

A Comprehensive Review on Various Optimization Techniques for Zero Ripple Input Current DC-DC Converter

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Abstract

The paper presents a new methodology for optimizing the design of DC-DC converters. To exhibit the effectiveness of proposed algorithm, the performance of the Honey Bee Mating Algorithm (HBMA) controller has been compared with the classical Proportional Integral Derivative (PID) controller and the necessary results are presented to validate the Honey Bee Mating Algorithm (HBMA) for control purposes. The comparative study results emphasize that the optimized HBMA controller provided better performance and superior to the other control strategies because of fast transient response, minimum steady state error and good disturbance rejection under various variations of the operating conditions and, hence, the most tightly output voltage regulation is achieved and power losses are minimized. The conventional DC-DC boost converter is the most admired configuration for this scheme, even if the converter efficiency is restricted at duty cycle near to maximum value. In order to find solution to the problem and improve its conversion capability, many converter configurations have been implemented so far. The major benefits and disadvantages related to the available techniques are also briefly conveyed.

1. Introduction

The most important requirements expected from a DC-DC converter for renewable energy applications are high voltage gain and low current ripple [Giuseppe Marsala, 2013]. In a power conditioning system (PCS) for renewable energy applications, in fact, under single phase or un-balanced three-phase operation, a large second current ripple harmonic is produced and the current ripple is mirrored to the DC-DC converter input. The current drawn from the renewable source is typically not purely dc and a large current ripple (100Hz in 50Hz grids) could decrease the accuracy of the common maximum power point tracking algorithm (MPPT) in a photovoltaic system, produce additional heating, reduced conversion efficiency [Giuseppe Marsala, 2013].

The different DC/DC converter topologies are compared in terms of output current ripple reduction, conversion ratio, energy efficiency, and power switch fault-tolerance. Besides, remarks on the state-of-the-art and remaining key issues regarding DC/DC converters are provided [Damien Guilbert, 2017]. The various types of DC-DC converters such as buck, boost, buck boost, CUK, SEPIC, fly back, fly forward are mainly classified in to isolated and non-isolated type. If there exist an electrical contact between the input and output through transformer then it is known as isolated and at the same time the converter with absence of transformer is non isolated [o. c. onar, 2012].

The output of the fuel cell and solar panel is low voltage; usually a DC-DC converter is required for boosting the output voltage to a higher value. Therefore, this aim can be obtained by a DC-DC boost converter that converts the unregulated DC input to a controlled DC output at a desired voltage level. In a conventional power conditioning system (PCS), where there new able source supplies AC loads or grid, a first stage is normally a DC-DC converter, that boosts the source output voltage, and a second stage is a DC/AC inverter. In this system, under single phase or un-balanced three phase operation, a large second current ripple harmonic is produced in the inverter DC link [Giuseppe Marsala, 2015]. This aim is obtained simply coupled two inductors of an available topology of a boost converter, just designed by the authors [Giuseppe Marsala, 2011], characterized by a high gain and a single switching device.

A detailed mathematical analysis of operating mode, steady-state working condition and the comparison with the same topology without coupled inductors is presented [T. Arunkumari, 2017]. Analysis and Design of a dc-dc Converter with High Boosting and Reduced Current Ripple for PEM FC Analysis and Design of a dc-dc Converter with High Boosting and Reduced Current Ripple for PEM FC treats of the boost dc-dc converter with high voltage gain and low ripple input current. This converter is suitable for voltage boosting of fuel cell system in vehicle applications; moreover it has advantages as compared to classical topologies of boost converters. The complete steady state and dynamic analysis of the system is proposed as well as its output voltage control with

classical PID structure [Wu Chen, 2008]. Compared to other applications, a voltage fed converter may not be optimal due to its large ripple of the input current.

To reduce the current ripple in the voltage-fed converter, an additional LC filter is required and the power efficiency is consequently lowered. Also, high turns ratio between the primary and the secondary sides of the high-frequency transformer is required. However, a current-fed dc-dc converter decreases the current ripple due to the use of an inductor and then requires less input filtering in order to minimize the high frequency current ripple drawn from the electrical energy source. The basic single switch dc-dc converter topologies, such as the traditional boost, can be theoretically considered as alternatives to conventional insulated bridge converters, in order to obtain a good compromise between cost and efficiency. However, such topologies achieve the required voltage gain (up to 10) with close to unit duty cycles, forcing the diode to conduct large currents during very short time periods. As a result, due to the diode reverse recovery mechanism, large power losses are experienced, largely degrading the overall efficiency of the converter [Wu Chen, 2008].

