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Three-Phase Six-Legs Full Bridge DC/DC Converter With P&O MPPT Controller for Battery Charging from Solar PV

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ABSTRACT

Solar PV has unique characteristic called maximum power point (MPP). This MPP will always changed depend on sun light intensity and electrical characteristic of the load. To maintain MPP of solar PV, external device is needed such as DC DC converter. Most of DC DC converters are using boost converters or buck-boost converters nowadays, but they has limitation power transfer rate (typically double). This paper discuss three phase DC to DC converter to achieve MPP of 67V solar PV for charging 300V battery pack. Pertube and Observe (P&O) method was used to control the switching and to maintain MPP of solar PV by sensing the output voltage and the output current. As the result, this DC DC converter was able to step up the voltage from 67V to 300V and nominal charging current is 0.7A. In the other hand, the MPP of solar PV can reached up to 260 WP. The effectiveness of the proposed method was proven in PSIM simulation.

KEY WORDS: *Pertube & Observe, Full Bridge Converter, Six-Legs, Three-Phases, MPPT.*

NOMENCLATURE

DC	Direct Current
PV	Photovoltaic
MPP	Maximum Power Poin
MPPT	Maximum Power Poin Tracking
V_{OC}	Voltage Open Circuit
SCC	Expansion
PO	Pertube and Observe
PWM	Pulse Width Modulation
I_{SC}	Current Short Circuit

1.0 INTRODUCTION

For some of the renewable energy resources, solar PV is one of them which has to be considered [1]. It is clean and free energy source, less maintenance and easy to install. Photovoltaic converts the sun light into electricity on the atomic level. Some materials exhibit a property known as the photoelectric effects that cause these material to absorb photons of light and release electrons. When these free electrons are captured, will produce an electric current that can be used as electricity. However, solar PV has its own problem. One of the most critical challenges is its power efficiency. Solar PV efficiency is absolutely dependent of material junction, solar radiation, temperature, and uncertaint load. One way to keep output power of solar PV stays in maximal range is by using power point tracker (PPT). Several methods are used to maximize PPT and the common usage is Pertube and Observe. DC/DC converter is very important device to achieve maximum power point, especially for stationary power aplication. Basically, there are three basic dc dc converters which are: buck

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converter, boost converter and fly-back converter. Another development for these three basic dc dc converters are: half bridge converter, full bridge converter or even three phase half bridge converter. Most of them are valid in limited load range. The idea used in this paper is to step up solar PV few times using isolated circuit by using Y-Δ transformer connection to minimize transformer ratio. At the load side, 300V battery is needed. And all processes are simulated in order to get the data reference for real implementation.

Changrong Liu [2] in his project quotes that, 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 Tse, K.K [3] and Fabregat [4] that, 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 [5] with several methods such as OVC and SCC based on MPPT, look up table method, curve fitting based MPPT, PO method, INC MPPT and many more [6]. 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 [7] that; MPPT successfully optimized using several algorithms including PI controller. However, due to most of the researches are using 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 researchj [8], but it has to be mounted in parallel and therefore will increasing 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 [9], [10], [11], [12]. Still, most of the experiments and researches use DC stabile power supply such as battery or fuel cell, not solar PV which has a fluctuate power depends on the environmental condition.

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 3 phases to increase efficiency and reduce switching losses by Pertub and modified Observe method plus a PI controller.

In this simulation, dc/dc converter 3 phase 6legs is able to be used as MPPT hardware by using pertube & observe method. DC/DC converter 3 phases 6 legs is applied for maximize power output from two solar PVs type CHN200-72M. At the power storage side, battery modeling R-C order 1 is used from acid battery type GS premium model GMZ5-3B with 12v DC arranged in series as many as 25 pieces in order to reach total voltage as high as 300 DCV.

