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Control Techniques for Direct Current to Direct Current Power Electronic Converter

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Abstract: The fact that the static and dynamic characteristics of power electronic DC-to-DC converters become highly nonlinear due to the time variation and switching nature, has led to the implementation of different control techniques in literature to ensure stability in the system operating condition. However, in most system of practical interest, the problem is to minimize the deviation of actual output voltage from desired voltage while maintaining satisfactory transient response and efficient voltage/power transfer. Though in some cases where desired performance has been achieved, integral winding and nonlinearity effect associated with classical controllers have persisted. It is therefore recommended from the reviewed control techniques that multiloop controller will offer with improved transient response performance.

Index Terms- Control System, DC-To-DC Converter, Power Electronic, Multiloop Control, Switching

I. INTRODUCTION

DC-to-DC converters are designed to meet the requirements of certain applications [1]. DC to DC converters are often times called based on their function. For example, Buck converter, Boost converter, Buck-Boost converter, and Zero Current Switching (ZCS) and Zero Voltage Switching (ZVS) [2]. A DC-to-DC step-up conversion technology has witnessed rapid development, and has been widely used in computer hardware and industrial applications such as computer periphery power supplies, power supplies of car auxiliary, servo-motor drives and medical equipment [3]. It is an important and integral part of alternative and renewable energy conversion, portable devices, and many industrial plants. It plays an essential role in delivering a regulated DC voltage from unregulated DC source which may be the output of an AC to Dc converter (rectifier) or a battery, or a solar cell etc. [4]. However, a significant aspect of the Dc supply is the variation in the source. This is mainly due to the variation in the line voltage which is running out of a battery [4] or any other DC source, but varying within a given limit. Considering these effects, the objective will be to regulate the voltage at a referenced or desired value while ensuring adequate delivering to a widely varying or changing load. As a result of its better efficiency and higher current-driving capability, a DC to Dc switching regulator is known to be superior over a linear regulator.

There are different types of DC-to-DC converters that have been presented in literature and are already implemented for use in certain applications. The well-known Pulse width Modulation (PWM) based DC to DC converter technique accomplishes its control by varying the duty cycle of an external fixed frequency clock through one or more feedback loops at any time a parameter varies [4]. Presently, modern electronic systems require power with high reliability, low weight with high quality and easy control capacity and are largely be employed as switch mode power supply (SMPS) system in electric vehicles.

One major area of applications of DC-to-DC converters is in motor drives. A DC-to-DC converter converts a source of direct current (DC) from one voltage level to another. Most DC-to-DC converters also adjust the output voltage. Some exceptions include high- efficacy drive sources, which are a type of DC-to-DC converter that control the current during the drive, and easy accuse pumps which twice or triple the crop voltage. Electronic switch-mode DC to DC converters change one DC voltage stage to one additional, by storing the input energy in the short term and then releasing that energy to the output of a dissimilar voltage. The storage can also be in magnetic field storage elements such as inductors, transformers or electric field storage elements capacitors [5]. This conversion method is more power efficacy often 75% to 98% than linear voltage imperative, which dissipates surplus power as heat. DC-to-DC

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converters, energy are occasionally stored into and free from a magnetic field in an inductor or a transformer, classically in the range from 300 kHz to 10 MHz [5]. By regulating the duty cycle of the charging voltage that is, the relation of on/off time, the quantity of power transfer can be controlled. Regularly, this is functional to organize the output voltage, while it could be practical to organize the input current, the output current, or maintain a constant power. Transformer-based converters may give isolation between the input and the output.

In order to ensure stability in the operating condition of the power electronic converters, a good control strategy is usually employed. Such control strategy should ensure that good response in terms of load variations rejection, input voltage variations and even parameter uncertainties [1].

Some significant work has been done to enhance the performance response of power electronic converters using different control techniques. In this paper, the intention is to review different controllers that have been presented with purpose of improving the performance response of a power converter.