Overall the disadvantages in those converters are no stable efficiency, stable voltage gain, switching loss and conduction. This review work will give a clear about the suitable converter and to identify the converter topology with better efficiency and high voltage transmission ratio [T. Arunkumari, 2017]. The zero ripple input current DC-DC converter with coupled inductors, designed by the Authors, based on the use of two optimization techniques: Genetic Algorithm (GA) and Particle Swarm Optimizations (PSO) algorithm. The design criteria is based on the minimization of power losses of the DC-DC converter, and in particular the conduction losses and switching losses of the converter switch, the losses of the diodes and the losses in the coupled inductors, both in the windings and in the magnetic material. The Genetic Algorithm (GA) and Particle Swarm Optimization algorithms evaluate the constrained optimized values of the design converter parameters in order to minimize all the losses and enhance the efficiency [Young-Kiu Choi, 2007].

From this a bridged survey of load profile clustering using Honey Bee Mating Optimization Algorithm (HBMO) for metering solutions in the field of electricity market, it is illustrated that it has the potential to offer solutions to several other optimization problems by presenting a significantly desirable behavior in terms of strength and properties. Thereby, this little survey confirms that HBMO algorithm's broad applicability, ease of use, and global perspective are the important properties to conclude that the HBMO algorithm has greater potential in efficiently addressing the metering issues [T. Chakaravarthy, 2015].

The main objective of proposed optimization technique allows obtaining an efficiency of about 93% with a raise of about 10% respect to the same converter without optimization. Moreover, the procedure allows obtaining a reduction on the size, weight and, as a consequence, the cost of the coupled inductors.

The paper is organized as follows. In Section II, proposed circuit topology is discussed. Comparison with proposed technique is discussed in section III. In section IV explain the honey bee mating optimization technique.

2. Proposed Topology:

The schematic in Fig. 1 (a) illustrates the proposed topology. It is characterized by a high voltage gain and a zero input current ripple. The two inductors, L_1 and L_2 , are coupled, with coupled inductors, the inductors L_1 and L_2 are coupled, in opposite winding orientation, with a mutual inductance, M , suitable designed, in order to obtain a condition of zero input current ripple.

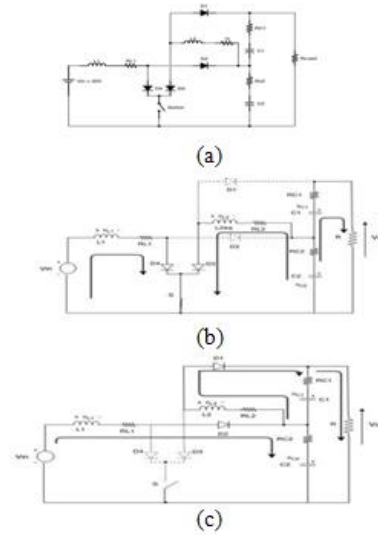


Fig. 1: Circuit Schematic of the Proposed Converter: (a) Topological Realization, (b) Equivalent Circuit for the On-state, and (c) Equivalent Circuit for the Off-state

The equivalent circuits for the one and off-state are depicted in Fig. 1 (b) and (c), respectively. To analyze the operating principle of this converter topology, it can be represented by an equivalent circuit with two uncoupled inductors L_{1eq} and L_{2eq} given by,

$$L_{1eq} = \frac{L_1 n (1 - D) (1 - k^2)}{n (1 - D) + k} \quad (1)$$

$$L_{2eq} = \frac{L_2 (1 - k^2)}{1 - n k (1 - D)} \quad (2)$$

With:

$$k = \frac{M}{\sqrt{L_1 L_2}}; \quad n = \sqrt{\frac{L_2}{L_1}} \quad (3)$$

In this way the analysis of the operating modes (ON and OFF state) within a switching period, T , of the converter, shown in Fig. 2, becomes the same of a converter with uncoupled inductors with $L_1 = L_{1eq}$ and $L_2 = L_{2eq}$ and $M=0$. For each desired value of duty ratio D , there exists a condition of free ripple input current that depends on the three design parameters: D , k and n .