2.0 SYSTEM DESIGN

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

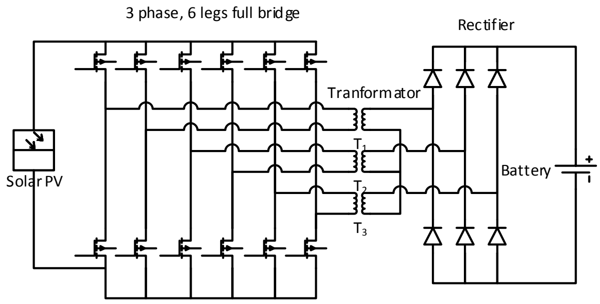

Figure 1. lay out 3 phases 6 legs dc/dc converter

It was consisted of solar PV as electricity energy generator, DC/DC converter as power regulator and battery as energy storage.

This research used incremental steps or procedure of simulation as follow:

1. Understood characteristics of each PV cell and modeling.
2. Gained battery modelling.
3. Earned PO-MPPT method.
4. 6 legs 3 phases converter modeling.

The modeling of each part represented the real parameter components based on data sheet and measurements. The colected data will be inserted into available simulation parameters. PSIM simulation was used in this experiment.

2.1 Solar PV Characteristic

As seen on figure 2, two modules of solar PV type Helios CHN200-72M were used for this study which had been combined in series to gain more current. From datasheet, each solar PV had maximum power rate at 200W, voltage open current (Voc) of 45V, and current sort circuit (Isc) doubled into 5,8A.

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Figure 2. Solar PV type CHN200-72M

In order to gained knowledge of solar PV real characteristics, measurement on the field had been conducted. Mensuration required 3kVA variable resistor. It had 20 times step with resistance value 1.5A for each step.

Figure 3. Variable resistor 3KVA 30A

Measurement referred to circuit in figure 4. Sampling of measurement had been done for three times between 12.00 PM until 16.00 PM at the same day. For every time, current and voltage data were taken out at each alteration of variable resistor.

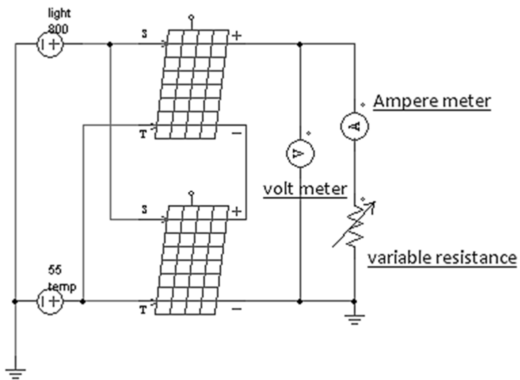
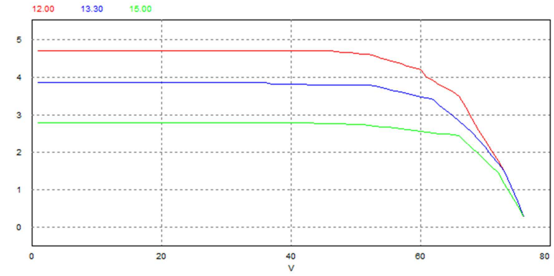
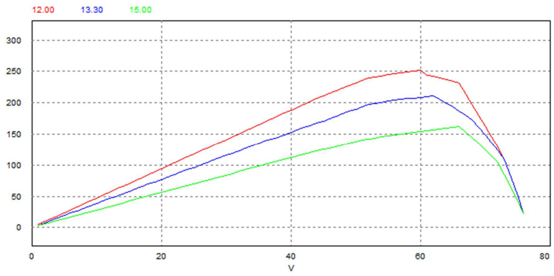


Figure 4. Circuit measurement of V-I solar PV

From measurement result. V-I and P-V characteristics were gained as in the graph 5 below:



(a)



(b)

Figure 5. (a)Characteristic V-I of solar PV, (b)Characteristic P-V of solar PV. (1 at 12.00PM, 2 at 13.30PM, 3 at 13.00PM)

It could be seen, over the time, current value was also decreased due to the lessening amount of sunlight exposure. Nevertheless, Voc value was still constant at 76V.
Apart from that data, P-V graphic was gained from V-I curve. As the time went by, maximum power value of solar PV was also decreased. The same case also applied to voltage value at the maximum power.

