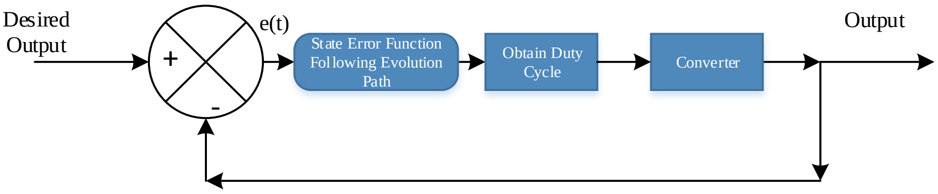

Fig. 2.4 Basic structure of DEC

Consider, for instance, the realm of electric vehicles, where rapid acceleration and deceleration are routine, demanding swift dynamic responses. In the case of fuel cell-based electric vehicles, achieving such promptness proves challenging. This setback finds resolution in pairing a storage component with the fuel cell [18-19], coupled with a bidirectional power converter employing the aforementioned control strategy. The outcomes of employing this controller in such scenarios demonstrate its capability to handle dynamic loads effectively, allowing for battery recharging whenever the fuel cell's voltage exceeds the load requirements or during regenerative braking.

2.5 Model Predictive Controller (MPC)

The Fig. 2.5 showcases the model predictive controller in an elaborate manner, representing an enhanced iteration of the predictive control technique. By incorporating functions, it guides the system variables to track the reference values, resulting in a swift system facilitated by microprocessor advancements. Initialization of this controller demands the formulation of mathematical models to predict future values, integrating past values into the algorithm model. These predicted values are then directed to an optimizer, tasked with resolving optimization dilemmas utilizing a predefined cost function and the forecasts at each time interval. Consequently, this procedure yields optimal control measures for converters.

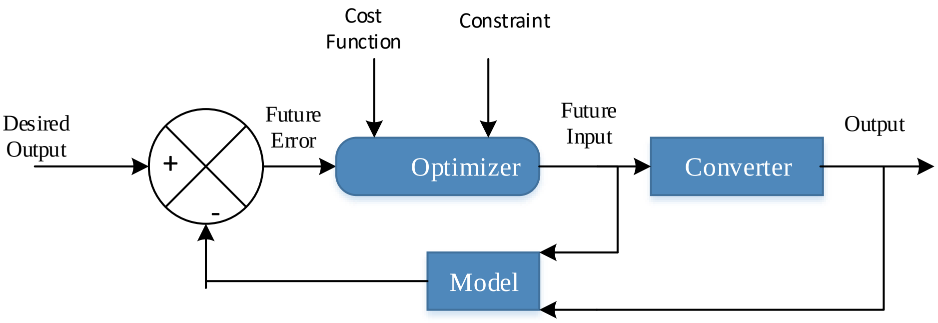

Fig. 2.5 Basic structure of MPC

The system is segregated into distinct phases like idle, charge, and discharge modes, contingent on the existing and target voltage values. Subsequently, the control algorithm takes charge of all system operations, undergoing rigorous testing like BBBC for diverse applications [20]. The enhanced renditions of these models encompass linear MPC, multi-MPC, and dynamic matrix control. The converter model is envisioned as a linear entity within the control algorithm, embodying a constraint inherent to the linear MPC approach. To surmount this obstacle, multi-MPC emerges, employing a multi-model system to linearize non-linear models locally at various operational points, addressing nonlinearity at every sampling stage [21]. It meticulously considers the variance between linear and nonlinear models to minimize discrepancies, effectively tackling the limitations linked with multiple MPC algorithms.

2.6 Fuzzy Logic Control (FLC)

The fundamental concept of fuzzy logic control in power converters such as DC-DC converters is depicted in Fig. 2.6 DC-DC converters, being nonlinear systems, can be precisely regulated even in the absence of a mathematical model. This feat is achieved through the application of fuzzy logic [41-43], where the analytical power of the human brain is harnessed to discern system traits. The insights gained from such analysis can be structured into a rule base incorporating uncertain inputs. In the realm of power converters like bidirectional buck-boost systems, FLC operates on two key inputs: the error signal e(k) and the rate of change in the error signal de(k). Fuzzy rules are devised for these inputs based on the dynamic behaviour of the error signal [28]. Various algorithms can be employed for the processes of fuzzification and defuzzification. An illustrative example of a fuzzy rule could be expressed as follows: IF X is Medium AND Y is Zero, THEN Z is Positive.

