

## Complementary Buck-Boost Converter with Variable Voltage Tracking System for Photovoltaic Applications

**Sameer Khader**

*Electrical & Computer Engineering Department  
Palestine Polytechnic University, Hebron, Palestine*

E-mail: [sameer@ppu.edu](mailto:sameer@ppu.edu)

Tel: +970-2-2230068; Fax: +970-2-2217248

### Abstract

This paper proposed solutions for enhancing the behaviors of photovoltaic generation module (PV Array) with and without using buck-boost converter for realizing constant output voltage according to reference voltage at constant and variable solar irradiation. The proposed solutions describe single and double buck-boost (complementary) dc chopper with presence of various control strategies/modules such as pulse width modulation, maximum power point tracking strategy (MPPT) and variable voltage tracking strategy (VVT). The obtained results according to proposed models state that complementary chopper realized better performances in case of VVT strategy rather than MPPT control strategy when direct grid connection is required as major criteria for constant output voltage. As first stage Matlab/ Simulink is used to simulate the proposed models, where the obtained analytical and simulation results are going to be experimentally verified in the second stage of this work.

**Keywords:** Photovoltaic systems, DC Choppers, Smart Grids, PWM, Soft Switching.

### 1. Introduction

Photovoltaic energy resources presents alternative and friendly to the environment sources. It presents unique solution for providing remote area with clean and sustainable energy during the daytime in heating, lighting, refrigeration and water pumps systems without the need of battery system (Ho-sung et al, 2009; Tseng S.Y et al, 2008; Khaligh, 2008). While during the night time the accumulated energy can be fully or partially used to cover the energy domain. The output circuit connected to the photovoltaic system is usually dc-dc converter mainly boost chopper in order to boost the voltage to the predetermined levels.

The DC/DC converters are widely used in regulated switch mode power supplies, where the input voltage to these converters varies in wide range especially in the case of photovoltaic (PV) supply source due to unpredictable and sudden change in the solar irradiation level as well as the cell operating temperature. Several connection topologies concerning the switching systems have been proposed (Ahmed, 2005; Balkarishnan et al, 2008; Santos et al, 2006) aiming at realizing the required voltage level during different periods of day for certain applications such as pumps, motors in general and power supplies.

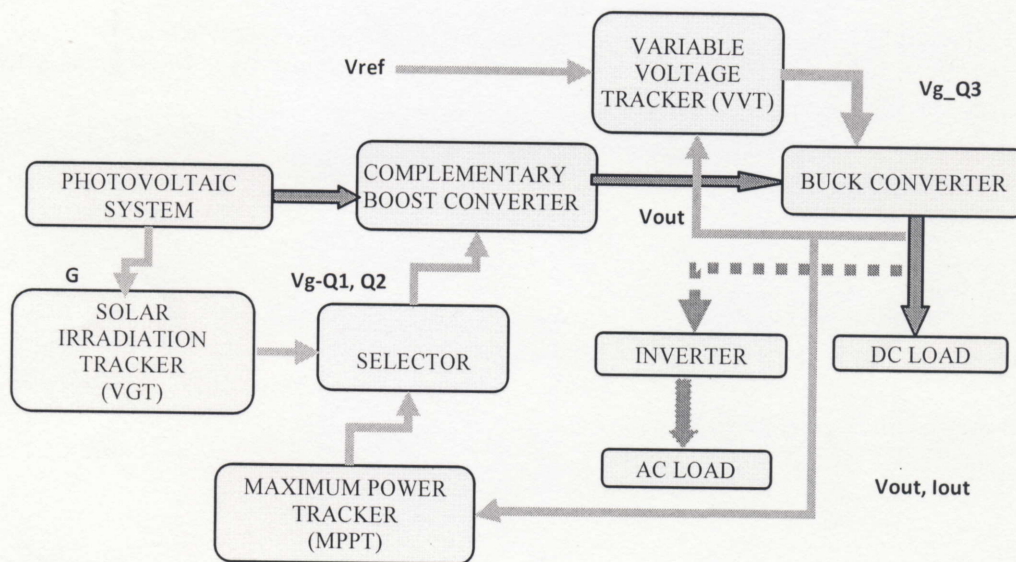
During the design process of PV array powered systems; a simulation must be performed for system analysis and parameter settings. Therefore an efficient user friendly simulation model of the PV

array with various control strategies is always needed. The proposed model in this paper is based on circuitry model to be used with Simulink for various control strategies as follows:

- *Single and Double (Complementary) Buck-Boost Chopper*: this module boosts up the PV voltage to the predetermined levels. Conversely in case of high PV voltage, the output voltage is reduced.
- *Maximum Power Point Tracking Module (MPPT)*: this module maintains the PV generated power at maximum level (Azab, 2008; Atlas and Sharaf, 2007).
- *Variable Voltage Tracking Module (VVT)*: this module regulates the output chopped voltage according to predetermined level by controlling the buck chopper.
- *Variable Solar Irradiation Tracking Module (VGT)*: this module generates gate pulses to the complementary boost chopper.

Figure 1 illustrates overall block diagram of the proposed simulation circuit, where the modules are connected in such a way to form the required design.

Figure 1: PV system block diagram



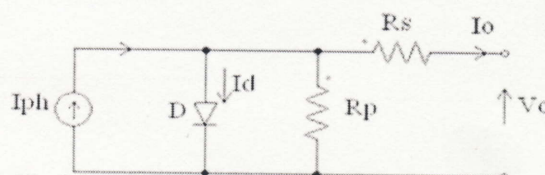
## 2. Modelling & Simulation of PV Array

Studying the behaviors of PV Array can be conducted as follows:

### 2.1. Characteristics of PV Array

Basically, PV cell is a P-N semiconductor junction that directly converts light energy into electricity. It has the equivalent circuit shown in Figure 2 (Chouder et al, 2006; Buresch, 1983).

Figure 2: Equivalent circuit of PV cell.