2.2 Energy Storage

As energy storage used 25 pieces batteries, 12 volt battery each was connected in series to get 300VDC. One measurement at one real battery was enough to have an idea about battery characteristics and modeling. Battery type for this experiment would be acid GS premium model GMZ5-3B.

Figure 6. Cell layout in the system architecture

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Measurement method was done by quantified battery voltage at charging power/current and discharging power/current of battery. Power supply GW Instek type PSW 30-36 was used for this research. Measurement result could be seen at figure 7:

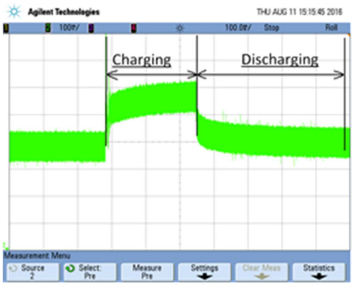

Figure 7. Result of charging-discharging battery

Battery charging used voltage source 13vdc with 1A current for 0.25 seconds. At that moment, exponential voltage stepped up and down, approximately valued for 0.2 VDC. This was due to self impedance of battery. Normally, impedance was formed as R and C circuit arrangement, such as described in the figure 8 below:

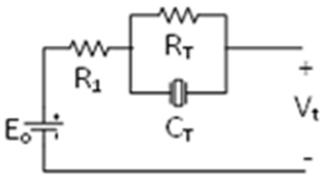

Figure 8. Thevenin Battery Model

Battery equation consisted of Eo=OCV, R1=Internal resistance, while RT and RC were the paralel network resistances. The addition of RT and RC aimed to gain transient curve from charging and discharging battery graphic.

2.3 MPPT

Figure 9 explained about I-V curve of solar PV, in which explained the characteristic of maximum power in solar PV or commonly referred to as maximum power point (MPP) which earned from certain coordinate point of maximum current (Impp) and maximum voltage (Vmpp) of solar PV. By using MPPT algorithm, maximum power could be reached with assumption that irradiant changed of sunlight was at constant value.

The output power had to be maintained at maximum point (MPP) in order to get good solar PV efficiency, such as described in figure 9(a).

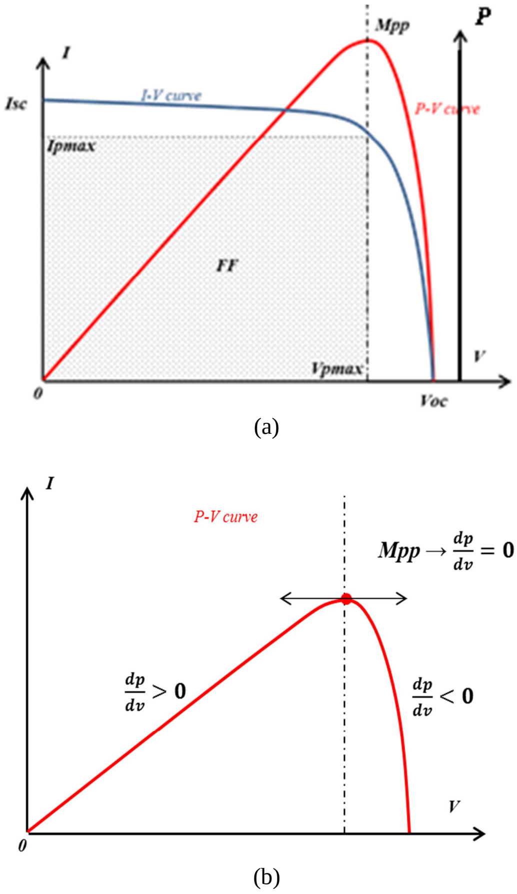

Figure 9. (a) Current and Voltage characteristic curve of solar PV, (b)Power and Voltage characteristic curve of solar PV

Maximum power point tracker (MPPT) was a system that designated to get the highest power point in solar PV. The way it worked by changing work point of current and voltage in I-V curve with the help of DC/DC converter. MPPT system served adaptively towards maximum point, taken into account that maximum power of solar PV would always changed in accordance with solar radiation and work temperature of solar PV.

