Voltage Stabilization of hybrid PV and battery systems by considering temperature and irradiance changes in standalone operation

Seyed Masoud Mohseni Bonab1,*
Department of Electrical engineering
University of Zanjan
Zanjan, Iran
s.m.mohsenibonab@ieee.org

Sayyad Nojavan3
Department of Electrical engineering
University of Tabriz
Tabriz, Iran
Sayyad.nojavan@tabrizu.ac.ir

Saeid jalilzadeh2
Department of Electrical engineering
University of Zanjan
Zanjan, Iran
jalilzadeh@znu.ac.ir

Tohid Jafari4
Young Researchers and Elite club
Tabriz Branch, Islamic Azad University
Tabriz, Iran
Jafari.tohid@gmail.com

Abstract— Solar and battery energy storage systems are very useful for consumers who live in deprived areas and don’t have access to electricity distribution networks. Nowadays one of the problems that photovoltaic systems (PV) have changing of output power in temperature and irradiance variations, which directly affects the load that is connected to photovoltaic systems. In this paper, with considering the fact that the solar array varies with change in temperature and solar power radiation, a voltage stabilizer system of a load connected to photovoltaic array is designed to stabilize the load voltage and to transfer surplus power of the battery. Also, in proposed hybrid system, the needed load power amount is supplemented considering the voltage stabilization in standalone operation for supplying unbalanced AC load. Electrical energy storage system for voltage control and improvement of the performance of PV by a DC/DC converter is connected to the DC bus. The load is also fed by an AC/DC converter. In this paper, when the voltage increases in its reference limit, the battery gets charged by the photovoltaic array and when it decreases in its defined limit, the power gets injected to the DC bus by this battery. The constant of DC bus Voltage is the cause for the reduced harmonics generated by the inverter. In addition, a series of filters are provided in the inverter output in to reduced harmonics. The inverter control circuit is designed that the voltage and frequency of the load remain almost constant at different load conditions. This paper has focused on controlling strategies of converters to improve their performance.

Keywords— Photovoltaic array (PV), DC/DC Boost converter, battery converter, inverters control.

I. INTRODUCTION

Global Warming and energy policies have become important issues in international laws, during the recent years. Developed countries are trying to reduce greenhouse gases. For examples European Union has produced at least 20 percent of the energy needed for renewable sources by 2020, in order to reduce 20 percent of greenhouse gas emissions. In this issue, photovoltaic power generator (PV) plays an important role in green energy sources. Because of energy crisis and environmental issues such as pollution and global warming, the use of photovoltaic systems is a very good solution to solve the problem of energy shortage [1]. Unfortunately the energy conversion efficiency of photovoltaic modules is relatively low therefore to overcome this problem and to obtain the maximum possible efficiency all the components of photovoltaic systems must be optimized. Another issue is to manage the power consumption of the energy, produced by the photovoltaic system that means energy should be consumed or stored. All the energy which is produced by considering the fact that the output of the photovoltaic array vary through irradiance and temperature rates the consumed power of load connected to photovoltaic system, depends on the amount of irradiance and temperature. The purpose of this system is that the consumed power of load is not dependent on environmental factors. Some advantages of the load voltage stabilizer system connected to a photovoltaic system include:
• Stabilizing the load voltage connected to a photovoltaic system and constant power consumption by the load.
• Transfer of surplus power into the battery
• Feeding both the load and the battery which are connected to photovoltaic system simultaneously.

One of the problems that photovoltaic systems have is that their output power changes when some changes happen in temperature and irradiance rates, and this problem directly affects the load connected to the photovoltaic system.
In order to make the consumer achieve the constant energy from photovoltaic system, the load voltage stabilization controller is proposed which connected to the photovoltaic system [2].

