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PERFORMANCE IMPROVEMENT OF A SINGLE PHASE DIFFERENTIAL-MODEL C'UK INVERTER FOR PV SYSTEM USING MODIFIED DISCONTINOUS MODULATION SCHEME

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ABSTRACT: In this paper we present a single-stage differential-mode Cuk´ inverter (DMCI) for photovoltaic (PV) system. Among other topologies it has many dominant features. It provides advantages because of low cost, higher power density and compactness. It has many applications in renewable-energy especially for PV associated with isolated as well as non-isolated structures. Originally two types of modulation schemes were introduced for this inverter. First continuous modulation scheme (CMS) which triggers all the sections of DMCI. Discontinuous modulation scheme (DMS) triggers only one section of DMCI in each of the half line-cycle and yields discontinuous operation of sections. This paper discusses the modified discontinuous modulation scheme and a mechanism to realize it. A performance of CMS and DMS is provided by simulation of open-loop results of the DMCI. The dc-voltage gain of CMS is linear function of duty cycle that's why it reduced total harmonic distortion present in the output voltage. Existing DMS has reduced the losses and circulating power but has non-linear dc–voltage gain which results in higher harmonic distortion. The proposed DMS keeps all the advantages of existing DMS. It also provides pure sine wave in output voltage along with negligible harmonic distortion. So, the proposed DMS solved the problem of non-linear dc-voltage gain.

Keywords: Renewable energy, Modulation schemes, Discontinuous Modulation, PV System, C'uk Inverter

INTRODUCTION

Inverters which have High-frequency-link (HFL) with galvanic isolation have introduced as a potential front runner, to developing low-cost inverter solutions, that can be used in renewable energy, alternative energy as well as vehicular applications (Harb and Balog, 2013; Kim *et al.*, 2012). To overcome the increasing cost of high-frequency transformer and their reliability, loss and power density such inverters have multistage topological. Common mode leakage current is a serious issue for certain applications in typical topologies that does not have transformers (Meneses *et al*., 2012) which have a cascaded boost-buck or buck-boost architecture. The best solution for these types of applications and others is to use an isolated HFL inverter topology. The topologies mentioned in (Khan *et al.*, 2018; Khan *et al.*, 2016) boost unidirectional power flow, while Kim et al. (Kim *et al.*, 2012) have introduced bidirectional multistage HFL topologies. Although numerous HFL-inverter topologies comprise of a front-end direct current to direct current converter followed by a decoupling direct current capacitor, other topologies with multistage does not focus on the need of an intermediate dc-link electrolytic capacitor. In general, a cautious consideration is needed to save cost tradeoffs of a multistage HFL inverter topology for low power applications. In literatures (Chen and Wang, 2010; Khan and Rizvi, 2013) researchers discuss single-stage topological solutions for the applications having low-power single-phase along with HFL inverters.

In literature (Harb and Balog, 2013; Kim *et al.*, 2012), first time a switching direct current to direct current converter is formed which comprises of minimum number of storage elements (including inductive and also capacitive elements) and switches, and so far truly follow the ideally desired direct current to direct current transformer which have no ripple on input currents and output currents just as pure dc quantities. The result of this paper was introduced a new concept termed as integrated magnetic. Integrated magnetic uses some special types of switching structures for integration which was not used earlier. In this literature, a more complex structure have introduced which consists of additional elements having new connection connected electrically and magnetically for two reasons: 1) because more features and functions could achieve by this method for example basic non-isolated converter with dc isolation or extension of dc isolation for power amplifiers which support four-quadrant bidirectional switching; 2) because

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it minimizes cascaded boost-buck converter into the C'uk converter by initializing the intermediate step for more simplification.

Further the literature (Harb and Balog, 2013; Kim *et al.*, 2012) also proposed design and analysis of differential mode c'uk inverter (DMCI) topology for photovoltaic (PV) and fuel cell applications. The inverter which discussed in this paper results 60-Hz sinusoidal output by working differentially and consists of two isolated C'uk converters. This output an easy drive circuitry and made possible to direct current to alternating current conversion with low device count.

In this paper two modulation schemes for DMCI is discussed. This topology can be improved by using high frequency transformer. The differential mode C'uk inverter consists of only four switches which reduced the cost and made the fabrication of inverter simple. Initially continuous modulation scheme is developed for this topology which turns on the all modules of inverter and flow of power is continuous and the power in reverse direction also flows in the inverter. Due to reverse power an unnecessary power circulate in inverter. This power circulation increases the ratings of devices and average power flow of modules. Hence, increases the losses and decreases the efficiency of device.

