APPLICATION OF PSPICE IN SIMULATION OF A PHOTOVOLTAIC (PV) SYSTEM

Frehiwot Woldehanna
Department of Electrical Engineering
Addis Ababa University

ABSTRACT

There are two approaches in computer simulation of any system- developing custom software from the scratch or application of one of the commercially available software packages. In the later approach, either dedicated simulating software can be used or general-purpose software can be adapted to suit particular needs. The work done is based on the general-purpose electronic simulation package (PSpice) for which a custom library of PV components and subsystems has been developed.

INTRODUCTION

Simulation is a technique by which any system, be it physical, chemical, or social, can be modeled and its performance predicted without actually building the system. This is done by converting the model of the system into a computer program the execution of which is expected to result in the desired performance parameters. With the advent of high-speed computers, it has become an essential step to simulate systems in various disciplines.

Currently, there are numerous computer software packages based on different algorithms and approximations to simulate PV systems. In some cases, it may be easier to use these programs. The basic problem with most of these available simulation programs, however, is that it is difficult to change the underlying assumptions and approximations that may not be valid for local conditions. In some cases, it may not be easy even to supply the basic local variables – ambient temperature and solar irradiance. An alternative is to start from scratch and write the complete source code which obviously needs quite a lot of time and energy. In an attempt, to minimize this effort and yet use the built-in analysis and output facilities, the electronic workbench *PSpice* is used to simulate a PV system.

PSpice is the PC version of the *Spice* (Simulation Package for Integrated Circuit Electronics). As its name indicates, the software was originally developed to simulate electronic devices and circuits. Over the years, by expanding the model libraries, it has become possible to simulate various systems that are neither electronic nor integrated. The feature utilized for the simulation process is the analog behavioral modeling and a custom library based of the built-in symbols and components is developed.

OVERVIEW OF THE PV SYSTEM

The general PV system consists of a PV array, power electronic interface and the load. The system can be stand-alone type, perhaps with a storage battery, or grid-connected type. In the later type, the grid absorbs excess PV power and load power deficiency is covered by the same grid supply.

The PV array is composed of PV modules which are basically interconnection of PV cells in series and parallel to provide the required voltage and current level. The array produces DC power that fluctuates in response to the fluctuation in the solar irradiation and temperature.

The simplest stand-alone system contains only the array directly connected to the load without any intermediate subsystem. The reliability in terms of system failure for such directly connected system is relatively high since major the weak components in PV systems are the storage batteries and power electronic interface circuits. The need for an ac power or for connection to the grid system requires an inverter that converts the inherent DC output of the PV array into an AC form but then the system will be of lower reliability. Inclusion of a deep discharge solar grade battery allows the system to work in the nighttime as well as during low solar radiation.

ANALOG BEHAVIORAL MODELING

Behavioral modeling is the process of developing a model for a device or system component from the viewpoint of externally observed behavior rather than from a microscopic description. Two important applications of behavioral modeling in analog simulation are: modeling new device types, and black-box modeling of complex systems.

The Analog Behavioral Modeling (ABM) feature provided in *PSpice* allows for flexible descriptions of electronic components in terms of transfer function or lookup table. In other words, a mathematical relationship is used to model any component so there is no need of detailed electronic design.

The *PSpice* symbol library contains several ABM parts that can be classified as either control system or as *PSpice* equivalent parts. Control system parts are defined with the reference voltage preset to ground so that each controlling input and output are represented by a single pin in the symbol. The *PSpice* equivalent parts reflect the structure of the E- and G- device types which respond to a differential input and have double-ended output.

The device equation option can also be used for similar type of modeling but using the ABM feature is much better in terms of its applicability to any type of problem.

Weather Source

A useful part of *PSpice* which can simulate time variations of arbitrary form is the piecewise linear voltage (or current) source, PWL-FILE. The source works with a named disk file in which pairs of values for time and amplitude information are stored.

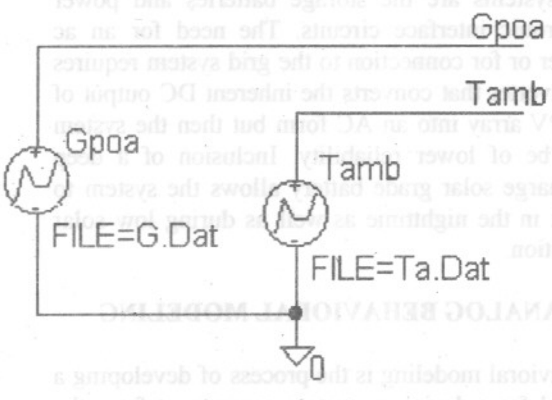

Figure 1 Modeling of Weather Variables

To simulate the weather influence on the PV system, two PWL-FILE sources (one for solar irradiance and the other for the ambient temperature) are required as shown in Fig. 1 with two controlled voltage outputs is created and included in the custom library.