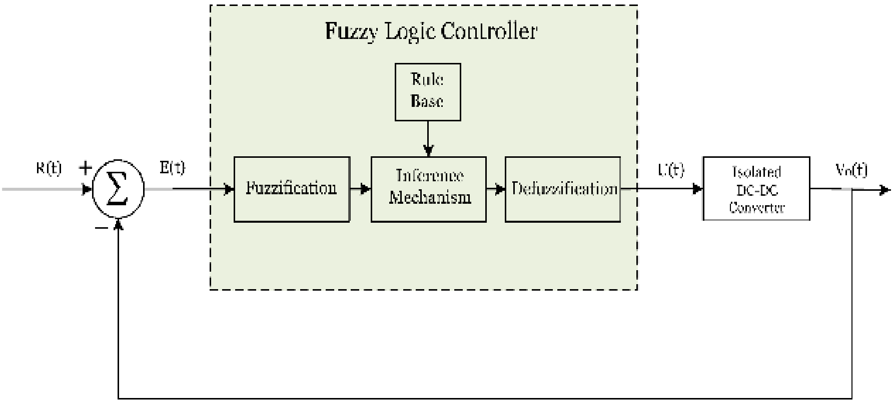

Fig. 2.6 Basic structure of FLC

The fulfilment degree for both the antecedent and consequent is determined by their respective membership functions. The nature of the fuzzy interference technique falls into categories such as Mamdani type [22,27] and Takagi-Sugeno-Kang type [29]. The outcome of the defuzzification process translates into a control signal that initiates the generation of a switching signal for the device. This approach can supplant the conventional PID control logic which heavily relies on intricate mathematical modelling [44,50]. The guiding principle of the fuzzy base rule is to establish a hybrid model known as fuzzy-PID control, promising superior transient response amidst changes in load [26].

2.7 Artificial Neural Network (ANN) Control

The burden of computation in FLC can be alleviated by leveraging ANN for the generation of precise control signals [30-32]. ANN not only enhances system performance but also plays a pivotal role in DC-DC converter control by employing prediction control, surpassing fuzzy control. Intelligent control methods with ANNs are preferred for their simplicity in implementation. When it comes to PID control, an ANN-based approach yields superior system response compared to fuzzy-based PID control [23,25].

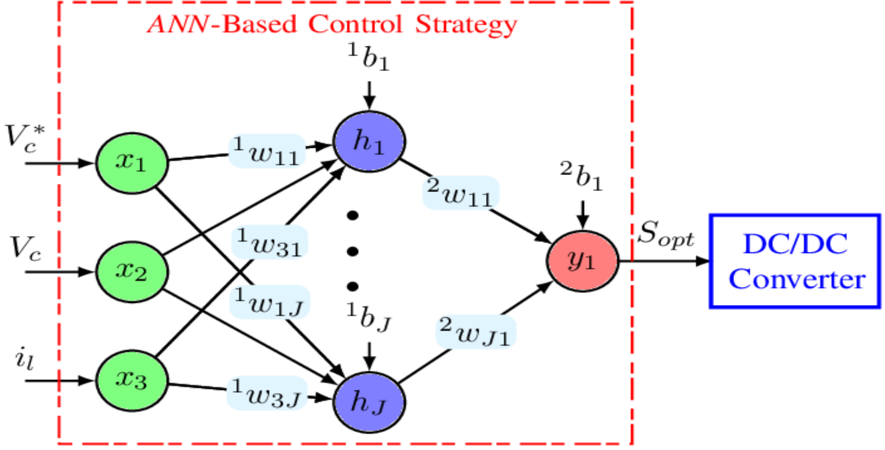

Fig. 2.7 Basic structure of ANN Control

Drawing on expert knowledge from fuzzy logic, conventional neural network techniques such as FFNN and RBFN are integrated to form various control algorithms like FNN and ANFIS [34]. The architectural design of the entire DC-DC control system with ANN is illustrated in Fig. 7. Traditional PID falls short in efficiently controlling bidirectional buck-boost converters (BBBC) due to the changing load parameters over time. To address this issue, a model predictive control algorithm is employed as an expert to train the ANN for precise tuning in controlling BBBC, ensuring optimal efficiency and performance [35].

