Voltage Control and Harmonics Investigation on Loads Supplied by Off-Grid Solar Power Plant

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Abstract

In this research, voltage control and harmonics reduction on loads supplied from an off-grid solar power plant are addressed. After converting the solar voltage from direct current to alternating current, the voltage on the load was tried to be kept constant at 380V/50Hz. The 2-level inverter used here is controlled through 2DOFPI and the switching signals required for Pulse Width Modulation (PWM) are produced. Meanwhile, the harmonics on the voltage were attempted to be limited to below 5% in accordance with international standards. Thus, clean energy was tried to be supplied by setting the load voltage and harmonics. The system consists of solar panels, filters, an inverter, an inverter control unit, loads, and measurement elements. To model the environment, the sunlight level was altered continuously. The temperature was maintained constant at 250. The simulation study was executed in Matlab/Simulink environment.

Keywords: Solar power, 2DOFPI, Voltage control, Harmonics.

Nomenclature

S_x	Solar radiation level, W/m^2
T_x	Temperature of the solar panel, C^0
K_P	Proportional constant
K_I	Integral constant
K_D	Derivative constant
V_{PV}	Cell output voltage, V
I_{PH}	Photocurrent, A
I_{PV}	Cell output current, A
I_{SC}	Cell short circuit current, A
I_0	Reverse saturation current, A
R_S	Series resistance of cell, ohm
M	Parallel strings
λ	Constant coefficient
N	Series cells per string
c	Set point weighting (derivative)
b	Set point weighting (proportional)
Tf	Derivative filter time
Ti	Integrator time, s
Td	Derivative time, s
N	Filter coefficient
r	Reference input
y	Output
e	Error

1. Introduction

Solar energy is one of the major renewable energy sources. Together with other important sources such as wind energy, hydrogen energy, wave energy, etc., they constitute clean energy sources. These sources are referred to as green energy because they are naturally renewed continuously.

Solar energy and wind energy are the most frequently employed renewable energy sources. Since they are influenced by environmental conditions, the power value they obtain changes continuously. No matter what the source is in the production of electrical energy, the power, voltage, and frequency obtained must be tuned. Since the distribution networks have alternating currents, the necessary transformations and adjustments must be made [1].

The voltage obtained from solar energy is direct current. Therefore, choppers and inverters can be employed particularly in high-power generation systems. Whatever power electronic converters are used, they must be controlled [2].

All power electronics-based devices used in renewable energy sources are controlled by using different control techniques. Devices such as choppers, charge regulators, maximum power point trackers, synchroscopes, ambient measuring units, and inverters are controlled using techniques such as PID, fuzzy logic controllers, and model predictive control [3-5].

Another major problem of renewable energy source generators is harmonics. Especially off-grid systems need to solve this problem with their own resources. Usually, active and passive filters are used to solve this problem. Harmonics are limited by IEEE 519 and EN 61000-3-2 standards [6].

In this research, the control of the voltage and harmonics on the loads in a solar power generation system consisting of 2500 panels that transfer power to the loads and work as an off-grid system is described. The voltage on the loads was kept at 380V and the frequency at 50Hz, while the harmonic on the load voltage was aimed to be kept below 5%. The system is composed of solar panels, filters, inverter, loads, and measurement devices. The inverter is controlled by switching signals with the help of a 2DOFPI controller. The ambient irradiance level Sx was continuously varied to force the system. The ambient temperature was maintained constant at 25°C. A Simulink module of Matlab software was used for the simulation study.

2. Content

2.1. Solar Panels

Solar panels are semiconductor systems that generate electricity as a consequence of the photons received from the sun starting the electric current. Figure 1 illustrates the equivalent circuit of a solar cell [7].

