International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

September 2018 | Issue 36 | Volume 10 | Number 3 | Pages 14-18

POWER MANAGEMENT STRATEGY OF GRID CONNECTED SOLAR POWER GENERATION

D. Celik M.E. Meral

Department of Electrical and Electronics Engineering, Van Yuzuncu Yil University, Van, Turkey
dogancelik@yyu.edu.tr, emeral@yyu.edu.tr

Abstract- This paper presents a power management (PM) strategy based on various operating scenarios to share power among solar system, electric grid and load. The synchronous reference frame-proportional integral (SRF-PI) based control strategy is applied to the grid connected three phase inverter based solar power generation. The compared with previous similar studies, the excess power supplied by solar cell is transmitted to grid without using storage devices. The characteristic of solar sell is examined by changing radiation and temperature. In order to verify the availability of the power sharing control based PM strategy, proposed system is established and implemented by using PSCAD/EMTDC software package.

Keywords: Solar Power, Power Management, Power Sharing, SRF-PI Controller.

I. INTRODUCTION

With increasing of distributed generation systems (DGs) in AC microgrids, the power management (PM) strategies of different DGs, loads and electric grid have been a great importance [1]. Therefore, a proper PM strategy based power sharing control among parallel sources is required. Some control strategies for power sharing control of hybrid power systems have been proposed in the literature [2, 3, 4]. Reference [2] proposes two control methods as unit power flow and feeder power flow in grid connected hybrid system (photovoltaic and fuel cell). Power sharing method based PM strategies are discussed to share the power among the available AC/DC microgrids-multiple sources in [3, 5].

Reference [4] also presents an overview of PM strategies for hybrid AC/DC microgrids. The fuzzy control based PM strategy is used for maximum utilization from renewable energy sources [6]. The battery storage devices are modeled and wind turbine is connected to the electric grid in order to optimize power flow among the battery, the wind farm, and the electric grid in [7]. The PM strategy is designed for a grid-connected solar-fuel cell hybrid system to reduce energy cost, taking into account the time-of-use electricity tariff in [8, 9, 10, 11].

Particle swarm optimization-proportional integral (PI) controllers based PM is used to control of hybrid renewable energy sources in order to ensure power demand between grid, battery devices and energy sources [12]. Grid connected hybrid system is presented and controlled by synchronous reference frame-PI based current controller in [13]. While some of abovementioned studies consist of storage elements to store excess power in grid connected mode, other studies discuss PM strategies in islanded mode. In this paper, the configuration of grid connected solar power system is shown in Figure 1.

This paper proposes a SRF-PI based PM strategy to design power flow among solar cell, electric grid and load power demand. The SRF-PI based power controller enhances to share power between distribution systems. The three phase inverter is connected between DC output of solar system and AC grid. Solar cell is modeled, design and analyzed under variation of temperature and radiation. Various PM scenarios are performed in the grid connected solar power system. The excess power supplied by solar energy is also transferred to the grid without using storage devices.

The rest of paper is arranged in following. Section I overviewed the pervious similar studies. The characteristic of solar system is analyzed and discussed in Section II. The SRF-PI controller based PM strategies are presented and tested under various cases such as different load values and night/day mode for solar system in Section III. Section IV summarized the conclusion derived from this study.

II. SOLAR POWER

In accordance with the circuit diagram of a solar cell as shown in Figure 2, the solar current is determined by Equation (1) [14]. The characteristic of a solar cell depends on temperature as shown in Equation (1).