Where  $I_{ph}$  represents the cell photocurrent;  $R_p$  and  $R_s$  are the intrinsic shunt and series resistance of the cell respectively;  $I_d$  is the diode saturation current;  $V_o$  and  $I_o$  are the cell output voltage and current respectively. The following are the simplified equations describing the cell output voltage and current:

$$V_o = \frac{A.K.T_c}{q} \ln \left( \frac{I_{ph} + I_d - I_o}{I_o} \right) - R_s I_o \quad (1)$$

$$I_o = N_p (I_{ph} - I_d \left( e^{\frac{q.V_o/N_s}{A.K.T_c}} - 1 \right)) \quad (2)$$

$$I_d = I_{or} \left( \frac{T_c}{T_r} \right)^3 . e^{\frac{q.E_g}{B.K} \left( \frac{1}{T_r} - \frac{1}{T_c} \right)} \quad (3)$$

$$I_{ph} = N_p . \{ I_{sc} . \phi_n + I_t (T_c - T_r) \} \quad (4)$$

Where,  $K$ - Boltzman constant;  $N_p$  and  $N_s$  are the number of parallel and series connected cells respectively;  $E_g$  is the band gap of the semiconductor;  $T_c$  and  $T_r$  are the cell and the reference temperature respectively in Kelvin,  $A$  and  $B$  are the diode ideality factors where their values varied between 1 and 2;  $\Phi_n$  is the normalized insulation;  $I_{sc}$  is the short circuit current given at standard condition;  $I_t$  and  $I_{or}$  are constants given at standard conditions.

## 2.2. Modified Model for PV Array

With purpose simplifying the mathematical model Silvestre, Boronate, and Chouder (2009) propose modified model that takes into account the effect of changing cell temperature, solar irradiation and diode connection configuration. According to their method, for a known temperature and a known solar irradiation level, a model is obtained and then is modified to handle the different cases of temperature and irradiation level.

Let  $T_a$  and  $T_x$  are respectively ambient and actual cell temperature and  $G_c$  and  $G_x$  are reference cell irradiation and actual solar irradiation respectively, therefore their change affects both cell voltage and current leading to new obtained values as follows by applying scaling equations:

$$V_{ox} = C_{TV} . C_{GV} . V_o \quad (5)$$

$$I_{phx} = C_{TI} . C_{GI} . I_{ph}$$

Where  $C_{TV}$ ,  $C_{GV}$ ,  $C_{TI}$ ,  $C_{GI}$  are scaling coefficients represents the effect of change in temperature and irradiation level over the cell voltage and current respectively. Atlas and Ashraf (2009) define the coefficients as follows:

$$C_{TV} = 1 + \beta_T (T_a - T_x)$$

$$C_{TI} = 1 + \frac{\lambda_T}{G_c} (T_x - T_a)$$

$$C_{GV} = 1 + \beta_T \alpha_s (G_x - G_c)$$

$$C_{GI} = 1 + \frac{1}{G_c} (G_x - G_c)$$

Where  $\beta_T=0.0035$  and  $\gamma_T=0.062$  are constants depends on the ambient temperature ( $T_a=25^\circ\text{C}$ ).  $S_x$  and  $S_c$  are the actual and benchmark reference solar irradiances respectively;  $\alpha_s=0.2$  is the slope of the change in the cell operating temperature due to a change in the solar irradiation level.

## 2.3. Maximum Power Derivation

In order to get the shape of the injected power to the grid, it is necessary to calculate the coordinates of the maximum power point ( $V_{MPP}$ ,  $I_{MPP}$ ). For this, and to simplify the model in Simulink, the coordinates of the maximum power point are given by the following equations:

$$I_{MPP} = I_{ph} - I_d . \left( e^{V_{mpp}/V_T} - 1 \right) \quad (7)$$

$$V_{MPP} = V_T \cdot \ln \left( 1 + \frac{I_{ph} - I_{mpp}}{I_{ph}} \left( e^{V_{oc}/V_T} - 1 \right) \right) \quad (8)$$

Where  $V_T$  and  $V_{OC}$  are the thermal voltage and the cell open circuit voltage respectively and given by:

$$V_T = \frac{K \cdot T_c}{q} \quad (9)$$

$$V_{OC} = V_T \cdot \ln \left( \frac{I_{sc}}{I_d} + 1 \right)$$

### 2.4. Photovoltaic Current and Power Performance

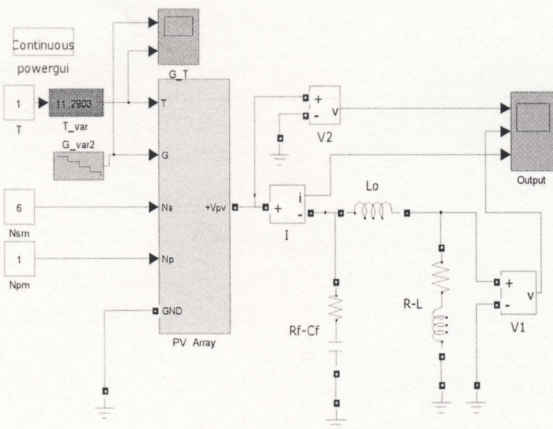
In order to study the I-V performance of the PV circuit and to look for appropriate dc chopper for boosting up the output voltage to predetermined value it is necessary to illustrate the obtained PV voltage, current and output power for single module according to specifications given in table 1 at reference irradiation of  $1000 \text{ W/m}^2$ .

**Table 1:** Data specification for PV Array.

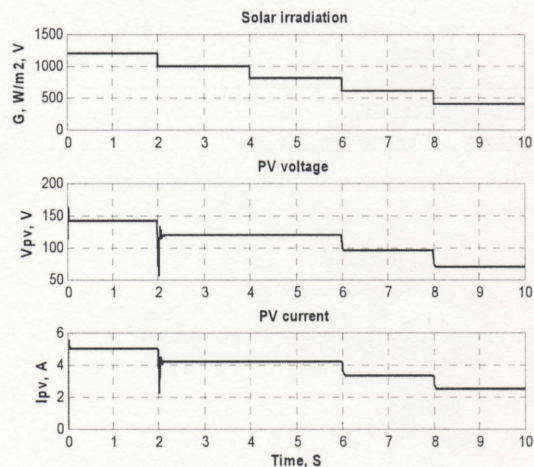
q	K	$I_{ph}$	$I_d$	$R_s$	$R_p$	$T_c$	$I_{sc}$	$V_{MPP}$
$1.602 \times 10^{-19} \text{ C}$	$1.38 \times 10^{-23} \text{ J/}^\circ\text{K}$	4 A	0.2mA	$1 \text{ m}\Omega$	$10 \text{ k}\Omega$	$25^\circ\text{C}$	4A	17.5V
$N_{sm}$	$N_{pm}$	$V_{pv\_out}$	$N_s$	$N_p$	$V_o$	$V_{oc}$	$I_{MPP}$	
6	1	130V	38	4	0.6V	21.5 V	3.7A	