To increase reliability and improve power quality in the independent mode of grid, along with solar cells energy storage systems are used in special cases to compensate the needed power in special cases. In [3] to improve the power quality of photovoltaic systems PV-AF (Photovoltaic active filter) with V2G technology has been realized. In [4] a specific control strategy (μG-VSC) has been used for HGICB (high gain integrated cascaded boost) converter and also a battery energy storage system has been applied. To examine the combined solar system and electrical energy storage system in islanding operation, different methods such as reviews based on dynamic programming and comparison with fuzzy [5] are noted. To stabilize voltages in photovoltaic systems and grid-connected to wind turbine we can also refer to [6].

The goal of all these algorithms is to track the maximum power point and to extract the maximum power of the photovoltaic system. The other significant goal is how to consume this produced maximum power, so that the loads connected to photovoltaic system remain safe and the maximum use can be made of this produced power. It means that any change on power due to environmental variations should not affect load power consumption, and the maximum extracted power of this tracking system will be the maximum point of power management. For this purpose, the voltage stabilizer system is proposed. In the proposed system, both the load and battery are used simultaneously. The solar array system has been designed so that PV power changes can only be applied to the battery and the load will always have constant power.

To manage consumption and to store the produced power by the maximum power point tracking system in solar array, the load voltage stabilization system connected to a photovoltaic array is proposed while the battery and load are used simultaneously then the maximum use of the power produced by the solar array is achieved.

In this paper a new control strategy is designed in a way that both solar system and electrical energy storage system will provide the consumed power throughout the day and when the DC bus voltages increase, the energy will be stored in the battery and when the voltage is reduced, the energy will be compensated through batteries.

To transmit power form the DC bus to the AC load, an AC/DC converter with VF control structure of the system is shown in figure 1.

II. MODELING OF PHOTOVOLTAIC ARRAY

Each photovoltaic array is made up of several solar cells in parallel and series form. For each cell modeling the electrical equivalent circuit model is used as it’s shown in figure 2. Based on electrical equivalent circuit, equation (1) which the output voltage of the cell.

\[
V_c = \frac{AKT_e}{e} \ln \left( \frac{I_{ph} + I_0 - I_c}{I_0} \right) - R_c I_c
\]

Where;
- e: Electrical load which equals \((1.60217646 \times 10^{-19} \text{[c]}\),
- k: Boltzmann constant \((1.3806503 \times 10^{-23} \text{[J/K]}\),
- I_c: Cell output current,
- I_{ph}: Optical current which is a function of irradiance and temperature,
- I_o: Reverse saturation current of a diode \((0.0002)\),
- R_s: Series resistance of the cell \((0.001)\),
- T_c: Reference temperature of the cell
- V_c: The output voltage of the cell

The V-I characteristic curve of the cell is obtained from equation (1) and these cells are connected to each other in both parallel and series from in order to build a photovoltaic array. To affect the impact of temperature and irradiance the following relations are used [7].

\[
C_{TV} = 1 + \beta_T (T_u - T_x)
\]

\[
C_{TI} = 1 + \gamma_T \left( T_a - T_x \right)
\]

\[
C_{SV} = 1 + \beta_s \alpha_s (S_x - S_c)
\]

\[
C_{SI} = 1 + \frac{1}{S_c} (S_x - S_c)
\]

\[
\Delta T_c = \alpha_c (S_x - S_c)
\]

\[
V_{CX} = C_{TV} C_{SV} V_C
\]

\[
I_{phx} = C_{TI} C_{SI} I_{ph}
\]

In these equations: \(\beta_T = 0.004, \gamma_T = 0.06\) and \(T_c = 20\).

In the above equations irradiance \((S_x)\) and temperature \((T_x)\) can be changed respectively to suit to the weather conditions. In the equations (7) and (8), the output voltage and the reference optical current are respectively due to the environmental conditions. In fact with the changes in irradiance and temperature the characteristic curve of the
Output cell will also change which thoroughly discussed in [8, 9, and 10].