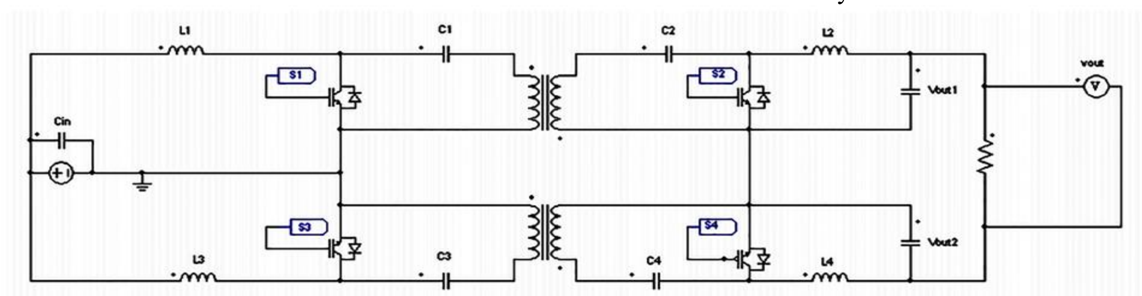
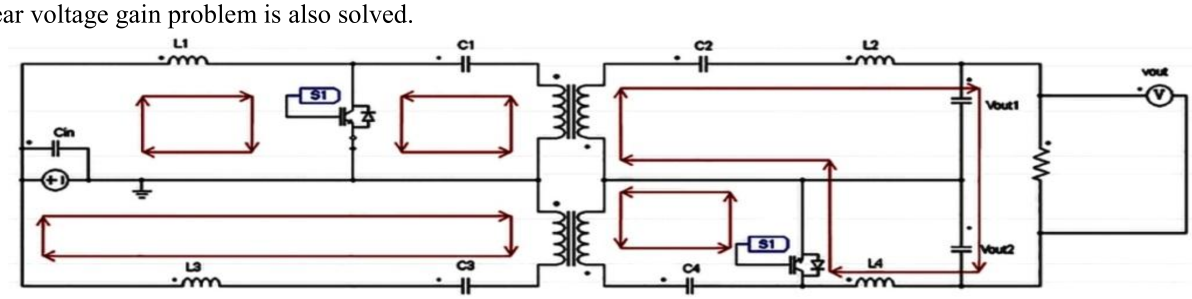


Figure-1: Differential Mode C'uk Inverter

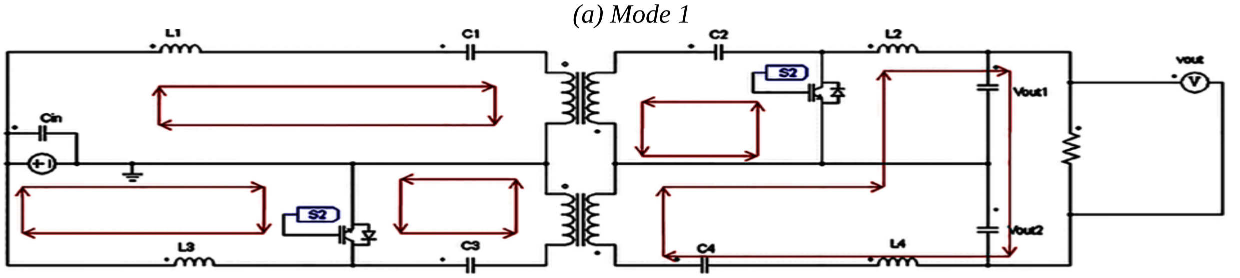
MATERIALS AND METHODS

This section first describes the Continuous modulation scheme and discontinuous modulation scheme for completeness and explains the working modes of CMS and DMS. And hence, the output power of both modulation schemes is similar the main difference is in discontinuous power of modules and current by using DMS. Moreover, in modified DMS non-linear voltage gain problem is also solved.

