PV Output Power Smoothing Using Energy Capacitor System

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Abstract **– Photovoltaic systems are being considered as one of the major sources of electrical energy for next decades. The cost of PV cells is decreasing more and more and this will help increase its penetration in power systems. One of the main issues of PV systems is their dependency on irradiance of the sun and temperature of the cells. As during day-time both these factors are changing continuously, the output power of PV cells would have considerable fluctuations that would not be acceptable in power systems with high penetration of PVs. In order to solve this problem, this paper proposes a system to smooth the output power of the PV using Energy Capacitor System. A case study for investigating the performance of the proposed configuration is simulated and results show that it can considerably smooth the output power of the PV system.**

Index Terms **– Photovoltaic Cells, MPPT System, Energy Capacitor System, Output Power Smoothing.**

I. Nomenclature

I – Output current of the PV cell [A],
I_{pv} – Current generated by the incident light [A],
I_0 – Reverse saturation current of the diode [A],
V – Output voltage of the PV cell [V],
R_S– Series resistance of the PV model [Ω],
R_{Sh}– Shunt resistance of the PV model [Ω],
a– Ideality factor,
$I_{0,ref}$– Nominal saturation current [A],
T– Temperature of the PV cell [K],
T_n– Nominal temperature [K],
ε– Material band gap energy [eV],
a_{ref}– Nominal ideality factor of the PV cell [K],
V_{OC}– Open circuit of the PV module [V],
V_t– Thermal voltage [V],
N_S– Number of series cells,
K– Boltzmann constant = 1.38×10^{-23} [J/K],
q– Electron charge = 1.6×10^{-19} [C],
I_{SC}– Short circuit current of the PV [A],
k_i– Short circuit current/temperature coefficient [A/K],
G– Irradiance of the sun [W/m^2],
G_n– Nominal irradiance of the sun [W/m^2].

II. Introduction

PENETRATION of green sources of electrical energy in power system is rapidly increasing in last decade. The rising of the fossil fuels cost and tendency toward decreasing the pollution caused by conventional power plants are two major reasons for this increased attention. Among all of the renewable technologies, Photovoltaic (PV) is the fastest growing renewable energy in the world with 50% annual increases cumulative in installed capacity in 2006 and 2007 [1]. The total capacity of PV cells installed is estimated to be around 10.7 GW at the end of 2009. USA has been ranked 5th in the world by producing 587 MW using PV in 2009. It is expected that this number would be increased to 3-6 GW in 2014 [2].

PV systems need Maximum Power Point Tracking (MPPT) modules because of their V-I characteristics. This module increases the efficiency of the PV systems noticeably. Several authors investigated PV-characteristics and proposed different MPPT techniques ([3]-[9]).

One of the main problems of the PV (in addition to its high production cost) is that, the output current of the PV cells is highly dependent to the irradiance of the sun and temperature of the cell. This will cause some fluctuations in the output power and voltage of the PV cell. This situation is not acceptable in power system especially in a system with high penetration of PV systems.

This paper proposes the use of Energy Capacitor System (ECS) in parallel with PV module to smooth the output power of the PV. By decreasing the cost of producing super capacitors, utilizing ECS in power system is growing. ECS can deliver power to the system very fast. The super capacitors are capable of working while there is continuous switching of the DC/DC converter of the ECS, without losing their performance considerably. In the next section the modeling of different parts of the proposed system would be presented. Then the proposed configuration for using ECS with PV would be introduced and then using a case study the performance of the configuration would be investigated. PSCAD software [10] is used for implementing the system.

III. Modeling of the System

The proposed configuration has three different components.

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The electrical model of each of them is as follows.

A. *PV Cell*

The schematic diagram of the PV cell model is shown in Figure 1. Basic formula of PV is [11]:

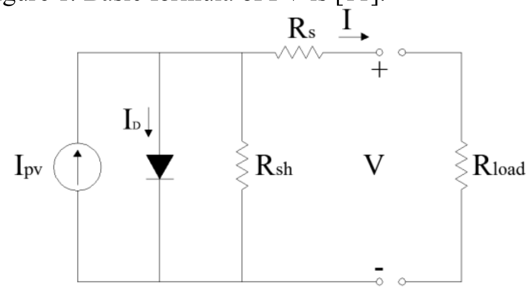

Figure 1 – Schematic diagram of the PV model

$$I = I_{pv} - I_0\left[e^{\frac{V+IR_S}{a}} - 1\right] - \frac{V+IR_S}{R_{sh}} \qquad (1).$$