The Array voltage can be obtained by multiplying the module voltage and current by  $N_{sm}$  and  $N_{pm}$  representing number of series and parallel connected modules respectively. Figure 3 illustrates the proposed PV array with R-L load built in simulink environment by using Matlab version R2008a, and the obtained results for different variation levels. From this performance it is shown that the total output PV voltage and current varies according to irradiation level with around 65W maximum power at  $G=1000 \text{ W/m}^2$ .

**Figure 3:** PV Array simulation model and its performances.

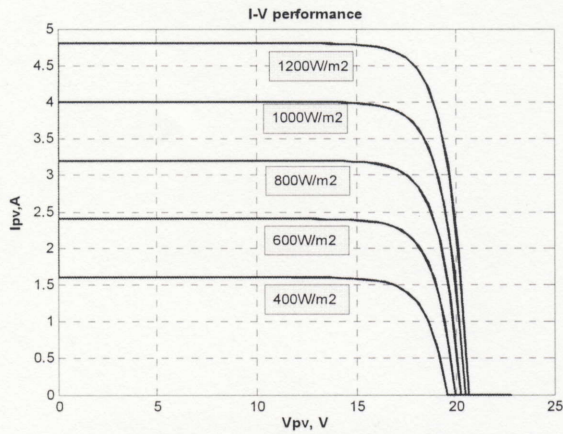


a) Proposed model in simulink environment

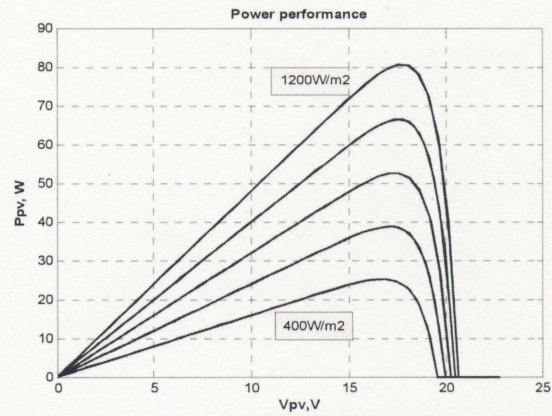


b) Solar irradiation profile.

**Figure 3: PV Array simulation model and its performances. - continued**



c) I-V Performance of PV model



d) Power performance of proposed model

### 3. Modelling and Simulation of Proposed Chopper Circuit

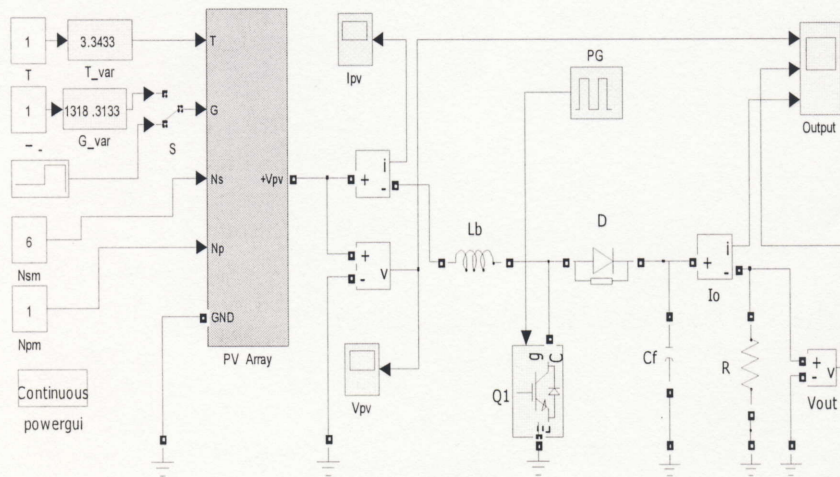
The reduction of output power can be attributed to many factors, but the most effected factors are the shadows and season change Therefore, there is a need to boost up the output PV voltage to be suitable for domestic and industrial use without a need of battery during the daytime. Two circuits are proposed for this purpose:

- Single-chopper / boost converter.
- Double- chopper /boost converter.

#### 3.1. Single Chopper PV Array

Figure 4 shows the electrical circuit of PV Array with single-chopper boost converter "Q<sub>1</sub>" with PWM pulse generator "PG" required to boost up the PV voltage at rated values. According to Hart (2010) the boost inductance  $L_b$  is used to increase the output voltage and to maitian the current ripples within acceptable values, while the capacitor  $C_f$  is used to smooth the obtained chopped voltgae. These elements depends on chopping frequency, duty ratio and circuit configuration.

**Figure 4: Simulink model of PV Array with single-chopper boost converter**



The output PV voltage  $V_{pv}$  fluctuates between minimum and maximum values resulting change in duty cycle in order to maintain the output voltage  $V_O$  at fixed value. The PV voltage can be expressed as follows:

$$V_{pv} = V_o(1 - D) + \frac{V_o.r_L}{R(1 - D)} \quad (10)$$

Where  $D$  is the duty ratio;  $R$  is the load resistance;  $r_L$  is the inductance resistance;  $f_{ch}$  is the chopper frequency. Selecting  $L_b$  requires determination of the circuit inductance for worst variation conditions of PV voltage, current ripples and duty cycle as follows:

$$v_{pv}.I_{Lb} = V_o.I_o + I_L^2.r_L; \quad I_o = \frac{V_o}{R}$$

$$L_{b1} = \frac{V_{pv \min} . D_1}{\Delta i_{L \max} . f_{ch}} \quad (11)$$

$$L_{b2} = \frac{V_{pv \max} . D_2}{\Delta i_{L \min} . f_{ch}}; \Rightarrow L_b \geq |(L_{b1} \text{ or } L_{b2})|_{\max}$$

