Simulation of Grid Connected Photovoltaic Systems

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Rising attention to distributed generation (DG) and green energy alternatives to conventional fossil fuel-based electricity has revived the interest in grid-connected photovoltaic (PV) systems. As the cost of PV has come down, applications such as building integrated PV systems are becoming increasingly popular [1]. When larger PV installations are designed, studies need to be performed at the power system level to examine the impacts of integration. For small scale distributed generation, interconnection standards, such as IEEE 1547 2003 [2] and local utility interconnection regulations define the grid interface requirements.

The protection is based on the philosophy that in case of grid disturbances (e.g. voltage drops or frequency deviation), distributed generators will be disconnected from the network immediately. The protection at the grid interface and the DG control must be designed to meet requirements. PSCAD®/EMTDC™ can be used for studies involving controller tuning, protection setting, power quality investigations and system validations among others [3].

PV Array Model A solar cell can be modelled using an electrical equivalent circuit that contains a current source anti-parallel with a diode, a shunt resistance and a series resistance as shown in Figure 1a. The DC current I_g, generated when the cell is exposed to light, varies linearly with solar irradiance.

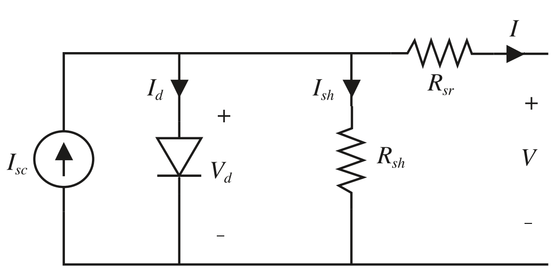

Figure 1a PV cell equivalent circuit.

The current I_d through the anti-parallel diode is largely responsible for producing the nonlinear I-V characteristics of the PV cell (Figure 1b).

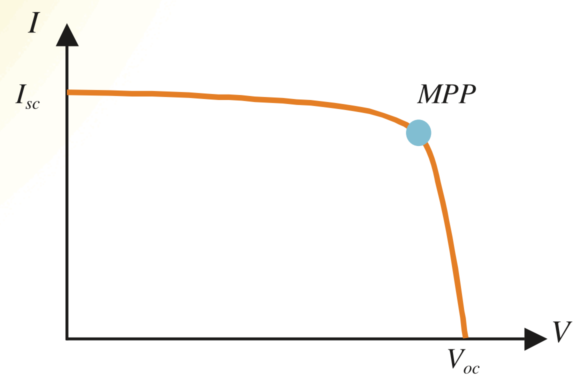

Figure 1b PV cell typical I-V characteristics.

The basic equation that characterizes the solar cell I-V relationship can be derived considering the equivalent circuit shown in Figure 1. The Kirchoff's current law provides

$$I = I_{sc} - I_d - I_{sh}. \tag{1}$$

Substitution of relevant expressions for the diode current I_d and the shunt branch current I_{sh} yields

$$I = I_{sc} - I_o\left[exp\left(\frac{V + IRsr}{nkT_c/q}\right) - 1\right] - \left(\frac{V + IR_{sr}}{R_{sh}}\right). \tag{2}$$

In (2) I_{sc} is the photo current and it is a function of the solar radiation on the plane of the solar cell G and the cell temperature T_c

$$I_{sc} = I_{scR}\frac{G}{G_R}\left[1 + \alpha_T(T_c - T_{cR})\right] \tag{3}$$

where I_{scR} is the short circuit current at the reference solar radiation G_R and the reference cell temperature T_{cR}. The parameter _T is the temperature coefficient of photo current. The current I_o in (2) is called the dark current, a function of cell temperature only, and is given by

$$I_o = I_{oR}\left(\frac{T_c^3}{T_{cR}^3}\right) exp\left[\left(\frac{1}{T_{cR}} - \frac{1}{T_c}\right)\frac{qe_g}{nk}\right] \tag{4}$$

where I_{oR} is the dark current at the reference temperature. The other parameters appearing in (2)-(4) are the electron charge q, the Boltzmann constant k, the band-gap energy of the solar cell material e_g, and the diode ideality factor n.

