Journal of
Green Energy
Research and Innovation

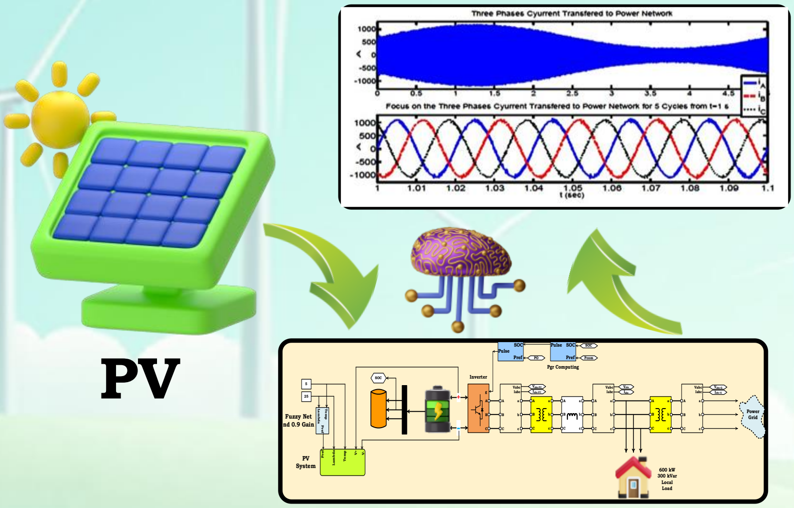
Modeling and Optimization of The Photovoltaic System Connected to the Grid

Yaser Ebazadeh, Reza Alayi, Eskandar Jamali Shakarab, Abdolreza Behvandi

Highlights

- The study focuses on a photovoltaic system with batteries for distributed generation, adjusting power flow based on the battery charge status to optimize energy use.
- The goal is to absorb the maximum power from the PV system under any temperature and radiation conditions, using part of the energy to charge the battery when needed.
- The research presents a structured design with controllers for efficient energy management, ensuring optimal power extraction from the PV system and effective integration into the grid or local load.

Graphical Abstract



Use your device to scan and read the article online

Citation
Y. Ebazadeh, R. Alayi , E.J. Shakarab, and A. Behvandi, " Modeling and Optimization of The Photovoltaic System Connected to the Grid," *Journal of Green Energy Research and Innovation*, vol. 2, no. 1, pp. 32-43, 2025.

https://doi.org/10.61186/jgeri.2.1.32

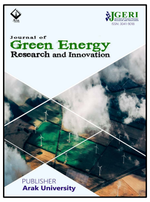
JGERI
Journal of Green Energy Research and Innovation

Journal of Green Energy Research and Innovation 2.1 (2025) 32-43

Online ISSN: 3041-9018

Journal of Green Energy Research and Innovation

Journal Homepage: www.jgeri.araku.ac.ir



Modeling and Optimization of The Photovoltaic System Connected to The Grid

Yaser Ebazadeh [1], Reza Alayi [2,*], Eskandar Jamali Shakarab [2], Abdolreza Behvandi [3]

[1] *Department of Computer Engineering, Germi Branch, Islamic Azad University, Germi, Iran.*
[2] *Department of Mechanical Engineering, Germi Branch, Islamic Azad University, Germi, Iran.*
[3] *Department of Electrical Engineering, Ramhormoz Branch, Islamic Azad University, Ramhormoz, Iran.*

ARTICLE INFO

Keywords:
Photovoltaic,
Controller,
On-grid,
Electrical energy.

Article History:
Received: 11 July 2024;
Revised: 20 August 2024;
Accepted: 11 September 2024.

Article type:
Research Article

* ***Corresponding author***
E-mail address:
reza.alayi@yahoo.com (R. Alaiy)

ABSTRACT

In recent years, distributed production as a source of local loads and continuous economic exploitation has gathered attention. On this thread, this study focuses on distributed production using a photovoltaic package with batteries so that the power drawn from the distributed generation system for injection into the global network or receiving it is adjusted based on the battery charge status. The goal is to absorb the maximum power received from the photo-voltaic system at any temperature and hypothetical radiation. If the battery charge is not optimal, part of this power is applied to the battery for charging. By presenting a suitable structure, a photovoltaic system with a battery package is presented as a distributed generation source with the design of appropriate controllers. The results showed that at any temperature and radiation, the maximum power received from the photovoltaic system could be estimated. By controlling switching, a converter, the required amount of energy can be obtained from the photovoltaic system. It can be concluded that such a structure, as a desirable distributed generation source, is realized. With the proper design of the necessary controllers, optimal management can be done for power management.

1. Introduction

Distributed production as a source of local loads as well as continuous and economic exploitation have been considered by researchers in recent years. For this reason, different structures and several control algorithms have been presented in most different research [1-3]. In some research, the issue of island-building and the recognition of the necessity of island-building to continuously feed the local load has been considered [4-6] in which the island-building problem is investigated when the national network is shut down and the islandization of the distributed generation system is intelligently designed by terminal voltage and network frequency to detect transient errors from the total blackout of the system [7,8]. In the IEEE 929-2000 standard, the islanding conditions of the distributed generation system are described from the national network, but the main issue in observing this standard is the detection of transient errors and disturbances caused by local load changes from the national network blackout [9-11]. A control technique has been introduced to determine the necessity of island-building in which only local and available parameters are measured and remote signals are excluded [12,13]. Also, without the use of telecommunication signals, the connection of the scattered system and the global network is designed using a hybrid technique based on multi-inverter performance [14,15]. In addition, in [16,17] a method for safe detection of island-building based on reactive power flowing under normal conditions and its investigation during sudden changes is presented, and the same method has been carried out in [18] taking into account the power factor and its sudden changes, in which after deciding to island-building, the disconnection order is sent to the switch. In [19,20] considering the moment of a sharp drop in active and reactive power, the island-building problem was analyzed. In 2022 [21] presented a collaborative Optimization of PV Greenhouses and Clean Energy Systems in Rural Areas. The purpose of this research a novel method for optimizing the collaboration between photovoltaic greenhouse load control and rural energy systems. The combined coordination model of agriculture and energy networks is established, and the combined model involves carbon, electrical energy, and thermal energy. Fu et al. [22] have done modeling with the purpose of Stochastic Optimal Planning of Distribution Networks Considering a Dynamic Correlation and Dimension Reduction. Fu et al. [23] presented a statistical machine-learning model for capacitor planning considering uncertainties in photovoltaic power.

