A Dual Power Distribution-based control strategy for Three-Phase VSC with ABC-Optimized DC–DC Converter for Pulsed Power Applications

PASPULA SAVITHRI [1] | DR B.SHIVAJI[2]

[1]Pg Scholar, Dept of EPS, Kodada Institute of Technology & Science for Women-Kodad, Telangana.

[2] Associate Professor, Dept of EEE, Kodada Institute of Technology & Science for Women-Kodad,Telangana.

ABSTRACT: Due to a high peak-to-average power ratio, pulsed loads demand high current in a short duration. It requires fast-energy-delivery power converters without affecting grid stability. The transient nature of these pulsed loads, which draw megawatts of power for milliseconds, can cause severe voltage sags, frequency deviations, and high harmonic distortion. In addition, maintaining a constant output voltage during rapid load transitions is difficult due to an imbalance in energy between the input and output. The system exhibits nonlinear and time-varying behavior, making classical control methods, such as PI control methods, less effective. To address this problem and enhance power quality for pulsed loads, a dual power distribution three-phase AC-DC converter integrated with an artificial bee colony (ABC)- based DC-DC converter is proposed. The proposed converter employs a dual-power-distribution framework comprising a single-stage and a two-stage power path. In the single-stage path, power is directly transferred from the AC–DC converter to the load. However, this path is limited in its ability to handle rapid power variations. To overcome this limitation, a two-stage path is introduced, in which power is stored in the upper decoupling capacitor and then delivered to the load via a DC–DC converter. To enhance the system's dynamic performance and voltage stability, the DC–DC power converter is controlled by an advanced ABC control algorithm. The coordinated operation of the dual-output AC–DC converter and the ABC-controlled DC–DC converter is efficient and maintains output-voltage stability under highly dynamic pulsed-load conditions.

KEYWORDS: AC-DC CONVERTER, ABC, PULSED LOADS, HARMONICS.

I Introduction:

The usage of several impact, asymmetric, and nonlinear loads presents new problems to power systems with the advancement of power electronics [1]. Radar transmitters [2], laser ranging [3], sewage treatment [4], precision machining [5], and other industries all make extensive use of pulsed current loads. High power low frequency radar is an example of a typical pulsed power load (PPL). The load voltage is steady, the current shows a high peak-to-average ratio, and its fluctuation frequency typically runs from tens to hundreds of Hz. It is highly susceptible to creating voltage fluctuation, frequency flicker, and current distortion in the power grid, which compromises the power system's stability and security [6], [7].

Static var generators and active power filters can partially compensate for low-order harmonics that PPLs introduce into the power system. They are unable to offset harmonics at pulse frequencies, but [8], [9]. Additionally, active power adjustment is possible with flywheels and diesel generators, but the mechanical component limits the output power change rate to kilowatts per second. This makes it impossible for them to monitor the kilowatt-per-microsecond power change rate needed by millisecond-level pulsed loads. Dc bus voltage fluctuates as a result of the bus capacitor having to make up for the power differential [10]. The obvious method to reduce the PPL's voltage ripple is to simply connect a big capacitor in parallel to the dc bus [11], [12]. However, as Fig. 1(a) illustrates, the huge capacitor Co causes grid current distortion even if it significantly increases the volume and weight of the pulsed power supply (PPS). In order to reduce the necessary capacitance and separate the input average power from the output pulsed power, active decoupling circuits are crucial.

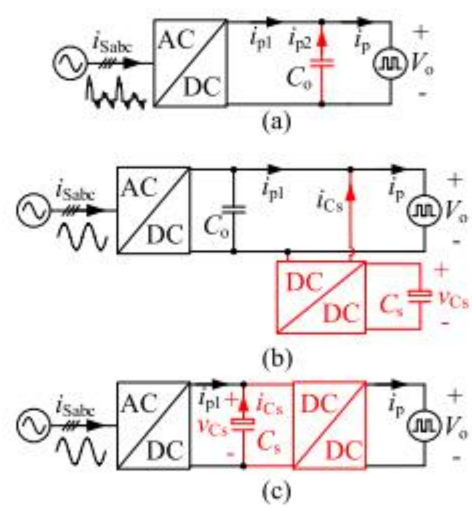


Fig. 1. Three different PPS structures. (a) Single-stage PPS. (b) P
type PPS. (c) Two-stage PPS.

