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Simulation of a PV Connected to an Electrical Energy Distribution Network with Internal Current Loop Control and Voltage Regulator

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Abstract

In this paper, a control method based on internal current control loop and dc link voltage regulator for three-phase photovoltaic (PV) system connected to the distribution network is presented. Current control method, the dynamics of the PV system separate it from the dynamics of the grid and the loads in it, and dc link voltage control improves control and increases the output power of the PV system. Also, a feedback control method is proposed to adjust the dc link voltage in order to improve the transient response of the PV system, which distinguishes the dynamics of the PV system from the nonlinear characteristics of solar cells and enables the design and optimization of system controllers in a wider range of workstations. In order to achieve a constant voltage level, a dc/dc converter is recommended to prevent the transfer of voltage harmonics to the inverter. The proposed method is investigated using a simulation of a PV system connected to the distribution network in the MATLAB software environment.

Keywords: Distribution network, Feedback control method, Output power, Photovoltaic system
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1. Introduction

Attention to economic benefits and environmental problems in recent years has led to the expansion of the use of distributed generation (DG) resources in the world [1,2]. These resources, while meeting consumer demand, increase reliability and reduce system losses [3,4]. Most DG sources use renewable energy to generate electricity to reduce the adverse effects of fossil fuel use on the environment [5,6].

Solar energy technologies are divided into two parts: direct and indirect conversion of electricity [7,8]. The direct sun division of the system (PV) is shown in Fig. 1. As can be seen, the photovoltaic system is divided into two groups: grid-connected photovoltaic system and off-connected photovoltaic system [9].

Inverter-based distributed generation sources such as photovoltaic (PV) systems are more widely used than other distributed generation sources among electricity subscribers and investors [10,11].

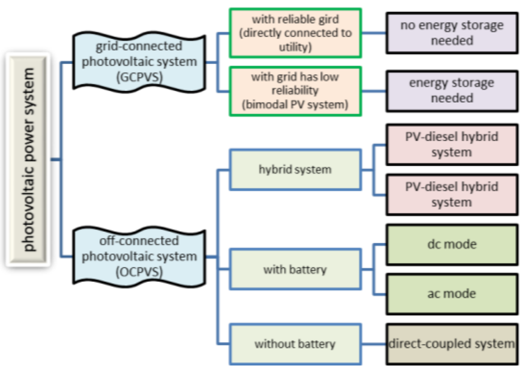

Fig. 1. Single-line diagram of PV system in connection to distribution network

In recent years, the construction of solar power plant units in various dimensions and production capacities is expanding and various studies have been conducted in the field of application and design of their control systems [12,13].

In a number of studies, dc voltage is considered as a constant source, in other words, the dynamics of PV sources are completely neglected [14]. In [15] different drop coefficients and their effect on the performance of the PV system and output power are investigated and the allowable range for changing the drop coefficients in the operation mode of islands is determined so that the selection of drop coefficients outside the allowable range causes system instability. In [16] to adjust the control parameters using the usual drop characteristics and in order to improve the transient stability of the system, the particle optimization algorithm is used and to investigate the effect of load dynamics on low frequency fluctuations of the system, various loads are investigated. They are located. The effect of dynamic modes of load types such as induction motors on medium voltage microgrids has been evaluated in [17]. The problem of proper load sharing in an independent microgrid has been studied in [18] in which a complementary loop around the typical droop control of each DG converter is proposed to stabilize the system. Also, the coordinated design of complementary control loops for each DG is formulated as a parameter optimization problem and solved using an evolutionary technique.

Various studies on the modeling of solar systems and the types of controllers used in it have been presented [19,20]. In [21] for modeling three-phase grid-connected solar systems is presented. In this model, different modes of performance and control have been investigated in order to analyze the effect of different parameters. An optimal control of the network-connected microgrid PV source in somewhat shady conditions is presented in [22] when the system consists of a PV array, a network simulator and two converters connected to a typical DC bus. In this system, the voltage source inverter is controlled to keep the DC voltage constant, where the voltage control technique is combined with a phase-locked loop algorithm for voltage synchronization.

In the field of the effects of high infiltration of solar sources on power quality phenomena, various studies have been conducted that the results show that high power of these sources causes voltage fluctuations, flicker formation and reduced reliability [23,24]. In [25], the effects of high-power solar sources on power quality phenomena such as voltage and frequency are investigated. According to the results, the effect of output power fluctuations on voltage and frequency in scattered systems is less than centralized systems. In [26], the effect of 20% penetration of solar resources during the passage of clouds and power fluctuations is investigated. This study shows that these oscillations do not have a significant adverse effect on the system flicker, but they do severely affect the performance of the pulsates and reduce the life of the equipment. To improve the performance of an independent water pumping station based on the solar PV system in [27], an active power control with increased maximum power point tracking (MPPT) algorithm has been proposed, which in order to achieve MPPT with less oscillation by protecting the battery energy storage system against overvoltage, a turbulence algorithm is used and the step-by-step observation of the variable power ratio is used.