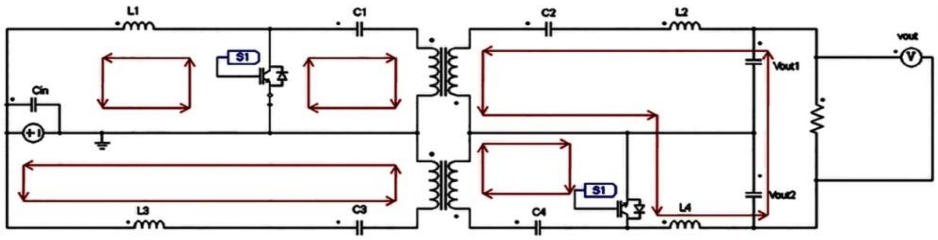
Continuous Modulation Scheme: In continuous modulation scheme both modules of the differential mode Cuk′ inverter are working simultaneously. The output voltage (Vout) of the inverter is the difference of the output voltage (Vout) of module 1 and the output voltage (Vout) of module 2. The dc voltage gain for CMS can be determined by the following equations. Different modes of continuous modulation schemes are shown in fig 2.



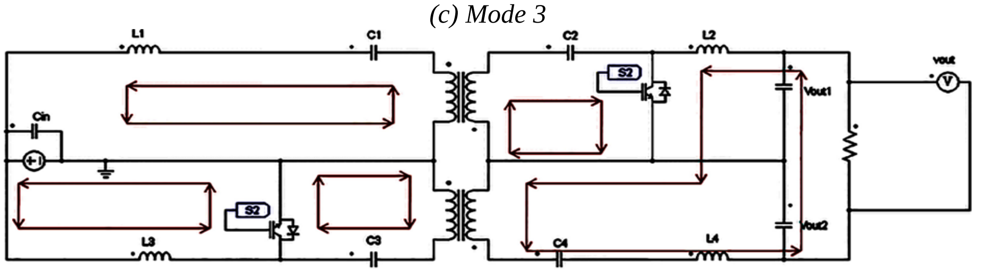
(a) Mode 1



(b) Mode 2



(c) Mode 3



(d) Mode 4

Figure-2: Four Modes of Continuous Modulation Scheme (CMS)

$$\frac{V_{out}}{n\times V_{dc}}=\frac{V_{out1}}{n\times V_{dc}}-\frac{V_{out1}}{n\times V_{dc}}=\left[\frac{D_1}{1-D_1}-\frac{D_2}{1-D_2}\right] \quad (1)$$

Where Vdc = dc input voltages
n = turns ratio of the transformer
$D1$ and $D2$ = duty ratio of module 1 and 2

Discontinuous Modulation Scheme: The main purpose of developing discontinuous modulation scheme is to discontinue one module of differential mode C´uk inverter and reduced the circulating power. Maximum current and the maximum voltages of switching devices is high due to this circulating power and it also increases the ratings of devices. Further, discontinuous modulation scheme helps in reduction of cost of inverter by reducing extra losses in inverter. The inverter voltage gain consists of duty cycle D1 and D2 in a piecewise manner.

By solving the equation in terms of $D1$ the voltage gain becomes

$$g=\frac{V_{out}}{n\times V_{dc}}=\frac{2D_1-1}{D_1\left(1-D_1\right)} \quad (2)$$

For continuous modulation scheme the diagonal switches are controlled by same gating signals.

$$\frac{V_{out}}{n\times V_{dc}}=\left[\frac{D_1}{1-D_1}\right] \quad \text{for } V_{out}>0 \quad (3)$$

$$\frac{V_{out}}{n\times V_{dc}}=\left[\frac{D_2}{1-D_2}\right] \quad \text{for } V_{out}<0 \quad (4)$$