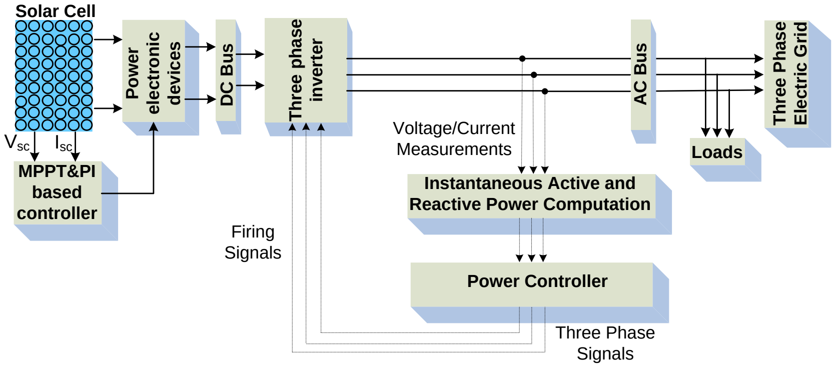

Figure 2. The configuration of grid connected solar power system

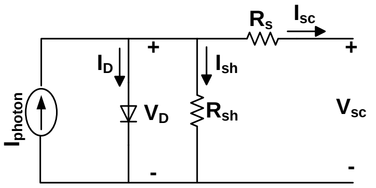

Figure 2. Circuit diagram of a solar cell

The shunt resistance R_{sh} is used for accounts of leakage current [15] and R_s, I_{sc}, V_{sc}, k, q, I_o, T and T_{ref} are represent the internal resistance of the cell, the solar cell current, the reverse saturation current, open circuit voltage, the Boltzmann's constant, the charge of an electron, operating and reference temperature of solar cell. The solar cell system is modeling based on equivalent with mathematical equations. The relationship between solar current and voltage is written as follow equations [16, 17].

$$I_0 = I_{oref}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\left(\frac{qE_g}{nk}\right)\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)\right] \quad (1)$$

$$I_{sc} = I_{ph}\left(1+C_0\left(T-273.15\right)\right)-I_o\left(e^{\frac{q(V_{sc}+I.R_s)}{nkT}}-1\right)-\frac{(V_{sc}+IR_s)}{R_{sh}} \quad (2)$$

$$P_{sc} = \eta_{boost\_conv} V_{sc} I_{sc} \quad (3)$$

The incremental conductance algorithm based maximum power point (MPP) is implemented in PSCAD/EMTDC software. The characteristic of solar system is tested under variation radiation and temperature as shown in Figure 3 and 4. The DC/DC boost converter is connected to the solar cell. The control of converter is based on MPP and PI controller. Incremental conductance algorithms based MPP has been proposed to track maximum power under weather conditions. The MPP can be obtained by changing the reference voltage with the amount of ΔV. As shown in Figure 4a, solar cell voltage V_{SC} is tracking MPP voltage V_{mpp}, successfully. The incremental conductance method exhibits good performance under rapidly changing radiation and temperature in Figure 4b and 4c. The effect of variation of radiation has been also examined on solar cell current and power.

III. SRF-PI CONTROLLER BASED PM STARTEGY

A. SRF-PI Based Power Controller

The well-known synchronous reference frame (SRF) based various control method can be used for control of the active power filters, micro-grid, distribution generation systems [18]. In balanced three-phase systems, SRF-PI based power and current controllers provide good performance. The three AC signals V_{abc}, I_{abc} convert to in synchronous reference frame V_{dq}, I_{dq} in order to use in power and current controller. The schematic diagram of SRF-PI based control strategy consist three main parts: i) synchronization unit, ii) power controller and iii) current controller as shown in Figure 5. The orthogonal voltage-current signals V_{dq}, I_{dq} using in power and current controller is expressed in following Equations (4)-(6).

$$S_d = \left[I_{dref} - I_q\right].\left[K_p + K_i / s\right] + \omega.L.I_d + V_d \quad (4)$$

$$S_q = \left[I_{qref} - I_d\right].\left[K_p + K_i / s\right] - \omega.L.I_q + V_q \quad (5)$$

$$\begin{cases} I_{dref} = \dfrac{2}{3}\left(\dfrac{V_d P_{ref} + V_q Q_{ref}}{V_d^2 + V_q^2}\right) \\ I_{qref} = \dfrac{2}{3}\left(\dfrac{V_q P_{ref} - V_d Q_{ref}}{V_d^2 + V_q^2}\right) \end{cases} \quad (6)$$

Active and reactive powers related with orthogonal d-q signals are written in following [19]:

$$\begin{cases} P_{inv} = \dfrac{3}{2}\left(V_d I_d + V_q I_q\right) \\ Q_{inv} = \dfrac{3}{2}\left(V_q I_d - V_d I_q\right) \end{cases} \quad (7)$$

B. PM Strategies

The remaining power or excess power (ΔP) supplied by solar system is calculated by the difference between grid P_g and the load electric power P_L. The excess power ΔP can be transmitted to the grid storage devices. The flowchart of the PM strategies is shown in Figure 6.