Where

$$I_0 = I_{0,ref}\left(\frac{T}{T_n}\right)^3 . e^{\frac{\varepsilon N_S}{a_{ref}}\left(1-\frac{T_{ref}}{T}\right)} \qquad (2)$$

$$a = \frac{T}{T_{ref}} a_{ref} \qquad (3).$$

Also,

$$I_{0,ref} = \frac{I_{sc}}{e^{\frac{V_{oc}}{aV_t}} - 1} \qquad (4),$$

$$V_t = \frac{N_S KT}{q} \qquad (5),$$

$$I_{pv} = \left[I_{sc} + k_i\left(T - T_{ref}\right)\right]\frac{G}{G_n} \qquad (6).$$

As it can be seen the output current of the PV cell is dependent to irradiance of the sun and the temperature of the cells. Figure 2 and Figure 3 show the V-I characteristic of the PV for different irradiances and temperatures, respectively.

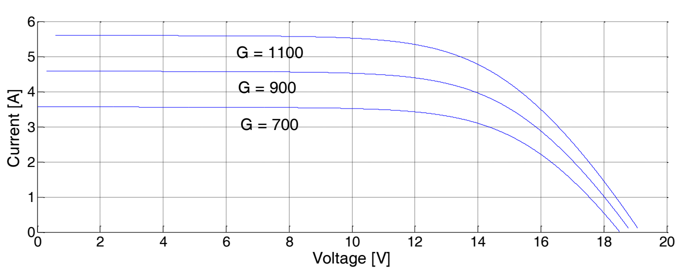

Figure 2 – V-I characteristics for three different values of irradiances

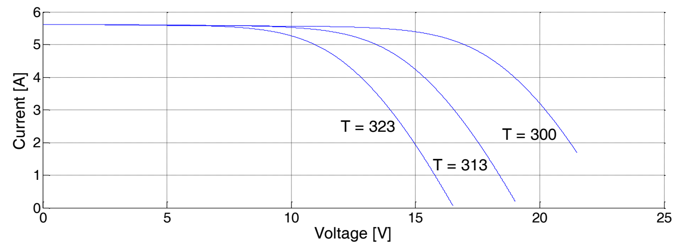

Figure 3 - V-I characteristics for three different values of temperatures

B. *MPPT System*

When a photovoltaic unit is connected to a load, the operating point of photovoltaic unit is determined by the intersecting of the I-V characteristics of PV module and load, which is called load line. Generally speaking, this operating point rarely happens to be at the PV module's maximum possible producing power. For example from Figure 2 it can be inferred that the power of the PV cell is maximum when $V = 13.67\,V$ and $I = 4.07\,A$ (while $G = 900\frac{w}{m^2}$). It means that the resistance that can be seen from the cell should be $\frac{V}{I} = 3.36\,\Omega$. But, the problem is that the load is fixed and is not under our control, thus it is possible that it would not be even near the optimum resistance. It means that the output power of the PV would be so much less than its nominal value. Therefore, in order to solve this issue, a MPPT module can be applied to sustain the PV module operating point at Maximum Power Point.

Nowadays, Maximum power point tracker systems play an important role in photovoltaic systems; they maximize the power output from a PV system for any given set of conditions, maximize the array efficiency, and therefore minimize the overall system cost. MPPT systems find and sustain operating point at the maximum possible power point, using an MPPT algorithm. Many different algorithms have been proposed in literature ([3]-[9]). Some of the well-known algorithms are: perturb-and-observe (P&O) method, Ripple-based extremum seeking, Constant voltage and current, Pilot Cell, Incremental Conductance, Parasitic Capacitance, etc. In a specific irradiance and temperature, the output power of the PV cell can vary from zero to a maximum value based on the load.

In this paper a Hill Top algorithm [12] is used for MPPT purpose. The flow chart of the algorithm is shown in Figure 4. In each step, after sensing voltage and current of the PV cell, by comparing them with the previous value of the output power, the duty cycle of the Insulated-Gate Bipolar Transistor (IGBT) would be changed. If the power has been decreased the duty cycle would be increased and vice versa.

Finally, this duty cycle is compared with a triangle waveform to generate the switching signal of the IGBT.