II. TYPES OF DC-TO-DC CONVERTER

A. Boost Converter

The Boost Converter is a step-up DC/DC voltage. It works in second quadrant operation. The output voltage increases in arithmetic progression. Boost converter has limitation over DC link voltage level and complexity of control circuit. Figure 2.1 is a circuit diagram of a typical boost converter.

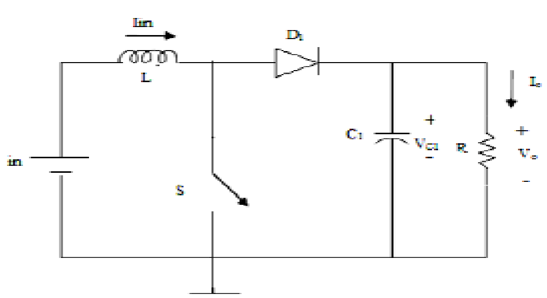

Fig.1: Boost converter [5]

The circuit analysis is established in Equations (1) to (5) for the output voltage, average output current, voltage transfer gain, ripple current in the inductor, and duty cycle of conduction period as follows [5]:

$$V_o = \frac{T}{T - t_{on}} V_{in} \qquad (1a)$$

Or

$$V_o = \frac{1}{1-G} V_{in} \qquad (1b)$$

$$I_o = I_{in}(1-G) \qquad (2)$$

$$K = \frac{1}{1-G} \qquad (3)$$

$$\delta I = \left(\frac{V_{in}}{L} G\right) T \qquad (4)$$

$$G = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} \qquad (5)$$

where T is the repeating period ($T = \frac{1}{f}$), f is the chopping frequency, t_{on} is the switch-on time, and t_{off} is the switch-off time.

B. Non-Isolated Buck-Boost Converter

A typical buck-boost converter is shown in Figure 2. The circuit operation is presented based on analysis in [4].

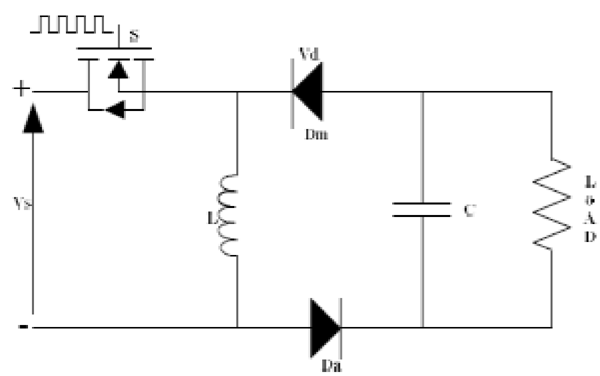

Fig. 2: Non-isolated buck-boost converter [4]

The circuit operation is divided into two modes. Switch closed operation (Mode 1): When the switch is closed, the diodes D_m and D_a are reverse biased operation mode. The input current rises, flows through inductor L and switch S. This results in accumulating energy in inductor L. The capacitor C discharges

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through load R. Switch open operation (Mode 2): When switch is open, the current, which was flowing through inductor L, would flow through L, C, D_a, D_m and the load. The energy stored in inductor L would be transferred to the capacitor and load, inductor current would fall until transistor switch Q is switched on again in the next cycle [4].

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L} V_{in} \\ \dfrac{dV_{out}}{dt} = \dfrac{1}{C}\left(-\dfrac{V_{out}}{R}\right) \end{cases}, 0 < t < dT, Q : ON \quad (6)$$

and with the switch in OFF state:

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L} V_{out} \\ \dfrac{dV_{out}}{dt} = \dfrac{1}{C}\left(-i_L - \dfrac{V_{out}}{R}\right) \end{cases}, dT < t < T, Q : OFF \quad (7)$$

The buck-boost converters have a pulsating output current and it require current handling capability. In order to overcome these drawbacks, the Luo converter is used, it has the capability to reduce ripple voltage and current levels without inverting the polarities [6].

C. Voltage Lift Converter

The first three stages of Positive Output Super-Lift Converters are presented here. They are Elementary (self-Luo) circuit, Re-Lift circuit and Triple-Lift circuit respectively. These circuits are shown in Figures 3 to 5.