Where  $V_O$  and  $I_O$  are total PV average voltage and load current;  $D_1$  and  $D_2$  are duty cycles that can be determined by solving the following equations:

$$V_{pv \min} = V_o(1 - D_1) + \frac{V_o.r_L}{R(1 - D_1)}; \Rightarrow D_1 = |(D_{x1} \text{ or } D_{y1})|_{\min} \quad (12)$$

$$V_{pv \max} = V_o(1 - D_2) + \frac{V_o.r_L}{R(1 - D_2)}; \Rightarrow D_2 = |(D_{x2} \text{ or } D_{y2})|_{\min}$$

Where  $D_{x1}$ ,  $D_{y1}$ ,  $D_{x2}$  and  $D_{y2}$  are corresponding roots for  $V_{pv \min}$  and  $V_{pv \max}$  respectively.  $\Delta i_{L \max}$  and  $\Delta i_{L \min}$  are maximum and minimum inductance current fluctuations that can be determined as follows:

$$I_{Lx1, y1} = \frac{V_{pv \min} \pm \sqrt{V_{pv \min}^2 - 4r_L V_o I_o}}{2r_L}; \Rightarrow I_{L \max} = |(I_{Lx1} \text{ or } I_{Ly1})|_{\min}$$

$$I_{Lx2, y2} = \frac{V_{pv \max} \pm \sqrt{V_{pv \max}^2 - 4r_L V_o I_o}}{2r_L}; \Rightarrow I_{L \min} = |(I_{Lx2} \text{ or } I_{Ly2})|_{\min} \quad (13)$$

$$\Delta i_{L \min} = \Delta i_{L \min} \% . I_{L \min}; \quad \Delta i_{L \max} = \Delta i_{L \max} \% . I_{L \max}$$

The required capacitor is calculated for the case of  $V_{pv \min}$  and maximum duty cycle  $D_{\max}$  with expression:

$$C_f = \frac{D_{\max}}{R \left( \frac{\Delta V_o}{V_o} \right) . f_{ch}}; \quad D_{\max} = D_1 \quad (14)$$

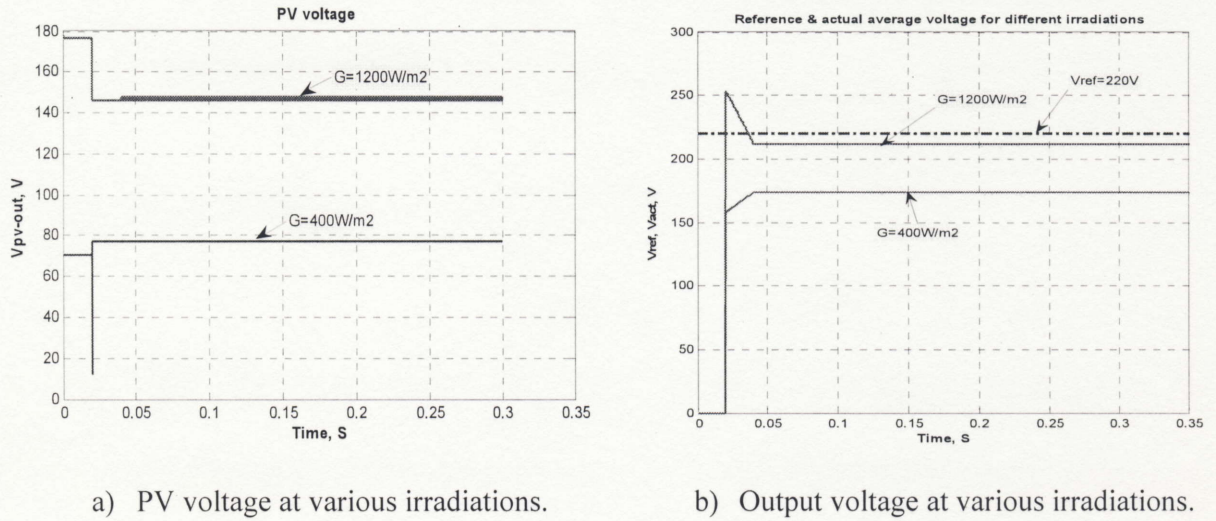
Where  $\Delta V_O$  is the output voltage ripples.

### 3.2. Simulation Results

Single-chopper PV array is analyzed for two irradiation cases  $1200W/m^2$  and  $400W/m^2$ , where the obtained results are stated in table 2 and the simulation results are displayed in Figure 5. From these figures it can be shown that the obtained output chopped voltage differs from the reference voltage which means additional circuit modification is needed in order to compensate this difference.

**Table 2:** Single-chopper analyzed results.

$G, \text{W/m}^2$	$V_{pv}, \text{V}$	$V_{out}, \text{V}$	$R, \Omega$	$D_{1,2}$	$L_{b1,2}, \text{mH}$	$C_f, \text{nF}$	$f_{ch}, \text{kHz}$	$L_b, \text{mH}$	$I_{Lmax}, \text{A}$	$I_{Lmin}, \text{A}$	$r_L, \Omega$
1200	145	220V	44	0.71	1.42	16.1	20	3.25	17.6	7.76	0.44
400	77			0.36	3.25						

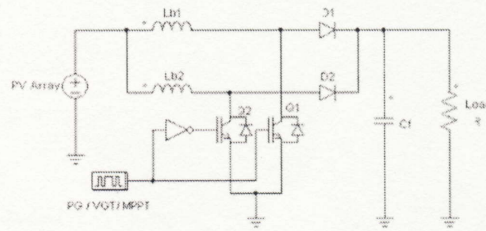
**Figure 5:** PV Array performances at various irradianations.

a) PV voltage at various irradianations.

b) Output voltage at various irradianations.

