Unbalanced Voltage Compensation by Interline Photo Voltaic Systems

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ABSTRACT

This paper presents a new system configuration for a large-scale Photovoltaic (PV) power system with multi-line transmission/distribution networks. A PV power plant is reconfigured in a way that two adjacent power system networks/ feeders can be interconnected. The inverter modules in a PV power plant are configured such that the system is represented as a back to back inverter connected multi-line system, called as Interline-PV (I-PV) system. The proposed I-PV system then can be controlled adequately allowing the PV solar plant to function as a flexible AC transmission system (FACTS) device, such as, interline power flow controller (IPFC). The control system of I-PV plants mainly consists of active and reactive power droop controllers, voltage and current controllers and unbalance compensator. The negative sequence current is injected from the I-PV power plant to compensate for the unbalanced loads. With the proposed I-PV system both active and reactive power flow control and energy management in a multi-line system can be achieved. The I-PV system can have various applications, for example, to regulate the feeder voltages, load reactive power support, real power transfer from over power generation line to under loaded line, improve the overall system performance against dynamic disturbances (such as, power system damping) and so on. A simulation study is carried out to illustrate one of the capabilities and effectiveness of the proposed I-PV system.

KEYWORDS: *Active and Reactive power control, FACTS Device, Interline power system, Voltage Regulation*

I. Introduction

Recent technological developments have made it possible to generate power, in order of tens of mega-watts (MW) to hundreds of MWs, using renewable energy resources, such as, photovoltaic (PV) solar and wind turbines systems. However, as the penetration levels of these distributed generators (DG) continue to grow to the extent that it is affecting the normal operation of a power system [1-4].

The large-scale real power injection by DG systems at certain locations on power transmission/distribution networks can violate the power system constraints, such as, excessive feeder voltage rise [4]. Apart from this, the issues related with poor power quality, harmonics, proper active and reactive power management, etc. are becoming more prevalent [1-3]. The adequacy of generating capacity in a power system can be improved by interconnecting two or more power systems. Better performance of power system can be achieved by controlling the flow of power in interconnected system.

Alternately, flexible AC transmission system (FACTS) devices have been utilized to increase the power transfer capability of transmission systems and regulate the power flow over transmission lines. Some of the important FACTS devices can be listed as, thyristor controlled reactor (TCR), thyristor controlled series compensator (TCSC), static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), unified power flow controller (UPFC), interline power flow controller (IPFC) and others [5-8]. The control method presented in [12] and [13] is based on using a two-inverter structure one connected in shunt and the other in series with the grid, like a series-parallel active power filter. The main role of the shunt inverter is to control active and reactive power flow, while the series inverter balances the line currents and the voltages at sensitive load terminals, in spite of unbalanced grid voltage. This is done by injecting negative sequence voltage

Recently, PV solar plant inverters have been called on to perform additional tasks, such as current harmonic compensation, load reactive power support and voltage regulation [9-14]. This paper proposes a new system configuration that can be considered as a FACTS device, realized using existing inverters in a PV solar power plant. Generally, a large-scale PV solar power plant is constructed by connecting several smaller inverter – solar array units (order of few hundred kW up to 500 kW or more) in parallel. The idea here is to reconfigure these several units such that two or more transmission (or even distribution) lines can be interconnected using the PV solar plant inverters. The system configuration thus achieved is termed as Interline PV (I-PV) system. This configuration is similar in construction to the IPFC. However, in the I-PV system two or more transmission/distribution lines are connected though shunt connected back to back converters contrary to IPFC where they are connected in series with the lines. The proposed I-PV system can be used to control the flow of active and reactive power in multi-line transmission networks, support leading or lagging reactive powers to different lines independently to regulate the line voltage, and so on. The I-PV system configuration could be an attractive solution especially during the period when PV solar power plant remains inactive, namely, late evening hours, throughout night hours and early morning hours. Furthermore, the concept of I-PV system can be extended during daytime hours providing further flexibility over control and regulation of real power generated by PV solar power station. In this paper the concept of interline PV system is introduced. A MATLAB/SIMULINK based study is carried to illustrate one of many capabilities of proposed I-PV system.

II. Interline –PV System Configuration

Fig. 1 shows a general representation of PV solar power plant based distribution/transmission network system. A largescale PV power plant, in the order of few MWs to few hundred MWs, is realized by installing an approximate number of the relatively smaller rating (200 kW to 500 kW) inverter modules. These inverter modules can be seen as small PV solar power generation units within a large-scale PV solar plant. Furthermore, two or more parallel connected modules are grouped together and connected to the main grid (such as, Feeder-1 in Fig. 1) using a step-up transformer. For example, eight 250 kVA (or four 500 kVA) inverter modules are grouped together (Inv-1 in Fig. 1) and connected to a 2 MVA step-up transformer (T-1 in Fig. 2). Each inverter module may be realized as three-phase PWM voltage source inverter as depicted in Fig.2. The point at which the PV solar plant is connected to Feeder-1 is referred as point of common coupling/connection (PCC). It is considered that a second network (Feeder-2 in Fig. 1) is available adjacent to the PV solar plant based transmission/distribution network. This second network/line can be originated from the same generation station or can be a complete different power source with different voltage ratings. Such a situation can occur in an actual practical system and is not completely hypothetical.