In this paper, modelling of PV system in connection to distribution network and loads connected to it is simulated. A control method for three-phase PV systems is presented, which is based on the optimized current control model and in addition to adjusting the power factor of the PV system, it also provides the possibility of controlling the dc link voltage of the converter. Therefore, by this control method, the active power of the PV system is regulated through voltage control. Also, to protect the PV system against faults and overloads in the system, the optimized current control method separates the dynamics of the PV system from the distribution network and loads.

2. Improving the performance of the PV system when connected to the distribution network

Fig. 2 shows the connection of the studied PV system to the distribution network at the common connection point. At the point between the common connection point and the network, once is provided for the distribution network. The resistance and inductance of the line between the common connection point and the load are indicated by the values of L1 and R1, respectively. L2 and R2 are also the values for inductance and line resistance between the load and the main network. It should be noted that the values of L1 and R1 also include leakage impedance and resistance of transformer windings Tr1. The load power factor correction capacitor is shown with the Cl parameter and Ps and Qs indicate the active and reactive power delivered by the PV system to the distribution network at the common connection point.

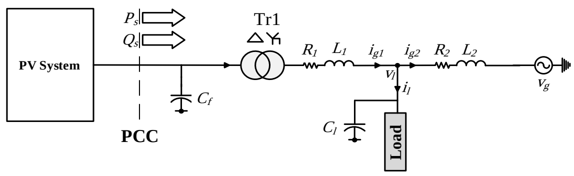

Fig. 2. Single-line diagram of PV system in connection to distribution network

High-throughput PV sources can cause severe voltage fluctuations when radiation changes or clouds pass. Since the allowable amount of voltage fluctuations is limited according to the standard and the desired power quality is necessary due to the increase of sensitive loads, so in the power system, multiple controllers are used to maintain the voltage level within the allowable range. In this section, the effect of sudden changes in weather conditions and the passage of clouds on cell performance and grid voltage is investigated and using a dc/dc converter and reactive power injection to compensate and control the voltage profile during rapid fluctuations in power output.

Solar systems are a relatively expensive resource [28,29]. Therefore, for optimal use and high efficiency, it is better to place these resources at the maximum operating point. As mentioned earlier, solar cells are characterized by temperature and radiation. Since solar systems are constantly exposed to changing environmental conditions such as shade, dust, and the like, their characteristics are constantly changing and with the direct connection of the solar panel to the system without No controller can extract maximum power from the source. Therefore, the maximum power point controller is an essential part of solar systems. Several control methods have been proposed for this purpose. These methods differ in features such as convergence speed, complexity in installation and execution, required sensors, cost, etc [30,31].

3. Simulation results

In order to evaluate the performance of the PV system when connected to the distribution network, the PV system shown in Fig. 3 is simulated with a general system model.

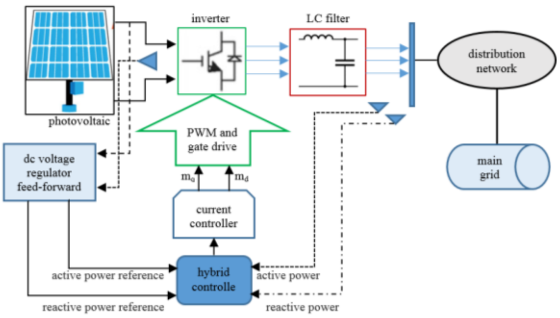

Fig. 3. The PV system studied in the network connection mode

According to this figure, the studied PV system is connected to the distribution network through Tr1 transformer. The network in question has two loads with values of 250 kW and 2 MW and is connected to the main network via a Tr2 amplifier transformer.

In this section, several modes for simulations are considered. These modes are designed for the following purposes:

- Investigating the performance of the feedback compensator due to climate change
- Investigation of passages caused by the entry of PV system into the network
- Evaluation of the performance of the dc link voltage regulation improvement strategy and the capability of control schemes in producing maximum power
- Check the resistance of the control system in the event of a fault in the network
- Observing the effect of feedback compensation strategy on improving the stability of the PV system
- Investigation of the effect of dc / dc converter on the performance of the PV system
- Investigating the effect of current controller in independent control of active and reactive power

A) Investigating the compensatory effect of feedback:

In this scenario, the effect of feedback compensation strategy on improving the transient stability and performance of the PV system in the event of radiation intensity changes is investigated. According to Fig. 4, the amount of radiation is initially equal to 1000 W/m2. In 0.5 seconds, the radiation intensity decreases slowly and steadily to 200 W/m2.