In order to remove the double-frequency ripple power in single-phase ac-dc systems, a number of active decoupling circuits have recently been proposed. The main concept is to use an active capacitor converter (ACC) to create a ripple port. In particular, the ripple port is the location of capacitor Cs, which transfers the ripple power to accomplish pulsed power suppression by absorbing and releasing the transitory unbalanced power. Additionally, the system's volume and weight can be decreased by lowering the necessary capacitance by expanding the ripple port's voltage fluctuation range. Researchers have creatively used various converters, such as Buck, Boost, or H-bridge circuits, to build the ripple port based on the relationship between the ripple port voltage and the dc bus voltage. Nevertheless, these techniques can only be used in single-phase systems to remove double-frequency ripple power.

Researchers applied the previously outlined techniques to low-frequency PPL applications. The structure of a proposed paralleled-type PPS is depicted in Fig. 1(b). It has been demonstrated that this approach can adjust to various frequency ranges. Nevertheless, it was noted that the ripple power increases the equivalent power conversion stages, flows in and out of the ACC, exits the ac–dc converter, and lowers system efficiency. A more effective PPS was suggested, and Fig. 1(c) shows its construction. The voltage of the active decoupling capacitor Cs varies greatly, and the decoupling port is integrated into the power route. Similar to a two-stage power conversion, the front-end converter transmits the average power while the back-end converter stabilizes the load voltage. A two-stage PPS and a three-phase unregulated rectifier were paralleled to create the hybrid-type PPS. Although this method allows for fault-tolerant control by increasing the number of converters, the overall efficiency is still somewhat low. The current-stacked PPS approximates a two-stage power conversion while providing high peak-to-average ratio pulsed loads.

According to the aforementioned analysis, current techniques can be divided into two categories based on the direction of power flow in the ACC: unidirectional and bidirectional. In particular, the two-stage PPS employs a unidirectional-type scheme, whereas the paralleled-type PPS uses a bidirectional-type scheme. By removing reverse current pathways, the unidirectional type ACC lowers the number of power conversion stages. However, system efficiency is compromised since it must process all of the load power. Therefore, accomplishing pulsed power decoupling will unavoidably result in higher system losses regardless of the type of ACC utilized to construct the decoupling port.

II System layout:

Fig.1 illustrates the system layout of a dual-output AC-DC converter integrated with an ABC algorithm-based DC-DC converter for PPL. The grid-side input filters mitigate harmonics in the grid current and deliver stable power to the dual-output AC–DC converter. The system operates through two coordinated power paths: a single-stage path, where power flows directly from the AC–DC converter through the lower capacitor to the load. In a two-stage path, where power is first stored in the upper capacitor and then delivered to the load through a DC–DC converter. The DC–DC converter, controlled by an ABC–PI control algorithm, stabilizes the output voltage by compensating for rapid load variations. It adjusts the DC-DC converter's output voltage so that the overall load voltage remains constant.

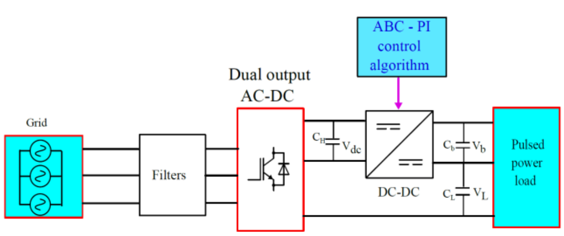


Fig.1 Circuit diagram of dual output AC-DC converter with DC-DC converter for PPL.

III Proposed control method:

This section presents the three-phase AC–DC converter system with dual power distribution. To enhance the power quality pulsed load condition, the dual output AC-DC converter integrated with an optimization-based ABC-controller for DC-DC converter. This hybrid approach improves system dynamic response, robustness, and efficiency. The proposed work regulates DC output voltage to the pulsed loads along with stable input currents. The AC–DC converter is controlled using a dual-loop vector control scheme. A synchronous reference frame (dq-based) control strategy, combined with zero-sequence power distribution control, is employed to achieve efficient system operation. The outer control loop regulates the DC-link voltage V_{dc}. This ensures that the converter draws the required active power from the grid. The inner current control loop regulates the d-axis and q-axis currents independently using PI controllers. The VSC provides dual DC output ports, and therefore, a power distribution mechanism is framed to enable controlled power sharing between the dual DC ports. This is achieved by introducing zero-sequence voltage injections.

