Particle Swarm Optimization Strategy to Increase Efficiency of Dual Active Bridge Dc-Dc Converter

Suliana Ab-Ghani, Hamdan Daniyal, Nur Huda Ramlan & Meng Chung Tiong
FKEE, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

Abstract

The isolated bidirectional dual-active bridge (DAB) converter have gained attention in DC-DC applications such as electric vehicle (EV) and energy storage system as the DAB converter provides galvanic isolation and promising high power density. The precise control in controlling the phase angle is important to ensure the optimal efficiency are producing in the DAB system. Thus, this paper proposes an optimization of modulating phase shift angle for DAB system using particles warm optimization (PSO) algorithm. A simulation of 200 kW DAB system has been carried out in MATLAB Simulink to analyse the proposed method under various reference voltage and load changes conditions. Comparative analysis between the proposed method and the PI controller performance is presented. As expected, the DAB system with proposed method produces fast convergence speed and higher power efficiency as compared to the DAB system with PI controller

Keywords: *Dual Active Bridge, Particle Swarm Optimization, PI Controller, Efficiency*

Introduction

As the renewable energy (RE) growth rapidly due to the global energy crisis and environmental issue, it led to the expansion of the DC micro grid that comprises of the RE resources with the energy storage system (ESS) (H.Higa and J.Itoh , 2017). Recently, the bidirectional DC-DC converters with galvanic isolation are preferable in integrating the RE sources and ESS applications, as well as the electric vehicles (EV) (H. Akagi et al.,2015 ; H. Zhang, X. Tong, and J. Yin , 2017 ;F. Krismer and J. W. Kolar,2012 ; P. X. Khiet and Y. Mitani, 2012). The dual active bridge (DAB) is the most desirable DC-DC topology (H. Shi, H. Wen, Y. Hu and L. Jiang, 2018) as promising the high efficiency, high density and zero voltage switching.

There are a few modulation techniques that have been applied in the DAB system (H. Shi, H. Wen, Y. Hu and L. Jiang, 2018 ; B. Zhao, Q. Song, W. Liu, and Y. Sun,2014). The single-phase shift (SPS) modulation is the conventional and simplest strategy, which only one angle need to controlled. Then, the 3-phase-modulated techniques like extended phase shift (EPS), dual-phase shift (DPS) and triple-phase shift (TPS) have been introduced to improve the SPS control flexibility. Those techniques required more than one controlled angle and most difficult to realise. In this paper, the SPS modulation is applied in the DAB system sinceitis most reliable, and it can produce high efficiency(P. Sathish kumar et al,2017 ; T. Lagier et al ,2018). As for voltage operating range in the proposed system, the voltage for lithium-ion battery specifications in an EV application is referred.

The PI controller is the common controller that has been widely used in power electronics application as well as in DAB converter (A. Rodr et al ,2015 ; K. Ishaque, Z. Salam, M. Amjad, and S. Mekhilef, 2012). In thiswork, as comparison, the basic PI controller is used to control the phase-shift-angle in the DAB system to perform as desired. Ziegler Nichols (ZN) tuning methodisapplied to get the KP and KI. Next, as proposed controller, the Particle Swarm Optimization (PSO) is deployed to directly search the optimal phase-shift-angle. The performance of both tuning methods is analysed in MATLAB Simulink simulation software.

ISSN: 2005-4238 IJAST
Copyright ⓒ 2019 SERSC

Dual Active Bridge

The DAB DC-DC converter was introduced early 1990s (R. W. A. A. De Doncker, D. M. Divan, and M. H. Kheraluwala, 1991) is consisting of primary and secondary full bridges with high frequency transformer interconnection for isolation purpose. The inductance leak age , Lkplay an important role of transferringenergy in the DAB circuit which determine the maximum power transferred with designated switching frequency . The circuit configuration of the DAB is portrayed in Fig. 1.