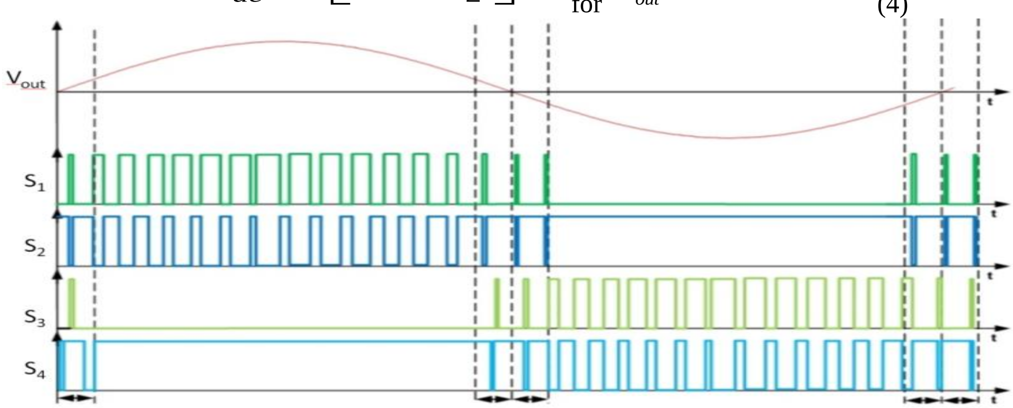


Figure-5: Gate signals of four switches for DMS and output

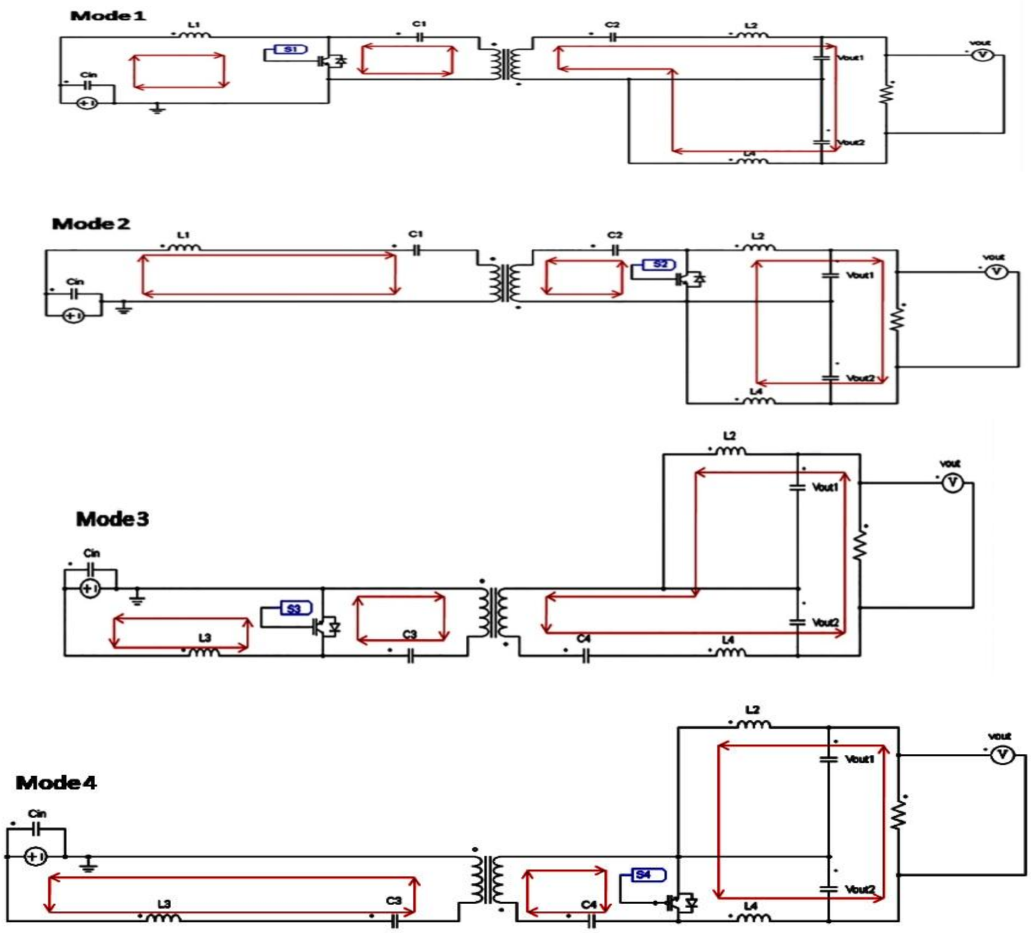


Figure-6: Four Modes of Discontinuous Modulation Scheme (DMS)

The main purpose of developing a new modified discontinuous modulation scheme is to adjust the switching signals in such a manner that it reduces the extra flow of power. Due to reduction of extra power flow the conduction losses and switching losses is reduced in the inverter. The inverter can perform better efficiency. First time the literature (Abeywardana *et al.*, 2012; Xu *et al*., 2004) gives the concept of discontinues one module at a time but this literature does not explain the practical problems and modulation.