For the analyzed converter, the inductor currents i_{L1} and i_{L2} , are obtained by the superimposition of the ripple component i_1 and i_2 over the dc component, respectively, i_{L1min} and i_{L2min} , that represent the initial and final values of inductor currents in each switching interval:

$$i_{L1} = i_1 + i_{L1min} \quad ; \quad i_{L2} = i_2 + i_{L2min} \quad (4)$$

In particular, their expressions are:

$$i_{L1}(t) = \frac{V_{in}}{L_1} \frac{n(1-D) + k}{n(1-D)(1-k^2)} t + \frac{P_{in}}{V_{in}} - \frac{V_{in}DT}{2L_{2eq}} \quad (5)$$

$$i_{L2}(t) = \frac{nk(1-D) + 1}{(1-D)(1-k^2)} t + \frac{V_{in}}{R(1-D)} \left[\frac{1}{(1-D)^2} - \frac{DRT}{2L_{2eq}} \right] \quad (6)$$

Moreover, the relations that define the ripple of the inductors currents, Δi_{L1} and Δi_{L2} , are:

$$\Delta i_{L1} = \Delta i_{L1(DT)} - i_{L1min} = \frac{1}{L_{1eq}} V_{in}DT \quad (7)$$

$\Delta i_{L2} = \Delta i_{L2(DT)} - i_{L2min} = \frac{1}{L_{2eq}} \frac{V_{in}}{(1-D)} DT$ (8) Furthermore, the values of the average value of the two currents $\bar{i}_{L1}$ and $\bar{i}_{L2}$, are given by:

$$\bar{i}_{L1} = \frac{P_{in}}{V_{in}} \quad (9)$$

$$\bar{i}_{L2} = \frac{V_{in}}{R(1-D)^3} \quad (10)$$

Finally, the average value of the voltage across the storage capacitor C_1 and C_2 , V_{C1} and V_{C2} are given by:

$$V_{C1} = V_{in} \frac{D}{(1-D)^2}; \quad V_{C2} = \frac{V_{in}}{(1-D)} \quad (11)$$

As relation (11) shows, V_{C1} and V_{C2} are not affected by the coupling of the inductors and the voltage gain is:

$$G = \frac{V_0}{V_{in}} = \frac{V_{C1} + V_{C2}}{V_{in}} = \frac{1}{(1-D)^2} \quad (12)$$

3. Comparison with the proposed technique:

The conventional method comparison with the proposed technique is mentioned in the table 1.

Different techniques	Transient response	steady state error	output voltage regulation	Disturbance/ ripples	power losses	efficiency	conversion capability	cost-performance	Power density
Computer-Aided Optimization (CAO) [Timothy C. Neugebauer, 2000]	Medium	Medium	Poor	High	High	Low	Medium	High	High
Ant Colony Optimized [Mahendran, G, 2013]	High	Medium	Moderate	Medium	Medium	Low	Medium	High	High
Firefly Algorithm [Muhammad Yaqoob, 2014]	Low	Low	Better	Low	Low	Better	Low	High	Low
Bacterial Foraging Optimization Algorithm (BFOA) [D. M. Mary Synthia Regis, 2011]	Medium	Medium	Poor	High	High	Low	Medium	High	High
Bat Algorithm [PrabhuOrner, 2016]	Medium	High	Poor	High	High	Low	Medium	High	Low
Artificial Fish Swarm Algorithm [Mingxuan Mao, 2017]	High	Medium	Better	Low	Low	Better	Low	Medium	Low
Artificial Bee Colony (ABC) [Yusuf Sonmez, 2015]	High	High	Moderate	Medium	Medium	Low	Better	Medium	Low
Cuckoo Search [PiyushVerma, 2016]	High	Medium	Poor	High	High	Low	Low	High	Low
Eagle Strategy [M. Sarvi, 2015]	Medium	High	Moderate	Medium	Medium	Low	Better	Low	High
Differential Search Algorithm [Dipayan Guha1, 2016]	Medium	High	Better	Low	Low	Low	Low	Medium	Low
Fruit fly Algorithm [Rizk M Rizk Allah, 2016]	low	High	Moderate	Medium	Medium	Low	Good	High	Low
Fireworks Algorithm [Rajsekar N, 2016]	High	High	Moderate	Medium	Medium	Low	Medium	High	Low
Lion Optimization Algorithm [Saber ArabiNowdeh, 2016]	Medium	High	Better	Low	Low	Better	Good	Medium	Low
Gravitational Search Algorithm [AnnabGhosh, 2015]	Medium	No	Moderate	Medium	Medium	Low	Medium	High	Low
Grey Wolf optimization [M.ValanRajkumar, 2017]	High	High	Poor	High	High	Low	Medium	High	Low
Particle Swarm Optimization [J.B.L. Fermeiro, 2016]	High	High	Moderate	Medium	Medium	Low	Medium	High	Low
Flower Pollination Algorithm [NitishKatall, 2016]	Medium	Medium	Better	Low	Low	Better	Medium	High	High
Genetic Algorithms [Young-Kiu Choi,2007]	Medium	No	Better	Low	Low	Better	Medium	High	Low
Glowworm Swarm Optimization (GSO) [Qiang Chen, 2015]	Medium	High	Moderate	Medium	Medium	Low	Low	Medium	Low
Shuffled Frog Leaping Algorithm [XiaohuaNie, 2017]	Low	No	Moderate	Medium	Medium	Low	Medium	Medium	Low
Honey Bee Mating Optimization (HBMO) [Reza Bazyar, 2015]	low	No	Better	Low	Low	Better	better	Low	High