2.8 Digital Control

In this approach to regulation, sensors gather voltage/current signals from either the origin (feed-forward control) or destination (feedback control). These sensor readings undergo a transformation into digital signals through an A/D converter, illustrated in Fig. 2.8. Subsequently, they are compared to the intended output value. Control algorithms such as PID, PIDN, PSO-PID, fuzzy, fuzzy-PID, and adaptive-network-based fuzzy interface system (ANFIS) are employed to minimize the error signal to zero by adjusting the control parameters, ensuring a stable output signal [36]. Ultimately, the control signal is directed to the digital pulse width modulation (DPWM) unit, responsible for producing a control signal for the power converter. In high-power converters, DSP/FPGA control boards are utilized to execute these control algorithms due to their superior computational capabilities at a reasonable price, thanks to their advanced processing cores like cortex cores in DSPs and Spartan cores in field programmable gate array (FPGA) boards [37].

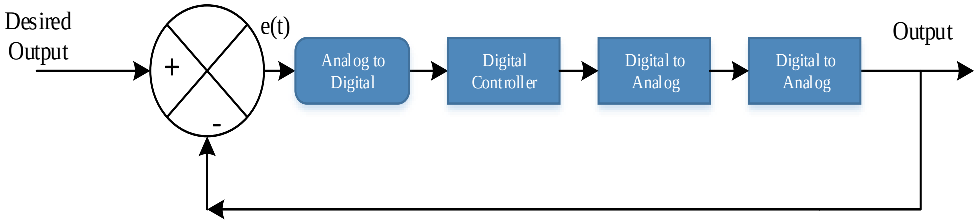

Fig. 2.8 Basic structure of Digital Control

Moreover, these boards boast exceptional resilience against electromagnetic interference. To facilitate alterations in power distribution, intelligent control algorithms like dead-band, switch, and soft-start control are recommended in to adjust the power flow within the converter smoothly, safeguarding it against sudden rushes of current during the rise or fall periods.