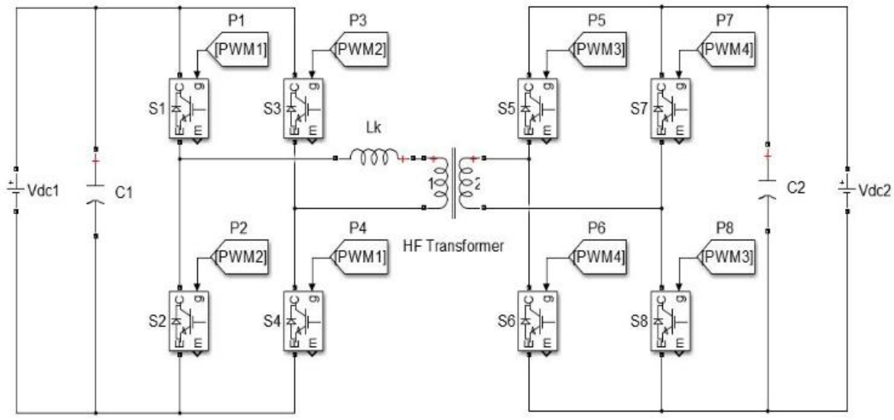

Figure 1 Circuit Configuration of the Dual Active Bridge

In primary bridge, the S1 and S4 is same and have complemented signal with S2 and S3 , as well as in the secondary side which the diagonal switches have identical value with 180° phase shift of each other's. Both full bridges is controlled to generate the square waveforms with a fixed duty ratio of 0.5 and same switching frequency. The phase shift between VDC1 and VDC2willdetermine the amount and the direction of the power flow. The forward power flow occurs during VDC1leading the VDC2 and vice versa. For bidirectional power flow analysis, normally the VDC2 are represented as the active load (battery or super capacitor), that the load can be acting as source during the discharging mode. As this paper just focusing on unidirectional power flow, the resistor (passive load) is replaced at the secondary output. The following equations are correspondingly to calculate the system power flow, turns ratio and voltage conversion ratio for the DAB converter.

$$P_{12} = \frac{V_1 n V_2 \phi_{12}}{2\pi f_s L_k}\left(1 - \frac{|\phi_{12}|}{\pi}\right), \phi_{12} = \phi_1 - \phi_2 \quad (1)$$

$$n = \frac{V_1}{V_2} \quad (2)$$

$$k = \frac{nV_o}{V_{in}} \quad (3)$$

Proposed Modulation Strategy

The PSO techniques is a stochastic global optimization that the nature was inspired by bird flocks' behaviour(J. Kennedy And R. Eberhart, 1995). In PSO, a swarm of individuals as known as particles represents a candidate solution. Each particles with set of initialization parameters (within the range) will explore the search space by evaluating the given objective function through an iterative process. After every it eration, each particles will update its fitness and the best fitness will be keep as Pbest. Then, all the Pbest values will be compared in order to get the G best value (best fitness among all

Copyright ⓒ 2019 SERSC

particles). Updating process of the velocity and position of each particle will be made at the end of each iteration by using both of Pbest and Gbest value. The standard equation to update the velocity and position algorithm can be defined as the following:

$$v_i(k+1) = wv_i.(k) + c_1.r_1.\{P_{best_i} - x_i(k)\} + c_2.r_2.\{G_{best} - x_i(k)\} \quad (4)$$

$$x_i(k+1) = x_i.(k) + v_i(k+1) \quad (5)$$

Where w is the inertia weight, r1 and r2 is the random number with a range of [0, 1], and c1 and c2 is the acceleration coefficients. P best is the best position of particle i based on its own experience and G best represented the best position of the particles in the over all swarm population.

In this paper, the online PSO strategy is proposed. The phase shift angle is adjusted directly in the algorithm without PI controller. The optimal phase shift angle will generate the PWM of the DAB system. The objective is to minimize the error voltage in all conditions that resulting the great efficiency of the DAB converter. Fig.3 and Fig.4 correspondingly depict the block diagram and the flowchart of the proposed algorithm. In short, the difference value between the actual output voltage and reference voltage will be evaluated in PSO algorithm. Then, the obtain ederror voltage will generate the phase shift angle as to produce the desired output voltage. The angle will bealte reddirectly according to the reference voltage through the PSO strategy.