Self-Lift Circuit

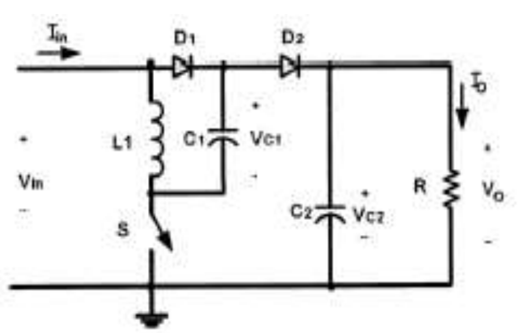

Fig. 3: Schematic diagram of self-lift converter [1]

This converter (Figure 3) consists of V_{in} capacitors C_1 and C_2, inductor L, power switch S and freewheel diodes D_1 and D_2. Also, it has a voltage lift circuit (VLC). VLC consists of diode D_1 and capacitor C_1. Switch S and diode D, are alternately on and off. Usually, this pump works in continuous operation mode, inductor current is continuous in this case. The output terminal voltage and current are usually positive. In this positive output Luo converter, it should be noted that there are two states that is, when switch is on and when switch is off [7].

The Voltage across capacitor $C_1$is charged to V_{in} .The current I_{L_1} flowing through inductor L_1 increases with voltage V_{in} during switching-on period kT and decreases with voltage – (V_o – 2V_{in}) during switching-off period $(1 - K)T$. Therefore [1]:

$$KTV_{in} - (1-K)T \times (V_o - 2V_{in}) = 0 \quad (8)$$

The output voltage can be calculated from Equation (8), and is given by:

$$V_o = \left(\frac{2-K}{1-K}\right) V_{in} \quad (9)$$

The analysis of self-lift circuit converter for output voltage, average output current, voltage transfer gain, and ripple current in inductor is given in terms of the duty cycle of conduction period G by Gunasekaran [5]:

$$V_o = \left(\frac{2-G}{1-G}\right) V_{in} \quad (10)$$

$$I_o = \left(\frac{2-G}{1-G}\right) I_{in} \quad (11)$$

$$K = \frac{V_o}{V_{in}} = \frac{2-G}{1-G} \quad (12)$$

$$\delta I = \left(\frac{V_o - 2V_{in}}{L}\right) t_{off} \quad (13)$$

$$G = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} \quad (14)$$

Re-Lift Circuit

In order to derive Re-Lift circuit, the parts (L_2-D_3-D_4-D_5-C_3-C_4) of the Elementary circuit are added. The circuit diagram of a re-lift DC to DC converter is shown in Figure 4.

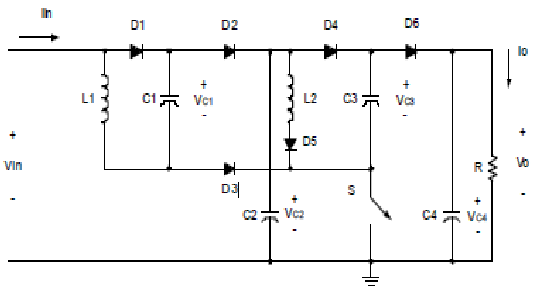

Fig. 4: Schematic diagram of re-lift converter [8]

The voltage across capacitor C_1 is charged to V_{in} . As described above for the elementary (self-lift) circuit, the voltage V_{C2} across capacitor C_2 is given by:

$$V_{C2} = \frac{2-K}{1-K} V_{in} \qquad (15)$$

The voltage across capacitor C_3 is charged to V_{C2}. The current flowing through inductor L_2 increases with Voltage V_{C2}during switching-on period k and decreases with voltage – (V_o-$2V_{C2}$) during switching-off period (1-k) T. Therefore, the output voltage V_o across capacitor C_4 is:

$$KTV_{C2} - (1-K)T(V_o - 2V_{C2}) = 0 \qquad (16)$$

$$V_o = \left(\frac{2-K}{1-K}\right) V_{C2} = \left(\frac{2-K}{1-K}\right)^2 V_{in} \qquad (17)$$

Triple-Lift Circuit

In order to derive Triple-Lift circuit, the parts (L_2-D_3-D_4-D_5-C_3-C_4) of the Elementary circuit are added three times. The circuit diagram of a re-lift DC to DC converter is shown in Figure 5.