To achieve fast dynamic response and robust voltage regulation in the proposed DC–DC converter, an advanced optimization-based control strategy using the ABC algorithm is employed. Fig.2 depicts circuit configuration of proposed ABC control framework for DC-DC converter.

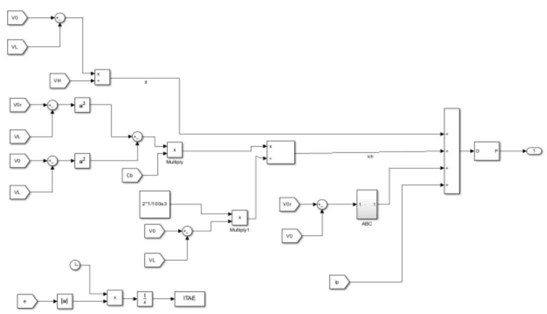


Fig.2 Proposed ABC control framework for DC-DC converter.

The primary objective of the control scheme is to regulate the output voltage $v_o$of the converter to its reference value V_{or}under varying load conditions. The control error is defined as:

$$e(t) = V_{or} - v_o(t)$$

This error signal is used to determine the optimal control input for the converter switch $S$by minimizing a predefined objective function using the ABC optimization algorithm.

The ABC algorithm consists of three types of agents: employed bees, onlooker bees, and scout bees, which collaboratively search for the optimal solution in the control parameter space. In this application, each food source represents a candidate control parameter.

Initially, a population of no. food sources candidate solutions is randomly generated within the feasible search space:

$$x_{ij} = x_j^{\min} + rand(0,1)\left(x_j^{\max} - x_j^{\min}\right)$$

where x_{ij}represents the j^{th}parameter of the i^{th}solution.

During the employed bee phase, each solution is updated based on neighboring information:

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj})$$

where: $k \neq i$ and $\phi_{ij} \in [-1,1]$is a random number

The updated solution is evaluated using a fitness function derived from the control error:

$$f(x) = \int_0^T t \mid e(t) \mid dt$$

and a greedy selection process is applied to retain better solutions.

During the onlooker bee phase, solutions are selected probabilistically based on their fitness:

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fi\,t_i}$$

where the fitness value is defined as:

$$fit_i = \begin{cases} \dfrac{1}{1+f(x_i)}, & f(x_i) \geq 0 \\ 1+|\,f(x_i)\,|, & f(x_i) < 0 \end{cases}$$

If a solution does not improve over a predefined number of iterations, it is discarded and replaced with a new randomly generated solution during the scout bee phase, ensuring global exploration.

The optimal solution obtained through the ABC algorithm is used to generate the control signal for the DC–DC converter. The reference control current is expressed as:

$$i_{ref} = i_p + i_f + i_{ch} + u_{ABC}$$

where: $i_p$is the load current,$i_f = \frac{v_o - v_L}{v_H}$represents the input voltage, $i_{ch}$is the capacitor energy compensation and $u_{ABC}$is the optimized control output from the ABC algorithm

The compensation current $i_{ch}$is derived based on the energy variation in the output capacitor:

$$i_{ch} = \frac{C_b[(V_{or} - v_L)^2 - (v_o - v_L)^2]}{2T_1(v_o - v_L)}$$

The final duty cycle $D(t)$for the converter switch $S$is obtained by:

$$D(t) = \frac{i_{ref}}{i_{\max}}$$

This duty cycle is used to generate the PWM signal for the DC–DC converter, ensuring precise regulation of energy transfer.

IV Simulation results:

Fig.3 represents the MATLAB circuit layout dual output AC-DC converter integrated with ABC algorithm-based DC-DC for pulse power loading. The simulation study is carried out transient pulse load varying conditions to investigate the robustness and effectiveness of the proposed control strategy.

