Implementation of Single Phase Grid Tied Photovoltaic System by Employing Embedded Controller

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Abstract - This paper presents simulation and hardware implementation of single phase grid tied photovoltaic system. A grid tied PV system is one in which solar power system is connected to the load & power grid. This enables us to sell surplus energy to the electricity board. Compared to the traditional energy resources, photovoltaic (PV) system that uses the solar energy to produce electricity considered as one of renewable energies has a great potential and developing increasingly fast compared to its counterparts of renewable energies. Such systems can be either stand-alone or connected to utility grid. However, the disadvantage is that PV generation depended on weather conditions.

I. INTRODUCTION

The increasing of the world energy demand, due to the modern industrial society and population growth, is motivating a lot of investments in alternative energy solutions, in order to improve energy efficiency and power quality issues. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photovoltaic (PV) sources are used today in many applications as they have the advantages of effective maintenance and pollution free. Solar electric energy demand has grown consistently by 20% to 25% per annum over the past 20 years, which is mainly due to its decreasing costs and prices. This decline has been driven by the following factors.

1) An increasing efficiency of solar cells
2) Manufacturing technology improvements
3) Economies of scale.

The use of photovoltaic energy is considered to be a primary resource, because there are several countries located in tropical and temperate regions, where the direct solar density may reach up to 1000W/m. At present, photovoltaic (PV) generation is assuming increased importance as a renewable energy sources application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. The cell conversion ranges vary from 12% of efficiency up to a maximum of 29% for very expensive units. In spite of those facts, there has been a trend in price decreasing for modern power electronics systems and photovoltaic cells, indicating good promises for new installations. However, the disadvantage is that photovoltaic generation is intermittent, depending upon weather conditions. Thus, the MPPT makes the PV system providing its maximum power and that energy storage element is necessary to help get stable and reliable power from PV system for both loads and utility grid, and thus improve both steady and dynamic behaviors of the whole generation system. In this paper we have studied a grid-connected photovoltaic generation system which is composed of PV array, cuk converters, inverters, controllers, local loads and utility grid as shown in figure 1. The paper discusses the detailed modeling of the whole system. PV array is connected to the utility grid by a cuk converter to optimize the PV output and DC/AC inverter to convert the DC output voltage of the solar modules into the AC system. The DC input of the inverter must be constant and it is controlled by the use of a PI control circuit. An LC filter has been introduced to insure a clean current injection to the grid. The proposed model of the entire components
and control system are all simulated in Matlab/Simulink Software.

Fig 1: Configuration of grid connected photovoltaic generation system

II. MODELING THE PV ARRAY

The direct conversion of the solar energy into electrical power is obtained by solar cells. A PVG is composed by many strings of solar cells in series, connected in parallel, in order to provide the desired values of output voltage and current. Fig. 2 shows the equivalent circuit of a PVG, from which non linear I–V characteristic can be deduced.

![Solar-Cell Equivalent Circuit.](image)

The cells are connected in series and in parallel combinations in order to form an array of the desired voltage and power levels.

Applying Kirchhoff’s current law, the terminal cell current is

\[ I = I_L - I_D \] (1)

The light current is related to irradiance and temperature and the light current measured at some reference conditions:

\[ I_L = \left( \frac{G}{G_{REF}} \right) (I_{L,REF} + \mu_{ISC} (T_C - T_{C,REF})) \] (2)

Where

IL,REF= Light current at reference conditions .

G, GREF= Irradiance, actual and at reference condition [W/m²].

T, TC, REF= Cell temperature, actual and at reference condition [° K].

μISC=Manufacturer supplied temperature coefficient of short circuit current [A/°K].

The diode current is given by Shockley equation:

\[ I_D = I_0 \left[ \exp \left( \frac{q(V + I R_s)}{a k T_C} \right) - 1 \right] \] (3)

Where:

V= terminal voltage [V], I= reverse saturation current [Amps], γ= shape factor.

Rs= series resistance [Ω], q= electron charge 
1.602.10-19 K = Boltzmann constant=1.381.10-23J/K.