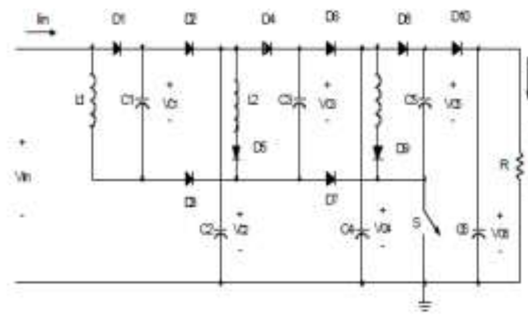

Fig. 5: Schematic diagram of triple-lift converter [8]

The voltage across capacitor C_1 is charged to V_{in} . As described before, the voltage across capacitor C_2 is charged to V_{C2} as given in Equation (15), and the voltage across capacitor is charged to:

$$V_{C4} = V_o = \left(\frac{2-K}{1-K}\right)^2 V_{in} \qquad (18)$$

The voltage across capacitor C_5 is charged to V_{C4}. The current flowing through inductor L_3 increases with voltage V_{C4} during switching-on period and decreases with voltage – (V_o-$2V_{C4}$) during switching-off (1-k) T. Therefore, the output voltage V_o across capacitor C_6 is:

$$KTV_2 = (1-K)T(V_o - 2V_{C4}) \qquad (19)$$

$$V_o = \left(\frac{2-K}{1-K}\right) V_{C4} = \left(\frac{2-K}{1-K}\right)^2 V_{C2} = \left(\frac{2-K}{1-K}\right)^3 V_{in}$$

…. (20)

This subsection has presented some types of DC-to-DC converter with respect to recent advance power regulation technology.

D. Buck Converter

In a buck converter, the arrangement basically comprises a transistor and diode that applies a supply voltage on an inductor and capacitor, LC circuit. The resulting voltage at the output is taken across the capacitor over a connected load of resistance R as shown in Figure 6. The input voltage of the LC circuit is controlled by a pulse width modulation (PWM) with input U via a solid-state device such as insulated gate bipolar transistor (IGBT) that serves as an electronic switch.

Buck converter is generally a switched system that consists of two switching states as shown in Figure 7.

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In the first state, when the switch is connected to node 1, the system is on a charging state. The second state occurs at the switch is connected to node 2 and it is called the discharge state.

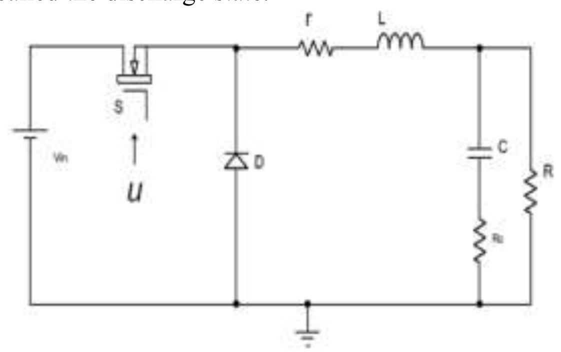

Fig. 6: Buck converter schematic diagram [9]

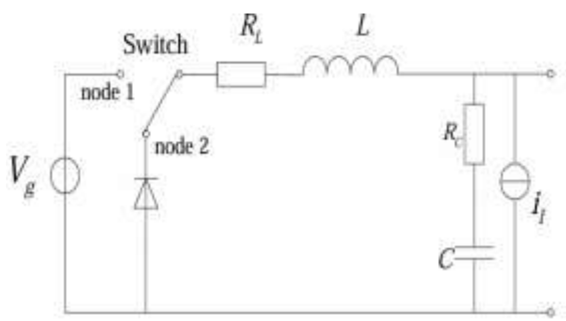

Fig.7: Illustration of switching mode of buck converter [10]