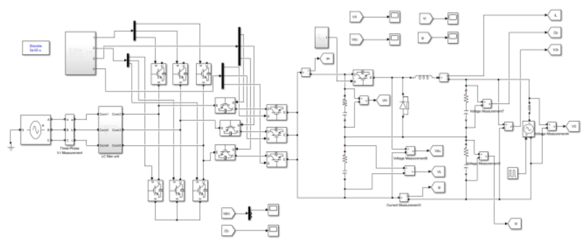
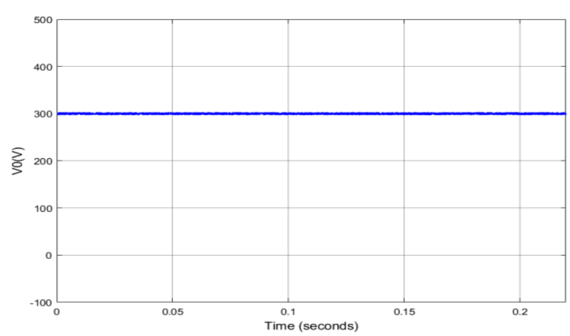
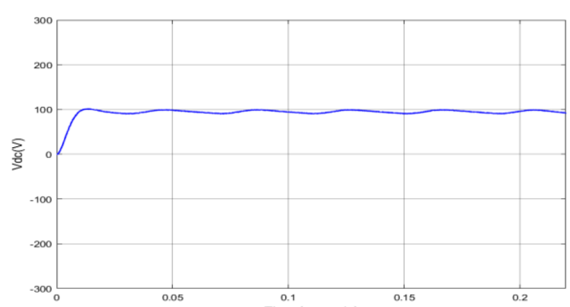
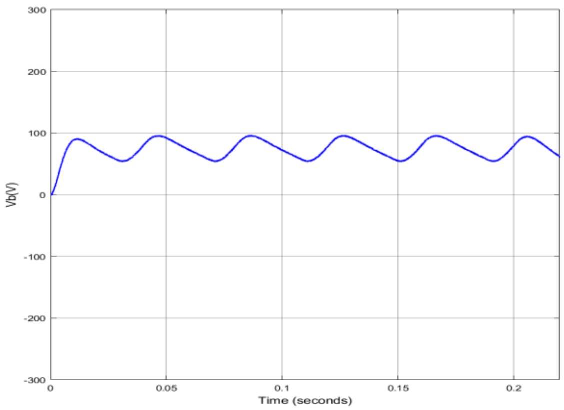


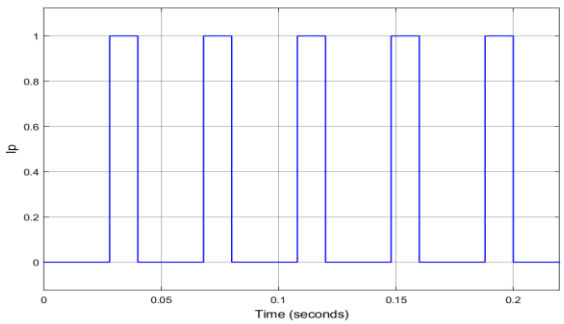
Fig.3. MATLAB layout of dual output AC-DC converter integrated with ABC algorithm-based DC-DC converter for pulse load