From table 1. the honey bee mating algorithm gives best results among all. Honey bee mating algorithm description is in below section.

4. Honey Bee Mating Algorithm/ Optimization Technique

Honey bee mating algorithm (Figure 2.) can be considered as a general method based on insect behavior for optimization which, the search algorithm inspired from mating process in real bees life. Honey bee behavior is an interaction among genetic potential, physiologic and ecologic environment of hive social conditions and the hybrid of mentioned cases. A honey bee hive including: a queen with long life for laying eggs, about 10000 to 60000 worker bee, and up to hundreds of drone (according to the season). Queens have the main roll to generate some honey bee species, and laying eggs. Drones are the hive father. They are mono-sexual and intensify the mother genes without changing in their genetic combination. Worker bees do laying eggs and mother-craft. Queen bee would feed by “royal jelly” that is a milky white jelly. Worker bees hide the dietary substances and consume it for the queen. This kind of feeding makes the queen larger than the others. The queen lives between 5-6 year, while the worker bees live about 6 months.

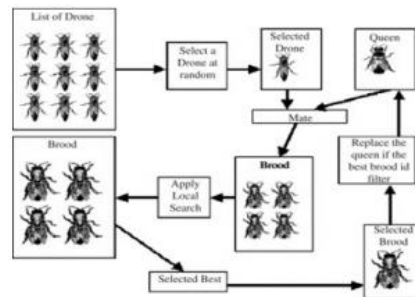


Fig. 2: Honey Bee Mating Process

Abbas 2001a, Afshar et al. 2007, presented mating flight starts with a danced performed by the queen who then starts a mating flight during which the drones follow the queen and mate with her in the air. The Second stage of evolutionary process starts after the genetic was filled with chromosomes and consists in breeding eggs with genetic information from spermatheca modified queen bee evolution model by using the weighted crossover operator and applied the algorithm for the tuning of input and output scaling factors. Final stage of evolution process consists in raising the broods generated during the second stage, and creating a new generation of bee based on mutation process.

Honey Bee Mating Optimization Algorithm (HBMO)

Thus, an HBMO algorithm maybe constructed with the following five main stages: Table 2 explain the HBMO algorithm starts with the mating flight, where a queen (best solution) selects drones probabilistically to form the spermatheca (list of drones). A drone then selected from the list randomly for the creation of broods. Creation of new broods (cluster centers) by crossover the drone's genotypes with the queens.

Table 2: HBMO Process

Natural honey bee	Artificial honey bee
Queen	Best solution
Drones	Incumbent solution
Broods	New trail solution
worker	Heuristic search
Mating Breeding	Crossover

- Use of workers (heuristics) to conduct local search on broods (trial solutions).
- Adaptation of worker's fitness, based on the amount of improvement achieved on broods.
- Replacement of weaker queens by fitter broods.
- Honey bee algorithm proposing is composed by three main a citrates.
- Exploration recruitment.
- Harvest.

5. Conclusion

The paper proposes a new design procedure for a DC-DC converter with coupled inductors using the honey bee mating Optimization method. The design procedure is based on the minimization of the converter losses. The paper introduced a constrained optimization procedure to design a DC-DC converter with coupled inductors for minimizing the power losses. The proposed topology is competitive against existing alternatives in the literature.

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