III. CONTROL TECHNIQUES FOR DC-TO-DC CONVERTER

Prasanna *et al.* [1] designed and analyzed a positive output lift Luo (POTLLC). It states that the proposed system was characterized of robustness around the operating point, good transient response performance under changing operating conditions and/or input voltage, invariant dynamic performance under varying conditions. It maintained that the converter was able to perform voltage conversion from positive source voltage to positive load voltage. The entire system was implemented in MATLAB/Simulink. In the work, no control circuit was implemented rather system was examined in its conventional state.

Dhanasekar and Kayalvizhi [3] developed a fuzzy logic controller as the control system for the converter. It stated that the performance of the triple lift Luo converter with the fuzzy logic controller were evaluated in the presence of line and load disturbances using MATLAB/Simulink based simulation. It maintained that the results achieved were satisfactory and that the fuzzy logic controller effectively rejected the line and load disturbances. Despite the performance, systems with fuzzy logic alone are prone to steady state error.

Jayachandran *et al.* [7] analyzed open loop power stage dynamics relevant to voltage mode control for elementary (self-lift) Luo DC to DC converter for certain application such as Hybrid Electric Vehicles (HEV) and fuel cell vehicles (FCV). It carried out a comparative analysis of the output super lift series of converters to evaluate voltage gain, output voltage ripple, stresses on the switches and efficiency. The most suitable of the series of converter studied was modelled and verified using state space average method and circuit average technique. A transfer function was obtained for the output and input voltage. It stated that the transfer function could be used in modelling the complete Luo converter using voltage mode control. A modelling was performed in MATLAB/Simulink and was used for simulation so as to confirm the predicted results. This work only focused only on modelling a Luo type DC-DC converter and examining it performance in open loop state.

Suguna et al [6] developed a super lift Luo to boost up the power from PV cells. It stated that there exist many maximum power point (MPP) techniques for extracting the maximum power from PV cells are available and differ in convergence speed, simplicity, sensors, hardware implementation, cost and acceptability. An improved perturb and observe (MPP) technique combining a supper lift Luo converter was implemented. The circuit was modelled and simulated using MATLAB software. By using the super lift Luo converter and improved perturb and observe algorithm for the PV cells, a high output was obtained.

Vijay and Palwalia [11] presented a novel analysis and modelling of boost and buck converter. It modelled and simulated a non-isolated DC-DC boost and buck converter using PI controller. The boost converter was designed for 12 V to 24 V with output current of 1 A

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at switching frequency of 100 KHz. The buck converter was similarly designed for 24 V to 12 V with output current of 0.86 A at switching frequency of 100 KHz. It concluded by recommending that the performance of the system can be improved by tuning the parameters of the PI controller for better response of DC-DC converter.

Alavi and Dolatabadi [12] studied analysis and simulation of full-bride boost converter using MATLAB. It used a transformer to generate a higher voltage in the secondary side in similar operation as a transformer-isolated full-bridge boost converter. It used 30 Volts nominal input voltage for simulation which produced output voltage of 55V.

Rashed *et al.* [13] designed and development a DC-DC boost converter based on DSP TMS320F2812 for PV application. It implemented a DC-DC boost converter for photovoltaic application using the control voltage signal of Pulse Width Modulation (PWM). The boost converter is tied between the PV panel and the load. The converter was controlled via the Perturbed and Observed (P and O) and Maximum Power Point Tracking (MPPT). The control action was achieved using PWM at a specific frequency and the switching device is Insulated Gate Bipolar Transistor IGBT. The proposed system is modelled using MATLAB software and the performance verified through simulation results obtained.