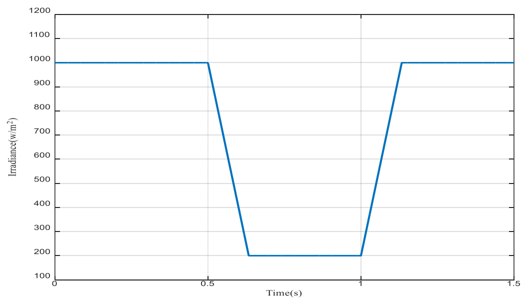

Fig. 4. Radiation intensity

Then in one second s increases again to the original value. Fig. 5 shows the value of vdc voltage due to these changes in a state where the feedback compensation strategy is inactive. Fig. 6 also shows the vdc voltage changes using the proposed strategy. As can be seen, the use of feedback compensation strategy effectively improves the system response to radiation changes and improves transient stability. According to these results, keeping the vdc value constant reduces the fluctuations in the output power of the PV system.

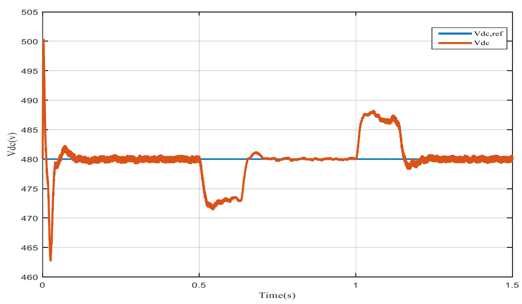

Fig. 5. Dc link voltage without the use of a feed compensator

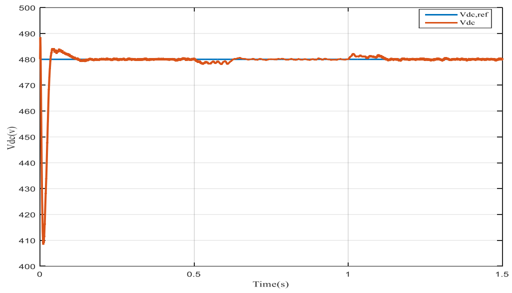

Fig. 6. Dc link voltage using feed compensator

B) Operation of PV system in normal conditions and during connection to the network*:*

In this case, the PV system is connected to the distribution network but is inactive for 0.2 seconds. Therefore, according to Fig. 7, the dc link capacitor is pre-charged through non-parallel diodes located in the VSC ports and the dc voltage reaches 568 V.

After 0.2 seconds from the simulation time, the voltage source converter and PV system controllers are activated. Then the dc voltage follows the reference value and reaches 480 V.

As can be seen, the locked phase loop responds to the dc link voltage response by following its reference value when the PV system enters the network. According to this figure, after fixing the passages related to the PV system input, the dc link voltage reaches its final values in less than 0.2 seconds.

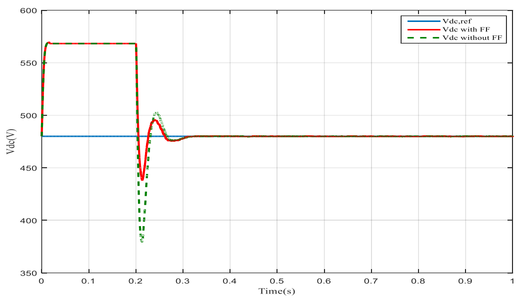

Fig. 7. Dc link voltage when connected to the network

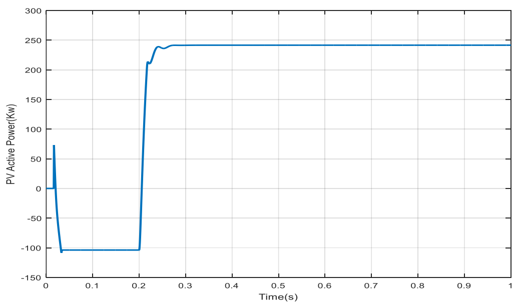

Fig. 8. Active output power of a photovoltaic panel array when connected to the grid

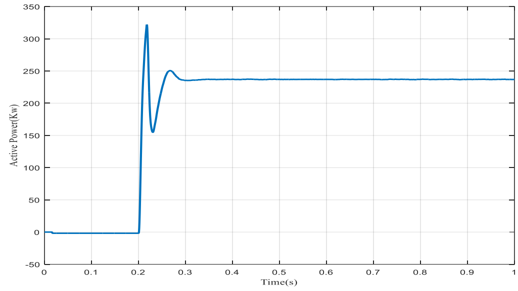

Fig. 9. Active output power of the photovoltaic system when connected to the grid

The active output power of the array of PV panels is shown in Fig. 8. The d-axis current of the array of PV panels reaches the final value of 0.95 p.u. Subsequently, according to Fig. 9, the output power of the PV system undergoes a momentary transient and then reaches the value of 236 kW.

