Simulation of Control Cascaded Boost Converter Series Connected and Applied in Electric Motor as Prime Mover of Irrigation Water Pump

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***Abstract*— The purpose of this paper is to achieve a system design that can supply energy from Photovoltaic (PV) to a water pump irrigation motor. Battery charging process and load supply was taken simultaneously when the sun irradiation still exist. Power plant supply to the motor load with the capacity 2 HP, 90% efficiency, 380 Volt 3-phase. Inverter power rating is 1,750 Watt with the input voltage is 650 Volt-DC. Terminal voltage of inverter is 380 Volt-AC, 3-phase. Pump operate within ten hours during daylight and fourteen hours during night. Batteries used is 3 x 48 V in series connected with the capacity of 40 Ah for each battery. Terminal voltage of PV is increased by using a quadratic boost converter. Maximum Power Point (MPP) is used to adjust the switching of quadratic boost converter in order to obtain maximum power PV. Controller is used for enhance the efficiency of MPP. From the output boost converter-2 terminal, it's connected to inverter that convert output DC voltage from the boost converter-2 to AC voltage 380 V, 3-phase and 50 Hz. Design of system model is simulated in PSIM® software. The result of simulation shows the proposed method could supply the power to energize the motor of water pump within 24 hours.**

Keywords—Maximum Power Point; Photovoltaic; Quadratic Converter

I. INTRODUCTION

Renewable energy play an important role in modern electric distribution system. Photovoltaic (PV) is kind of renewable energy resources that mostly used. In last ten years, there is a high increasing in research and development about solar photovoltaic – hybrid system [1]. The main reason is the high demand of electricity in the system, issues about environmental pollution impact, limitation of conventional energy resource for example oil and natural gas. Thus, hybrid system from solar PV and wind are expected to solve the limitation resource energy availability and clean environmental.

Low efficiency is the main problem off the use of PV system. Power that can achieve from PV is depend on sun irradiation that only available during daylight [2]. The purpose of this paper is to optimize and built the PV system design that able to increase the efficiency and decrease the output power fluctuation. Based on PSIM® software simulation results, designed system is able to provide 380 volts to serve the load demand of water pump motor for irrigation.

II. PROBLEM FORMULATION

A. PV Characteristic

The equivalent circuit of PV is represented by current source that connect in parallel with diode including the parallel resistor (Rsh) that represent the leakage current, and series resistor (Rs) represent the internal resistance. The model is shown in the following Figure 1.

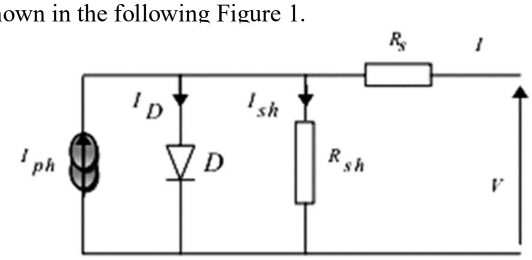

Figure 1. PV equivalent circuit

From the Figure 1 shows that the output current is depend on the total current from the current source (Ipv), diode current (Id) and current from parallel resistor (Ish). The equation of the output current is given in the equation (1) below:

$$I_{out} = I_{pv} - I_d - I_{sh} \tag{1}$$

Remarks:

I_{out} is the output current from PV

I_{pv} is the total current that produced from the current source

I_d is the current flow to the diode

I_{sh} is the current flow to the parallel resistor

Table 1 shows that the maximum output voltage that produced from PV by constant temperature while the irradiation is change.

Table 1. Maximum Voltage of PV

Temperature (C)	Irradiation (kW/m^2)	Maximum Voltage(V)
25	1	17.53
25	0.9	16.6
25	0.8	17.23
25	0.7	17.39
25	0.6	17.21
25	0.5	17.49
25	0.4	16.3
25	0.3	12.53
25	0.2	8.36
25	0.1	4.18