Oucheriah [14] presented a robust control of the DC-DC boost converter based on the uncertainty and disturbance estimator. It developed and implemented a robust nonlinear controller based on the uncertainty and disturbance estimator (UDE) technique. It lumped up system uncertainties, external disturbances and unknown nonlinear dynamics as a signal that is accurately estimated using a low pass filter and whose effect is cancelled by the controller. The effectiveness of the proposed robust controller was compared against the sliding mode control (SMC) through simulation. It maintained that the experimental results obtained indicated that the proposed system showed robustness to system uncertainties, large input and load disturbance.

Saito and Davis [15] developed a cascade-controlled boost converter for power factor correction, leveraging both voltage and current regulation. The study aimed to mitigate the effect of increased harmonic distortion in power lines, resulting in a decreased power factor and reduced overall power quality. The authors therefore maintained that it is crucial to enhance the power factor and minimize line current harmonics. Integrating a self-tuning regulator (STR) adaptive controller with online identification within each control loop, this system dynamically adjusts to fluctuations in current consumption over time. The method effectively reduces Total Harmonic Distortion (THD) and improves power factor, contributing to more efficient and reliable power systems. The study was only limited to boost converter.

Alisoy *et al.* [9] carried out mathematical modelling of the response of a step-down voltage converter to disturbing influences, which provides a two-stage transfer of a dynamic system from an arbitrary state to a state determined by the required output voltage value. The method of analytical construction of aggregated controller (ACAC) based on proportional integral and derivative (PID) control law with integral adaptation was used as a regulator of a buck converter in continuous conduction mode (CCM) and a constant frequency of the power switch was synthesized.

Ghamari *et al.* [16] developed a cascade system with two control loops for a DC-DC Buck-Boost converter that was a right half-plane zero (RHPZ) structure called a non-minimum phase system. The concept presented several challenging constraints for designing well-behaved control techniques. The strategy assumed the system as a black-box structure without the need for a mathematical model of the system. The authors stated that the approach offers the benefit of decreasing the computational burden and provides faster dynamics along with ease of implementation. The technique consisted of an outer Fractional-order PID voltage controller tuned with the Ant-lion Optimizer (ALO) algorithm, which provides a reference current for the inner control loop of the Neural Network-based LQR (NN-LQR) controller. The inner loop NN-LQR strategy was used to optimize and tune the gains of the LQR controller and showed faster dynamics and higher robustness. It should be mentioned that the number of neurons was limited to 2 and 4 in each layer to decrease the computational burden with lower complexity. Also, the ALO algorithm is a modern nature-inspired algorithm used to tune the PID gains with better results under-constrained problems with diverse search spaces. Considering the negative impacts of various disturbances on a power converter, a Fractional-order-based PID (FO-PID) control technique was implemented as a proper alternative since it showed higher robustness in load uncertainties along with better dynamical responses based on its extra degree of freedom. Moreover, to evaluate the superiority of this controller, two other controllers were designed using the PSO algorithm for PID and FO-PID controllers. Finally, the presented cascade controller was tested in various working conditions through simulation and experiment results proved it effectiveness.

Gueye *et al*. [17] investigated the performance of a boost converter regulating its output voltage using two control methods: Proportional-Integral (PI) control and neural control. Both methods were implemented on a simulation plat form (MATLAB/Simulink) and evaluated in terms of accuracy, response speed, and robustness to disturbances. The output voltage of converters exhibited imperfections that required a control method to optimize efficiency when applying a variable load. Results showed that neural control offered superior performance in terms of accuracy and response time, with faster and more precise regulation of the output voltage. On the other hand, PI control proved to be more robust against disturbances.

Sudalaimani *et al.* [18] carried out a comprehensive evaluation of bio inspired optimization algorithms in enhancing the dynamic performance of unity power factor AC-DC boost converter. In achieving constant output voltage and unity power factor at supply mains, Sliding Mode controller was cascaded with PID voltage loop controller used to control these converters and it was highly evident that the performance of these converters was highly influenced by PID controller gains. The feasibility of using bio inspired optimization algorithms to find an optimal PID gain that enhanced the dynamic and static performance of the converter was implemented. The objective function formed for the optimization problem was framed from time domain performance parameters. From simulation results, it was deduced that the bio inspired optimization based PID gain resulted in an enhanced converter performance compared to its traditional counterpart.