### 3.3. Double -Chopper PV Array

Compensating the voltage difference mentioned in previous paragraph could be achieved by adding another parallel connected inductance with complementary operated chopper (double-chopper circuit) as shown in Figure 6. Two operation modes are described concerning the current change in boost inductances as follows:

**Figure 6:** Complementary chopper circuit

Mode#1:  $Q_1=ON$  and  $Q_2=OFF$ ; for the time  $0 \leq t \leq D \cdot T_{ch}$ ,

$$(\Delta i_{L_{b1}})_{ON} = \frac{V_{pv}}{L_{b1}} D_{Q1} \cdot T_{ch} \quad (15)$$

$$(\Delta i_{L_{b2}})_{OFF} = \frac{V_{pv} - V_o}{L_{b2}} (1 - D_{Q2}) \cdot T_{ch}$$

Mode#2:  $Q_1=OFF$  and  $Q_2=ON$ ; for the time  $D \cdot T_{ch} \leq t \leq T_{ch}$ ,

$$(\Delta i_{L_{b1}})_{OFF} = \frac{V_{pv} - V_o}{L_{b1}} (1 - D_{Q1}) \cdot T_{ch} \quad (16)$$

$$(\Delta i_{L_{b2}})_{ON} = \frac{V_{pv}}{L_{b2}} D_{Q2} \cdot T_{ch}$$

Where  $L_{b1}$  and  $L_{b2}$  are boost inductances for both branches respectively and they are equals each other;  $T_{ch}=1/f_{ch}$  is the chopping period; and  $D_{Q1}$  and  $D_{Q2}$  are the duty cycles for  $Q_1$  and  $Q_2$  respectively.

According to volt-second balance principle, the current change in the inductance over the chopping period equals zero, thus:

$$\frac{V_{pv}}{L_{b1}} D_{Q1} . T_{ch} + \frac{V_{pv} - V_o}{L_{b1}} (1 - D_{Q1}) . T_{ch} = 0 \quad (17)$$

$$\frac{V_{pv}}{L_{b2}} D_{Q2} . T_{ch} + \frac{V_{pv} - V_o}{L_{b2}} (1 - D_{Q2}) . T_{ch} = 0$$

Solving these equations yield the overall duty cycle and the known boost equation:

$$D = D_{Q1} = D_{Q2} \quad (18)$$

$$V_o = \frac{V_{pv}}{1 - D}$$

The actual average voltage  $V_{act}=V_{out}'$  of both choppers operation can be determined as follows:

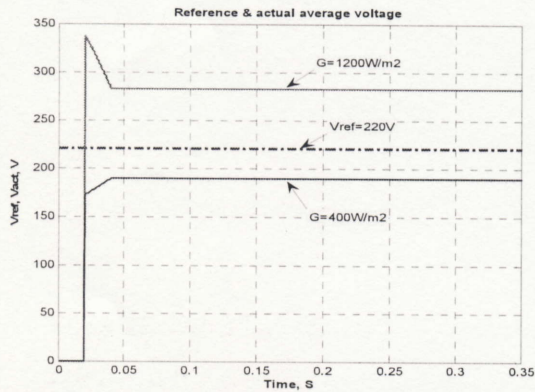
$$V_{out}' = \frac{1}{T_{ch}} \left\{ \int_0^{t_1} (V_{pv} + V_{Lb2}) dt + \int_{t_1}^{t_2} (V_{pv} + V_{Lb1}) dt \right\} \quad (19)$$

$$V_{Lb1} = L_{b1} \frac{di_{Lb1}}{dt}; V_{Lb2} = L_{b1} \frac{di_{Lb2}}{dt}$$

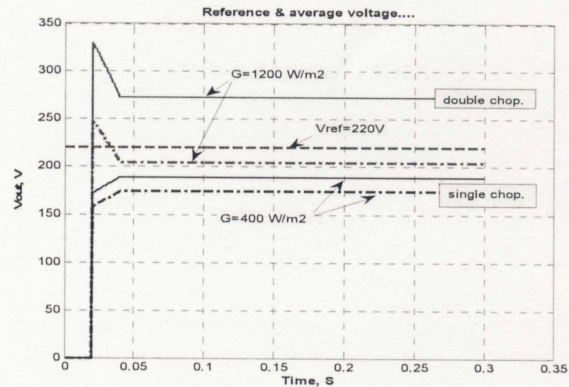
$$t_1 = D T_{ch}; t_2 = (1 - D) . T_{ch}$$

The obtained simulation result for average output voltage  $V_{out}$  is displayed in Figure 7(a), while Figure 7(b) shows the difference in output voltage when adding the compensation contour.

**Figure 7:** Output voltage for both chopper circuits.



a) Output voltage of complementary chopper configuration.



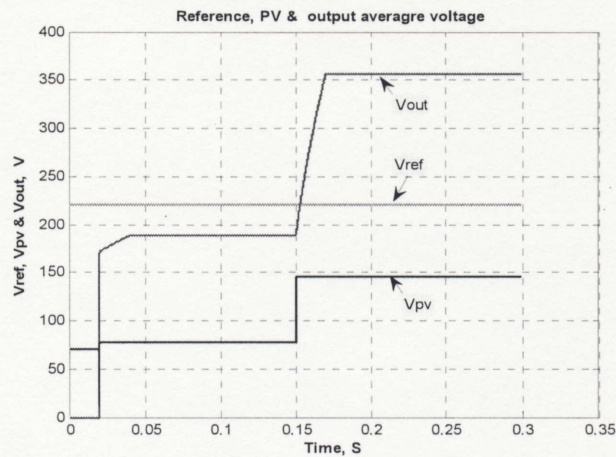
b) Output voltage at various circuits.

As well shown from the illustrated figures the mentioned drawback with single-chopper circuit is eliminated, and the output voltage increases, being closed or greater than the reference voltage. Therefore, complementary-chopper configuration is implemented in the hereinafter descriptions.

#### 4. Proposed Control Modules

Knowing that the irradiation level varies during the day time, causing significant change in the output chopped voltage for series connecting arrayes as shown in Figure 8 where two levels of irradiation change were taken as case study. Therefore, the task is to design a control module/s that should maintain the output voltage at constant value irrespective of irradiation level change.