III. FULL SYSTEM MODELLING

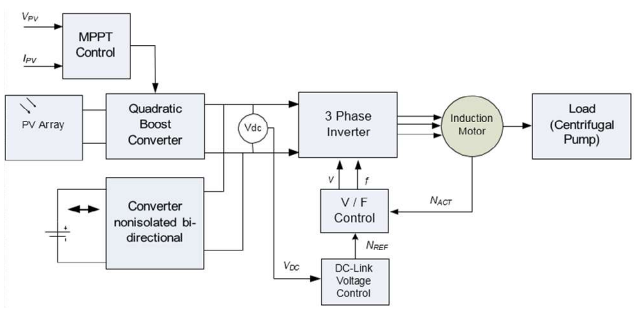

Figure 2 System Modelling

The battery used in this study is lithium ion that has good performance as a storage and load supply. Lithium ion battery has the nominal voltage about 48 V and 40 Ah of capacity. Three batteries arranged in series so the total output nominal voltage is about 144 V and the capacity is 40 Ah. PV panel used has the nominal voltage 57.3 V with the nominal current is 6A. Two PV panels arranged in series so that the nominal voltage become 114.6 V with the nominal current is 6 A. The load that connected is induction motor with the capacity 2 HP, 3-phase, 380 V of terminal voltage, and 50 Hz of frequency. Because the source side is DC and the load side is AC so that this system is using the 3-phase inverter to convert from DC to AC with controlled V/f in constant to control the speed of motor in a constant rotation.

IV. CASE STUDY

A. DC/DC Quadratic Boost Converter

Quadratic boost converter is a DC-DC converter has the function to give the step-up ratio from the input voltage to the output voltage by using a single switch [3]. The quadratic converter circuit scheme is made from two inductors, two capacitors, three diodes and a single switch that use MOSFET in this paper. Figure 3 shows scheme of quadratic boost converter

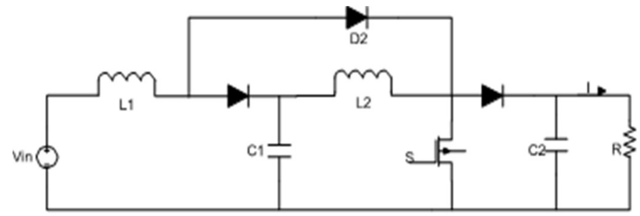

Figure 3 Circuit scheme of quadratic boost converter

Voltage ratio between input and output voltage is given:

$$\frac{v_o}{v_{in}} = \frac{1}{(1-D)^2} \tag{2}$$

B. Two Quadrant DC-DC Chopper

This kind of converter could operate with two different direction. It could be in boost mode when the batteries need to supply the load. While it could be in buck mode when there is a reverse current from the load and supply the power to the batteries [4]. The following figure below shows that the circuit of DC Chopper 2 quadrant.

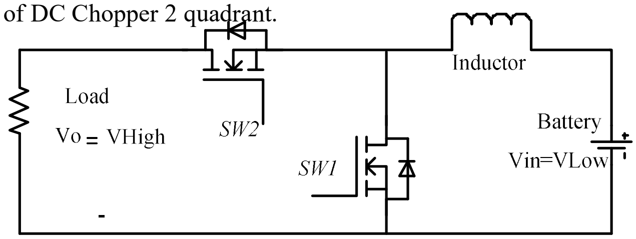

Figure 4 Two quadrant DC-DC chopper

In Figure 4, S1 switch is a switch when the converter operate as a boost while S2 is a main switch when the converter operate as a buck. This converter is to control the load DC voltage. The value in load side and battery side could be adjusted by controlling the duty cycle the switch.

The calculation of the duty cycle on the bidirectional converter is following.÷
The parameters of the system were:

1. Battery voltage 144 V – 168 V
2. Load voltage 650 V
3. Current ripple ± 10%
4. Voltage ripple ± 10%
5. Frequency of switching 100kHz

