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System Design of Three Phases Six Legs DC/DC Converter for Solar Cell

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Abstract— this paper describes the design of full bridge DC to DC converter 3 phase six legs for solar PV. The prototype is built with 5 kHz transformers, 2 lead-acid batteries with each energy storage of 12V, 7.2Ah and 20WP solar PV. Three phase switching is provided by analog op-amp comparator circuit with variable frequency 1 kHz-20 kHz. The controller of the converter use adjustable DC power supply as voltage reference for analog op-amp comparator, works varies from 0-11VDC (0%-50% duty cycle) and controlled manually.

Keywords: DC to DC Converter, Full Bridge, six legs three phase, inverter, solar cell

I. Introduction

For several renewable energy resources, solar PV is one of them which has to be considered. It can provide reliable electric power for almost all electrical applications, convenience to collect, clean, quiet and fuel-free. [1]

Changrong Liu in his dissertation (page 23) says that the major features of this converter are:

1. Able to improve power rating by phase parallelize, not by performing whole unit parallel.
2. Able to increase voltage output dramatically by transformer delta-y connection without adding more coil windings.
3. Able to reduce value of capacitor as output filter
4. Able to reach zero voltage – zero current switching.

It is stated by Fabregat [2] and Tse, K.K [3], Solar PV is one of the renewable electrical energy resources, has its own unique output power characteristic which is dependent to material, load impedance, temperature and solar lighting. Maximum Power Point Tracker or abbreviated as MPPT;is an important step in order to gain the maximal value of solar PV output power as reviewed by Bhatnagar [4] with several methods such as OVC and SCC based on MPPT, look up table method, curve fitting based MPPT, PO method, and INC MPPT. Other related researches about MPPT state that MPPT can also work using frequency modulation, fuzzy logic, and PI, as it has been observed by Efticios [5] that; MPPT successfully optimized using several algorithms including PI controller. However, due to most of the researches are using only DC/DC buck-boost converter as the MPPT medium, the application is basically used at relatively low power solar PV. DC/DC buck-boost converter application actually can be used in higher power appliances, such mentioned at Zang Fan research [6], but it has to be mounted in parallel and therefore will increase cost and component used in the designated application.

Other studies regarding power electronic technology has been done to streamline DC/DC converter by improving soft-switching PWM technique using full-bridge converter [7].

Some of these studies have their own advantages and disadvantages depend on the aim of the research. This study, however, will implement several combinations from related researches in order to apply the maximum power point tracking of solar PV using DC to DC converter.

II. Metodology

In this prototype device, DC/DC converter three phase six legs is able to be used as impedance controller for solar PV and can be combined with MPPT method by adjusting the reference voltage range of 0-11VDC. DC/DC converter 3 phases 6 legs is applied to maximize power output from a solar PV 20W. At the power storage side, used two lead-acid battery model No. LC-V127R2NA 12V 7,2Ah.

In broad outline, this study had circuit such as follows:

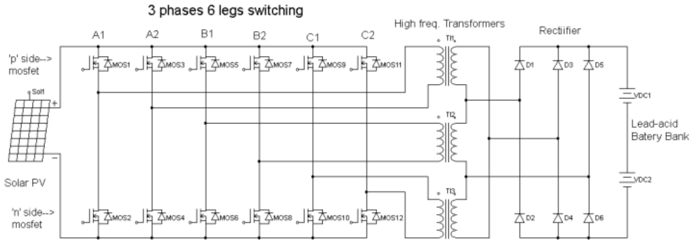

Figure 1
Lay out 3 phases 6 legs dc/dc converter for solar PV battery charging

Figure 1 shows the experimental setup consisting of a single solar PV module with STC maximum power 20W, maximum voltage power 17.6V, maximum current power 1.14 A, Isolated DC/DC converter 3 phase 6 legs and lead-acid battery bank storage, 12V and 7,2Ah each. The solar PV connected parallel with 6 legs N-channel mosfet to convert DC voltage of solar PV into AC signal voltage. The output of the 6 legs switching then get raised using 3 single phase 5KHz transformer connected delta at the output. The transformer output then get rectified using three half-bridge rectifier to charge the battery. The battery bank storage consists of two 12V, 7.2 Ah lead-acid battery connected in series, and the operating range of the battery bank range of 25-28VDC based on daily testing.