The results verify that the proposed model greatly improves planning performance while meeting accuracy requirements. The case study also considers a realistic power distribution system operating under stressed conditions.

This paper discusses the use of distributed production with a photovoltaic system and batteries. The power from this system is adjusted based on the battery charge status when it is either being injected into the global network or received. The goal is to maximize the power received from the photovoltaic system regardless of temperature and radiation levels. If the battery charge is not optimal, some of this power is used to charge the battery. The paper first describes the photovoltaic system model, then designs the necessary controllers. Finally, simulation results are presented to demonstrate the effectiveness of the proposed structure.

2. Materials and Methods

2.1. Structure description

The structure introduced in this paper consists of a photovoltaic system connected to a DC/DC converter whose output is connected to a battery package with the appropriate voltage, shown in Figure 1. The output of the converter is connected to a two-level inverter and after connecting to a transformer and a harmonic filter, the local load is fed through a distributed generation system and global network. The distributed generation system is connected to the global network through a distribution transformer and the local load is combined through the distributed generation system and global network. In this structure, two separate controllers are designed as follows:

- Power controller of a photovoltaic system, which absorbs reference and determines power from the photovoltaic system at any given temperature and radiation. This will be done by adjusting the pulse switching of the dc/dc converter, and in fact, the pulse switching controller of the mentioned converter adjusts the power received from the photovoltaic system to its reference value.
- The power controller is exchanged between the distributed generation system and the global network, which is done by adjusting the pulse switching of the inverter connected to the DC/DC converter and adjusting the transmission power of the photovoltaic/battery set to the reference value. It is obvious that when the power transferred from the distributed generation system is less than the power generated by the photovoltaic system, the rest of the absorbed power from the photovoltaic system is applied to the batteries and sets them in charging conditions. When the transmission power is higher, the batteries will supply the rest of the power and will be in a discharged state.

2.2. Modeling photovoltaic system

A photovoltaic system consists of several series/parallel cells as shown in Figure 2 as described in [12, 24-26] on how they are modeled. In modeling the system, a current source whose value depends on the sun's radiation is used and the relationships governing the voltage and current of this system are per Equations (1-4).

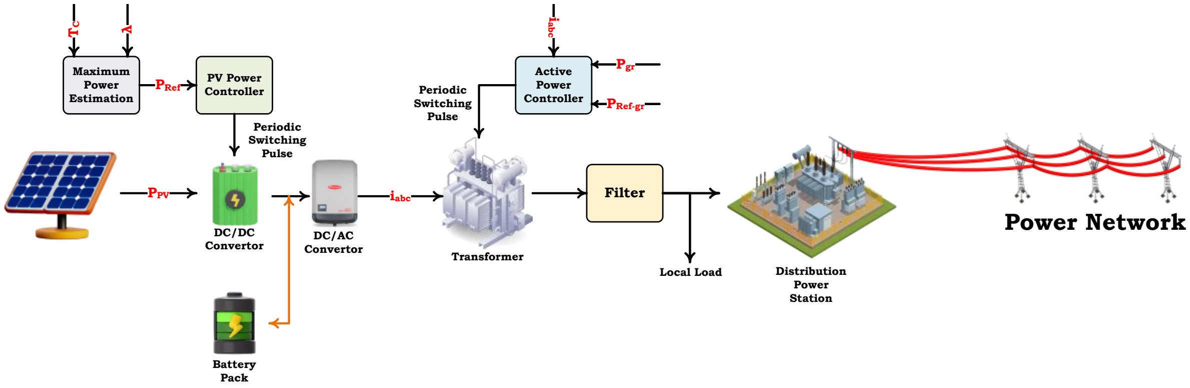


Figure 1. Power generation system with battery storage connected to the grid.

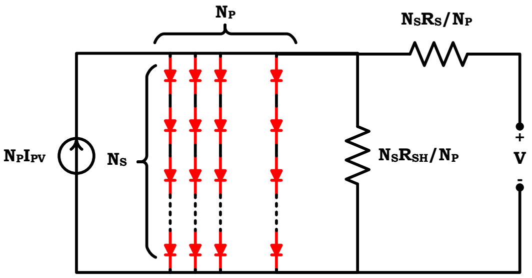


Figure 2. Model of the photovoltaic system consisting of series/parallel cells [12].

$$I_{PV} = \left[I_{sc} + K_l\left(T_{PV} - T_{ref}\right)\right], \lambda \tag{1}$$

$$I_{RS} = \frac{I_{sc}}{e^{\frac{q,V_{ec}}{N_S,k,A,T_{PV}}} - 1} \tag{2}$$

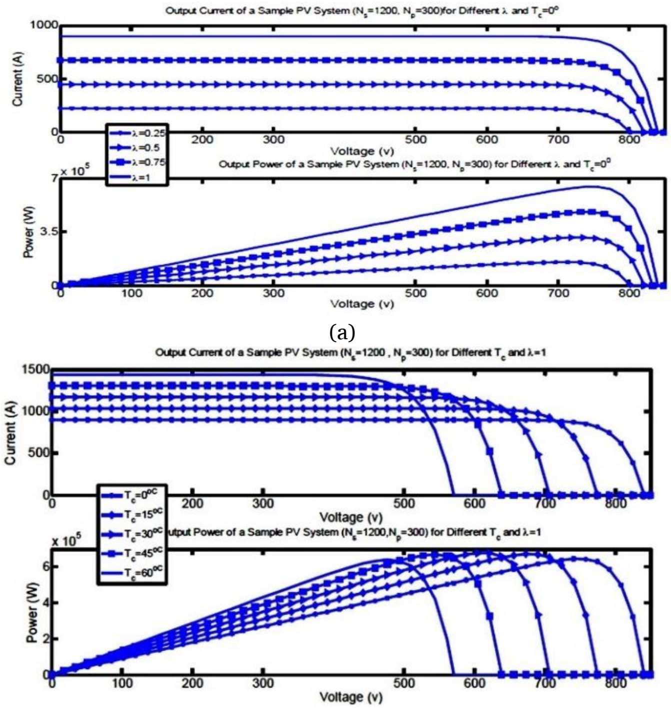
$$I_S = I_{RS}\left(\frac{T_{PV}}{T_{ref}}\right)^3 \cdot e^{\frac{q,G,\left(\frac{1}{T_{ref}\,T_{PV}}\right)}{k,A}} \tag{3}$$