Boost mode from bidirectional converter as shown in Figure 5

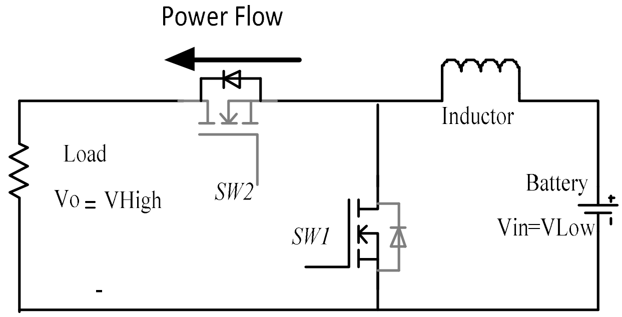

Figure 5 Boost mode from bidirectional converter

$$V_{hig} = \frac{V_{low}}{1-D} \quad (3)$$

$$D = 0.712$$

Calculating the value of the inductor

$$L = \frac{V_{low} \times D}{\Delta I_L \times f} \quad (4)$$

$$L = 420\ \mu H$$

Calculating the value of the capacitor

$$C = \frac{D}{R \times (\Delta V_{high}/V_{high}) \times f} \quad (5)$$

$$C = 1.64\ \mu F$$

Buck mode of bidirectional converter circuit shown in Figure 6

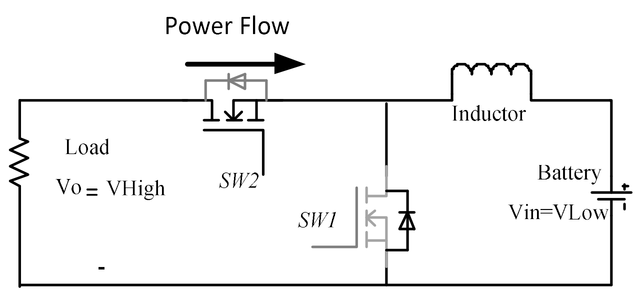

Figure 6. Buck mode from bidirectional converter

$$V_{low} = D \times V_{high} \quad (6)$$

$$D = 0.288$$

Calculate inductor value

$$L = \frac{V_{low}(1-D)}{\Delta I_L \times f} \quad (7)$$

$$L = 300\ \mu H$$

Calculate capacitor value

$$C = \frac{1-D}{8L \times (\Delta V_{low}/V_{low}) \times f^2} \quad (8)$$

$$C = 0.3\ \mu F$$

Switching methods used are Pulse Width Modulation (PWM). This method compares the reference signal with a carrier signal DC signal form the jagged edges of the comparator. PWM operation will result in the form of discrete numbers 0 and 1, with the length of time in accordance with the duty cycle is generated [5].

C. Battery Modelling

(3.5)The lithium ion battery used in this study with the specifications of the batteries used as table 2:

Table 2. Battery Model Specification

Parameter	Value
(3.6) specification	48.1V/40Ah
Capacity (Ah)	40
Nominal voltage (V)	48.1
Charge cut-off voltage (V)	≤54.6
Discharge cut-off voltage (V)	≥39.0
(3.7) Charging current	≤0.5C
Operating current	0.5C
Maximum discharge current	2C
Weight (kg) (without casing)	15.2
Weight (kg) (with casing)	17.3
Internal resistance (ohm)	≤50

The battery is then arranged in series 3 to get a nominal voltage of 144 V battery with a capacity of 40Ah. Battery modeling done in PSIM software. Parameter calculation is done in MATLAB. Figure 7 shows the schematic model of the battery to be modeled in PSIM software.

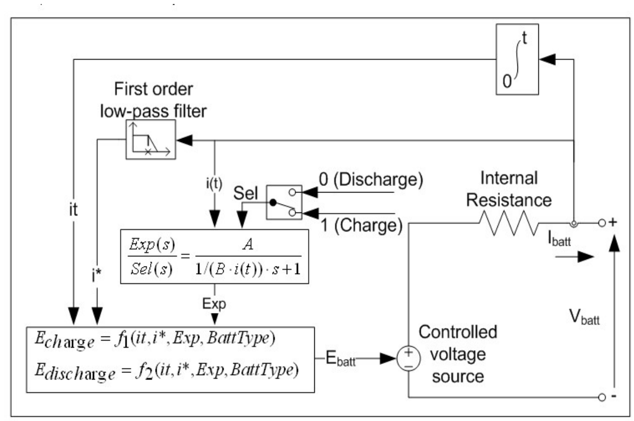

Figure 7. Schematic model of battery on MATLAB

for lithium ion models used:

Discharge Model (i*>0)

$$f_1(it, i^*, i) = E_0 - K\frac{Q}{Q-it}i^* - K\frac{Q}{Q-it}it + A\,exp(-B.it)$$

Charge model (i*<0)

$$f_2(it, i^*, i) = E_0 - K\frac{Q}{it+0.1Q}i^* - K\frac{Q}{Q-it}it + A\,exp(-B.it)$$

Where :

E_0 = Constant voltage (V)
K = Polarization constant (Ah^{-1}) or Polarization resistance (Ohms)
i^* = Low frequency current dynamics (A)
i = Battery current (A)
it = Extracted capacity (Ah)
Q = Maximum battery capacity (Ah)
A = Exponential voltage (V)
B = Exponential capacity $(Ah)^{-1}$

At the MATLAB program, will obtain discharge characteristics of the battery as shown in Figure 8.

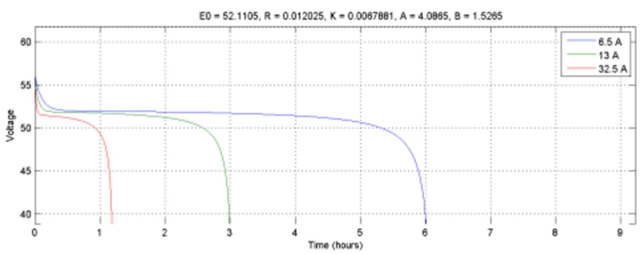

Figure 8 characteristics of the battery discharge with different discharge currents

From the data E_0, R, K, A and B can then be modeled in PSIM software, as shown in Figure 9.