In the other hand, 3 phase switching for the mosfets are provided by analog op-amp circuit. The circuit consist of square wave generator and two op-amp integrator circuits to produce sine wave signal, two phase delay op-amp circuits, three inverter op-amp circuits, and six comparator op-amp circuits.

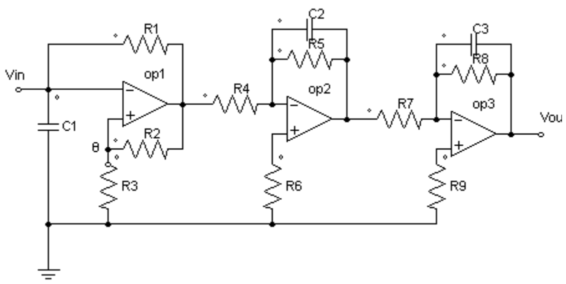

Figure 2
Sine wave generator circuit

The first op-amp (op1) in figure 2 will generate the square wave at the specific frequency depending on voltage divider (θ) as adapting reference and RC at the input side. The frequency of signal generator can also be calculated. The second and the third op-amp circuit in figure 2 will convert the square wave into sine wave. The concept of op2 and op3 is inverting amplifier with RC low-pass-filter.

III. DESIGN AND RESULT

The component type and detail can be seen on table 1 as follows;

Table 1.
Component Parameters used to the System

Voc Solar PV	21,6V
Isc Solar PV	1,21A
Transformer Core Material	Ferrite
Transformer Core Type	PQ 35/35
Transformer Turns Ratio	1;2
Switching Frequency	5KHz
Batery Model	LC-V127R2NA
Batery type	Lead-Acid
Batery voltage Stand by	13,6-13,8/25^{o}C
Batery capacity	7,2Ah/20h

The inverter itself consisted of six legs to obtained three phase switching with each of its phase used two legs. Switching regulation could be divided into two parts which were mosfet switching upper part (p) and lower part (n) at each of A1, A2, B1, B2, C1, and C2 legs. If the upper part of switch was connected then leg was in "on" position (condition 1), while if the lower part of switching was closed then the leg was "off" (condition 0). For example at A1 leg, if the upper switch was connected and lower switch was opened, it meant that A1 leg was "on" (condition 1) and vice versa. Further, this implied that for 6 legs would have 6 switching condition and earned 72 switching vectors with each cycle explained as table 2.

Table 2
Switching vectors for each transistor

	Cond.1	Cond.2	Cond.3	Cond.4	Cond.5	Cond.6
A1p	1	1	1	0	0	0
A1n	0	0	0	1	1	1
A2p	0	0	0	1	1	1
A2n	1	1	1	0	0	0
B1p	0	0	1	1	1	0
B1n	1	1	0	0	0	1
B2p	1	1	0	0	0	1
B2n	0	0	1	1	1	0
C1p	1	0	0	0	1	1
C1n	0	1	1	1	0	0
C2p	0	1	1	1	0	0
C2n	1	0	0	0	1	1

As the 2nd and 3rd phase signal with 120^{o} and 240^{o}, the system will use two phase shifter circuits in series(op4 and op5). The circuit consist of inverting op-amp with RC network at the reference side. The output will be lagging depends on RC value. The calculation can be seen in equation 3. The next step is to create the invert sine wave signal using inverting op-amp. The reference sets to 0 and the feedback voltage divider sets to 1 refer to figure 4. The calculation of the inverting signal can be seen in equation 4. From here the signal generator already have 6 sine wave signal at 0^{o}, 60^{o}, 120^{o}, 180^{o}, 240^{o}, and 300^{o}. The final step is to compare these signals with a controlled reference using six op-amp comparators for each sine wave. The goal is to obtain controllable switching time (duty cycle) for each leg of the inverter. The prototype device and component can be seen on figure 3 and table 3.