The major concern about this modulation technique is the dc voltage gain of the inverter for DMS shows more nonlinearity than CMS. Because of this nonlinearity the inverter yields higher distortion at the output voltage which can be compensated by using nonlinear revised duty cycle. The pure sinusoidal output voltage can be obtained by using following equations.

$$V_o = V \sin \omega t \quad (5)$$

$$M_i = \frac{V}{V_{in}} \quad (6)$$

$$D = \frac{(1 - M_i \sin \omega t)}{(2 - M_i \sin \omega t)} \quad (7)$$

$$D' = \frac{1}{(2 - M_i \sin \omega t)} \quad (8)$$

Where M_i is the Modulation Index.

The normalized dc-voltage gain of differential mode Cuk ´inverter when operated in continuous modulation scheme and discontinuous modulation scheme is shown in Figure 7. We need to compare the nonlinearity of both modulation schemes in order to determine efficiency and distortion of both modulation schemes. From Fig. 7 it is clear that nonlinearity of dc-voltage gain of discontinuous modulation scheme is more than continuous modulation scheme. This nonlinearity of dc voltage gain is the cause of distortion at the output voltage of the inverter which is compensated in this research by using revised duty cycle.

Voltage gain of modified discontinuous modulation scheme is the linear function of the duty cycle for modified.

RESULTS AND DISCUSSION

The simulation results of DMCI using CMS and modified DMS is shown in this section. Differential mode C'uk inverter topology which is shown in figure 1 is simulated and tested using both modulation schemes with open-loop control. The specifications of simulated topology are described in Table 1. The output voltage of inverter (Vout) for continuous modulation scheme as presented in figure 9. The output voltage of inverter is pure sinusoidal waveform having amplitude 200. Each module of continuous modulation scheme has always positive output voltage and the value of minimum voltage depends upon the amplitude of the modulating signal. Figure 10 describes the output voltage for discontinuous modulation scheme. In discontinuous modulation control scheme the output of inverter is also sinusoidal waveform but it has increased amount of distortion due to non-linear voltage gain of discontinuous modulation scheme. This problem is solved in modified discontinuous modulation scheme whose output voltage is presented in Figure 8. The output voltage of the inverter in case of modified discontinuous modulation scheme is pure sinusoidal waveform with minimum amount of distortion. This distortion is the only drawback in previous discontinuous modulation scheme which is compensated. The results obtained using the modified discontinuous modulation.

Table1. Specifications of Simulated Inverter

Input Voltage	Output Voltage	Output Frequency	Output Power	Transformer turns ratio(n)	Switching frequency
20-120V	120V	6o Hz	500 W	1	25kHz