From the figure 9(b) it could be seen that in the left hand side of MPP, the power transition to voltage transition dP/dV>0, whereas at the right hand side, dP/dV <0 [14]. If there was a change in solar radiance or solar PV temperature, then it would change power value to voltage. Hence the algorithm calculated whether dp/dv rate would be greater or smaller than 0 (null). If dp/dv < 0, voltage would be reduced to reach MPP, in reverse if dp/dv > 0, voltage would be increased to get MPP.

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2.4 Pertube & Observe

One most commonly method used for Maximum Power Poin Tracking was Pertube and Observe like described in the following flow chart:

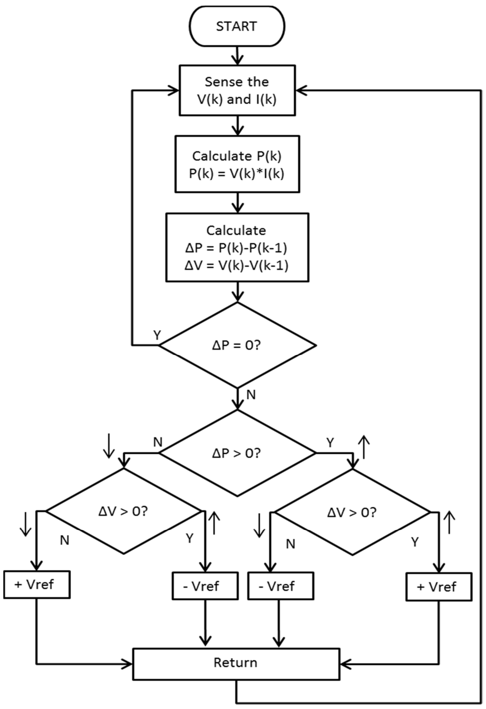

Figure 10. flow chart PO MPPT

At that flowchart in figure 10, current and voltage from solar PV were read and power value would be calculated. The recorded data were then compared with previous measurement. The results were used to determine voltage reference in order to reach optimal power from solar PV. By using this methode, maximum power of solar PV would always reached eventhough P-V solar PV curve decreased or increased due to natural factors (sun radiation and temperature).

2.5 DC to DC converter

DC/DC converter 3 phases 6 legs was used for MPPT hardware. This converter had switching component twice as much as 3 legs 3 phases converter. It was designated as such in order to gain higher efficiency in converter by reducing switching losses. This could be achieved because it already used IGBT component so that switching frequency could be elevated and in the end, ripples were reduced, so were filtering processes.

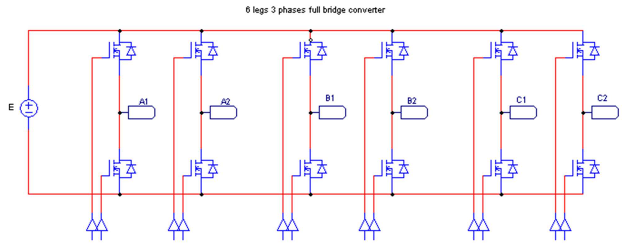

Figure 11. Dc/DC converter 3 phases 6 legs

Figure 11 described converter 6 legs-3 phases design which would be used in this research. It consisted of 6 legs for obtained 3 phases switching with each of its phase used 2 legs. Phase1 is A, phase 2 is B and phase 3 is C.

Table 1: Switching vectors for each transistor

	Time1	Time2	Time3	Time4	Time5	Time6
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

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 top-mosfet(p) of switch was triggered then leg was in “+” state (Time 1), otherwise if the bottom-mosfet(n) of switching was trigered then the leg was in “-” state (Time 1). For example at A1p and A1n legs, if the top-mosfet was triggered and botom-mosfet was opened, it meant that A1 leg was in “+” state (condition 1) and vice versa. Further, this implied that for 6 legs would have 6 time switching condition and earned 72 switching vectors with each cycle explained in Table 1.