$$I = N_P, I_{PV} - N_P, I_s\left[e^{\frac{q\left(\frac{V}{N_S+}\cdot\frac{R_S.I)}{N_p}\right)}{k,T_{PV}\cdot A}} - 1\right] - \frac{\frac{N_pV}{N_s}+R_s, I}{R_{sh}} \tag{4}$$

According to the above equations, voltage, current, and therefore the power of the system will depend on the temperature and radiation of the environment. In Figure 3, the sample curves of a photovoltaic system whose parameters are described in Table 1 are drawn from Equations (1-4).

Table 1. Parameters of a photovoltaic arrays.

Parameter	Rate
N_s	1000
N_p	250
K_i	0.025
V_{oc}	1200 × 0.6 = 720
I_{sc}	300 × 3.6 = 1090
T_{ref}	25°C
R_{sH}	10000 Ω
R_s	10 μΩ
A	3.3



(a)

(b)

Figure 3. Voltage-current curve and power voltage of a sample photovoltaic package at (a) certain temperatures and different radiations, and (b) at different temperatures and certain radiations.

2.3. Battery modeling

A well-known battery model is the built-in resistance model [7,8,27,28], where the battery's internal resistance is resisted in charging and discharging modes and fits the charging status. Open circuit voltage is also defined according to the charging state. This model is illustrated and Figure 4 also shows the internal resistance and open-circuit voltage for a sample battery.

Battery charging mode, which is one of the most important control parameters of the system discussed in this paper, can be calculated from Equations (5-7) [7-9]:

$$SoC = \frac{A,h - Ah_{seed}}{A,h} \tag{5}$$

$$Ah_{used} = Ah \times \left(1 - SoC_{(0)}\right) + \int \frac{I_b}{3600} dt \tag{6}$$

$$I_b = \frac{V_{\mathrm{oc}} - \sqrt{4R_{\mathrm{int}} \cdot P_{\mathrm{el}}}}{2R_{\mathrm{int}}} \tag{7}$$

In which, A,h and Ah_{seed} are the instantaneous battery clock ampere and clock ampere consumed battery, respectively.

2.4. DC/DC and DC/AC inverters

According to the proposed structure of this paper, which is shown in Figure 1, a DC/DC converter is applied to control the absorbed power of the photovoltaic system, which is used through the switching pulse width of this model at a specified switching frequency. Figure 5(a) shows this incremental converter. In Figure 5(b), a two-level inverter used in the structure is shown and its output power will be controlled by switching pulses.

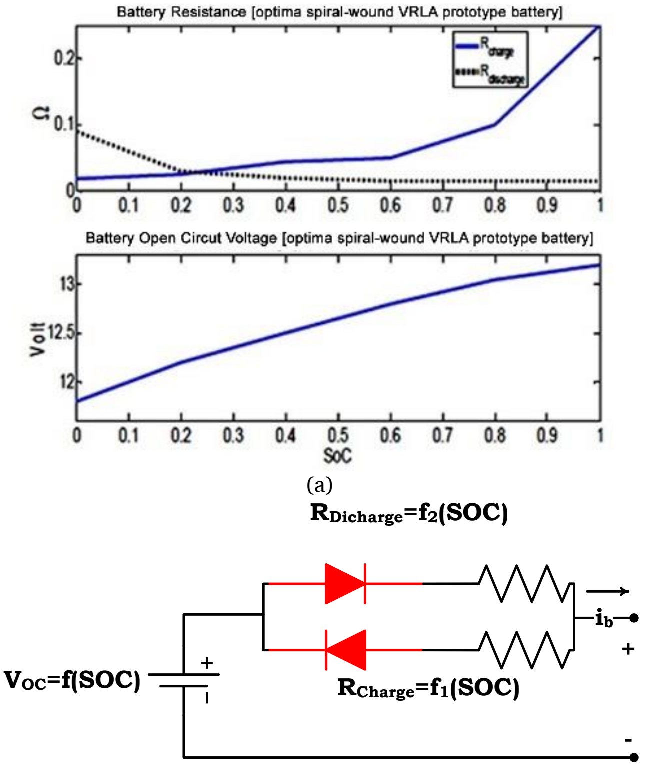
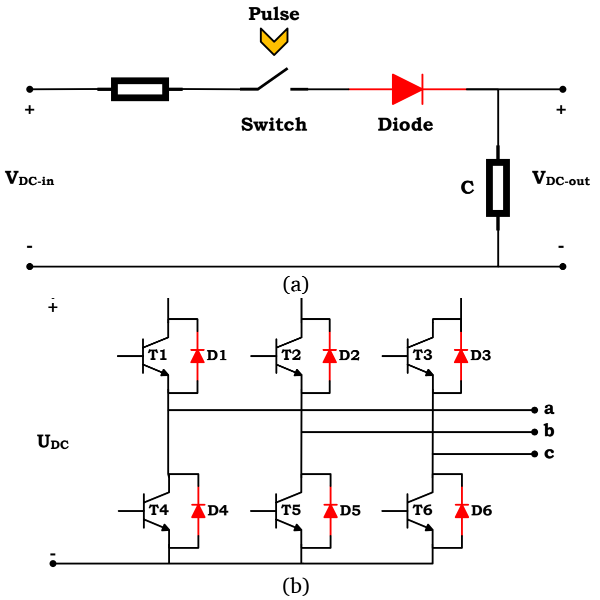