2.9 Boundary Control

Based on the trajectories followed by the converter in handling significant signals, a switching surface is defined to govern the switching maneuvers. An ideal switching surface has the potential to achieve overall stability, efficient large-signal operation, and rapid dynamics. Boundary control emerges as a control technique rooted in geometry, suitable for switching converters with dynamically changing circuit structures. Among a range of boundary control methods incorporating first-order switching surfaces, sliding-mode control and hysteresis control are extensively utilized in power converters. While these methods typically offer commendable performance and stability in large-signal scenarios, they do not optimize transient dynamics. A boundary control strategy utilizing second-order switching surfaces in buck converters, as proposed in [38], aims to attain nearly optimal large-signal responses and boost the tangential velocity of the trajectories along the switching surface. The interest in boundary control intensifies due to its pursuit of achieving responses in minimal time, yet ideal time-optimal control proves to be sensitive to variations in parameters and model accuracy, posing challenges to its realization. Consequently, a concept of proximate time-optimal control has been introduced to approximate the time-optimal response amidst large-signal disturbances. By combining either linear or nonlinear switching surfaces with conventional linear controls (e.g., PID), a proximate time-optimal digital control proposed in [39] accommodates arbitrary load disturbances and realistic component tolerances. Notably, this approach excels in voltage regulation of synchronous buck DC-DC converters. Boost converters, classified as non-minimum phase systems, exhibit sluggish dynamic responses when controlled using traditional compensators. Employing nonlinear curved switching surfaces aids in swiftly directing state variables toward the desired operating point. To maximize performance, a minimum-time control method is advocated, accounting for the inexactness of converter parameters [40]. The curved switching surface is formulated in the normalized domain to ensure versatility applicable to any combination of boost converter parameters. Under this boundary control framework, the converter demonstrates outstanding dynamic behaviour, achieving time-optimal responses for start-up and load disturbances without overshooting and reaching steady state in a single switching action. DC-DC converters commonly rely on PWM for control, where switch control signals are determined based on state variable sensing and compensators utilizing small signal averaged models and frequency-domain techniques. Several large-signal-oriented methodologies have been explored to enhance transient responses and robustness of converters with sliding mode control standing out for its ability to characterize the system under both small- and large-signal conditions and deliver robust outputs resistant to uncertainties and disturbances. The conventional SMC typically necessitates the switching surface, denoted as s D 0, to be a blend of the output voltage and either an inductor or capacitor current. In general, current sensing plays a key role increased sensitivity to noise and higher costs have led to the development of innovative solutions. One such solution is the second-order sliding mode (SOSM), which has proven effective in addressing this challenge. Unlike the surface in first-order SMC, which is a line where s equals 0, in SOSM, it becomes a point at s equals Ps equals 0. This unique characteristic allows trajectories in the phase plane to directly converge to the origin under SOSM control. The proposed digitally implemented controller offers the advantage of stabilizing synchronous buck dc-dc converters without the need for current sensing or an integral term in the control loop. It demonstrates rapid stability, quick transient responses, and strong performance even in the face of load disturbances and uncertainties in parameters. Moreover, the simplicity of implementation makes boundary control a reliable choice. Additionally, it provides flexibility in adjusting transient performance and ripple specifications with ease. In specific scenarios, it can effectively eliminate current and voltage overshoots, as demonstrated, where it counteracts the destabilizing impact of constant-power loads and steers the two-state buck converter system towards a desired operational state. By incorporating a hysteresis band, this approach effectively minimizes chattering and prevents the closed-loop system from stalling.

CONCLUSION

The bidirectional converters, known as isolated bidirectional converters, are classified based on their unique isolation property. Each topology is introduced along with its distinctive features and applications. The discussion delves into the potential of implementing smart control schemes. A control scheme utilizing artificial neural networks (ANN) with a blend of intelligent laws, referred to as hybrid ANN, emerges as a promising choice for control applications. The advantages and disadvantages of each control scheme for bidirectional DC-DC converters are thoroughly examined.

REFERENCE

[1] Viswanatha V, Venkata Siva Reddy R. "Characterization of analog and digital control loops for bidirectional buck–boost converter using PID/PIDN algorithms" J Electric Syst Inform Technol 7(1), pp.1–25, 2020

[2] Gorji SA, Ektesabi M, Zheng J. "Double-input boost/Y-source DC-DC converter for renewable energy sources". Proc. IEEE SPEC 16, 2016, Auckland, pp. 1–6, 2016

[3] Zhao C, Round SD, Kolar JW. "An isolated three-port bidirectional DC-DC converter with decoupled power flow management" . IEEE Trans Power Electron 23(5):2443–2453, 2008

[4] Hamasaki S, Mukai R, Tsuji M "Control of power levelling unit with super capacitor using bidirectional buck/ boost DC/DC converter". Proc. ICRERA, 2012, Nagasaki, pp. 1–6, 2012

[5] Ding S, Wu H, Xing Y, Fang Y, Ma X "Topology and control of a family of non-isolated three-port DC-DC converters with a bidirectional cell". Proc. IEEE APEC, 2013, Long Beach, CA, pp. 1089–1094, 2013

[6] Lee J et al "Auxiliary switch control of a bidirectional soft-switching DC/DC converter". IEEE Trans Power Electron 28(12):5446–5457, 2013

[7] Engelen K, Breucker SD, Tant P, Driesen J "Gain scheduling control of a bidirectional dc-dc converter with large dead-time". IET Power Electron 7(3):480–488, 2014