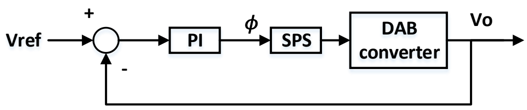

Fig 2 Block Diagram of the PI Controller

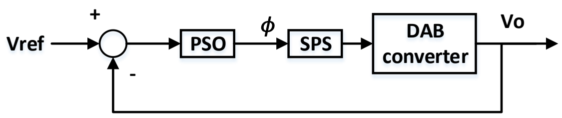

Fig 3 Block Diagram of the Propose Dalgorithm

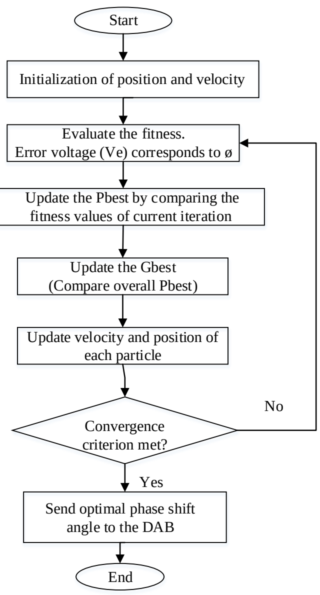

Figure 4 Flowchart of the Propose Dalgorithm

Simulation Results

The DAB converter was designed and simulate dusing MATLAB/Simulink and the main parameters are listed in Table 1. The SPS modulation method with PI controller and PSO algorithm were implemented in the DAB system. The convergence speed and the system efficiency were analysed and compared for a different reference voltage and changes of load.

In SPS, it will reduce power losses and most competitive as voltage ratio, K is closed to unity. Hence, the selected voltage operating range in this research are 250 V to 420 V, which the DAB converter was designed to operate for a range of K from 0.67 to 1.12. Since the K value is not further from one, the circulating current will decreases as resulting high efficiency. Fig. 5 illustrates the primary and secondary voltage with the inductance current of the SPS modulation. The phase shift angle, ϕbetween the voltages regulates the amount and direction of the power flow in the DAB converter.

The output voltage waveform for the various reference voltage of PI and PSO approach are presented in Fig.6 and Fig.7 respectively. Both methods depict that the output voltages can be regulated to the desired outputs. The settling time for PSO methods are slower compared to PI controller. This is because the searching movement by PSO particles required a bit complex computation than PI methods.

Table 1 Design Parameters

Item	Parameter
Input Voltage, V_{in}	750 V
Output Voltage, V_o	500 V
Rated Power, P_{max}	200 kW
Transformer ratio, N	2 :1
Switching frequency, f_s	20 kHz
Leakage Inductance , L_k	24 uH
Capacitance , C	0.39 mF