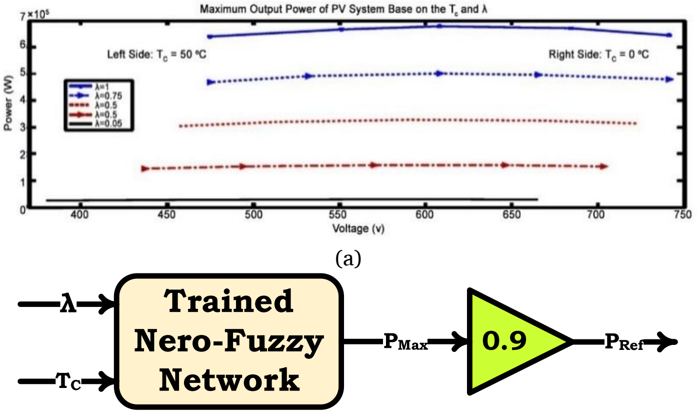
Figure 4. (a) Open circuit voltage and internal resistance of a sample battery, (b) Battery Internal Resistance Model.



(a)

(b)

Figure 5. (a) Incremental DC/DC converter implemented, and (b) Two-level inverter used in the structure.



(a)

(b)

Figure 6. (a) Maximum power received from sample systems listed in Table 1 in terms of temperature and radiation, (b) Fuzzy-neural network.

2.5. *Estimation of maximum absorbable power from a photovoltaic system*

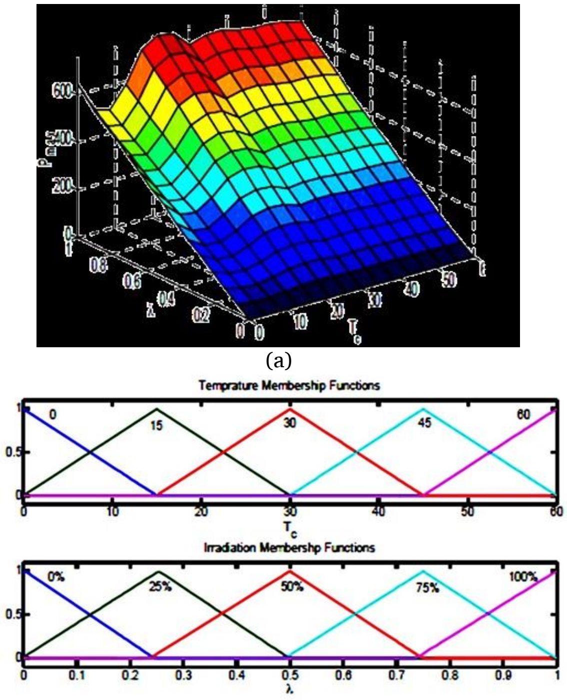
According to the previous explanations, the maximum absorbable power from the photovoltaic system depends linearly on two parameters temperature and ambient radiation. Therefore, it is necessary to estimate the maximum receivable power for each photovoltaic system with specific parameters. According to the parameters given in Table 1 used for the photovoltaic system in this paper, the maximum power received is obtained according to Figure 6(a). To estimate the maximum absorbable power, Figure 6(a) as data have been applied to a form-matching neural fuzzy network Figure 6(b). The membership functions of this network are considered by dividing radiation and temperature values into 5 different intervals according to Figure 12 and after network training, its fuzzy surface is formed according to Figure 11. To prevent damage to the photovoltaic system, after estimating the maximum power absorbed by the fuzzy neural network, 90% of this power is used as reference power and is applied to the absorbed power controller of the photovoltaic system.

2.6. *Design of essential controllers*

It is necessary to design two separate controllers for the whole system, which will be designed as follows.

The absorbed power controller of the photovoltaic system, which should be absorbed from the photovoltaic system at any temperature and radiation, can absorb the reference power determined by the fuzzy neural network. This controller performs power adjustment based on the DC/DC converter switching control described in the following sections.

The transfer power controller to the global network is required to adjust the transmission power to the network by the reference value. This is done by controlling the inverter switching described in the following sections.



(a)

(b)

Figure 7. (a) Fuzzy surface of the sample fuzzy-neural network, (b) Trained network input membership functions.

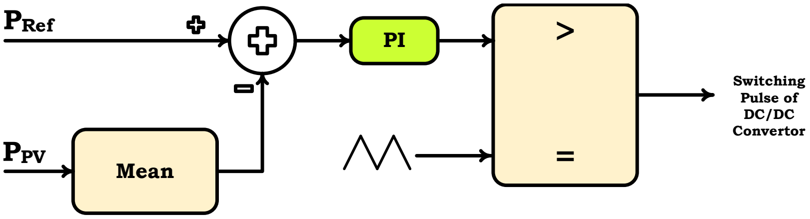


Figure 8. Generation procedure of pulse switching DC/DC converter to control the absorbed power of the photovoltaic system.

The transmission power will also be determined from the battery charge mode. This is in such a way that if the battery charging mode is desirable, more powerful than the nominal of the photovoltaic system is transferred to the network, which in this case means provision will be part of the power injected by the batteries. Also, if the battery charging mode is low, the power to the network is less than the available power of the photovoltaic system, which indicates the transfer of part of the power generated by the photovoltaic system to the batteries and causes them to be charged.

2.7. Power controller absorbed from a photovoltaic system

This controller must adjust the power transmitted from the photovoltaic system regarding the reference value generated by the trained fuzzy neural network. For this purpose, at a specified switching frequency, the pulse width of the switching is adjusted according to Figure 8.

2.8. Controller transferred to the network

For this purpose, the output current of the inverter is adjusted after converting to the dq0 frame by switching the controller with mend hysteresis. According to Figure 9, by stabilizing the two components 0 and q, the d component adjusts the current so that the transfer power to the network is equal to its reference value.