All of the constants in the above equations can be determined by examining the manufacturer's specifications of the PV modules and published or measured I-V curves. A PV array is composed of series and parallel-connected modules and the single cell circuit can be scaled up to represent any series/parallel combination.

A PV cell model based on the above equations was implemented as a custom component in PSCAD®.

Maximum Power Point Tracking The amount of power that can be drawn by a solar cell depends on the operating point on the I-V curve and the maximum power output occurs around the knee point of the curve. A maximum power point tracker (MPPT) is a power electronic DC-DC converter inserted between the PV array and its load to ensure that the PV module always operates at its maximum power point as the temperature, insolation and load vary. A popular MPPT algorithm based on the Incremental Conductance [4] method was implemented in PSCAD®.

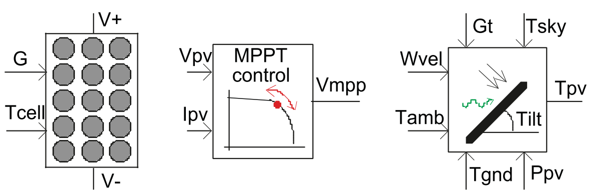

Figure 2 PV system simulation components library.

Simulation of a Grid Connected PV Inverter

A simple example of using these components for a system study is shown in Figure 3. The external grid is represented by its Thevenin's equivalent. Basic blocks of the MPP Tracking control are shown in Figure 4.

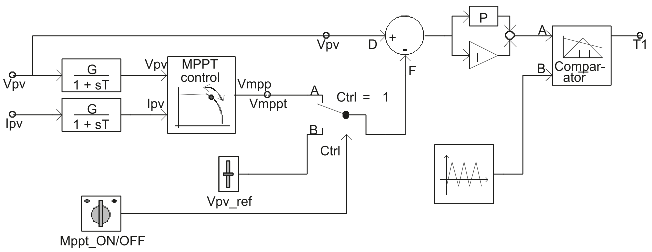

Figure 4 Simple DC-DC converter control with MMP tracking.

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References

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[2] "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems," *IEEE Standard 1547–2003*.

[3] A. D. Rajapakse, D. Muthumuni, N. Perera, and K. Strunz, "Electromagnetic Transients Simulation for Renewable Energy Integration Studies," Proceedings of IEEE PES Annual Meeting, Tampa, FL, USA, 24–28 June 2007.

[4] Hussein K.H., Muta I., Hoshino T., Osakada, M., "Maximum Photovoltaic Power Tracking: An Algorithm for Rapidly Changing Atmospheric Conditions," *Generation, Transmission and Distribution, IEE Proceedings-Volume 142 Issue 1, Jan. 1995, Pages: 59–64*

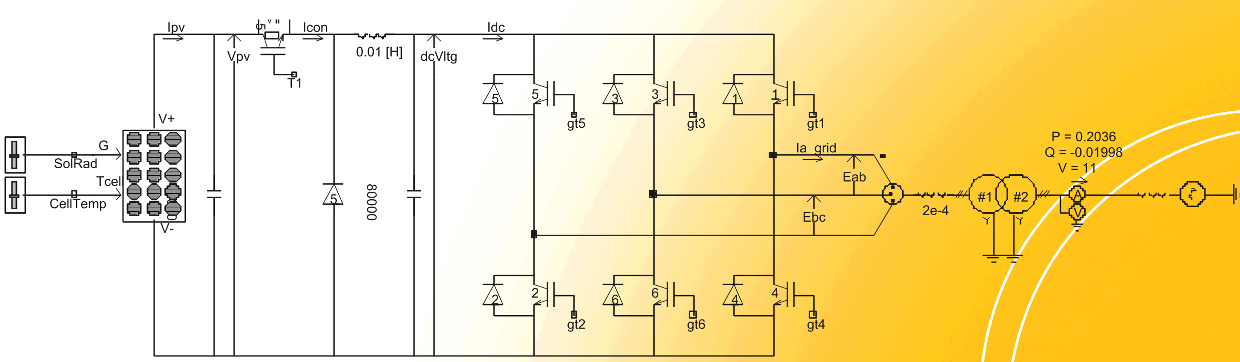

Figure 3 Example of simulating a grid connected PV system simulation.