[8] Filsoof K, Lehn PW "A Bidirectional multiple-input multiple-output modular multilevel DC–DC converter and its control design". IEEE Trans Power Electron 31(4):2767–2779,2016

[9] Cornea O, Andreescu G, Muntean N, Hulea D "Bidirectional power flow control in a DC microgrid through a switched-capacitor cell hybrid DC–DC converter". IEEE Trans Ind Electron 64(4):3012–3022,2017

[10] Tijerina Araiza A, Meza Medina JL "Variable structure with sliding mode controls for DC motors". Proc. CIEP 95, 1995, San Luis Potosi, Mexico, pp. 26–28,1995

[11] Martinez-Salamero L, Calvente J, Giral R et al "Analysis of a bidirectional coupled-inductor Cuk converter operating in sliding mode". IEEE Trans Circuits Syst I 45(4):355–363,1998

[12] Tahim APN, Pagano DJ, Ponce E "Nonlinear control of dc-dc bidirectional converters in stand-alone dc Microgrids". Proc. IEEE CDC 12, 2012, Maui, HI, pp. 3068–3073,2012

[13] Romero A, Martinez-Salamero L, Valderrama H et al "General purpose sliding-mode controller for bidirectional switching converters" . Proc. IEEE ISCAS '98, 1998, Monterey, CA, pp. 466–469,1998

[14] Ciccarelli F, Lauria D "Sliding-mode control of bidirectional dc-dc converter for super capacitor energy storage applications". Proc. SPEEDAM 2010, 2010, Pisa, pp. 1119–1122,2010

[15] Agarwal A, Deekshitha K, Singh S, Fulwani D "Sliding mode control of a bidirectional DC/DC converter with constant power load". Proc. ICDCM, 2015, Atlanta, GA, pp. 287–292,2015

[16] Dominguez X, Camacho O, Leica P, Rosales A "A fixed-frequency Sliding-mode control in a cascade scheme for the Half-bridge Bidirectional DC-DC converter". Proc. IEEE ETCM, 2016, Guayaquil, pp. 1–6,2016

[17] Cao J, Cao B, Bai Z, Chen W "Energy-regenerative fuzzy sliding mode controller design for ultracapacitor-battery hybrid power of electric vehicle". Proc. International Conference on Mechatronics and Automation, 2007, Harbin, pp. 1570–1575,2007

[18] Samosir AS, Yatim AHM "Dynamic evolution control of bidirectional DC-DC converter for interfacing ultracapacitor energy storage to Fuel Cell Electric Vehicle system". Proc. AUPEC, 2008, Sydney, NSW, pp. 1–6,2008

[19] Samosir AS, Yatim AHM "Implementation of dynamic evolution control of bidirectional DC–DC converter for interfacing ultracapacitor energy storage to fuel-cell system". IEEE Trans Ind Electron 57(10):3468–3473,2010

[20] Pirooz A, Noroozian R "Model predictive control of classic bidirectional DC-DC converter for battery applications". Proc. PEDSTC, 2016, Tehran, Iran, pp. 517–522,2016

[21] Ebad M, Song B "Accurate model predictive control of bidirectional DC-DC converters for DC distributed power systems". Proc. IEEE Power and Energy Society General Meeting, San Diego, CA, pp. 1–8, 2012

[22] Liping G., Hung J.Y., Nelms R.M. "Evaluation of DSP-Based PID and fuzzy controllers for DC–DC Converters," IEEE Transactions on Industrial Electronics, 56(6): 2237–2248,2009

[23] Hussain Sarwar K, Ihab SM, Kimmo K, Lantao L "Artificial neural network-based voltage control of DC/DC converter for dc microgrid applications". In: 6th IEEE Workshop on the Electronic Grid , pp.1–6, 2021

[24] Kanthi Mathew K, Dolly Mary A "Particle swarm optimization based sliding mode controllers for electric vehicle on board charger". Comput Electric Eng, 96, Part A,2021

[25] Das T, Roy R, Mandal KK "Impact of the penetration of distributed generation on optimal reactive power dispatch". Prot Control Mod Power Syst , pp.5–31,2020