Herein, according to the control algorithm, the amount of power reference transferred to the global network should be determined according to the battery charge status, which is applied using a data table as shown in Table 2. K_p is defined as the available power factor of the photovoltaic system and the transfer of power to the network is determined by Equation (8):

$$P_{\text{Ref-Tr}} = K_p, P_{\text{Ref-PV}} \tag{8}$$

3. Results

3.1. Simulation

The structure shown in Figure 1 is simulated in Simulink/ MATLAB@ environment according to Figure 10 and the parameters related to other parts of the system are under the values listed in Table 3 to 6.
To prove the proposed control performance, different conditions have been analyzed which are discussed in the next section.

3.2. Maximum radiation status, maximum charging mode in battery, and variable temperature

In this section, the simulation is performed for a battery with a full charge and maximum radiation ($\lambda = 1$). The ambient temperature is considered a variable temperature according to Figure 11(a). In addition, the temperature changes are considered exaggerated and at a faster rate than the actual state, which is due to the reduction of the simulation time, and, if the response to this situation is desirable, in real conditions that the speed of temperature changes is less, the desired response will surely be achieved.

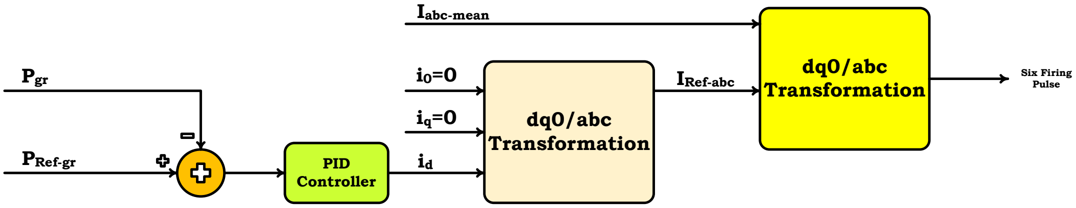


Figure 9. Injectable power controller to the network of the distributed generation system.

Table 2. Input data for battery charge status [29].

Soc	100%	95%	90%	85%	80%	75%	70%
Kp	1.7	1.7	1.5	1.35	1.15	1	0.75

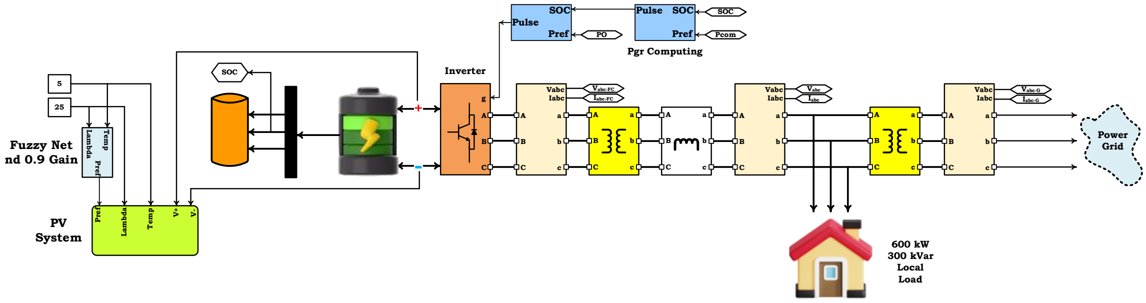


Figure 10. Injectable power controller to the network of the distributed generation system.

Table 3. Features of implemented batteries.

Parameter	Quantity
Np	65
A.hCap	110
Vb	10

Table 4. Transformer features connected to inverters.

Parameter	Quantity
N1/N2	0.5/0.5
Srate	1
Lm	470
Rc	470
L1 + L2	0.025
R1 + R2	0.0015

Table 5. Transformer features connected to the grid.

Parameter	Quantity
N1/N2	0.5/0.5
Srate	1
Lm	470
Rc	470
L1 + L2	0.025
R1 + R2	0.0015

Table 6. Features of load and overall grid.

Parameter	Quantity
Ssc	520
V	30
F	50
PL	750
QL	350
VL	360 × 1.08

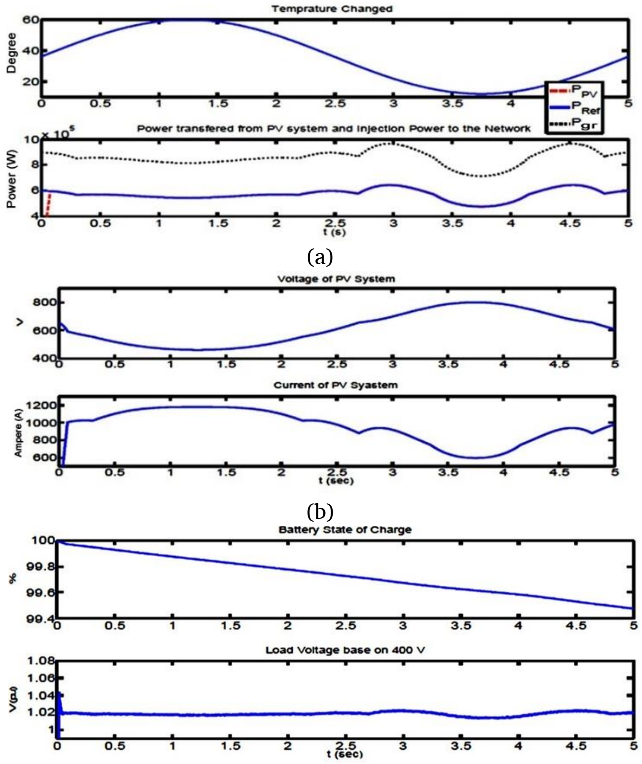
In Figure 11(a), in addition to ambient temperature, the power drawn from the photovoltaic system (p_{pv}), injectable power to the global grid (pπr) as well as the reference power commanded by the controller (p_{COM}) are displayed. In Figure 11(b), the voltage and current of the photovoltaic system are displayed, which are changed according to the variable temperature and adjusted by the controller at 90% of its peak value. Since the battery charging status has been favorable, the power transferred to the network exceeds the power drawn from the photovoltaic system, which means that part of the power is generated by the batteries, and conspicuously in these conditions, the battery is discharging conditions. This is specified in the upper part of the Figure 11(c). In addition, the load voltage is also stabilized by the inverter on the value of 1pu as specified in the lower part of Figure 11(c).