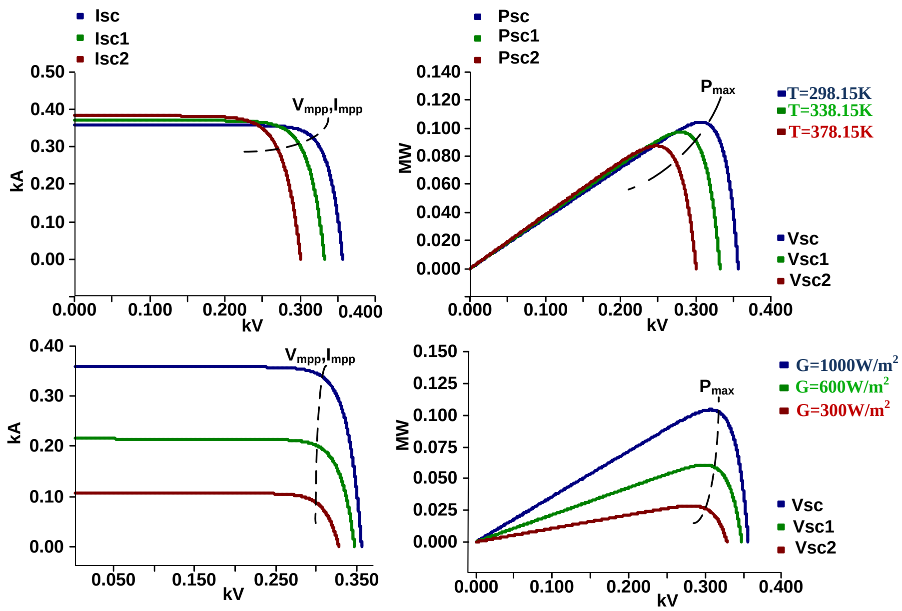

Figure 3. The characteristic of solar cell under various weather conditions

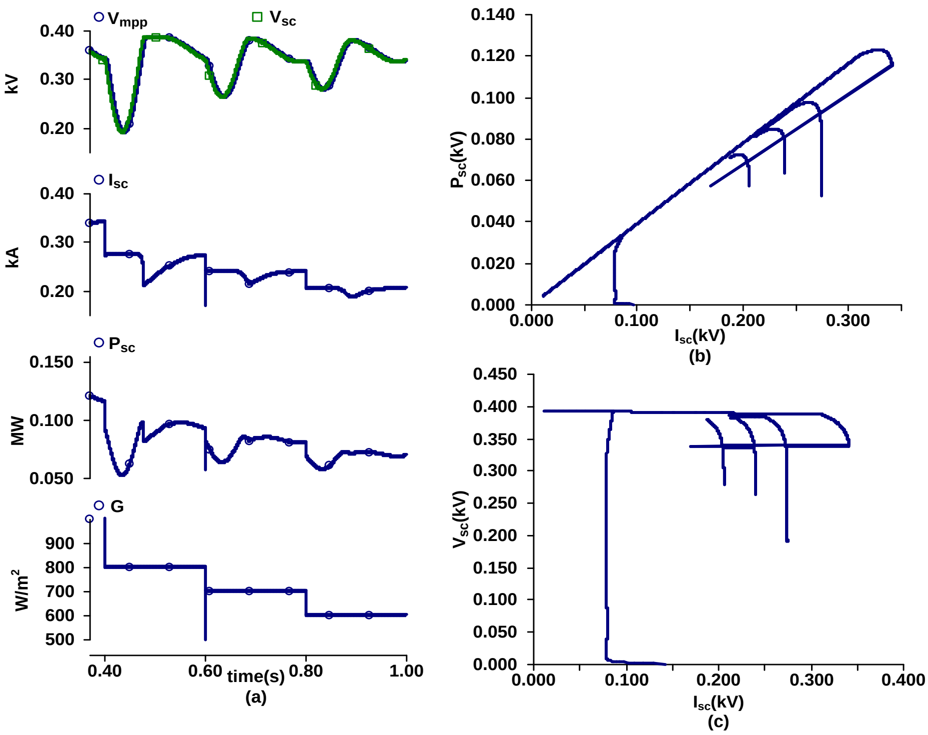

Figure 4. The characteristic of solar cell under variation of radiation

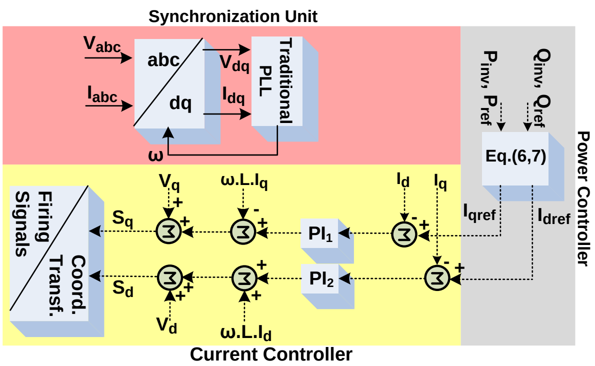

Figure 5. SRF-PI based power controller

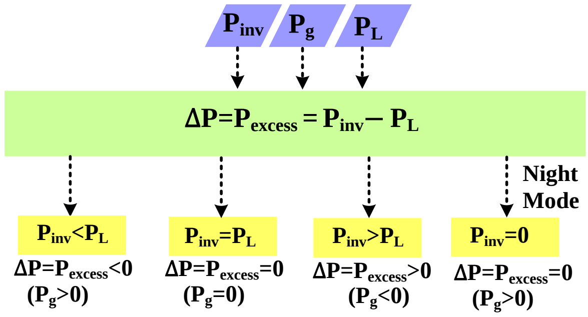

Figure 6. Flowchart of various PM scenarios

In order to confirm effectiveness and correctness of the performance of the power sharing control based PM strategies, the system is evaluated under various load power. The system is developed by PSCAD/EMTDC. The PM strategies depend on the magnitude of electric power load P_L. The several case studies with the PM strategies are written in following equations.

$$\Delta P = P_{inv} - P_L \tag{8}$$

- If $\Delta P < 0$ then the solar power production is not sufficient and grid power P_g should be operated.
- If $\Delta P = 0$ then the solar power production is sufficient and grid power P_g is not required to start-up.
- If $\Delta P > 0$ then the solar power production is sufficient and excess power P_{excess} is transmitted to grid.
- If solar power is at night mode, then electric grid supplies power to load demand.

The power balance in the DC bus and three phase output power can be written as follows equation.

$$\eta_{pv\_boost\_conv} P_{sc\_dc} - P_{inv} - P_{losses} = 0 \tag{9}$$

where, the power of P_{sc_dc} is ensured by the solar cell and P_{losses} is the power consumed by inverter. The efficiencies of inverter and boost converter are assumed to be constant $\eta_{inv} = 0.93$, $\eta_{pv\_boost\_conv} = 0.96$.

The simulation results for various PM scenarios are given as graphically in Figure 7. In this system, if solar power is sufficient, then power supplied by solar system is transferred to load power demand. Its excess power supplied by solar system is also transferred to electric grid as shown in Figure 7a. Figure 7b shows that if unavailability of solar energy is occurred, electric grid ensures power load demand. Figure 7c depicts that there is not excess power and so electric grid is not required start up. At night mode, solar system does not generate power. Load power demand is ensured by electric grid as shown in Figure 7d. Numerical results are also given for various PM strategies in Table 1.