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3.0 EXPERIMENT RESULT

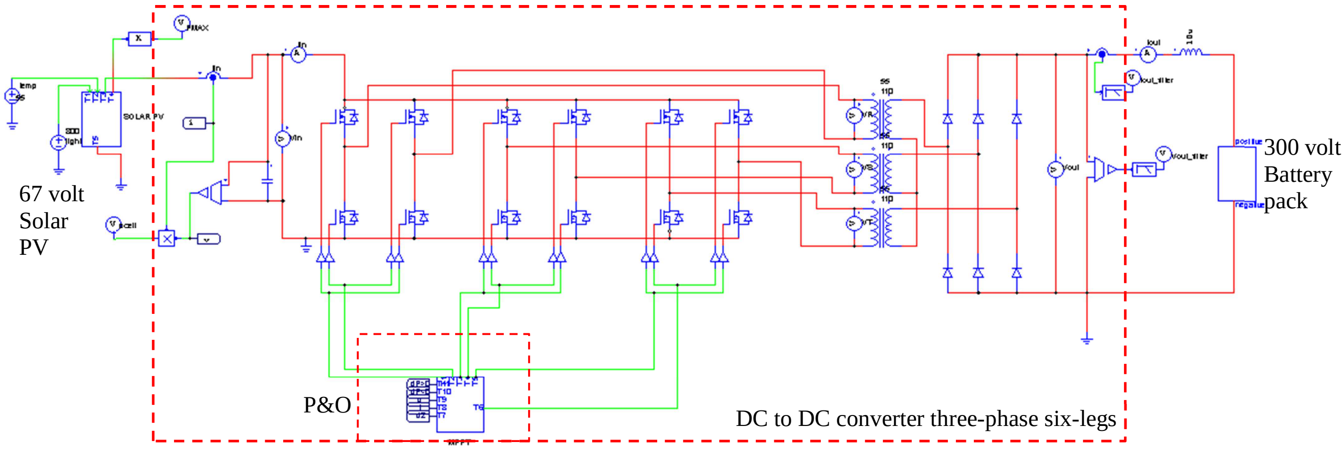


Figure 12. Complete simulation circuit of DC/DC converter three-phases six-legs

Experiment includes solar PV modelling, battery modelling, DC/DC converter examining and obtaining overall maximum power point solar PV response. PSIM simulator is used in this experiment. It has to be considered that all components in the simulation are at ideal conditions.

3.1 Solar PV Modeling

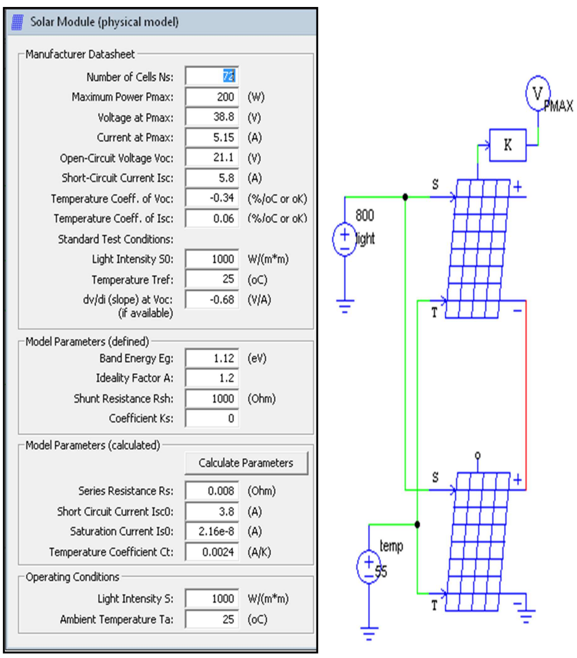
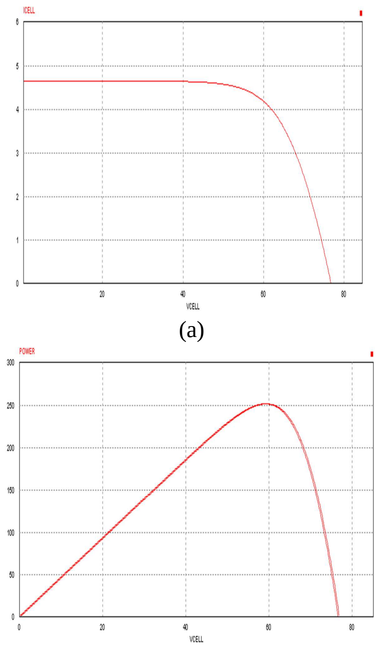