C) Controller resistance against system errors*:*

The possibility of recovering the control system after an error or disturbance in the network is one of the cases that affect the performance of the PV system and its effects on the distribution network. In this section, the resistance of PV system against the occurrence of single-phase and three-phase faults has been investigated.

Single-phase error to ground: In this part, after 0.5 seconds from the time of simulation of phase c, the high voltage side of transformer Tr1 is connected to ground for a period of three cycles (at a frequency of 60 Hz) and the single-phase error to Earth occurs.

As shown in Fig. 10, at the time of the fault, the phase voltage c equals zero and the amplitude of the line current increases.

The v_{dc} value is also experiencing momentary perturbations. After troubleshooting, the PV system maintains its stability and returns to normal operating conditions.

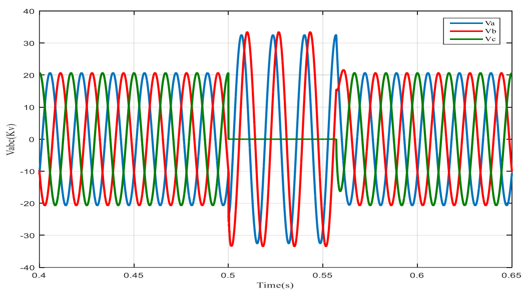

Fig. 10. AC side voltage connected to the network

Three-phase error: In this section, in 0.5 seconds, a three-phase short circuit occurs in the low voltage side of transformer Tr1. According to Fig. 11, the line voltage is equal to zero and the current amplitude is increased. The error also caused instantaneous fluctuations in the v_{dc} voltage. After troubleshooting, the system returns to normal operation after 0.2 seconds using the existing control loops. Examination of the results of this section shows that the PV system is resistant to faults and has the ability to recover the control system after troubleshooting.

D) DC link voltage control and maximum power control strategy*:*

The power of the array of PV panels, followed by the output power of the system, depends to a large extent on the level of radiation and the magnitude of the dc link voltage. In this scenario, the performance as well as the importance of using the MPPT strategy will be examined. According to Fig. 12, the initial value for the radiation level in this scenario is 1000 W/m^2. In this case, the dc link voltage is equal to 384 kV and the output power is equivalent to 198.5 kW is delivered to the network.

After 0.5 seconds from the time of simulation, the maximum power control strategy is activated and increases the output power to 236 kW by increasing the dc link voltage to 481 volts. The output power is increased by adjusting the dc link voltage at a constant radiation intensity.

Fig. 13 shows the changes in radiation intensity. Then in one second the radiation intensity is reduced to 500 watts per square meter while the dc link voltage continues to follow the reference voltage. According to Fig. 14, the output power is reduced to 117 kW due to the dependence on the radiation level, and in 1.5 seconds, when the MPPT control is deactivated, the output power is reduced to 100 kW. As can be deduced from this scenario and its related results, using the maximum power control strategy, at a constant radiation intensity by changing the dc link voltage and adjusting its optimal value can be used to produce the maximum output power and transmit it used to the network.

A) Independent control of active power and reactive power*:*

In this case, the capability of the PV system in controlling the active and reactive powers without interdependence is examined. The radiation intensity is considered to be 1000 watts per square meter. When the dc voltage is 480 volts, the output power is about 237 kW and the reactive power is zero. At 0.5 seconds, the reference dc voltage drops to 384 volts, and as shown in Fig. 15, after 0.2 seconds, the dc voltage follows this reference value.

The output power is then reduced to 198 kW, while the reactive output power does not change as shown in Fig. 16. Active reduction reduces the amplitude of the line current, but as shown in Fig. 17, the phase difference between the line current and the PCC voltage is still zero. In one second, the reactive power increases by 32 kV and the line current is post-phase in relation to the PCC voltage. Reactive power changes have no effect on the amount of active power. In 1.2 seconds, the reactive power of the system becomes zero again and the power factor of the system becomes equal to 1. Reactive power changes cause momentary changes in the current-carrying amplitude of the voltage converter, leading to an exchange of power between the line capacitor and the converter. Therefore, the capacitor absorbs reactive power by increasing the current amplitude and produces reactive power by decreasing it. Since the active power is set to the desired value and does not change, the transient created by the reactive power change must be exchanged with the dc side or the dc link capacitor. Therefore, the dc voltage is momentarily disturbed.