Nadweh *et al*. [19] introduced a filtering circuit design integrated with the DC-link of a medium power variable speed drive (VSD) system. The designed filtering circuit employed modern power electronic circuits to improve time response characteristics in both grid and dc-link sides. Depending on the widely used multi-level converters, a conventional three-level H-bridge four-quadrant chopper scheme was developed into a cascade five-level H-bridge four-quadrant chopper scheme. The time response of the proposed system was performed with both choppers, and results showed that voltage drop on cascade chopper transistors was reduced to half in comparison with voltage drop on conventional four-quadrant chopper transistors. Moreover, the sharp fluctuations in system's waves were mitigated; consequently, time response characteristics in both steady and transient states were remarkably improved. The total harmonic distortion factor THD% of the input current and voltage was reduced to 26.2% and 2.43% respectively and the ripple factor RF for DC-link current was reduced to 0.196.

Galeano *et al.* [20] presented a methodology for tuning cascade PI controllers for power electronics (PE) converters. In general terms, this paper presents a step-by-step mathematical procedure for obtaining the transfer functions useful for tuning PI controllers. Most of converters exhibit non minimum phase behaviour for voltage to duty transfer function; in consequence, cascade PI controller is needed. The proposed cascade PI controller features inner and outer loops. The inner loop allows controlling the inductor current while the outer loop permits to control the capacitor voltage and provides the reference current of the inner loop. The methodology was applied to the Boost converter. Controllers were tuned using MATLAB R2020b while control implementation was performed by using Open Modellica.

Nicola and Nicola [21] presented the topology and the mathematical modelling of a using differential equations and transfer functions of the DC-DC three-phase power electronic converter that provides the interface between the grid and a DC micro-grid. The main objective was to develop control systems to maintain the DC voltage supplied to the micro-grid at an imposed constant value, regardless of the total value of the current absorbed by the consumers connected to the DC micro-grid. The elements of fractional calculus that were used to synthesize a first set of FO PI, FO tilt-integral-derivative (TID), and FO lead-lag controllers with MATLAB R2021b and the Fractional-order Modelling and Control (FOMCON) toolbox, and these controllers significantly improved the control system performance of the DC-DC three-phase power electronic converter compared to classical PI controllers. The next sets of proposed and synthesized controllers were based on sliding mode control (SMC), together with its more general and flexible synergetic control variant, and both integer-order and FO controllers were developed. The proposed control structures were cascade control structures combining the SMC properties of robustness and control over nonlinear systems for the outer voltage control loop with the use of properly tuned synergetic controllers to obtain faster response time for the inner current control loop. To achieve superior performance, this type of cascade control also used a properly trained reinforcement learning-twin delayed deep deterministic policy gradient (RL-TD3) agent, which provides correction signals overlapping with the command signals of the current and voltage controllers. The MATLAB/Simulink R2021b implementations of the synthesized controllers and the RL-TD3 agent, along with the results of numerical simulations performed for the comparison of the performance of the control structures. The control system was implemented for a DC-DC boost converter.

Muoghalu *et al*. [22] investigated enhancing DC motor speed stability by utilizing a chopper circuit, controlled by a PID algorithm, to manage voltage and counteract speed variations. The authors employed MATLAB/Simulink to model the system, demonstrating how the PID controller improved performance through simulation. it was observed that the actual speed has time domain characteristics performance of rise time 0.19 seconds and settling time of 2.50 seconds. The speed of the DC motor was stabilized at 2.50 seconds at a value of 500rad/sec. The results showed that the error signal was maintained at a very small value of 0.01 rad/sec throughout the duration of operation of the DC motor represented by a simulation time of 10 seconds. This means that the controller ensured an effective tracking of the reference speed by the output speed throughout the duration of operation.