In the model, *Gpoa* is the Plane of Array Solar irradiance (the combined effect of the global, diffuse and ground reflected irradiance components) and *Tamb* is the ambient temperature. The disk files G.DAT and Ta.DAT are assumed to contain (G_k, t_k) and (T_k, t_k) values where t_k (k=1,2,…n) is the time variable.

Modeling of the weather variables has a significant influence on the simulation results. Simplified design of PV systems usually requires monthly average values of the solar irradiance and ambient temperature while acceptable simulation is based on hourly values of the same variables.

PV Array

The circuit behavior of a PV array composed of N_s modules in series (a string) and N_p of such strings can be understood in terms of the equivalent circuit of a PV module shown in Fig. 1.

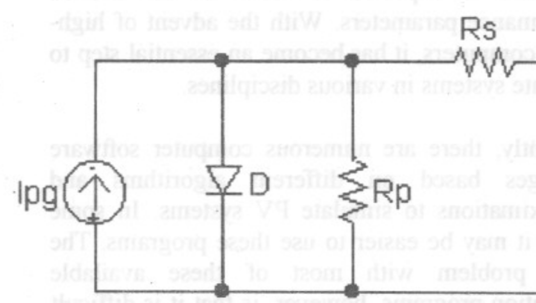

Figure 2 Equivalent Circuit of a PV Module

The output current I_o of a single module is given by,

$$I_o = I_{pg} - I_d - I_p \qquad (1)$$

where I_{pg} is the photo-generated current (the contribution of the solar irradiance dependent of the ambient temperature). The other currents are I_d, the diode current which represents the junction structure of the module and I_p, the current included to explain the reduction of output current due to the parallel loss resistance R_p. The series loss resistance R_s accounts for the output voltage reduction. The diode and shunt resistance current can computed using the basic relations,

$$I_d = I_r \left(e^{\frac{V_o + I_o R_s}{V_T}} - 1 \right) \qquad (2)$$

$$I_p = \frac{V_o + I_o R_s}{R_p} \qquad (3)$$

In equations (2) and (3), V_o is the output voltage of a single PV module, I_r is the reverse saturation current of the diode and V_T is the thermal voltage of the diode.

A similar relationship applies for the PV array but with scaled values for currents, voltages and resistances. The corresponding array parameters are given by,

$$I_{pg}' = N_p I_{pg} \qquad (4)$$

$$I_r' = N_p I_r \qquad (5)$$

$$R_s' = R_s \frac{N_s}{N_p} \qquad (6)$$

$$R_p' = R_p \frac{N_p}{N_p} \qquad (7)$$

The PV array sub-circuit, shown in the schematic diagram (Fig. 3), contains two major input variables representing Plane of Array Irradiance G_{poa} and Ambient Temperature, T_a. The additional parameters,

$NOCT$ = Normal Operating Cell Temperature
I_{scr} = Reference Short Circuit Current
V_{ocr} = Reference Open Circuit Voltage
I_{pr} = Reference Peak Current
V_{pr} = Reference Peak Voltage

Define the state of the PV array for arbitrary weather condition.

PV Module manufacturers normally specify the reference parameters at standard weather conditions, that is, temperature of $25°C$ and irradiance of $1kW/m^2$. The variations of current and voltage with temperature can then be determined using the current coefficient, α, and the voltage coefficient, β, respectively. During simulation, the above array parameters are computed at the specified weather condition which will be subsequently applied to determine the storage battery and load performance at the same weather conditions.

Storage Battery

An important component in a stand-alone PV system is the storage battery and different approaches are available to model the common lead acid batteries. Most of the approaches are based on empirical charge and discharge equations which depend on temperature, battery capacity, state of charge, and experimental constants.

The model used to represent the lead acid battery here is based on power flow from and to the battery. The model also includes output variables which represent the excess array power not utilized by the system and the load power which could not be covered by the array-battery combination. This helps to identify the percentage of loss of load power as well as loss of array power which is important in assessing the performance of the stand-alone system.

The connection of storage battery with the array and the load is made with an interface system which is equivalent to the charge control unit. The purpose of the interface is to protect the battery from overcharging and over discharging and also to make sure that power flow does not occur to the array side.