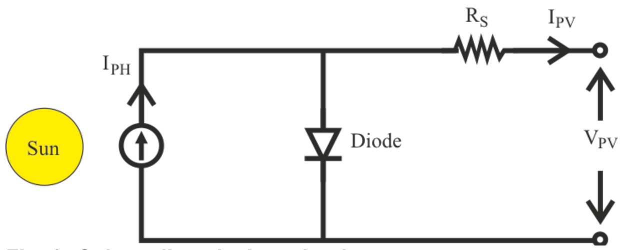

Fig. 1. Solar cell equivalent circuit

Equation 1 presents the calculation of the output voltage of the solar cell:

$$V_{PV} = \frac{N}{\lambda} \ln\left(\frac{I_{SC} - I_{PV} + MI_0}{MI_0}\right) - \frac{N}{M} R_s I_{PV} \quad (1)$$

2.2. Inverter

In the system, an inverter composed of 6 IGBTs with 2 levels is employed to generate an alternating voltage on the loads [8].

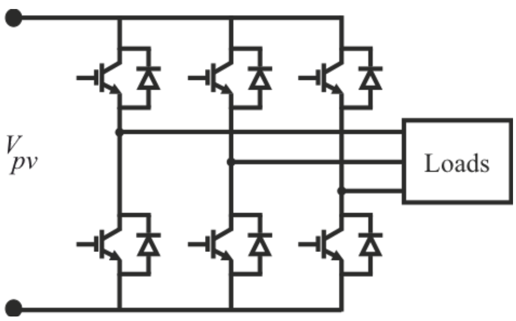

Fig. 2. Two-level inverter with IGBT

2.3. 2DOFPI

Instead of the standard PID controller, a 2DOFPID controller is utilized to improve performance. It is shown in Figure 3 [9].

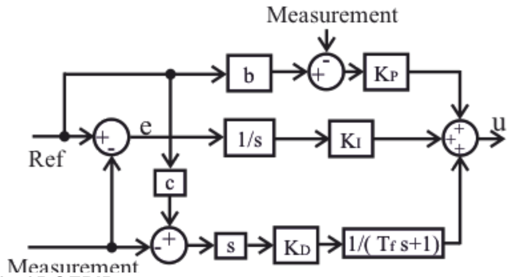

Fig. 3. 2DOFPID

Equation 2 illustrates the mathematical expression of the 2DOFPID controller:

$$u = K_P\left[(br - y) + \frac{1}{T_i s}(r - y) + \frac{T_D s}{\frac{T_d}{N}s + 1}(cr - y)\right] \quad (2)$$

2.4. Harmonics Filter

Active and passive filters can be deployed to eliminate harmonics. Passive filters are implemented with R, L, and C elements. Active filters are dynamic systems realized by switching with semiconductor power electronic elements [9].

3. Results

The simulated system is illustrated in Figure 4. In the solar farm, 2500 solar panels consisting of 50 series and 50 parallel arms are used. A 50kW/10kVAR RL load and a 100kW ohmic load were attached to the system. There is a 2-level inverter made up of 6 IGBTs and a 2DOFPI controller to control it. An LC filter was employed to reduce harmonics in the system.

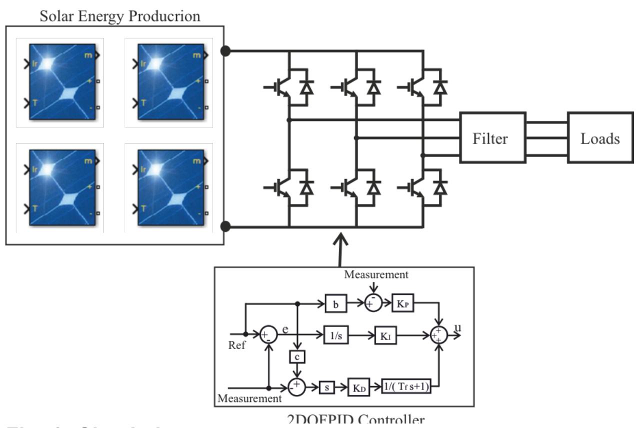

Fig. 4. Simulation system

The change in the amplitude of the voltage on the load is presented in Figure 5.