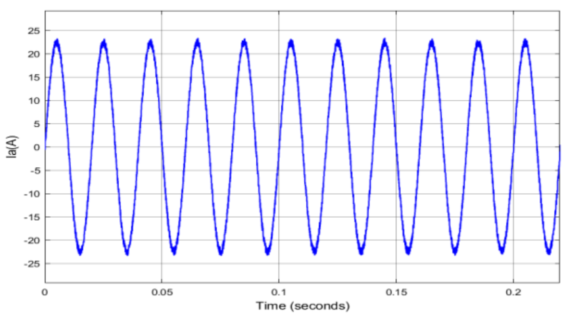
Case1 40 ms



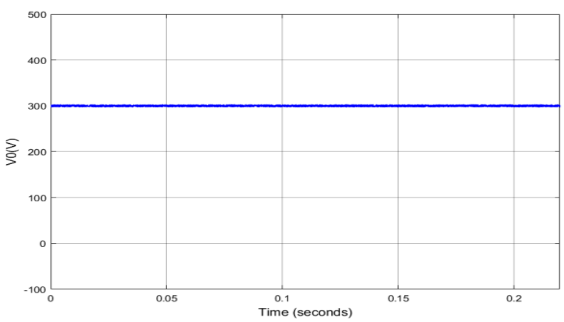


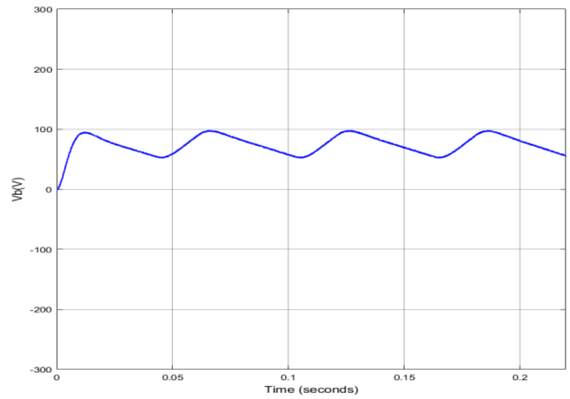

Vb(V)
Time (seconds)

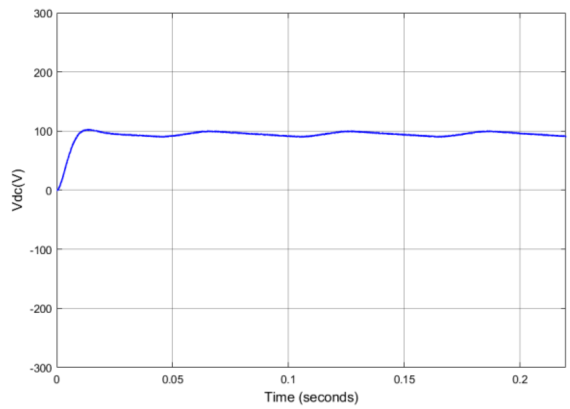

Ip
Time (seconds)

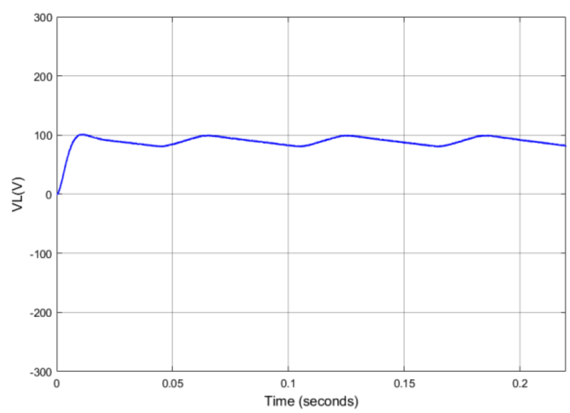

Ia(A)
Time (seconds)

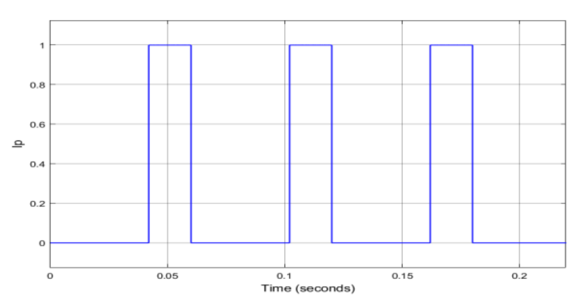
Case2 60 ms

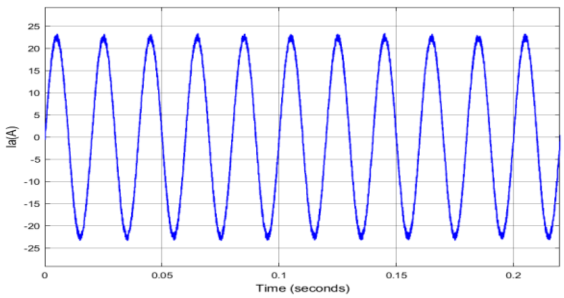

V0(V)
Time (seconds)


Vb(V)
Time (seconds)