**Figure 8:** PV, output & reference voltage at various irradianations

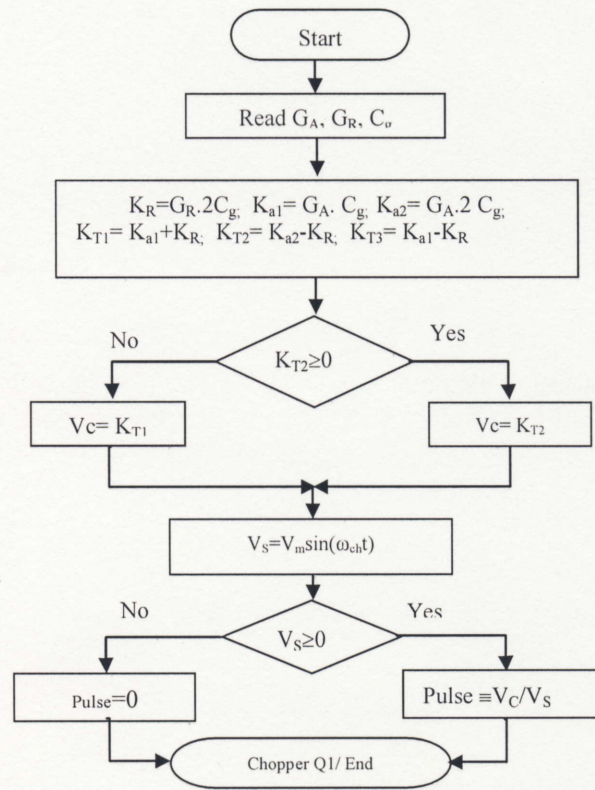


Three control modules are described as follows:

**4.1. Variable Voltage Tracking Module (VGT)**

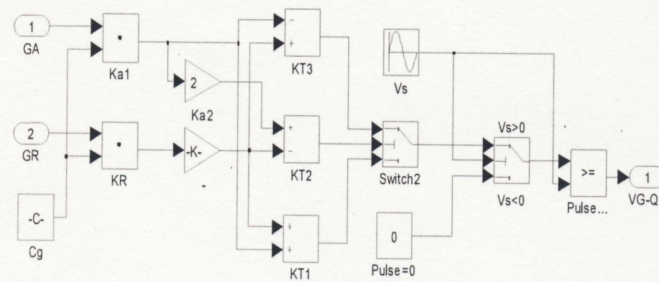
The actual irradiation is compared with reference value, where gate pulses are generated for controlling the boost complementary chopper according to irradiation difference. Figure 9 illustrates the designed flowchart and matlab/simulink model describing the operation of proposed module.

**Figure 9:** Algorithm flowchart & simulink model of VGT module



a) Algorithm flowchart

Figure 9: Algorithm flowchart & simulink model of VGT module - continued



b) Simulink model

Where  $G_R$  and  $G_A$  are reference and actual irradiation respectively; while  $C_g$  is the irradiation coefficient. For present work these parameters are assumed to be  $G_R=1000W/m^2$  and  $C_g=0.24mV/W$ .

#### 4.2. Maximum Power Point Tracking Module (MPPT)

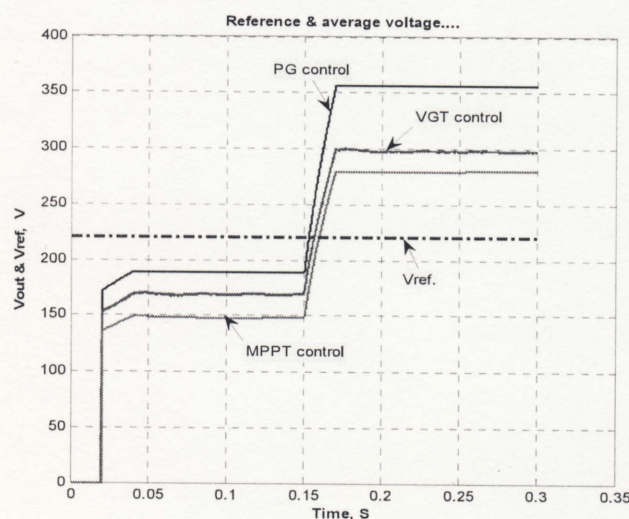
MPPT tracking system is used to operate the converter at maximum extracting power from the PV source by generating switching pulses with variable duty cycle. Observation and Perturbation approach is applied for present work with flowchart proposed by Azab (2008).

#### 4.3. Conventional PG control

A Pulse width generator (PG) is used to drive the complementary chopper with  $D_{max}=0.71$  and chopping frequency  $f_{ch}=20$  kHz. The illustration of this module is just for conducting comparison between various modules, and no longer will be described.

The obtained simulation results for these modules are displayed in Figure 10, where it is shown that the average output voltage increases by increasing the irradiation but with different increment rate depending on the applied modules. Furthermore the obtained voltage is far from the predetermined reference value, which means additional buck converter should be used in order to compensate the voltage difference.