[26] Osorio R, Alonso JM, Vazquez N, Pinto SE, Sorcia-Vazquez FD, Martinez M, Barrera LM “Fuzzy logic control with an improved algorithm for integrated LED drivers”. IEEE Trans Ind Electron 65(9):6994–7003, 2018

[27] Bubshait A, Simoes MG “Design of fuzzy logic-based dynamic droop controller of wind turbine system for primary frequency support”. In: IEEE Industry Appl. Soc. Ann. Meeting, pp. 1–7, 2018

[28] Chen WQ, Bazzi AM “Logic-based methods for intelligent fault diagnosis and recovery in power electronics”. IEEE Trans Power Electron 32(7):5573–5589, 2017

[29] Simoes MG, Bubshait A “Frequency support of smart grid using fuzzy logic-based controller for wind energy systems”. Energies 12(8):1–15,2019

[30] Bose BK “Artificial intelligence techniques in smart grid and renewable energy systems-some example applications”. Proc IEEE 105(11):2262–2273, 2017

[31] Soualhi A, Makdessi M, German R, Echeverria FR, Razik H, Sari A, Venet P, Clerc G “Heath monitoring of capacitors and supercapacitors using the neo-fuzzy neural approach”. IEEE Trans Ind Informat 14(1):24–34, 2018

[32] Zhao S, Blaabjerg F, Wang H “An overview of artificial intelligence applications for power electronics”. IEEE Trans Power Electron 36(4):4633–4658,2021

[33] Duchesne L, Karangelos E, Wehenkel L “Recent developments in machine learning for energy systems reliability management” Proc. IEEE,2020

[34] Joao Pinto RCG, Burak Ozpineci “Tutorial: Artificial intelligence applications to power electronics”. In: IEEE Energy Convers Congr Expo, pp. 1–139, 2019

[35] Liu R, Yang B, Zio E, Chen X “Artificial intelligence for fault diagnosis of rotating machinery: a review”. Mech Syst Signal Process 108:33–47,2018

[36] Zhao S, Makis V, Chen S, Li Y “Health assessment method for electronic components subject to condition monitoring and hard failure”. IEEE Trans Instrum Meas 68(1):138–150,2019

[37] Ndjependa PR, Boum AT, Essiane SN “A novel approach of a dynamic multi objective optimization of a power distribution system”. J Electric Syst Inf Technol 8:17,2021

[38] Vyas, M., Yadav, V.K., Vyas, S., Swami, R.K. (2022). An Intelligent Control Strategy for Power Quality Improvement of DFIG-Based Wind Energy Conversion System. In: Kumar, J., Tripathy, M., Jena, P. (eds) Control Applications in Modern Power Systems. Lecture Notes in Electrical Engineering, vol 870. Springer, Singapore.

[39] Vyas, M., Yadav, V.K., Vyas, S., Joshi, R.R. and Tirole, R. (2022). A Review of Algorithms for Control and Optimization for Energy Management of Hybrid Renewable Energy Systems. In Intelligent Renewable Energy Systems (eds N. Priyadarshi, A.K. Bhoi, S. Padmanaban, S. Balamurugan and J.B. Holm-Nielsen)

[40] Glavic M, Fonteneau R, Ernst D “Reinforcement learning for electric power system decision and control: Past considerations and perspectives”. IFAC Papersonline 50(1):6918–6927,2017

[41] Sutton RS, Barto AG “Reinforcement learning: an introduction”. MIT press,2018

[42] Kofinas P, Doltsinis S, Dounis AI, Vouros GA “A reinforcement learning approach for MPPT control method of photovoltaic sources”. Renew Energy 108:461–473,2017

[43] V. K. Tayal, J. S. Lather, Piyush Sharma and S. K. Sinha, “Power System Stability Enhancement Using Fuzzy Logic based Power System Stabilizer” Proceedings of the Third International Conference on SocPros 2013 ,Advances in Intelligent Systems and Computing, 2014 ,vol 259,pp. 55-68.,2013