3.3. Temperature and specified charging mode and different radiation

In this section, simulation is performed for a certain temperature of 25 °C, charging status of 80% battery, and variable radiation by Figure 12(a) which, due to the reduction of simulation time, radiation changes are considered more than real conditions. According to Figure 12(a), the power transferred to the network is exactly equal to the power absorbed from the photovoltaic system, and in other words, the battery has no involvement in the transmission of power to the network. The lack of power absorption from the battery is due to the resort state that has a battery charge mode and no power is absorbed from the battery. According to these results, it can be concluded that the performance of the controller is accurate, and the transmission power to the network and absorbed from the photovoltaic system is set to the desired and predetermined values. In Figure 12(b), to show the harmonic state of the system and the function of the embedded filter, the current waveform is shown along with a small part of it, and as it is known, the harmonic state of the flowing current is appropriate.

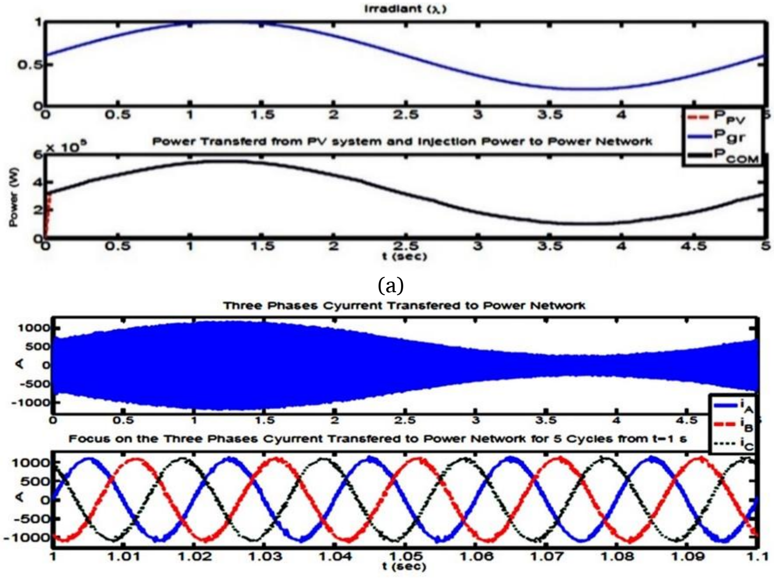
3.4. Specified temperatures and radiation and different modes of battery charge

In this section, simulation is performed for constant temperature and radiation, but different charging conditions have been performed. The injectable active power is shown in the global network in Figure 13(a). It is seen that when the charging situation is better, due to the battery's participation in the injection of active power, more power is transferred to the network. In addition, in Figure 13(b), the battery charging status is shown. Due to this, when the battery is charged more, the battery's discharge is done more quickly. Also, as is evident in the lower part of Figure 13(b), in 70% of the charge, the battery is in charge and the charging mode is incremental.



(c)

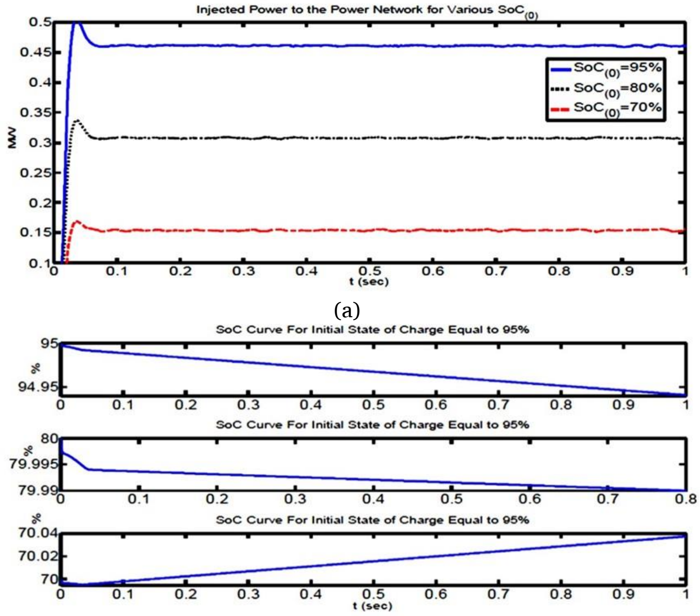
Figure 11. Maximum radiation status, maximum charging mode in battery, and variable temperature.



(a)

(b)

Figure 12. (a) Injectable power to the network and drawn from photovoltaic systems under variable radiation conditions, (b) Current waveform and part of it under variable radiation conditions.



(a)

(b)

Figure 13. (a) Injectable power to the network in different battery charge situations, (b) Changes in battery charging mode under different battery mode conditions.

4. Conclusions

In this paper, by presenting a suitable structure, a photovoltaic system with a battery package is presented as a distributed generation source with the design of appropriate controllers. The results of this paper showed that at any temperature and radiation, the maximum power received from the photovoltaic system can be estimated, and by controlling switching, a converter, the required amount of power can be obtained from the photovoltaic system. On the other hand, by designing another control, and controlling the inverter switching, it managed the power transmitted from the battery set and the photovoltaic system and divided between the two sources of battery and photovoltaic in a way that the battery charge mode always remained in the above-mentioned state. According to the results, it can be concluded that such a structure, as a desirable distributed generation source, is realized, and with the proper design of the necessary controllers, optimal management can be done for power management. To continue the process of studying, it is recommended to provide different structures for controllers for better performance as well as different switching structures of converters to reduce switching losses, or to use multilevel inverters.