Table 1. Numerical results for power management strategies

	P_L	P_g	P_{inv}	$\Delta P=P_{excess}$
	0.05 MW	-0.038 MW	0.088 MW	0.038 MW
	0.15 MW	0.062 MW	0.088 MW	-0.062 MW
	0.088 MW	0.0 MW	0.088 MW	0.0 MW
Night Mode	0.088 MW	0.088 MW	0	0

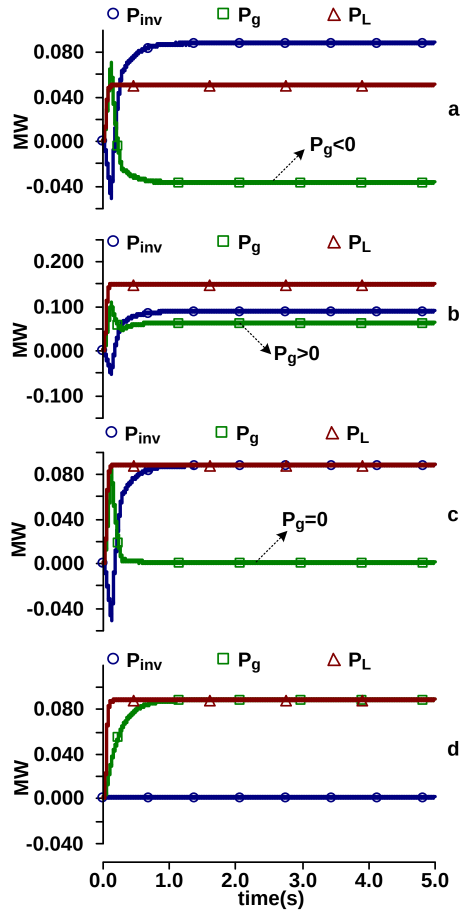

Figure 7. Results for power management under load variations; (a) excess power, (b) solar power is not sufficient, (c) not excess power, (d) not generated power by solar (night mode)

IV. CONCLUSION

In this paper, SRF-PI controller based PM strategy is applied to the grid connected solar system. Power sharing method is discussed to share power flow among the electric grid, solar system and load. According to the availability of solar system power, electric grid supplies power to load demand or the excess power supplied by solar system is transferred to electric grid. Compared with previous similar studies, there is no need to store energy storage in the system. This advantage provides low cost system. The grid connected solar power system is examined and analyzed under various load values and night/day mode of solar system. The effectiveness of the system is verified by using PSCAD/EMTDC software package.

REFERENCES

[1] N. Eghtedarpour, E. Farjah, "Power Control and Management in a Hybrid AC/DC Microgrid", IEEE transactions on smart grid, Vol. 5, 1494-1505, 2014.

[2] L.N. Khanh, J.J. Seo, Y.S. Kim, D.J. Won, "Power-Management Strategies for a Grid-Connected PV-FC Hybrid System", IEEE Transactions on Power Delivery, Vol. 25, pp. 1874-1882, 2010.

[3] E. Dursun, O. Kilic, "Comparative Evaluation of Different Power Management Strategies of a Stand-Alone PV/Wind/PEMFC Hybrid Power System", International