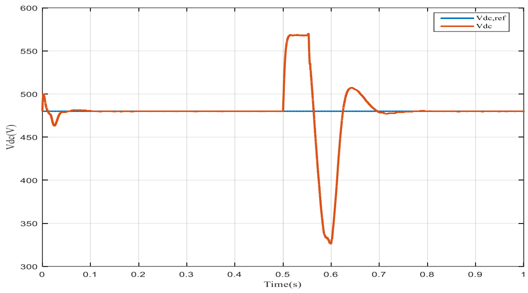

Fig. 11. Link dc voltage

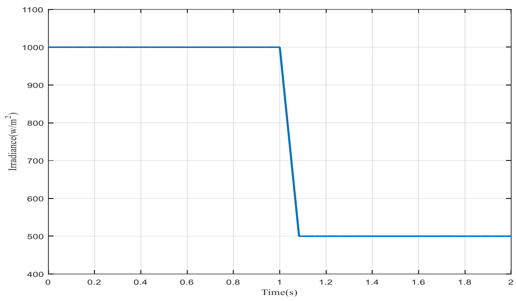

Fig. 12. Link voltage dc

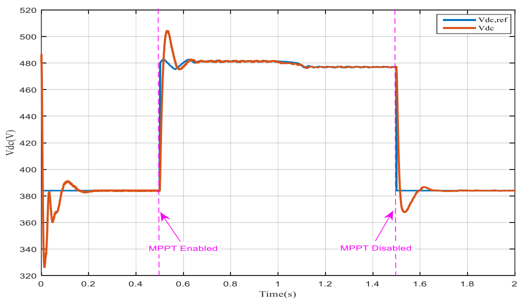

Fig. 13. Changes in radiation intensity

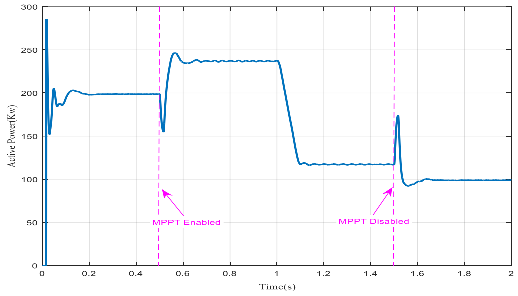

Fig. 14. Output power of photovoltaic system

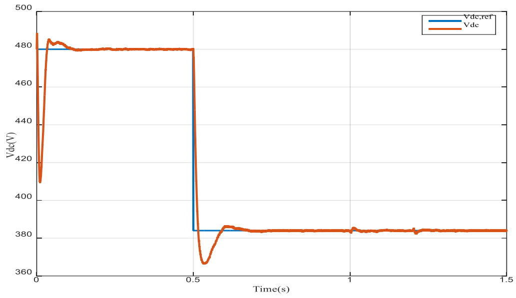

Fig. 15. Dc link voltage in independent control of power

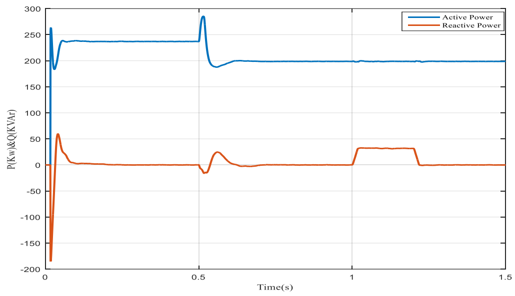

Fig. 16. Active and reactive power System output in independent control of active and reactive power

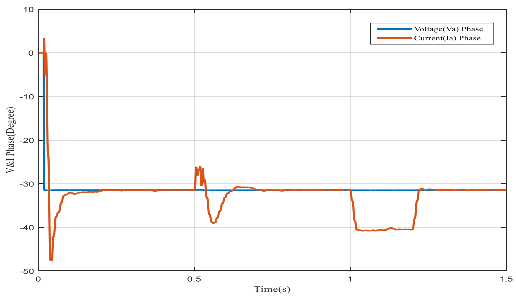

Fig. 17. PCC line current and voltage phase in independent control of active and reactive capacities

B) System performance without feedback compensator*:*

All the scenarios proposed so far have been simulated assuming that the feedback compensation mechanism is active. As it was observed, using the proposed control strategies, the PV system maintains its stability under different conditions and various disturbances and has a desirable performance. In this scenario, the operation of the PV system will be investigated without considering the feedback compensating effect.

Fig. 18 shows the response of the PV system during v_{dcref} changes and when the feedback compensator is inactive. According to this figure, the v_{dcref} is reduced from 480 volts to 384 volts, 360 volts, 336 V and 326 V. In the first two steps, vdc follows the v_{dcref} value optimally and the system is stable. In the third stage, by changing the v_{dcref}, the system oscillates. The persistence of these fluctuations causes similar fluctuations in the output power, PCC voltage and operating frequency of the corresponding PV system.

These fluctuations penetrate the distribution network and can stimulate the torsional mode of some motor loads related to consumers. In the fourth step, reducing the v_{dcref} value to 326 V causes system instability. At 1.5 seconds, the d-axis current does not follow the reference value and the system becomes unstable.