Figure 10: Output voltage at various control modules & irradiancies

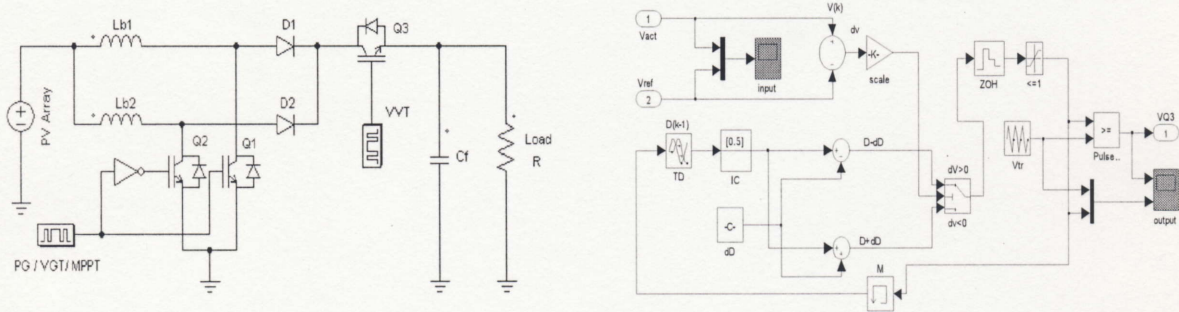


### 5. Complementary-Buck-Boost Converter

#### 5.1. Proposed Circuit

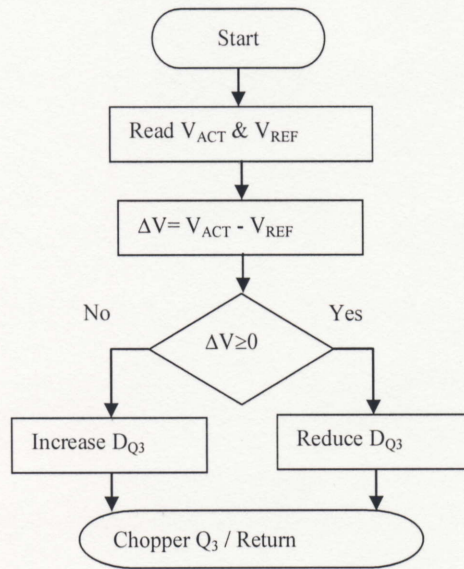
According to obtained results in previous paragraph the chopped voltage still needs further treatment in order to maintain it at reference value. This could be achieved by applying complementary buck-boost chopper displayed in Figure 11, where additional buck converter with switch  $Q_3$  is added to the boost circuit and corresponding control model called Variable Voltage Tracker "VVT" is added to the circuit.

Figure 11: Complementary buck-boost circuit



a) Principle complementary buck-boost circuit.

b) Matlab/Simulink of VVT model



c) Algorithm flowchart of proposed VVT model.

### 5.2. Results & Comparison Analysis

#### 5.2.1. Average Output Voltage

The obtained output voltage after adding buck converter is:

$$V_{out} = V_{act} \cdot D_{Q3}; \quad 0 \leq D_{Q3} \leq 1 \tag{19}$$

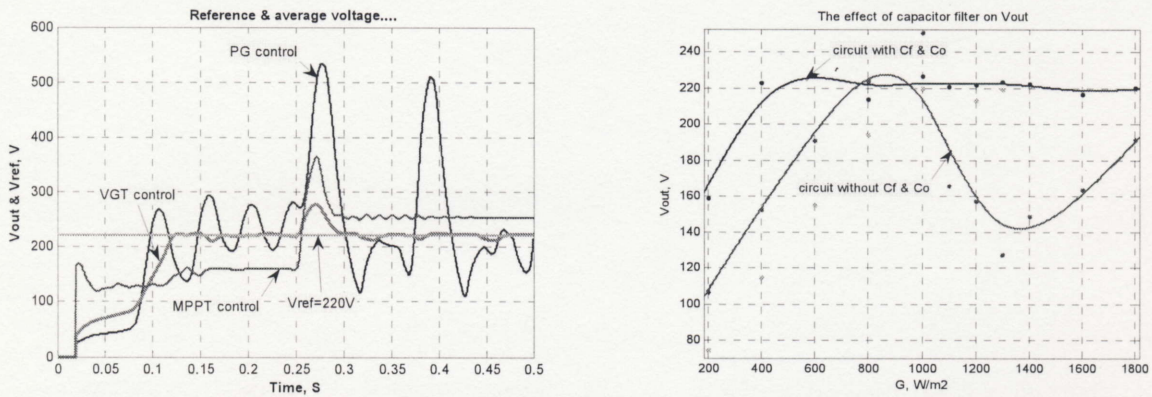
Where  $D_{Q3}$  is the duty cycle of buck converter controlled by VVT module.

The implemented control modules in previous paragraph are simulated with adding the VVT module, where the obtained results at the same conditions are displayed in Figure 12(a). It is shown

that combination control of VGT and VVT results good coincidence between the output and reference voltage.

Furthermore, adding the capacitors results smoothing and stabilizing of  $V_{out}$  at low rate of irradiation levels as shown in Figure 12(b). These results present satisfied solution of aforementioned task.

**Figure 12:** Output voltage at various irradianations and control modules.



a) Dynamic performance of output voltage.

b) Output voltage vs irradiation level.

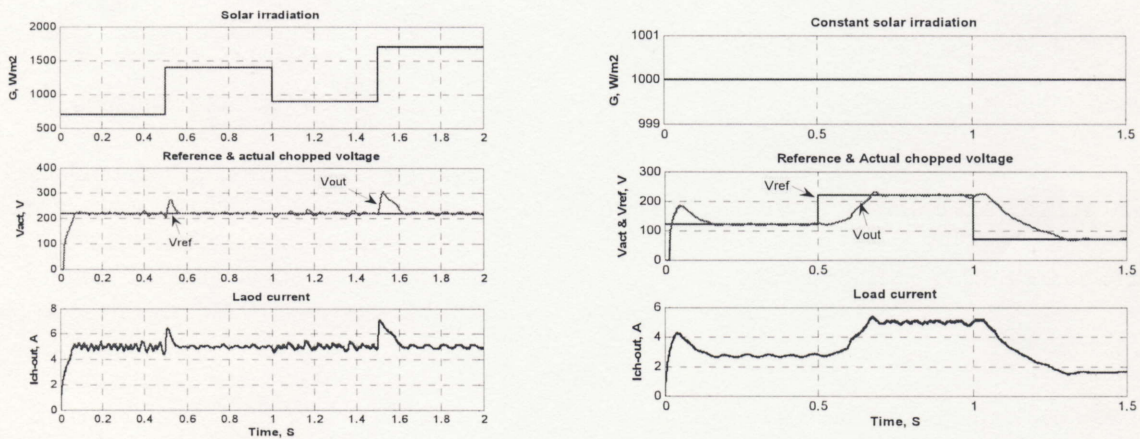
### 5.2.2 Constant & Variable Output Voltage

Consider shadow weather causes significant variation in irradiation levels, therefore keeping the output voltage at constant value requires regulating both  $D_1$  and  $D_{Q3}$  throughout VGT & VVT modules.

Figure 13(a) shows the irradiation variation and output voltage and current at constant reference voltage. It is shown that these modules functioned correctly and keeping  $V_{out}$  at constant value, while Figure 13(b) shows the variation in output voltage according to the reference voltage change at constant irradiation.