Figure 13. solar PV spesification and modeling

By entering several parameters of solar PV like description in figure 13, solar PV characteristic will be earned like in figure 14 belows:



(a)

(b)

Figure 14. (a)Current-Voltage simulation of solar PV, (b) Power-Voltage simulation of solar PV

At simulation 1 (figure 13-a), actual current amounts to ISC = 4,8A with saturated voltage OCV = 78V and maximum power point MPP= 200W.

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3.2 Battery Modeling

As it is explained in figure 8 and equation 1, with voltage of 13 VDC and 1 A current, resistance value R1 can be calculated. However, impedance rate is assumed constant by eliminating other factors such as fluctuative temperature and solar radiation.

$$Ri = \frac{V2 - V1}{i} \tag{1}$$

$$Ri = \frac{12{,}05 - 12{,}07}{1} \tag{2}$$

After having R1 result, some experiments will be done in order to get the values of RT and CT with the smallest error possible, such as explained in this following table:

Table 2. Experiment results for RT and CT

No	R1	C1	Error
1	0,01	0,1	0,01099
2	0,01	1,5	0,01099
3	0,01	2	0,01099
4	0,05	0,1	0,01099
5	0,05	1,5	0,01099
6	0,05	2	0,01099
7	0,1	0,1	0,01099
8	0,1	1,5	0,01099
9	0,1	2	0,01099

According to the calculation and experimental result of simulation, inner resistance is found, such as shown in figure 15:

- R1 = 0,12 Ω
- RT = 0,05 Ω
- CT = 1,5 F

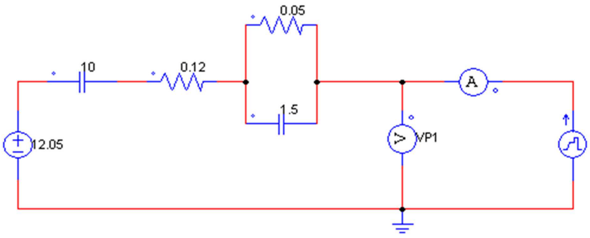

Figure 15. Result of battery modelling using thevenin model

While this following graph compares between measurement of single cell battery and battery modelling:

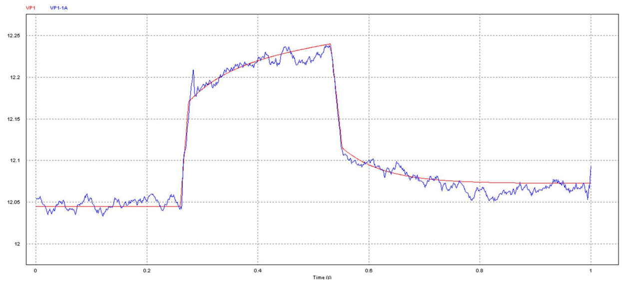

Figure 16. Measurement result of battery modelling using thevenin model

At figure 16, parameter of battery modelling (shown with the red line) is nearly approaching the real battery model (blue line) (figure 7). The simulated batteries are then connected in series (25 cells) in order to have 300V voltage as desired.