Fig. 19 shows the response of the PV system to the gradual changes of the dc voltage reference with the presence of a feedback compensation strategy. As can be seen, using the proposed strategy, dc reference voltage changes have no effect on the stability of the PV system and follow the reference values in all conditions of dc voltage and d-axis current. The stability of the PV system in the absence of feedback compensator due to the nonlinear characteristic of the PV system strongly depends on the changes in the working point.

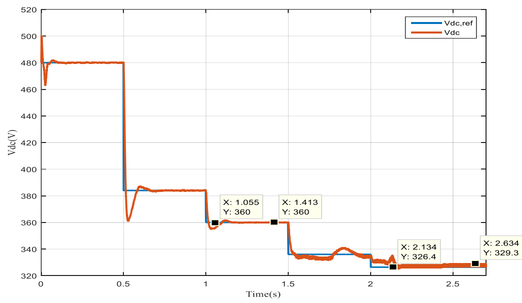

Fig. 18. Reference voltage of dc link

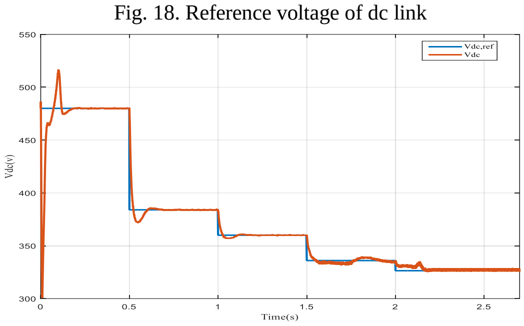

Fig. 19. DC link voltage

C) The effect of the proposed dc/dc converter on the performance of the PV system*:*

In this scenario, the array of PV panels is connected to the mains via a dc/dc converter and a three-phase voltage source converter.

Figs. 20, 21 and 22 show the simulation results of this scenario. Maximum power tracking in this scenario is applied to the dc/dc converter gate based on the incremental conduction strategy.

The 5 kHz dc / dc converter increases the normal voltage of the PV array, which at a maximum power of 273 volts' dc, to 500 volts' dc. The voltage source converter converts the dc link voltage of 500 volts to an ac voltage of 260 volts. The voltage source converter uses the power control loop to generate reference currents. The scenario starts in standard conditions with a temperature of 25ºC and a radiation intensity of 1000 watts per square meter.

The switching pulses of the dc/dc and dc/ac converters are cut off from zero to 0.05 seconds. At this time, the dc link capacitor is charged and the dc link voltage reaches 500 volts. In fact, this voltage is equivalent to the open circuit voltage of an array of PV panels. In 0.05 seconds, the dc/dc and dc/ac converter pulses are activated and the dc link voltage is set to 500 volts. The duty cycle of the dc/dc converter in this case is set to 0.5. In 0.25 seconds, the system reaches a steady state and reaches 250 volts according to the voltage relation of the array of PV panels. In this case, the output power of the photovoltaic array is 96 kW, while the maximum power in radiation of one kW per square meter should be 100.7 kW. At 0.4 seconds, the maximum power control mechanism is activated and by changing the duty cycle, the PV voltage is adjusted and the maximum power is received from the array. The maximum power is obtained in the duty cycle of 0.454. At 0.6 to 1.1 seconds, the amount of radiation has decreased from 1000 watts per square meter to 250 watts per square meter. However, using the MPPT strategy, maximum power is pursued. At 1.2 to 2.5 seconds, the amount of radiation returned to 1000 watts per square meter, then the temperature increased to 50 degrees Celsius. With increasing temperature from 25 °C to 50 °C, the amount of array power has decreased from 100.7 kW to 93 kW.

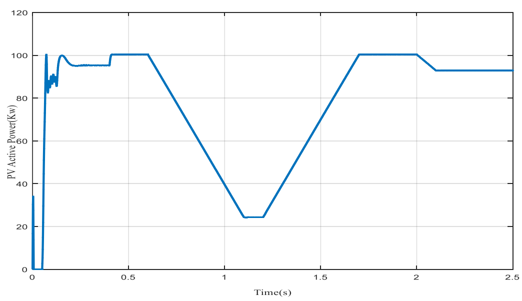

Fig. 20. PV output power

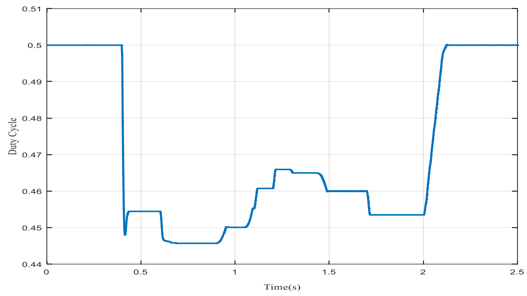

Fig. 21. Task cycle

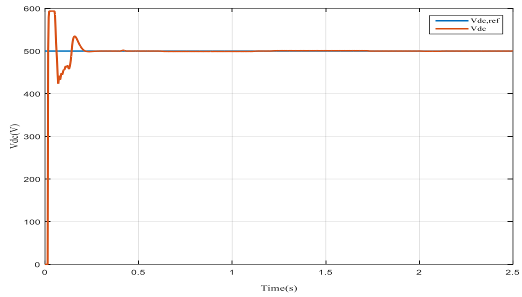

Fig. 22. Link dc voltage

4. Conclusion

This paper presents a feedback strategy for completing the DC voltage control loop. Using this strategy, the nonlinear characteristic effect of PV panels is eliminated. Therefore, using this method allows the design of DC link voltage controller independently of the operating point of the PV system.