The reverse saturation current is:

\[ I_0 = DT_c^3 \exp \left( \frac{q E_G}{k A T_c} \right) \] (4)

Where:

D = diode diffusion factor,

E_G= material band gap energy (1.12 eV for Si, 1.35 eV for GaGs)

A = completion factor

The reverse saturation current is actually computed by taking the ratio of equation (4) at two different cell temperatures, thereby eliminating D, similar to the termination of IL, I0 is related to the temperature and the saturation current estimated at some reference conditions:

\[ I_0 \sim I_{0,REF} \left( \frac{T_c}{T_{C,REF}} \right)^3 \exp \left( \frac{q E_G}{k A} \left( \frac{1}{T_{C,REF}} - \frac{1}{T_c} \right) \right) \] (5)

And thus the I-V characteristic is described by:

\[ I = I_L - I_0 \left[ \exp \left( \frac{q(V + I R_s)}{a k T_C} \right) - 1 \right] \] (6)

The shape factor α is a measure of cell temperature and is related to the completion factor as

\[ \alpha = A.NCS.NS \] (7)

NCS is the number of cells connected in series per module. A module is defined as an array of cells, usually encapsulated for protection, as it is supplied by manufacturer; NS is the number of modules connected in series of the entire array. While Rs and α are assumed to be constant, IL is a function of irradiance and cell temperature and I0 is a function of temperature only. The cell temperature can be determined from the ambient temperature and with the help of some standard test information.
III. CUK CONVERTER

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. The efficiency of switch-mode dc–dc converters is widely discussed. Most switching-mode power supplies are well designed to function with high efficiency. Among all the topologies available, both Cuk and buck–boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Although the buck–boost configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient. On the other hand, the Cuk converter has low switching losses and the highest efficiency among non-isolated dc–dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage. Thus, the Cuk configuration is a proper converter to be employed in designing the MPPT. Figs. 3 and 4 show a Cuk converter and its operating modes, which is used as the power stage interface between the PV module and the load. The Cuk converter has two modes of operation. The first mode of operation is when the switch is closed (ON), and it is conducting as a short circuit. In this mode, the capacitor releases energy to the output. The equations for the switch conduction mode are as follows:

\[ V_{L1} = V_g \]  
\[ V_{L2} = -v1 - v2 \]  
\[ i_{C1} = i_2 \]  
\[ i_{C2} = i_2 - \frac{v_2}{R} \]

The principles of Cuk converter operating conditions state that the average values of the periodic inductor voltage and capacitor current waveforms are zero when the converter operates in steady state. The relations between output and input currents and voltages are given in the following:

\[ \frac{V_o}{V_{in}} = -(D) \]  
\[ \frac{I_{in}}{I_o} = -(\frac{D}{1-D}) \]

The components for the Cuk converter used in simulation and the hardware setup were selected as follows:
1) input inductor L1 = 5 mH;
2) capacitor C1 (PV side) = 47 μF;
3) filter inductor L2 = 5 mH;
4) switch: insulated-gate bipolar transistor [(IGBT)—IRG4PH50U];
5) freewheeling diode: RHRG30120;
6) capacitor C2 (filter side) = 1 μF;
IV. PROPOSED MULTILEVEL INVERTER TOPOLOGY

The proposed single-phase seven-level inverter was developed from the five-level inverter. It comprises a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by $C_1$, $C_2$, and $C_3$, as shown in Fig. 5. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitors for inverters of the same number of levels.

Fig. 5: Proposed single-phase seven-level grid-connected inverter for photovoltaic systems.

Photovoltaic (PV) arrays were connected to the inverter via a dc–dc boost converter. The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used. The dc–dc boost converter was required because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid. A filtering inductance $L_f$ was used to filter the current injected into the grid. Proper switching of the inverter can produce seven output voltage levels ($V_{dc}$, $2V_{dc}/3$, $V_{dc}/3$, 0, $-V_{dc}$, $-2V_{dc}/3$, $-V_{dc}$) from the dc supply voltage.

The required seven levels of output voltage were generated as follows:

1) Maximum positive output ($V_{dc}$): $S_1$ is ON, connecting the load positive terminal to $V_{dc}$, and $S_4$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $V_{dc}$.

2) Two-third positive output ($2V_{dc}/3$): The bidirectional switch $S_5$ is ON, connecting the load positive terminal and $S_4$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $2V_{dc}/3$.