Nomenclature

The ideal coefficient related to the photovoltaic cell model	A
Current battery (A)	I_b
Current source related to photovoltaic system model (A)	I_{PV}
Short circuit current in diode used in photovoltaic cell model (A)	I_{sc}
Reverse saturation current in diode used in photovoltaic cell model (A)	I_{RS}
Boltzmann's constant	K
The temperature effect coefficient on the current of the diode used in the photovoltaic cell model	K_I
The number of cells in series in the photovoltaic system	N_s
Photovoltaic system power (kW)	P_{PV}
The power injected from the distributed generation system to the network (kW)	P_{gr}
The maximum power available from the photovoltaic system (kW)	$P_{Max\text{-}PV}$
The numerical value of the electron	q
The number of parallel cells in the photovoltaic system	N_P
The series resistance of each diode in the photovoltaic system (Ω)	R_s
The parallel resistance of each diode in the photovoltaic system (Ω)	R_{sh}
Internal resistance of the battery model (Ω)	R_{int}
The temperature of the environment around the photovoltaic system (°C)	T_{PV}
Reference temperature in the photovoltaic system model (°C)	T_{ref}
Open circuit voltage in the battery model (V)	V_{oc}
Radiation coefficient in the photovoltaic system model	λ
The intensity of the sun's radiation (W/m^2)	G
Number of batteries	N_p
Capacity of each battery (A.h)	$A.h_{Cap}$
Nominal voltage of each battery (V)	V_b
Nominal voltage on both sides (kV)	N_1/N_2
Nominal power (MVA)	Srate
Magnetization Endoctanus (Pu)	L_m
Resistance of core losses (Pu)	R_c
Endoctans Dispersion (Pu)	L_1+L_2
Resistance of two coils (Pu)	R_1+R_2
The magnitude of the short circuit of the grid (MVA)	S_{sc}
Nominal voltage (kV)	V
Frequency (Hz)	F
Local Active Load Power (kW)	P_L
Local reactive Load Power (kVAR)	Q_L
The nominal voltage of local loads (V)	V_L

References

[1] R. Alayi, F. Zishan, et al., "A Sustainable Energy Distribution Configuration for Microgrids Integrated to the National Grid Using Back-To-Back Converters in a Renewable Power System," *Electronics*, vol. 10, no. 15, 1826, 2021.

[2] L. Mehigan, J. Deane, B. Gallachóir, and V. Bertsch, "A Review of the Role of Distributed Generation (DG) in Future Electricity Systems," *Energy*, vol. 163, pp. 822–836, 2018.

[3] P. D. Huy, V. K. Ramachandaramurthy, J. Y. Yong, K. M. Tan, and J. B. Ekanayake, "Optimal Placement, Sizing and Power Factor of Distributed Generation: A Comprehensive Study Spanning From the Planning Stage to the Operation Stage," *Energy*, vol. 195, 117011, 2020.

[4] L. F. Fuentes-Cortés, and A. Flores-Tlacuahuac, "Integration of Distributed Generation Technologies on Sustainable Buildings," *Applied Energy*, vol. 224, pp. 582–601, 2018.

[5] M. Azmy, "Management of Distributed Generation for Smart Buildings," *Advances in Control Techniques for Smart Grid Applications*, pp. 173–199, 2022.

[6] Fleischhacker, H. Auer, G. Lettner, and A. Botterud, "Sharing Solar PV and Energy Storage in Apartment Buildings: Resource Allocation and Pricing," *IEEE Transactions on Smart Grid*, vol. 10, no. 4, pp. 3963–3973, 2019.

[7] F. Wei, Z. Bo, and X. Fuqiang, "Evaluation on Load Restoration of Distribution System Based on Distributed Generation in Smart Buildings After Extreme Disasters," *Power Generation Technology*, vol. 40, no. 5, p. 440, 2019.

[8] A. D. Georgakarakos, M. Mayfield, and E. A. Hathway, "Battery Storage Systems in Smart Grid Optimised Buildings," *Energy Procedia*, vol. 151, pp. 23-30, 2018.

[9] S. M. Mirbagheri, D. Falabretti, and M. Merlo, "Voltage Control in Active Distribution Grids: A Review and a New Set-Up Procedure for Local Control Laws," *2018 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM)*, pp. 1203–1208, 2018.

[10] R. Alayi, F. Zishan, et al., "Optimal Load Frequency Control of Island Microgrids Via a PID Controller in the Presence of Wind Turbine and PV," *Sustainability*, vol. 13, no. 19, 10728, 2021.

[11] J. Babqi, Z. Yi, and A. H. Etemadi, "Centralized Finite Control Set Model Predictive Control for Multiple Distributed Generator Small-Scale Microgrids," *2017 North American Power Symposium (NAPS)*, pp. 1–5, 2017.

[12] Vukojevic, and S. Lukic, "Microgrid Protection and Control Schemes for Seamless Transition to Island and Grid Synchronization," *IEEE Transactions on Smart Grid*, vol. 11, no. 4, pp. 2845–2855, 2020.

[13] R. Bisht, A. Suresh, and S. Kamalasadan, "Multiple Single Phase Inverters Based Combined Active Power Management and Voltage Regulation of Power Distribution System Based on A Novel Optimal Control Architecture," *2019 North American Power Symposium (NAPS)*, pp. 1–6, 2019.

[14] X. Guo, and W. Chen, "Control of Multiple Power Inverters for More Electronics Power Systems: A Review," *CES Transactions on Electrical Machines and Systems*, vol. 2, no. 3, pp. 255–263, 2018.

[15] K. Naraghipour, K. Ahmed, and C. Booth, "A Comprehensive Review of Islanding Detection Methods for Distribution Systems," *2020 9th International Conference on Renewable Energy Research and Application (ICRERA)*, pp. 428–433, 2020.

[16] R. Sedaghati, and M. R. Shakarami, "A Novel Control Strategy and Power Management of Hybrid PV-FC-SC-Battery Renewable Power System-Based Grid-Connected Microgrid," *Sustainable Cities and Society*, vol. 44, pp. 830–843, 2019.

[17] M. Bajaj, and A. K. Singh, "Grid Integrated Renewable DG Systems: A Review of Power Quality Challenges and State-of-the-art Mitigation Techniques," *International Journal of Energy Research*, vol. 44, no. 1, pp. 26–69, 2019.