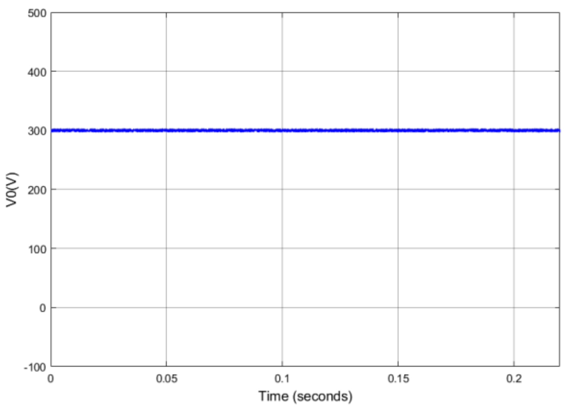

Vdc(V)
Time (seconds)

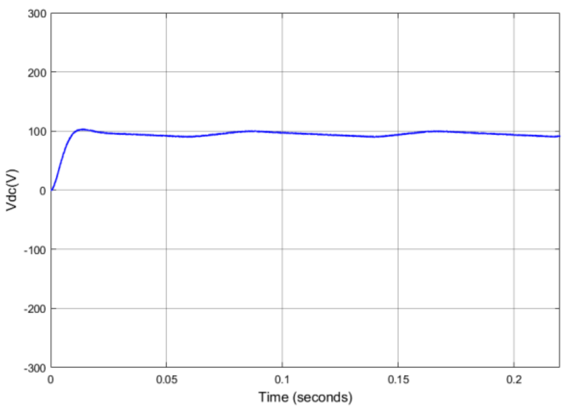

VL(V)
Time (seconds)

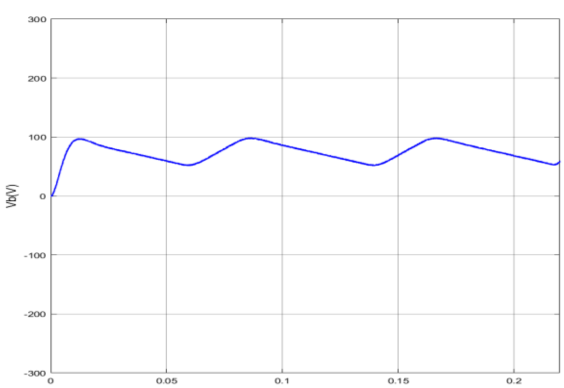

Ip
Time (seconds)

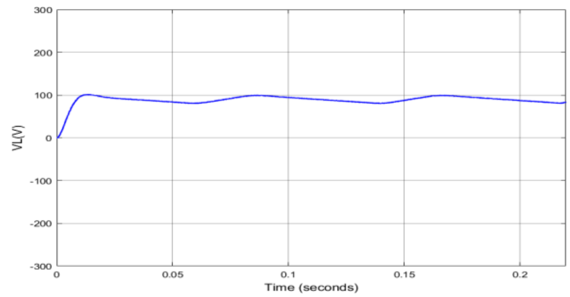


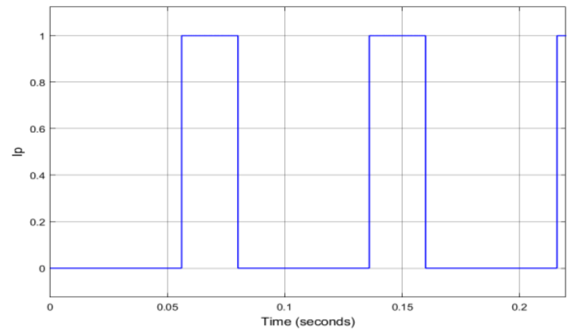
Case 3 80 ms











V Conclusions:

In this work presented an efficient solution for powering pulsed loads by combining advanced converter topology and intelligent control techniques. It ensures high efficiency, reduced system size, stable output voltage, and improved power quality, making it suitable for modern pulsed power applications. The integration of the AC–DC dual power distribution converter with ABC-based control strategy provides an intelligent and adaptive framework for regulating the DC–DC converter. By optimizing the control signal, the system achieves stable output voltage, efficient energy transfer, and improved overall performance under dynamic pulsed load conditions. From the simulation outcomes, it is evident that the coordinated operation of the dual distributed power converter, along with the integration of the ABC-based DC–DC converter, maintains output voltage stability, improved transient response, and ensures grid power quality under rapidly varying pulsed load conditions.

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