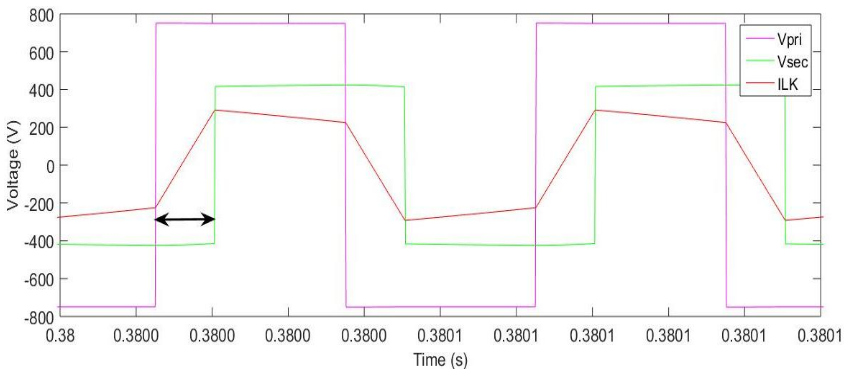

Figure 5 SPS Waveform

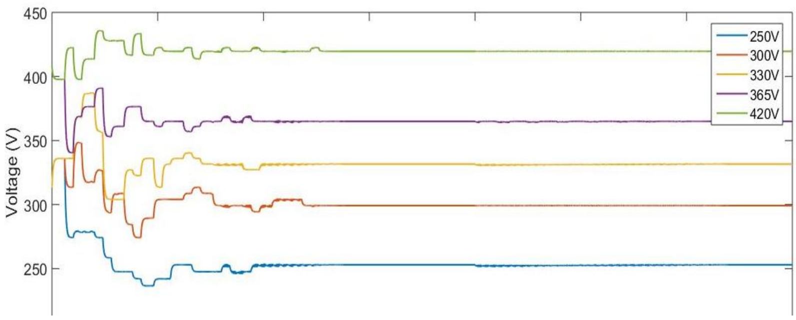

Figure 6 Output Voltage Waveform for Proposed Controller

ISSN: 2005-4238 IJAST
Copyright ⓒ 2019 SERSC

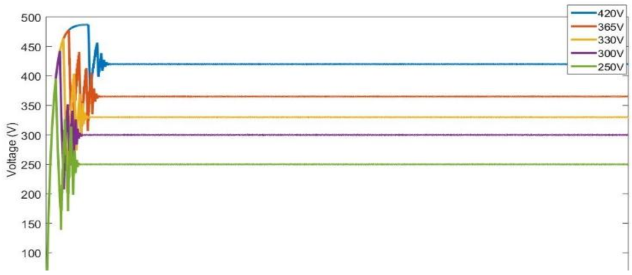

Figure 7 Output Voltage Waveform for PI Controller

The convergence speed results of the DAB system with PI controller and PSO strategy under numerous reference voltage testing was tabulated in Table II. The convergence time is analysed based on the time taken for the algorithm machieveit 98% of tracked phase-shift-angle value. It clearly shows that the DAB converter with proposed algorithm have fast convergence speed compared to the PI controller for all conditions. The PSO achieve the convergence point around 0.2s faster than the PI method. Also, Fig. 9 proves that the DAB system with PSO algorithm have high efficiency which under all the tested reference voltage, the efficiency are more than 99%. Though, the same efficiency have been produced in both methods for the 420 output voltage

Table 2 Convergence Time under Various Reference Voltage

Method	Vref (V)	Convergence Time (S)
PI	420	0.35
PSO		0.13
PI	365	0.36
PSO		0.11
PI	330	0.34
PSO		0.12
PI	300	0.34
PSO		0.17
PI	250	0.29
PSO		0.11

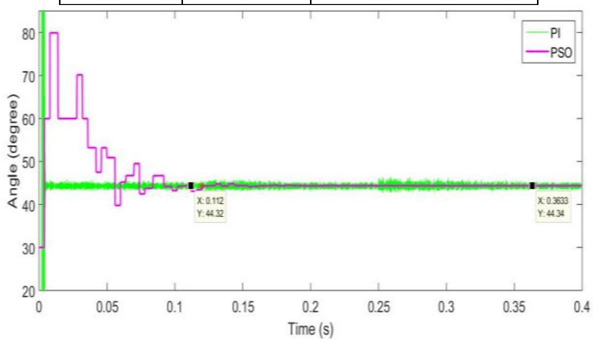

Figure 8 Convergence Time of PSO and PI Controller for 365 Vo

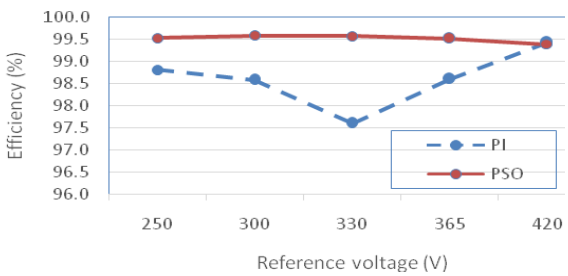

Figure 9 Efficiency under Various Reference Voltage

ISSN: 2005-4238 IJAST
Copyright ⓒ 2019 SERSC

Moreover, the performance of the DAB system was analyzed by changing the load with two different reference voltages. The convergerve time of full load, third-quarter load and half load for both reference voltages in PSO approach are obviously faster than the PI controller as presented in Table III. The efficiency under the light load for PI controller is lowest from other loads as represents in Fig. 10 and Fig. 11. However, the efficiency for PSO in heavy and light loads have approximate values which above than 99% for both reference voltages.

Table 3 Convergence Time under Various Loads

Method	Power(kW)	Vref (V)	Convergence Time (S)
PI	200	420	0.35
PSO			0.13
PI	150	420	0.34
PSO			0.14
PI	100	420	0.3
PSO			0.1
PI	200	250	0.29
PSO			0.11
PI	150	250	0.36
PSO			0.11
PI	100	250	0.15
PSO			0.1

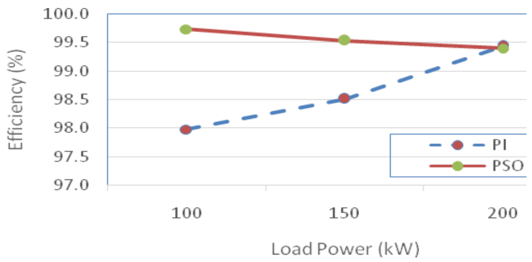

Figure 10 Efficiency under Load Changes with 420 Vref

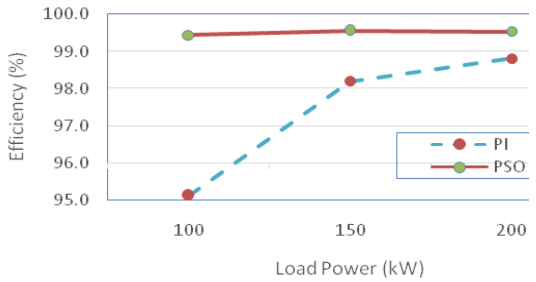

Figure 11 Efficiency under Load Changes with 250 Vref

Yet, by using Ziegler Nichols (ZN) method, the fine tune of KP and KI value cannot well performed under such circumstances. Thus, the PSO that categorized under swarm intelligence is proposed in this paper as to optimize the optimal phase shift angle and perform excellently compared to the PI controller. Compared with other optimization, the PSO technique is preferable due to its fast convergence speed, easy implementation as less parameter needs to be altered [6], [11].