The equation relating the array power, the load power and the battery power is dependent on the relative magnitudes of the power difference,

$$\delta P = P_a - P_l \qquad (8)$$

where P_a is the array power and P_l is the load power. One of the parameters describing the storage battery is the current state of charge, SOC. Positive value of δP with $SOC < SOC_x$ (the maximum SOC) implies- battery charging and negative value of δP with $SOC > SOC_n$ (the minimum SOC) leads to battery discharging. Otherwise, again depending on the sign of δP, wasted array power or deficiency of load power not satisfied by the system occurs.

Inverter

Performance of AC loads is governed by the characteristics of the associated inverter systems. The simplest model for the inverter is represented by a constant efficiency, i.e., independent of the power level. For better modeling, it may be enough to characterize inverters by their efficiency curve as a function of the power level. Typical curve is a cubic equation which may be given by,

$$P_o = \alpha_1 P_i + \alpha_2 P_i^2 + \alpha_3 P_i^3 \qquad (9)$$

where P_o denotes the power output and P_i denotes the power input. The coefficients, α's, are the parameters of the inverter model. If the inverter is reasonably linear over the operating range, then the simulation model may contain only the linear coefficient, α_1.

Load Profile

Load variation can be modeled by a similar disk file based source used for weather simulation. For electrical load variation power levels at discrete time instants. For certain applications such as water pumping, the water demand variation must be converted into equivalent power level variation.

EDITING CUSTOM LIBRARY

Expanding the simulation capability of *PSpice* for a black-box system lies in the ability to create new symbols and models applicable to the system under interest. In the current application, photovoltaic system is required to be simulated and symbols representing the external behavior of photovoltaic modules, storage batteries, charge controllers, inverters, converters, and typical loads such as electrical appliances and water pumps are necessary.

In addition, the weather profile, i.e., the variation of the irradiance and temperature should be accurately modeled in the system. This is made possible by using the *PSpice* nonlinear source – PWL (piecewise linear) voltage or current source with corner points representing the hourly values of the desired weather parameters.

Two custom libraries are created for the purpose. The first named ***PVArray.lib*** consists of sub-circuit definitions of each system and the second, ***PVNew.lib*** improves the input-output terminal configuration for each of the symbols. The number of symbols per library file, the number of library files available on a session, and the number of parts on a schematic page is limited by the software version.

Figure 3 shows a schematic file using the major components, the PV array, the storage battery, the array-battery interface, and the load profile with the weather profile. The three disk files representing the temperature, irradiance and load power variations can be edited on the same schematic file.

CONCLUSION

Analog behavioral modeling allows one to simulate any arbitrary input-output relationship without the need for internal details. Thus the feature available in ***PSpice*** can save the time and energy necessary to develop high-level software packages. The built-in analysis and outputs utilities makes the approach attractive. The only limitation is this approach is the version limitation in the number of schematic pages, devices per schematic, and components handled.

ACKNOWLEDGMENT

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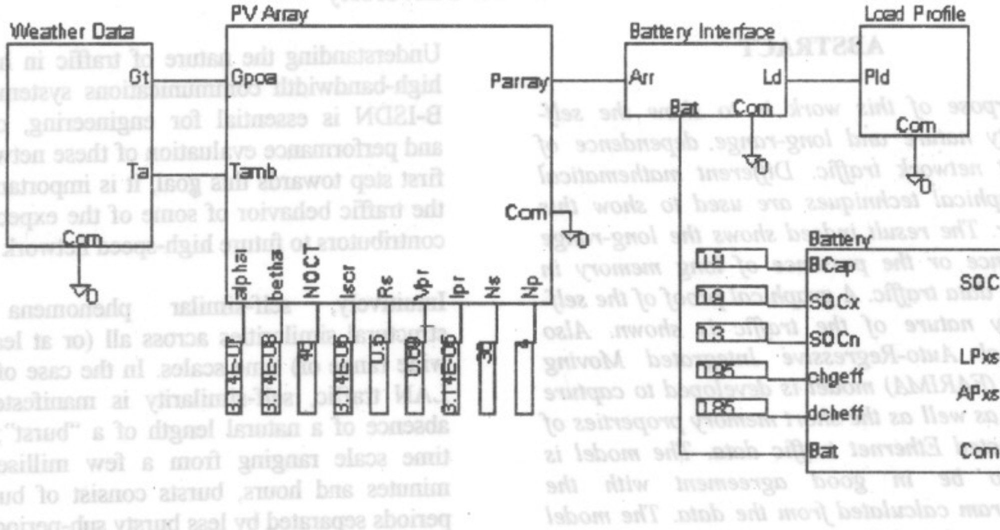

Figure 3 Sample Schematic File for PV System