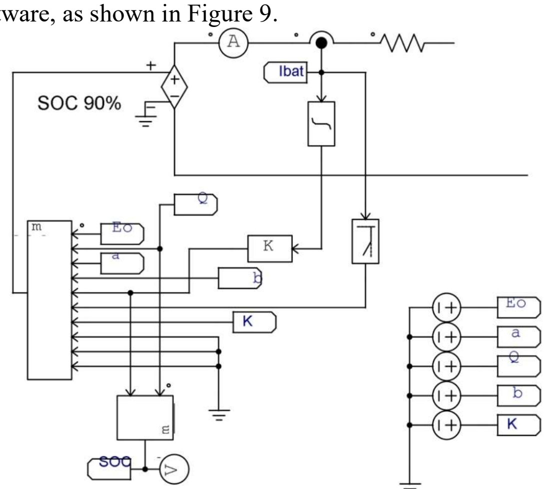

Figure 9. Modeling battery on PSIM

To calculate the battery capacity (State of Charge) Use the following equation

$$SOC = 100\left(1 - \frac{\int_0^t i\,dt}{Q}\right) \quad (8)$$

Where :

100 = the initial condition of the battery, 100 for the Battery in a state of full charge, 0 for the battery to be empty
i = Battery current (A)
Q = maximum capacity of the battery (Ah)

Tests conducted in the state of the battery 90% as in figure 9. So it must be noted that the current value has been absorbed or Initial Output Value in coulomb unit, Ampere-hour multipled by 3600 (1 hour = 3600 s). Here is the calculation for value Initial Output Value:

$$\begin{aligned} Initial\ Output\ Value &= \frac{(100-SOC)}{100} \times \text{Capacity(Ah)} \times 3600 \\ &= \frac{(100-90)}{100} \times 40 \times 3600 \\ &= 14400\ \text{C} \end{aligned}$$

V. Simulation Result

A. System Block Diagram

This research is using the simulation model as shown in the Figure 10. and 11. Generally, input irradiation and the model built in several main unit that is:

1) PV as an energy source.
2) MPPT algorithm with Hill Climbing method that can optimize the output power from PV array.
3) DC-DC boost converter that can change output voltage from PV or battery to the DC link voltage.
4) Inverter that can convert the voltage from the 650 Vdc to the 380 Vac, 3-phase, 50 Hz.

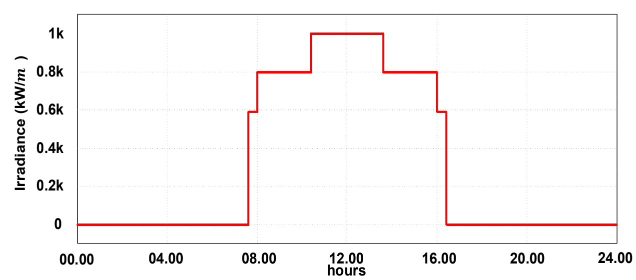

Figure 10. input Irradiance (kW/m^2) of PV

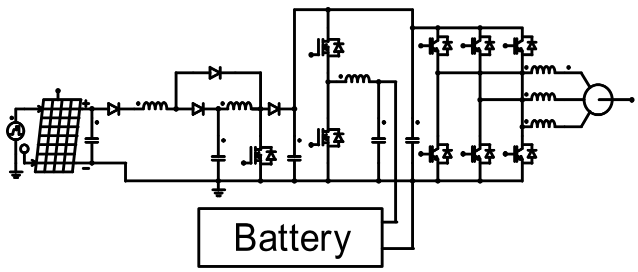

Figure 11 Simulation scheme model

B. *Voltage from DC-DC converter*

Based on the examination in the simulation, Figure 12 below shows that the output voltage that produced from the DC-DC converter is 650 V with the ripple factor below 5%.

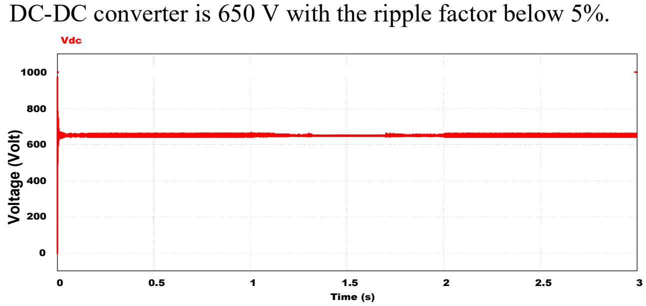

Figure 12. Output DC voltage

C. *Charge and Discharge mechanism from batteries*

Charge and discharge process are controlled by using inter locking switching system. While battery charging process the battery condition is unable to discharge and so the other way. When first converter circuit charge second converter circuit the battery only able to charge until its maximum capacity. Battery only able to supply second converter circuit when sun radiation is below electric motor rating power (PV=Inactive). Charging and discharging value of battery is on 114 Vdc. Figure 13 shows value of battery current while charging and discharging.