Conclusions

This paper proposes a PSO strategy for optimal searching for the phase-shift-angle of DAB DC-DC converter. The performance parameters of the DAB with PI controller tuned by the ZN method and the online angle search using proposed method are compared. The PSO strategy outper form the PI controller in term of convergence speed and efficiency under numerous reference voltages and loads circumstances. In average, the proposed method yield 99% efficiency and less than 0.15s of convergence speed.

Acknowledgements

This work is supported by Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, under research grant RDU1703129 and RDU190318.

References

1. H. Higa and J. Itoh, "Extension of Zero-Voltage-Switching Range in Dual Active Bridge Converter by SwitchedAuxiliary Inductance," 2017 IEEE Energy Convers. Congr. Expo., pp. 5324–5331, 2017.
2. H. Akagi et al., "Power-Loss Breakdown of a 750-V 100-kW 20-kHz BidirectionalIsolated DC – DC Converter UsingSiC-MOSFET / SBD Dual Modules," IEEE Trans. Ind. Appl., vol. 51, no. 1, pp. 420–428, 2015.
3. H. Zhang, X. Tong, and J. Yin, "Optimal triple phase shift controller design of IBDC based on Ant ColonyAlgorithm and BP Neural Network," IECON 2017 - 43rd Annu. Conf. IEEE Ind. Electron. Soc., 2017.
4. F. Krismerand J. W. Kolar, "Efficiency-Optimized High-Current Dual Active Bridge Converter for Automotive Applications," IEEE Trans. Ind. Electron., vol. 59, no. 7, pp. 2745–2760, 2012.
5. P. X. Khiet and Y. Mitani, "Development and Evaluation of DC-DC Converter for Isolated PV Power Supply System with EV," Int. Power Energy Conf., pp. 424–427, 2012.
6. H. Shi, H. Wen, Y. Hu and L. Jiang, "Reactive Power Minimization in Bidirectional DC- DC ConvertersUsing A Unified-Phasor-BasedParticleSwarmOptimization," IEEE Trans. Power Electron., vol. 33, no. 12, pp. 10990–11006, 2018.
7. B. Zhao, Q. Song, W. Liu, and Y. Sun, "Overview of dual-active-bridge isolatedbidirectional DC-DC converter for high-frequency-link power-conversion system," IEEE Trans. Power Electron., vol. 29, no. 8, pp. 4091–4106, 2014.
8. P. Sathishkumar et al., "A blended SPS-ESPS control DAB-IBDC converter for a standalone solarpower system,"Energies, vol. 10, no. 9, 2017.
9. T. Lagier et al., "A 100 kW 1.2 kV 20 kHz DC-DC converter prototype based on the Dual Active Bridge topology," 2018 IEEE Int. Conf. Ind. Technol., 2018.
10. A. Rodr et al., "DifferentPurpose Design Strategies and Techniques to Improve the Performance of a Dual Active Bridge With Phase-Shift Control," vol. 30, no. 2, pp. 790–804, 2015.
11. K. Ishaque, Z. Salam, M. Amjad, and S. Mekhilef, "An ImprovedParticleSwarmOptimization(PSO)– Based MPPT for PV WithReducedSteady-State Oscillation," IEEE Trans. Power Electron., vol. 27, no. 8, pp. 3627–3638, 2012.
12. R. W. A. A. De Doncker, D. M. Divan, and M. H. Kheraluwala, "A Three-Phase Soft-Switched High-Power-Density DC/DC Converter for High-Power Applications," IEEE Trans. Ind. Appl., vol. 27, no. 1, pp. 63–73, 1991.
13. J. Kennedy and R. Eberhart, "Particleswarmoptimization," Neural Networks, 1995. Proceedings., IEEE Int. Conf., vol. 4, pp. 1942–1948 vol.4, 1995.

Copyright ⓒ 2019 SERSC