III. BATTERY ENERGY STORAGE SYSTEM

Battery energy storage system includes: battery bank, DC/DC converter and converter control scheme. The battery model is usually divided into the exponential model, the electrochemical model and equivalent circuit model. The equivalent circuit model is very suitable for dynamic simulation. General model for dynamic simulation of combined series of voltage source is controllable by resistance and is shown in the figure (3) [11].

\[
E = E_0 - K \frac{Q}{Q - \int i_s dt} + A \exp\left(-B \times \int i_s dt\right) \quad (9)
\]

Where:

- \(E_0\): No-load voltage (V)
- \(E\): Battery fixed voltage (V)
- \(K\): Polarization voltage (V)
- \(Q\): Battery capacity (Ah)
- \(A\): Amplitude of exponential part (V)
- \(B\): Inverse time constant of the exponential part (V)

The equivalent circuit of the storage converter in the battery bank is shown in figure 4. In this scheme, the DC/DC energy storage converter is equipped with the base-current controller to force the reference currents to be generated by the controller converter.

Output voltage of storage converter (DC bus voltage) is passed through a low-pass filter after measurement. Then it will be applied to a comparator domain.

DC voltage error \(V_{dc,ref} - V_{dc,lp}\) is applied to a PI controller with \(K_p\) slope in order to get the reference current of a battery (\(i_{Bat-ref}\)).

IV. THE PROPOSED CONTROL SYSTEM FOR INVERTER (DC/AC)

To control the DC/AC inverter the V-f control method is proposed. This method adjusts the voltage and frequency of the load. This adapter does not have any effect on the DC bus voltage regulation. Frequency (\(\omega\)) is controlled by a phase lock loop (PLL). AC load converter scheme is presented in the Fig. 6. The load phase voltage should be kept in a fixed and sinusoidal balanced frequency and domain. By Comparing voltages in abc coordinates of the triangle wave (PWM converter) the DC/AC converter of the load is used for switching.

In this paper, the DC bus voltage is considered 750 volts so that the voltage fluctuations are inhabited by capacitor storage system. DC bus voltage is shown in Fig. 6. This constant DC bus voltage reduces the harmonics which are generated by the inverter.

V. SIMULATION AND RESULTS

Simulation results are presented according to the rapid changes of temperature and irradiance, to examine the performance of the load voltage stabilization system in the best way. Environmental changes are applied in two ways:

- Rapid decline of the temperature from 47 [C] to 17 [C] in a constant irradiance 1[kw/m²]
- Rapid increase of the irradiance from 0.5 [kw/m²] to 1 [kw/m²] in a constant temperature 27 [C]

In Figs. 7, 8 and 9, the total produced power of photovoltaic systems, power consumption of the load and stored power of battery are shown, respectively according to the rapid decline of temperature from 47[C] to 17[C] in a constant radiation.
Fig. 5. Structure of the energy storage converter

Fig. 5. Scheme and structure of the load converter
These Figures show that the increased productivity of the solar array power, the power consumption of the load remains fixed and the extra produced power is stored in a battery. In figures 10, 11 and 12 the total produced power of photovoltaic systems, power consumption of the load and stored power of battery are shown respectively according to rapid change of irradiance from 0.5 [kw/m²] to 1 [kw/m²] in a constant temperature 27 [C]. Like the pervious situation, with the increased productivity of the solar array power, the power consumption of the load remains fixed and the extra power is stored in a battery.

By using this controlling scheme, when the voltage is increased in its reference limit the battery gets charged by the photovoltaic array and when it’s reduced the battery inject power to the DC bus. Figures 6-11 are illustrate the solar cell voltage and current is kept constant in different situations. Figures 13 and 14 have shown the load voltage in which it’s clear that frequency and current has remained relatively constant with the inverter control circuit design at different load conditions. In addition the inverter output filters have been included in order to reduce harmonics.
VI. CONCLUSIONS

In this paper the main objective is to supply the AC load by hybrid system of photovoltaic array and battery. In power surplus mode, PV output power has charged the battery, and in mode of PV power shortage the battery is discharged for supplying the load. Inverter control circuit is designed so that the load voltage and frequency are provided constantly under different conditions. The results are the indication of the good performance of this new proposed strategy in over system. Also, In addition the inverter output filters have been included in order to reduce harmonics.

REFERENCES