Journal of Electrical Power & Energy Systems, Vol. 34, pp. 81-89, 2012.
[4] F. Nejabatkhah, Y.W. Li, "Overview of Power Management Strategies of Hybrid AC/DC Microgrid", IEEE Transactions on Power Electronics, Vol. 30, pp. 7072-7089, 2015.
[5] C. Wang, M.H. Nehrir, "Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System", IEEE Transactions on Energy Conversion, Vol. 23, No. 2, pp. 957-967, 2008.
[6] M. Hosseinzadeh, F.R. Salmasi, "Power Management of an Isolated Hybrid AC/DC Microgrid with Fuzzy Control of Battery Banks", IET Renewable Power Generation, Vol. 9, No. 5, pp. 484-493, 2015.
[7] A.S. Subburaj, P. Kondur, S.B. Bayne, M.G. Giesselmann, M.A. Harral, "Analysis and Review of Grid Connected Battery in Wind Applications", Green Technologies Conference (GreenTech), pp. 1-6, April, 2014.
[8] M.M.A. Haque, M.M. Billah, S.K. Das, M.T. Islam, A.M. Hye, B.B. Pathik, "Integrated Photovoltaic Power Management System (IPPMS): A Grid Tied Solar Power Controller Combined with IPS Technology", IEEE Student Conference on Research and Development (SCOReD), pp. 198-203, December, 2015.
[9] M. Billah, S.K. Das, M.T. Islam, M.A. Haque, B.B. Pathik, "Design, Simulation and Implementation of a Grid Tied Solar Power Controller Integrated with Instant Power Supply Technology", Innovative Smart Grid Technologies-Asia (ISGT ASIA), pp. 1-6, November, 2015.
[10] S.M. Sichilalu, H. Tazvinga, X. Xia, "Integrated Energy Management of Grid-tied-PV-fuel Cell Hybrid System", Energy Procedia, Vol. 103, pp. 111-116, 2016.
[11] Y. Han, W. Chen, Q. Li, "Energy Management Strategy Based on Multiple Operating States for a Photovoltaic/Fuel Cell/Energy Storage DC Microgrid", Energies, Vol. 10, pp. 1-15, 2017.
[12] P. Garcia Trivino, A.J. Gil Mena, F. Lorens Iborra, C.A. Garcia Vazquez, L.M. Fernandez Ramirez, F. Jurado, "Power Control Based on Particle Swarm Optimization of Grid-Connected Inverter for Hybrid Renewable Energy System", Energy Conversion and Management, Vol. 91, pp. 83-92, 2015.
[13] V. Tejwani, B. Suthar, "Power Management in Fuel Cell Based Hybrid Systems", International Journal of Hydrogen Energy, 2017.
[14] S. Molaei, S. Jalilzadeh, M. Mokhtarifard, "A New Controlling Method for Maximum Power Point Tracking in Photovoltaic Systems", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 22, Vol. 7, No. 1, pp. 1-7, March 2015.
[15] T. Sathiyanarayanan, S. Mishra, "Synchronous Reference Frame Theory Based Model Predictive Control for Grid Connected Photovoltaic Systems", IFAC-Papers on Line, Vol. 4, pp. 766-771, 2017.
[16] D. Ipsakisa, S. Voutetakisa, P. Seferlisa, F. Stergiopoulosa, C. Elmasidesb, "Power Management Strategies for a Stand-Alone Power System Using Renewable Energy Sources and Hydrogen Storage", International Journal of Hydrogen Energy, Vol. 34, pp. 7081-7095, 2009.
[17] J.A. Ramos Hernanz, J.J. Campayo, J. Larranaga, E. Zulueta, O. Barambones, J. Motrico, I. Zamora, "Two Photovoltaic Cell Simulation Models in Matlab/Simulink", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 10, Vol. 4, No. 1, pp. 45-51, March 2012.
[18] A. Naderipour, A.A.M. Zin, M.H.B. Habibuddin, M.R. Miveh, J.M. Guerrero, "An Improved Synchronous Reference Frame Current Control Strategy for a Photovoltaic Grid-Connected Inverter under Unbalanced and Nonlinear Load Conditions", PLoS ONE, Vol. 12, No. 2, pp. 1-17, February 13, 2017.
[19] A.K. Panda, N. Patnaik, "Management of Reactive Power Sharing & Power Quality Improvement with SRF-PAC Based UPQC under Unbalanced Source Voltage Condition", International Journal of Electrical Power & Energy Systems, Vol. 84, pp. 182-194, 2017.

BIOGRAPHIES

Dogan Celik received the B.Sc. degree in Electrical and Electronics Engineering, Cukurova University, Adana, Turkey in 2013. He completed M.Sc. program at Department of Electrical and Electronics Engineering, Van Yuzuncu Yil University, Van, Turkey in 2016. He started to Ph.D. education in Van Yuzuncu Yil University since 2016. His research interest areas are distributed generation, distributed generation/integration of renewable energy systems, power quality, modelling and simulation of power systems dynamics, power system control and voltage sag/swells.

M. Emin Meral received the B.Sc. degree in Electrical and Electronics Engineering, from Inonu University, Malatya, Turkey in 2001 with the best second degree in Engineering Faculty. He completed the M.Sc. program at Department of Electrical and Electronics Engineering, Van Yuzuncu Yil University, Van, Turkey in 2003. He received the Ph.D. degree from Cukurova University, Adana, Turkey in 2009. His research areas are nonlinear power systems, numerical modelling, power quality, custom power, energy efficiency and neural networks.