3.3 Pertube and Observe

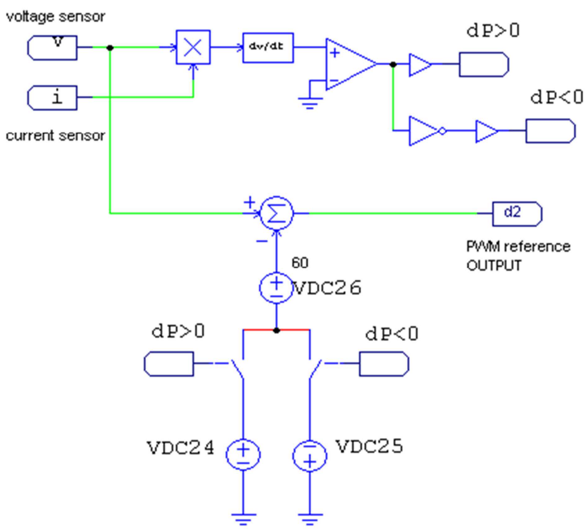

Figure 17. Pertube and Observe in PSIM schenario

Figure 17 is P&O circuit for PSIM simulator. It consists of voltage sensor, current sensor, comparator derivative and voltage adder for PWM reference output. PWM reference will be automatically increased or decreased to reach MPP of solar PV. Increment or decrement of PWM reference depends on voltage and current sensor connected to solar PV.

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3.4 DC to DC Converter

Simulation model of solar PV, converter and battery is assembled like the figure 14 above and the result of battery charging for 60 seconds is explained in the following image 18 and 19:

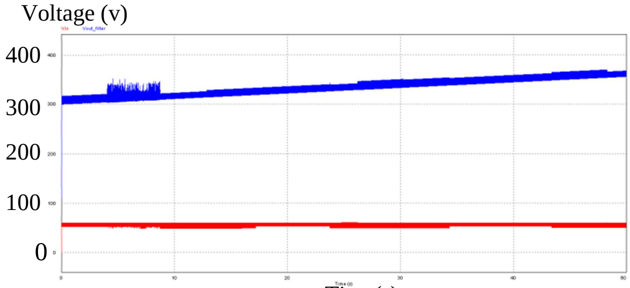

Figure 18. Voltage response (blue line) and Current response (red line) of battery charging

In the simulator, solar PV can produce 56 V voltage, by using 6 legs 3 phase DC to DC converter, the voltage can be stepped up until 300V voltage (blue line) to charge the battery pack. The voltage increases up to 360V in 50 seconds with average current injected is 0.7 ampere (red line).

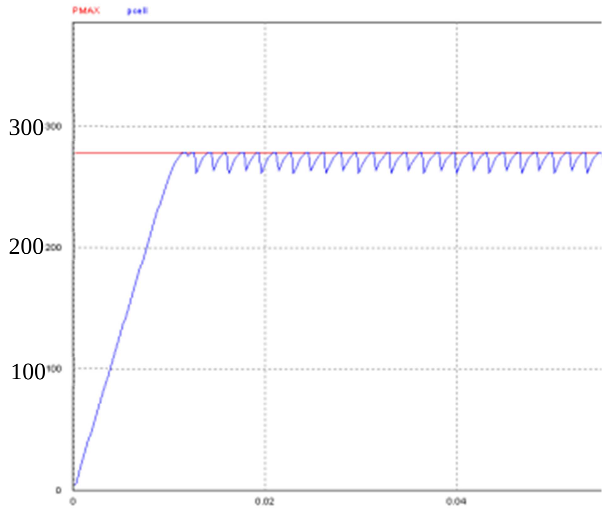

Figure 19. Maximum power point respons of Solar PV. (Red line is maximum power point reference base on datasheet. Blue line is actual power point result using P&O DC/DC converter three-phase six-legs).

From figure 18, power point result (blue line) can be adaptive to follow maximum power point reference. Time which is needed to reach maximum power point is 0.0126 seconds. Average power produced is 260W out of 278W (maximum power of solar PV).

4.0 CONCLUSION

This paper has proven that DC/DC Converter three-phase six-legs can be used as MPPT with PO method for solar PV to charge battery pack. Output voltage of solar PV which is 67 volt can be increased up to 300 volt using step up transformer. Nominal charging current is 0.7 ampere at average and it is capable to be used for power charging of 300V battery modelling.

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