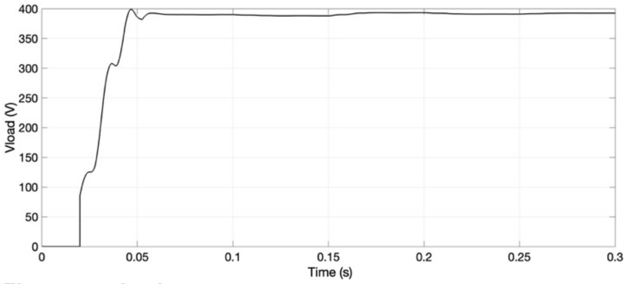

Fig. 5. Load voltage

Here the voltage on the load ranges between 375V and 392V.

The shift in the amplitude of the voltage on the load is visualized in figure 6.

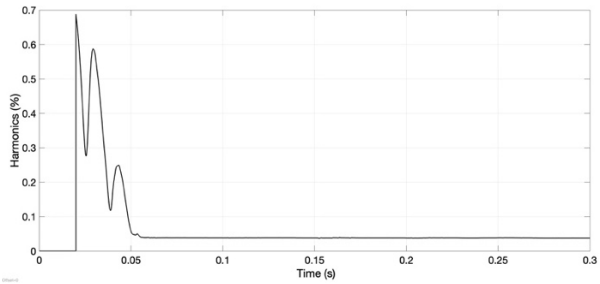

Fig. 6. Load harmonics

There are less than 5% (3.8%) harmonics on the load voltage in a steady state and within the standards.

4. Conclusion

In this simulation study, the control of the voltage on the loads supplied from an off-grid solar power generation plant and keeping the harmonics within the standards were achieved. The oscillation range of the voltage on the load is quite low. Harmonics were kept within the standards with the LC filter used. In further studies, the parameters of the 2DOFPI controller can be optimized by incorporating a maximum power point tracker into the system to achieve better results. In addition, harmonics can be further diminished by using more advanced active filters. All these optimizations will bring additional costs to this system.

References

[1]. Öztürk, H., Yenilenebilir Enerji Kaynakları, Birsen Yayınevi, 2013.

[2]. Akova, İ., Yenilenebilir Enerji Kaynakları, Nobel Akademik Yayıncılık, 2008.

[3]. Bu, Q., Cai, J., Liu, Y., Cao, M., Dong, L., Ruan, R. and Mao, H., The effect of fuzzy PID temperature control on thermal behavior analysis and kinetics study of biomass microwave pyrolysis, Journal of Analytical and Applied Pyrolysis, 2021;158:1-8.

[4]. Yang, R., Longbao, L., Yu, Y., He, X. and Hongsong, L., Hybrid improved particle swarm optimization-cuckoo search optimized fuzzy PID controller for micro gas turbine, Energy Reports, 2021;7:5446-5454.

[5]. Lopez-Bautista, A. O., Flores-Tlacuahuac, A. and Gutierrez-Limon, M., Robust model predictive control for a nanofluid based solar thermal power plant,Journal of Process Control,2020;94:97-109.

[6]. Uzunoğlu, M., Kocatepe, C., Karakaş, A., Yumurtacı, R. and Arıkan, O., Elektrik tesislerinde harmonikler, Birsen Yayınevi, 2003.

[7]. Altas, I. H. and Sharaf, A. M., A Novel On-Line MPP Search Algorithm For PV Arrays, IEEE Transactions on Energy Conversion, 1996;11:4:748-754.

[8]. Rashid, M. H., Güç Elektroniği, Nobel Yayıncılık, 2016.

[9]. Araki M, Taguchi H. Two-degree-of-freedom PID controllers. International Journal of Control Automation and Systems, 2003;1:401-11.