Constant irradiation status found applications in heating, lighting and motor speed control without the need of battery system, and can be directly operated during the daytime.

**Figure 13:** Output voltage at various operation cases



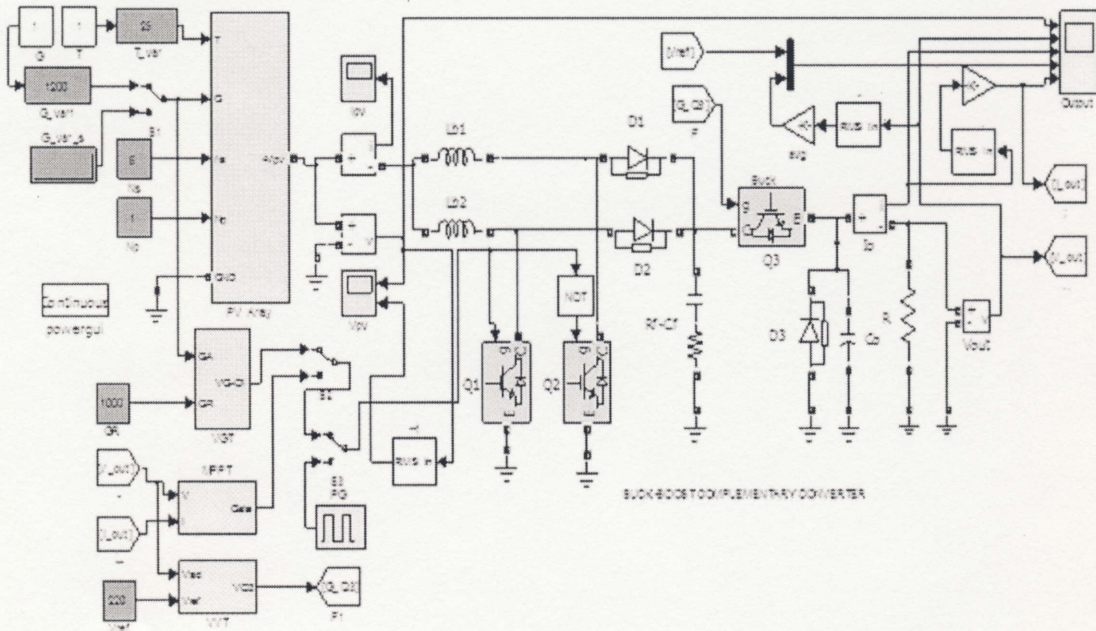
a) Output voltage at constant reference voltage and variable irradiation

b) Output voltage at variable reference voltage and constant irradiation

### 5.3. Complete Circuit Model

The complete circuit model built in matlab/simulink environment for PV complementary buck-boost converter is illustrated in fig.14, where the PV Array, power converter, and control modules are together connected and normally functioned.

**Figure 14:** Complete circuit model built in matlab/Simulink



## 6. Conclusion

This paper introduces a simulation model for complementary buck-boost dc chopper to be used in Matlab/simulink environment. The conducted simulation procedure covers photovoltaic array model, maximum power point tracking system, variable voltage tracking system, variable irradiation tracking system and buck-boost dc converter.

The proposed model has generalized structure so that it can be used as a direct PV power generator along, or integrated with either DC or AC converter.

Introducing VGT & VVT modules realized output voltage regulation irrespective of irradiation level which is perfect solution for direct PV energizing during the daytime at shadow weather conditions or weak solar irradianations. Meanwhile the output voltage can be regulated for certain application purposes with assumed reference voltage.

Optimum operation of this circuit can be realized by appropriate selection of filtering capacitors at VVT-VGT control approach, where the rated voltage can be achieved at low rate of solar irradianations.

Excluding the battery operation during the daytime reduces the system cost, increases its efficiency and life time.

This model can be considered as a part of hybrid energy system that uses both PV and AC grid.

## References

- [1] Ahmed N.A., " Modeling and simulation of ac-dc buck-boost converter fed dc motor with uniform PWM technique", *Electric Power systems Research* 73 (2005), pp363-372.

- [2] Atlas H., Sharaf A.M., " A Photovoltaic array simulation model for Matlab-simulink GUI environment, IEEE, Trans., 2007, pp.341-345.
- [3] Azab M., " Improved circuit model of photovoltaic array', PWASET, Vol.34, Oct.2008, pp.857-860.
- [4] Balkarishnan A., Toliyat and Alexander W.C., " Soft switched ac link buck-boost converter", APEC , 2008, Twenty-Third Annual IEEE, 24-28 Feb., 2008, pp.1334-1339.
- [5] Buresch M., " Photovoltaic energy systems design and Installation", McGraw-Hill, New York, 1983.
- [6] Chouder A., Silvester S., Malek A., " Simulation of photovoltaic grid connected inverter in case of grid-failure", Revue des energies Renouveables Vol. 9, No4, 2006, pp.285-296.
- [7] Hart D.W, " Power Electronics", Valparaiso University, 2010, McGraww Hill, pp.196-230.
- [8] Ho-sung Kim, Jong-Hyun Kim, Byung-Duk Min, " A highly efficient PV system using a series connection of DC-DC converter output with a photovoltaic panel", Renewable Energy 34(2009), pp2432-2436.
- [9] Khaligh A., " A Multiple-input dc-dc positive buck-boost converter topology", APEC2008, Twenty-Third Annual IEEE, 24-28 Feb., 2008, pp.1522-1526.
- [10] Santos J.L, Antunes F, Chehab A., and Cruz C., " A maximum power point tracker for PV systems using a high performance boost converter", Solar energy 80 (2006) pp.772-778.
- [11] Silvestre S., Boronate A., Chouder A., " Study of bypass diodes configurations on PV Modules", Applied Energy 86(2009) pp.1632-1640.
- [12] Tseng S.Y., Li Y.L., Wu J.Y, " Buck Converter Associated with Active Clamp Flyback Converter for PV Power System", ICSET 2008, pp.916-921.
- [13] Matlab and Simulink, The Mathworks, Inc., version R2008a, <http://www.mathworks.com>