[44] Swati Paliwal, Piyush Sharma,Ajit Kumar Sharma, “Power System Stability Improvement Using Different Controllers”, Fourth International Conference on SocPros 2014 , Advances in Intelligent Systems and Computing, 2014 ,Volume 1 , pp 571-583,2014

[45] Smrati Singh, Ankit Kumar, Piyush Sharma, “Speed Control of Multilevel Inverter Based Induction Motor Using v/f Method” Fourth International Conference on SocPros 2014, Advances in Intelligent Systems and Computing, 2014 ,Volume 1 , pp 231-243,2014

[46] P. Sharma, D. K. Dhaked, S. Saini, L. K. Tripathi and A. Shrivastva, "Analysis of Different Converters for Reduced Total Harmonic Distortion and Improved Power Factor," 2018 5th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2018, pp. 608-613, doi: 10.1109/SPIN.2018.8474197.,2018

[47] Piyush Sharma “Smart Charging for advanced Electric Vehicles: A Survey from the Algorithmic Perspective” Juni Khyat, Vol-11 Issue-01 2021, ISBN No: 2278-4632, 2020.

[48] R. Jangid; J.k Maherchandani; V.K Yadav and R.K Swami, “Energy Management of Standalone Hybrid Wind-PV System”, Journal of Intelligent Renewable Energy Systems (John Wiley & Sons, Inc.) Pages 179-198, 2022.

[49] H. Kumawat and R. Jangid, “Using AI Techniques to Improve the Power Quality of Standalone Hybrid Renewable Energy Systems”, Crafting a Sustainable Future Through Education and Sustainable Development, IGI Global, Pages 219-228, 2023.

[50] Piyush Sharma “Analysis and comparison of different PV array configurations under partial shading conditions”, Juni Khyat, Vol-11 Issue-01 2021, ISBN No: 2278-4632, 2020

[51] Sharma P., Dhaked D.K., Sharma A.K. “Mathematical Modeling and Simulation of DC-DC Converters Using State-Space Approach”. Proceedings of Second International Conference on Smart Energy and Communication. Algorithms for Intelligent Systems. Springer, Singapore. https://doi.org/10.1007/978-981-15-6707-0_2. 2021

[52] Sharma P., Sharma A.K., Priyadarshi N., Azam F., Padmanaban S., Bhoi A.K. “A Comprehensive Study on Electrical Vehicle in Charging Infrastructure, Challenges and Future Scope”. Electric Vehicles. Green Energy and Technology. Springer, Singapore. https://doi.org/10.1007/978-981-15-9251-5_16, 2021

[53] Piyush Sharma, Ashok Kumar Sharma, Ajay Kumar Vyas, “Comparative Study of DC-DC Converter with Different Control Techniques” RARES-2021, SSRN, Elsevier pp 1-6, 2021

[54] R. Jangid; J.k Maherchandani; R.R. Joshi and B.D Vairagi, “Development of Advance Energy Management Strategy for Standalone Hybrid Wind & PV System Considering Rural Application”, IEEE 2nd International Conference on Smart Systems and Inventive Technology, Organized by Francis Xavier Engineering College during November 27-29, 2019 at Tirunelveli, India.

[55] M. Aarif; D. Joshi; R. Jangid and S.S. Sharma, “Grid Power Smoothing Management for Direct Drive PMSG Variable Speed Wind Energy Conversion System with Multilevel Converter”, IEEE 7th International Conference on ICT for Sustainable Development, Organized by Global Knowledge Foundation during 29-30, July 2022 at Goa, India.

[56] Senthil, L., Sharma, A.K., Sharma, P. “Design and Development of Micro-grid Networks for Demand Management System Using Fuzzy Logic”. In: Noor, A., Saroha, K., Pricop, E., Sen, A., Trivedi, G. (eds) Proceedings of Emerging Trends and Technologies on Intelligent Systems. Advances in Intelligent Systems and Computing, vol 1414. Springer, Singapore. https://doi.org/10.1007/978-981-19-4182-5_20,2023.