Using the feed compensation mechanism for the dc link voltage control loop, the nonlinear characteristic effect of photovoltaic panels is removed from the control loop and allows the design and optimization of the dc link voltage controller for a wide range of work points. The efficiency of the forward compensation strategy and its effect on improving the transient response of the system have been investigated and confirmed using simulations of radiation level and temperature changes. Finally, the performance of the PV system as a distributed generation source was investigated and the most important system transitions were evaluated through simulation. The proposed control strategy makes it possible to maximize the output power by using dc link voltage control.

References

[1]. W.E. Vanço, F.B. Silva, J.R.B.A. Monteiro, C.M.R. de Oliveira, L.C. Gomes, "Theoretical-experimental analysis of the induction generator in the use of distributed generation", IEEE Latin America Transactions, vol. 19, no. 3, pp. 396-403, March 2021.

[2]. M. Ahmadi, S. Hosseini, M. Farsadi, "The effect of demand-response program and distributed generation resources on optimal establishment of electric vehicle

charging/discharging stations using a triple optimization algorithm", International Journal of Smart Electrical Engineering, vol. 10, no. 1, pp. 23-31, Winter 2021.

[3]. F. Hajimohammadi, B. Fani, I. Sadeghkhani, "Fuse saving scheme in highly photovoltaic-integrated distribution networks", International Transactions on Electrical Energy Systems, Vol. 30, No. 1, e12148, Jan. 2020.

[4]. I. Hamdan, A. Maghraby, O. Noureldeen, "Stability improvement and control of grid-connected photovoltaic system during faults using supercapacitor", SN Applied Sciences, vol. 1, Article Number: 1687, Nov. 2019.

[5]. R.N. Anthony, S.P. Navghare, "An insight to distributed generation of electrical energy from various renewable sources", Proceeding of the IEEE/ICEETS, pp. 341-344, Nagercoil, India, April 2016.

[6]. H. Ahn, B. Kim, Y. Lim, B. Lee, K. Oh, "Distributed coordination for optimal energy generation and distribution in cyber-physical energy networks", IEEE Trans. on Cybernetics, vol. 48, no. 3, pp. 941-954, March 2018.

[7]. O. Badran, R. Mamlook, E. Abdulhadi, "Toward clean environment: evaluation of solar electric power technologies using fuzzy logic", Clean Technologies and Environmental Policy, vol. 14, pp. 357–367, 2012.

[8]. S. Bahreyni, H. Shayanfar, "Loss reduction in a probabilistic approach for optimal planning of renewable resources", International Journal of Smart Electrical Engineering, vol. 6, no. 1, pp. 1-6, 2017.

[9]. J. Assadeg, K. Sopian, A. Fudholi, "Performance of grid-connected solar photovoltaic power plants in the Middle East and North Africa", International Journal of Electrical and Computer Engineering, vol. 9, no. 5, pp. 3375~3383, Oct. 2019.

[10]. M. M. Ghahderijani, A. Camacho, C. Moreira, M. Castilla, L. García de Vicuña, "Imbalance-voltage mitigation in an inverter-based distributed generation system using a minimum current-based control strategy", IEEE Trans. on Power Delivery, vol. 35, no. 3, pp. 1399-1409, June 2020.

[11]. M. Amin, Q.C. Zhong, Z. Lyu, "An anti-islanding protection for VSM inverters in distributed generation", IEEE Open Journal of Power Electronics, vol. 1, pp. 372-382, 2020.

[12]. G.G. Kim, W. Lee, B.G. Bhang, J.H. Choi, H.K. Ahn, "Fault detection for photovoltaic systems using multivariate analysis with electrical and environmental variables", IEEE Journal of Photovoltaics, vol. 11, no. 1, pp. 202-212, Jan. 2021.

[13]. D. Lin, X. Li, S. Ding, Y. Du, "Strategy comparison of power ramp rate control for photovoltaic systems", CPSS Transactions on Power Electronics and Applications, vol. 5, no. 4, pp. 329-341, Dec. 2020.

[14]. N. Bottrell, M. Prodanovic, T.C. Green, "Dynamic stability of a microgrid with an active load", IEEE Trans. on Power Electronics, vol. 28, no. 11, pp. 5107-5119, Nov. 2013.