[18] S. Kumar, K. K. Mandal, and N. Chakraborty, "Optimal DG Placement by Multi-Objective Opposition Based Chaotic Differential Evolution for Techno-Economic Analysis," *Applied Soft Computing*, vol. 78, pp. 70–83, 2019.

[19] M. N. AlMallahi, M. El Haj Assad, S. AlShihabi, and R. Alayi, "Multi-Criteria Decision-Making Approach for the Selection of Cleaning Method of Solar PV Panels in United Arab Emirates Based on Sustainability Perspective," *International Journal of Low-Carbon Technologies*, vol. 17, pp. 380–393, 2022.

[20] Shaqour, H. Farzaneh, Y. Yoshida, and T. Hinokuma, "Power Control and Simulation of a Building Integrated Stand-Alone Hybrid PV-Wind-Battery System in Kasuga City, Japan," *Energy Reports*, vol. 6, pp. 1528–1544, 2020.

[21] X. Fu, and Y. Zhou, "Collaborative Optimization of PV Greenhouses and Clean Energy Systems in Rural Areas," *IEEE Transactions on Sustainable Energy*, vol. 14, no. 1, pp. 642–656, 2023.

[22] X. Fu, Q. Guo, and H. Sun, "Statistical Machine Learning Model for Stochastic Optimal Planning of Distribution Networks Considering a Dynamic Correlation and Dimension Reduction," *IEEE Transactions on Smart Grid*, vol. 11, no. 4, pp. 2904–2917, 2020.

[23] X. Fu, "Statistical Machine Learning Model for Capacitor Planning Considering Uncertainties in Photovoltaic Power," *Protection and Control of Modern Power Systems*, vol. 7, no. 1, 2022.

[24] R. Alayi, H. Harasii, and H. Pourderogar, "Modeling and Optimization of Photovoltaic Cells with GA Algorithm," *Journal of Robotics and Control (JRC)*, vol. 2, no. 1, 2020.

[25] R. Alayi, A. Sevbitov, M. E. H. Assad, R. Akhmadeev, and M. Kosov, "Investigation of Energy and Economic Parameters of Photovoltaic Cells in Terms of Different Tracking Technologies," *International Journal of Low-Carbon Technologies*, vol. 17, pp. 160–168, 2021.

[26] N. Ganjei, F. Zishan, et al., "Designing and Sensitivity Analysis of an Off-Grid Hybrid Wind-Solar Power Plant with Diesel Generator and Battery Backup for the Rural Area in Iran," *Journal of Engineering*, vol. 2022, pp. 1–14, 2022.

[27] R. Alayi, M. Jahangiri, et al., "Modelling and Reviewing the Reliability and Multi-Objective Optimization of Wind-Turbine System and Photovoltaic Panel with Intelligent Algorithms," *Clean Energy*, vol. 5, no. 4, pp. 713–730, 2021.

[28] M. Jahangiri, F. Karimi Shahmarvandi, and R. Alayi, "Renewable Energy-Based Systems on a Residential Scale in Southern Coastal Areas of Iran: Trigeneration of Heat, Power, and Hydrogen," *Journal of Renewable Energy and Environment*, vol. 8, no. 4, pp. 67-76, 2021.

[29] D. Azuatalam, K. Paridari, et al., "Energy Management of Small-Scale PV-Battery Systems: A Systematic Review Considering Practical Implementation, Computational Requirements, Quality of Input Data and Battery Degradation," *Renewable and Sustainable Energy Reviews*, vol. 112, pp. 555–570, 2019.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Bibliography

Yaser Ebazadeh received the BS.c. in Computer Science from Tabriz University, Iran in 2004, MS.c. in Computer Engineering from Tabriz Branch, Islamic Azad University, Tabriz, Iran in 2017, and is currently pursuing the full-time Ph.D. degree in Computer Engineering of Qazvin Branch, Islamic Azad University, Qazvin, Iran. His major research interests include the resource management, task scheduling, and security of Cloud and Fog computing.

Email: Yaser_ebazadeh@yahoo.com

ORCID: 0000-0002-6106-6682

Contribution Statement: Data curation, Software, Validation, Visualization.

Reza Alayi holds a MSc. and a PhD in energy systems engineering from science and research branch Islamic Azad University (IAU) in Iran. He is leading the "Energy engineering" group the Saveh for Energy institute of higher education. He currently works Assistant Professor at the Department of Mechanical Engineering, Islamic Azad University Germi Branch. Dr. Alayi research is mainly focused energy systems analysis of renewable energy, especially solar energy and energy management in buildings and industry.

Email: reza.alayi@yahoo.com

ORCID: 0000-0003-2190-1185

Contribution Statement: Conceptualization, Project administration, Supervision.

Eskandar Jamali Shakarab received the BS.c. in Mechanical Engineering-design of solids from Tabriz University, Iran in 1999, MS.c. in Mechanical Engineering-energy conversion from Tabriz University, Iran in 2005, and Ph.D. degree in Mechanical Engineering-energy conversion of Science & Research Branch, Islamic Azad University, Tehran, Iran in 2024. His major research interests include the Thermodynamics, Renewable energies, Energy optimization in thermal systems, Design of heat exchangers, Design and analysis of power plants, Computational Fluid Dynamics (CFD) and Fluids Mechanic.

Email: Jamali917@yahoo.com

ORCID: 0000-0003-1193-6552

Contribution Statement: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Roles/Writing - original draft, Writing-review & editing.

Abdolreza Behvandi was born in 1987 in Iran. He received his B.Sc., M.Sc., and Ph.D. degrees all in Electrical Engineering (Power Systems) in 2010, 2012, and 2019 from Isfahan University of Technology, Isfahan University, and Shahid Chamran University of Ahvaz, respectively. Currently, he is an Assistant Professor at Department of Electrical Engineering, Ramhormoz Branch, Islamic Azad University, Ramhormoz, Iran. His special interests are power system studies, power system protection, renewable energy, and microgrids.
Email: rezabehvandi@gmail.com
ORCID: 0000-0002-4879-1994
Contribution Statement: Data curation, Formal analysis, Investigation, Resources, Validation.