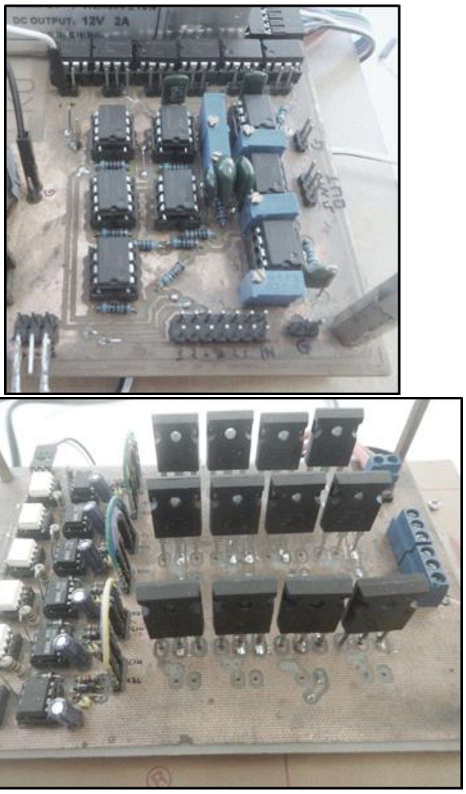

Figure 3.
Three phase six legs signal generator and switching

Table 3
Three phase signal generator components

resistance(Ω) and capacitor(F) value		
R1 = 27,57k	R9 = 99,1k	R17 = 9,8k
R2 = 102k	R10 = 9,72k	C1 = 33nF
R3 = 21,69k	R11 = 9,72k	C2 = 10nF
R4 = 0,994k	R12 = 2k	C3 = 10nF
R5 = 102,7k	R13 = 9,94k	C4 = 10nF
R6 = 9,88k	R14 = 9,76k	C5 = 10nF
R7 = 2,625k	R15 = 2,08k	op-amp LF356N
R8 = 112k	R16 = 9,8k	

All of the signal data result were observed under Yokogawa DL850.

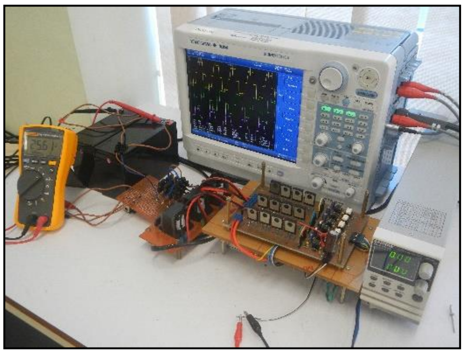

Figure 4.
setup experiment of battery charging from solar PV using DC/DC converter three phase six legs

The final result shows that at the battery side, switching duty cycle makes the inverter inject 26.7 volt and 225mA to the battery bank. This chart also show that 49% duty cycle was not the only maximum current that the inverter can produce. In fact, the inverter can makes the solar PV draw more current nearly at around 26%-42% duty cycle, with average current flow at 230mA.

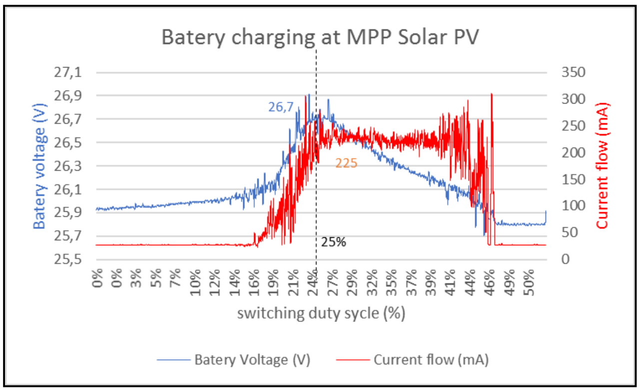

Figure 5
Battery voltage and current performance at optimum duty cycle 25%

CONCLUSION

This paper has presented that 3phase 6legs DC/DC converter was able to control solar PV impedance to get its maximum power point by adjust the amplitude of the reference manually. The maximum power point of 20watt solar PV was not the only highest value to draw more current to charge the battery bank. To get more precision signal of the signal generator, need to be consider the component must be at the precise value too.

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