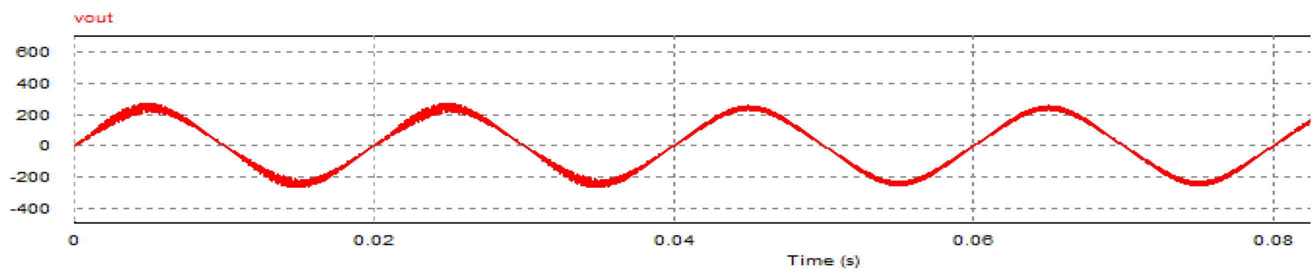


Figure-7: Output Voltage of modified Discontinuous modulation scheme

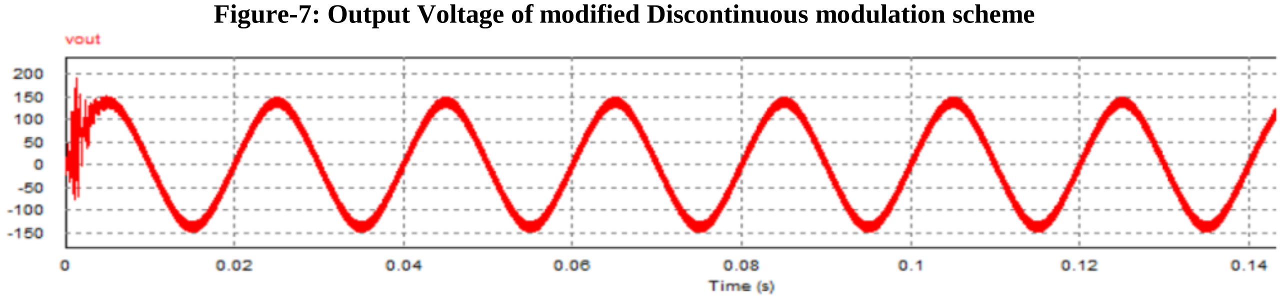


Figure-8: Output Voltage of Continuous modulation scheme

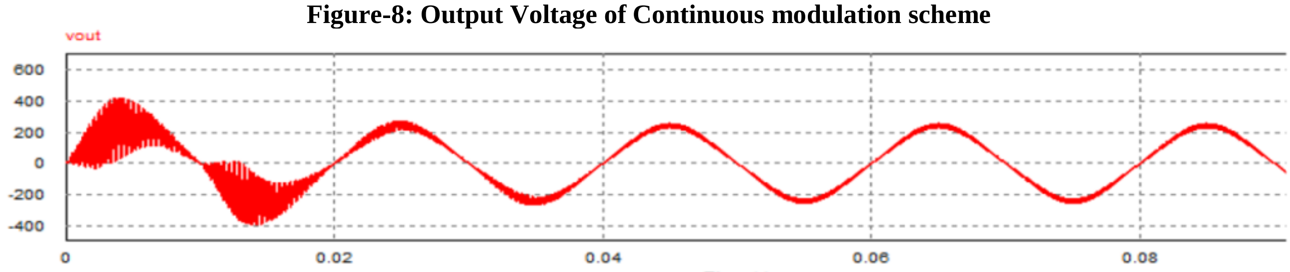


Figure-9: Output Voltage of Discontinuous modulation scheme

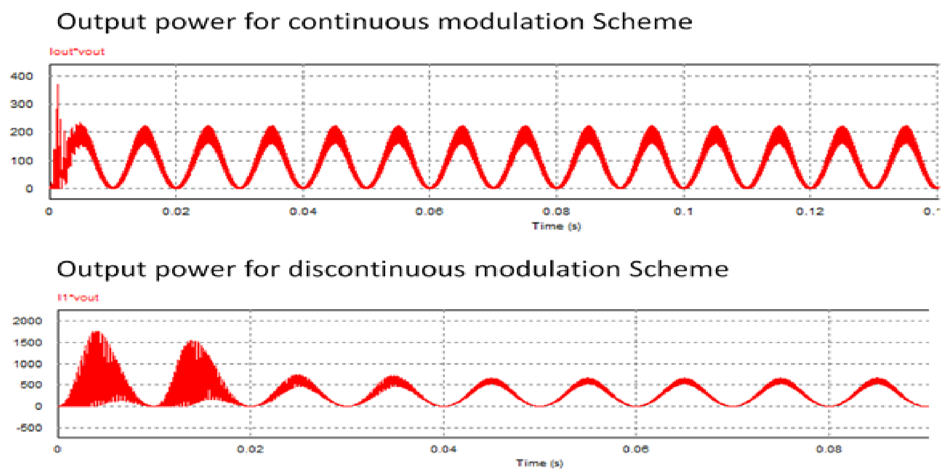


Figure-10: Instantaneous output power for DMCI using CMS and DMS

In Fig. 10 the total harmonic distortion of 8.81 is for continuous modulation scheme for Differential mode c'uk inverter and total harmonic distortion of 5.430 is for discontinuous modulation scheme which is smaller than continuous modulation scheme. This is the main advantage to operate DMCI in discontinuous modulation scheme.

Conclusion: This research describes a modified Discontinuous Modulation Scheme for a DMCI and compares the mechanism and performance of the Discontinuous Modulation Scheme based DMCI to that of a prior-art Continuous Modulation Scheme based DMCI. Moreover, to eliminate the non-linear gain problem of DMS, modified DMS was proposed. The proposed DMS technique kept all the advantages of existing DMS; it was also providing pure sinusoidal output voltage with negligible total harmonic distortion (THD). Furthermore, a complete analysis provided followed by the simulation of the inverters results for verification of the proposed approach.

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