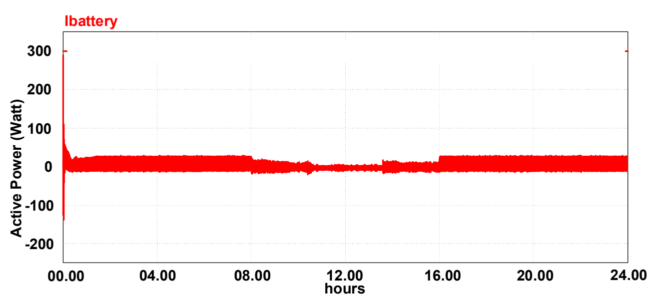

Figure 13. Battery current

D. *Output Voltage and current 3-phase inverter*

Based on the examination in figure 14. shows that the steady state condition already achieved in short time (0.2 sec) with the line to line voltage is 380 Vac

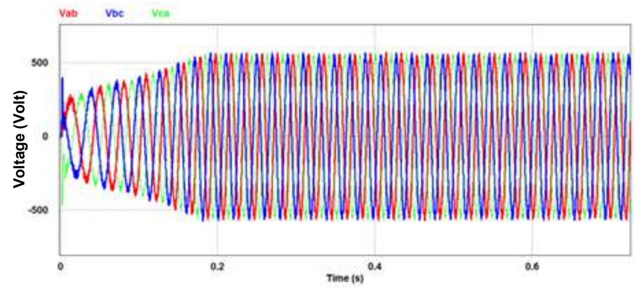

Figure 14. Output voltage from the inverter

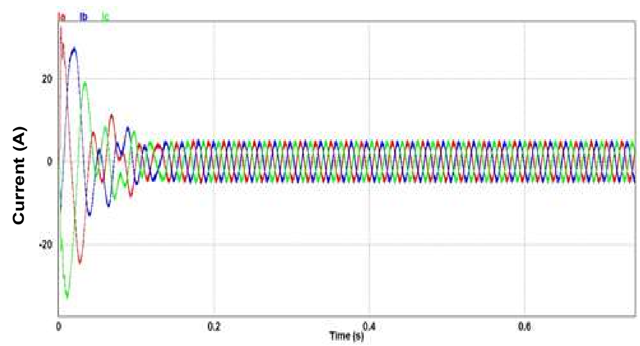

Figure 15. Output current from inverter

The following figure 16, below shows that the relation between battery power, absorbed power from motor load and power produced from PV. Load is supplied by power that produced from cascade system. Supply power is directly to the load when the power from PV meet the load demand. During day night when there is no power from PV, then the battery can supply the load. Based on the examination, it shows at figure 16, that the ability of PV system when the irradiation is fluctuative still meet the load demand including give the battery charge.

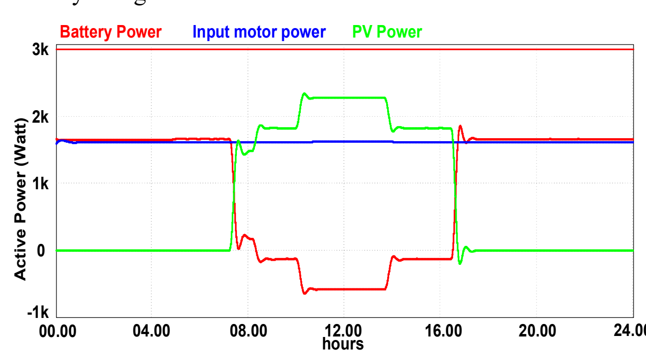

Figure 16. Curve shows the relation between PV power, Battery power and motor absorbed power within 24 hours.

VI. CONCLUSION

Based on experiment data, output voltage of boost converter and inverter is appropriate. Same goes with interlocking process between power supplies is running well.

Benefit of series boost converter cascaded system that used in this research is able to provide electric power needs of water pump for 24 hours, with assumption PV module operated 8 hour each day

To ascertain about power consumption of motor, we need to calculate power generated by PV Panel for 8 hours but equivalent with power consumption of electric motor for 24 hours.

It is proven that series boost converter cascaded system able to supply electric motor power and also charge battery.

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