Muoghalu *et al*. [23] demonstrated that implementing a Linear Quadratic Regulator (LQR) as a compensator significantly improved the dynamic response-specifically rise and settling times-of industrial belt conveyor systems. Utilizing MATLAB simulations, the research showed that this control approach resolved suboptimal performance inherent in raw machinery to enhance operational efficiency.

Idam *et al*. [24] demonstrated that a hybrid cascade control architecture, combining Fuzzy-PID with standard PID, improved voltage regulation and dynamic stability in power electronics converters. Simulations showed this approach significantly enhances performance, achieving a 3.01e-05s rise time, 0.000223s settling time, and reducing voltage overshoot to 10.9%.

Achebe and Muoghalu [25] demonstrated that a Linear Quadratic Regulator (LQR) designed via state-space modeling improved the stability of a two-phase hybrid stepping motor in robotic grinding. Using direct decomposition, the study showed that tuning the LQR's Q matrix achieved precise control with only 4.14% overshoot and a steady-state error of 0.01 to 0.02.

Onyeka et al. [26] demonstrated that a robust PID-tuned dual-loop compensator improved the tracking and dynamic response of a two-phase hybrid stepping motor, achieving less than 5% overshoot and settling times under 0.16 seconds. Utilizing MATLAB to optimize the system, the research highlighted enhanced precision benchmarks through an improved outer and inner loop controller configuration.

Idam et al. [27] evaluated PID-PID and Fuzzy-PID cascade controller configurations for improved voltage tracking in power electronics converters. Simulations indicated the hybrid Fuzzy-PID controller offered superior performance, characterized by a rapid 3.01e-05 second rise time, 0.000223 second settling time, and 10.9% voltage overshoot.

Sasikala and Krishnakumar [28] focused on identifying an optimum controller for Multi-Level Inverter Based Switched Mode Power Supply (MLIBSMPS) for constant voltage applications. Due to greater demand of constant voltage for the sensitive loads, a closed loop control was introduced in the converter circuit in order to obtain constant voltage quickly if there are any disturbances occur at the input side. Closed loop Proportional Integral (PI) as well as Proportional Resonant (PR) controlled MLI based SMPS systems were simulated and the comparison of their performance was done. It was observed that better performance was achieved using PR controlled MLI based SMPS than PI Controlled MLI based SMPS. It also proved that PR controlled SMPS with 7 level inverters has reduced steady state error and improved time domain response as compared to PI Controlled SMPS.

Muoghalu and Achebe [29] proposed an automated satellite antenna positioning system utilizing a two-phase hybrid stepping motor and a PID controller modeled in MATLAB to achieve precise, automated tracking. The study demonstrated that this PID framework successfully eliminated manual tracking inefficiencies by ensuring accurate, stable positioning of the antenna.

Shehata *et al.* [30] developed two techniques with the target of controlling the boost converter to improve the efficiency of the converter's performance. The two techniques used depended on fixed frequency mode instead of variable-frequency mode because of the demerits of the latter factor. The first technique was the sliding-mode control for the AC-DC converter to achieve power factor correction and reduce the harmonic ratio significantly while regulating the output voltage. This technique was used for the DC-DC converter to obtain a rapid dynamic response to control sudden or considerable changes in loads or input voltages with a regulated output voltage. Moreover, the two-loop cascade control was the second developed technique for the DC-DC converter to achieve an excellent dynamic response under step loads or input voltage variations with an excellently regulated output voltage. Simulation results validated the proposed design approach and illustrated the developed controller's robustness and faster response time.

IV. CONLUSION

In most of the control systems for power electronic converters reviewed, the classical PI and PID controllers are the most largely implemented as shown from the review. This can be attributed to simplicity in design and the ability to provide control solution to system with dynamic complexity usually in many process control operations in the industry due to its simplified structure. Another obvious trend is the use of cascade controllers to provide more stable, robust and high reliable power electronic converter in practical applications. These performance qualities are not offered by single-loop control approach. In the study carried out by Alisoy *et al*. [9], a single-loop controller based on PID algorithm was implemented for power electronic (buck) converter. The research direction is on the use of multiloop control technique for DC-to-DC converter.

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