3) One-third positive output ($V_{dc}/3$): The bidirectional switch $S_6$ is ON, connecting the load positive terminal, and $S_4$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $V_{dc}/3$.

4) Zero output: This level can be produced by two switching combinations; switches $S_3$ and $S_4$ are ON, or $S_1$ and $S_2$ are ON, and all other controlled switches are OFF; terminal $ab$ is a short circuit, and the voltage applied to the load terminals is zero.

5) One-third negative output ($-V_{dc}/3$): The bidirectional switch $S_5$ is ON, connecting the load positive terminal, and $S_2$ is ON, connecting the load negative terminal to $V_{dc}$. All other controlled switches are OFF; the voltage applied to the load terminals is $-V_{dc}/3$.

6) Two-third negative output ($-2V_{dc}/3$): The bidirectional switch $S_6$ is ON, connecting the load positive terminal, and $S_2$ is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $-2V_{dc}/3$.

7) Maximum negative output ($-V_{dc}$): $S_2$ is ON, connecting the load negative terminal to $V_{dc}$, and $S_3$ is ON, connecting the load positive terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is $-V_{dc}$.

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TABLE 1 Output Voltage According To The Switches’ On–Off Condition
Fig. 6. Switching pattern for the single-phase seven-level inverter

Fig. 7 Simulation output voltage for grid connected PV System.

V. WORKING PRINCIPLE OF GRID CONNECTED PHOTOVOLTAIC SYSTEM

Electricity is produced by the PV array most efficiently during sunny periods, independent power systems use storage batteries to supply electricity needs. With grid interactive systems, the grid acts as the battery, supplying electricity when the PV array cannot. During the day, the power produced by the PV array supplies load. An inverter converts direct current (DC) produced by the PV array to alternating current (AC) and transformer stepped up the voltage level as need for export to the grid. Grid interactive PV systems can vary substantially in size. However all consist of solar arrays, inverters, electrical metering and components necessary for wiring and mounting.

5.1 Conditions for Grid Interfacing

There are some conditions to be satisfied for interfacing or synchronizing the SPV system with grid or utility. If proper synchronizing is not done then SPV potential cannot be fed to the grid. The conditions for proper interfacing between two systems are discussed below:

- **Phase sequence matching**: Phase sequence of SPV system with conventional grid should be matched otherwise synchronization is not possible. For a three phase system three phases should be 120 deg phase apart from each other for both the system.

- **Frequency matching**: Frequency of the SPV system should be same as the grid. Generally grid is of 50 Hz frequency capacity, now if SPV systems frequency is slightly higher than grid frequency (0.1 to 0.5 Hz) Synchronization is possible but SPV system frequency should not be less than grid frequency.

- **Voltage matching**: One of the ital. point is voltage matching. Voltage level of both the system should same, Otherwise synchronization is not possible.

5.2 Advantages of Small Units Instead of Single Large Unit

The design for a grid connected photovoltaic system can be done in various ways like it can be made by small numbers of single phase units instead of single large three phase unit. Because this type of designing have some advantages over a large system design. The advantages are given below:

- **Efficiency of Operation**: It is logical to operate a small unit delivering rated output when the load increases another unit is connected with the one already in operation. This keeps the plant loaded up to their rated capacity and increases efficiency of operation.

- **Reliability or Continuity of service**: Several smaller units are more reliable than a large single unit, since if one unit fails the continuity of supply can be maintained by remaining units. On the other hand if the power stations consisted only of a single large units, in the event of breakdown, there will be complete shutdown (failure of supply).

- **Maintenance and repair**: It is considered necessary to carry out regular inspection and maintenance so as to avoid possibility of failure. This is possible only when the unit is out of service which means that the remaining units should be capable to take care of load.

- **Additions to power plant**: The additional unit can be installed as and when required with the growth of load on power station.
VI. CONCLUSIONS

In this paper, a grid-connected photovoltaic generation system is studied. In order to convert the solar energy efficiently, the maximum power point of the PV array should be tracked to ensure the PV array provide most power to both grid and the load. When solar irradiance or temperature fluctuates, PV generation will change as a result. The controller must act to maintain the DC bus voltage constant as possible and improve the stability of the whole system. The simulation results presented in this paper validate the component models and the chosen control scheme.

VII. REFERENCES