[15]. E. Barklund, N. Pogaku, M. Prodanovic, C. Hernandez-Aramburo, T. C. Green, "Energy management in autonomous microgrid using stability-constrained droop control of inverters", IEEE Trans. on Power Electronics, vol. 23, no. 5, pp. 2346-2352, Sept. 2008.

[16]. M.A. Hassan, M.A. Abido, "Optimal design of microgrids in autonomous and grid-connected modes using particle swarm optimization", IEEE Trans. on Power Electronics, vol. 26, no. 3, pp. 755-769, March 2011.

[17]. A. Kahrobaeian, Y. A. I. Mohamed, "Analysis and mitigation of low-frequency instabilities in autonomous medium-voltage converter-based microgrids with dynamic loads", IEEE Trans. on Industrial Electronics, vol. 61, no. 4, pp. 1643-1658, April 2014.

[18]. R. Majumder, B. Chaudhuri, A. Ghosh, R. Majumder, G. Ledwich, F. Zare, "Improvement of stability and load sharing in an autonomous microgrid using supplementary droop control loop", IEEE Trans. on Power Systems, vol. 25, no. 2, pp. 796-808, May 2010.

[19]. M. Chamana, B.H. Chowdhury, "Optimal voltage regulation of distribution networks with cascaded voltage regulators in the presence of high PV penetration", IEEE Trans. on Sustainable Energy, vol. 9, no. 3, pp. 1427-1436, July 2018.

[20]. G. Haghshenas, S.M.M. Mirtalaei, H. Mordmand, G. Shahgholian, "High step-up boost-flyback converter with soft switching for photovoltaic applications", Journal of Circuits, Systems, and Computers, Vol. 28, No. 1, pp. 1-16, Jan. 2019.

[21]. A. Yazdani et al., "Modeling guidelines and a benchmark for power system simulation studies of three-phase single-stage photovoltaic systems", IEEE Trans. on Power Delivery, vol. 26, no. 2, pp. 1247-1264, April 2011.

[22]. A. Guichi, S. Mekhilef, E.M. Berkouk, A. Talha, "Optimal control of grid-connected microgrid PV-based source under partially shaded conditions", Energy, vol. 230, Article Number: 120649, Sept. 2021.

[23]. S. Seme, N. Lukač, B. Štumberger, M. Hadžiselimović, "Power quality experimental analysis of grid-connected photovoltaic systems in urban distribution networks", Energy, vol. 139, pp. 1261-1266, Nov. 2017.

[24]. M. Rahimi, B. Fani, M. Moazzami, M. Dehghani, G. Shahgholian, "An online free penetration multi-stage fuse saving protection scheme in distribution systems with photovoltaic sources", Iranian Electric Industry Journal of Quality and Productivity, vol. 9, no. 2, pp. 24-35, 2020.

[25]. S.A. Pourmousavi, A.S. Cifala, M.H. Nehrir, "Impact of high penetration of PV generation on frequency and voltage in a distribution feeder", Proceeding of the IEEE/NAPS, pp. 1-8, Champaign, IL, USA, Sept. 2012.

[26]. G.K. Ari, Y. Baghzouz, "Impact of high PV penetration on voltage regulation in electrical distribution systems", Proceeding of the IEEE/ICCEP, pp. 744-748, Ischia, Italy, June 2011.

[27]. M. Rezkallah, A. Chandra, M. Tremblay and H. Ibrahim, "Experimental implementation of an APC with enhanced MPPT for standalone solar photovoltaic based water pumping station", IEEE Trans. on Sustainable Energy, vol. 10, no. 1, pp. 181-191, Jan. 2019.

[28]. M. Shahsavari, S.M.M. Mirtalaei, "Design and implementation of a non-isolated multi-port converter with high voltage gain", Journal of Intelligent Procedures in Electrical Technology, vol. 12, no. 46, pp. 33-48, Sept. 2021 (in Persian).

[29]. M. Kefayat, A. Lashkar Ara, S. Nabavi Niaki, "Optimal placement and sizing of DFIG-based wind farms, fuel cell, photovoltaic units by using particle swarm optimization algorithm and fuzzy logic", Journal of Novel Researches on Electrical Power, vol. 1, no. 3, pp. 27-36, 2013.

[30]. M. Zamani, G. H. Riahy, N. Abdolghani, M. H. Zamani, G. Shahgholian, "Utilization of thermal energy storage for reducing battery bank size of hybrid (wind-PV) systems", Proceeding of the IEEE/ICCEP, pp. 709-714, Ischia, Italy, June 2011.

[31]. F. Hajimohammadi, B. Fani, I. Sadeghkhani, "Fuse saving scheme in highly photovoltaic-integrated distribution networks", International Transactions on Electrical Energy Systems, Vol. 30, No. 1, e12148, Jan. 2020.