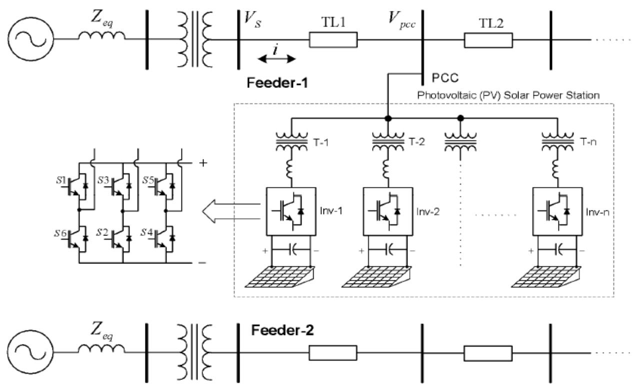

Fig.1 A photovoltaic power system.

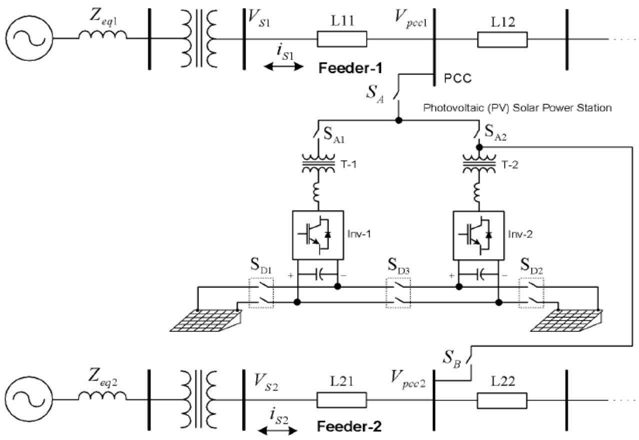

Fig.2 Proposed Interline PV (I-PV) system configuration.

The above discussed system, with few modifications, is reconfigured in Fig. 3 to form the proposed interline PV (IPV) system, i.e. to connect two feeders with each other through solar plant inverter modules. This kind of configuration is feasible and could be more appropriate during nighttime hours when PV solar power station remains inactive producing no real power. It is important to mention here that the current grid interconnection of renewable energy system standards, such as IEEE 1457 [15], does not allow the DG system owner to perform tasks other than injection of real power to the grid. These are not technical challenges and a mutual agreement between PV solar plant owner and transmission utility may be feasible. This paper address only the technical aspects of using a PV solar power plant as a versatile FACTS device and possible benefits achieved from such a kind of control. For simplicity, only two inverter units (*Inv-1* and *Inv-2*) are considered. In Fig. 3, *SA* and *SB* represent the main switches through which the PV power plant is connected to feeders-1 and -2. *SA1* and *SA2* represent the secondary switches to isolate an individual inverter unit within the PV power plant. The DC side switches, *SD1* and *SD2*, can be used to disconnect the PV solar arrays from the inverter units *Inv-1* and *Inv-2*, respectively. The switch *SD3* represents an additional switch to connect two inverter units back to back with each other. The switches *SA*, *SA1*, *SA2*, *SD1* and *SD2* may be presented in a typical PV solar power plant system. Thus, to reconfigure a PV solar plant into proposed interline PV system following additional components may be required:

a) DC bus network at the DC side of the solar system to form a common DC link between inverter units: corresponding line connections and the switch(s) *SD3*.

b) Connecting lines between the inverter units and adjacent feeder, and switch *SB*.

Furthermore, multiple switches *SD3* along with the necessary connecting lines will be required based on the number of inverter modules utilized to form the proposed interline system. Fig.4 shows the generalized representation of the proposed I-PV system. The switches *SA*, *SB*, *SA1* and *SD3* are closed and *SA2*, *SD1* and *SD3* are opened to realize the I-PV system configuration in Fig. 3.

The key functionalities that can be achieved using the proposed I-PV system are outlined below:

- Reactive power support to both the feeders for voltage regulation and/or load reactive power compensation or combination – simultaneously and independent control over each feeder is possible.
- Dynamic active and reactive power support to the feeder to improve the power system damping.
- Active power flow control and management between multi-line feeders.
- Optimal utilization of existing PV solar power station inverters, especially during nighttime hours to enhance the overall power system performance.

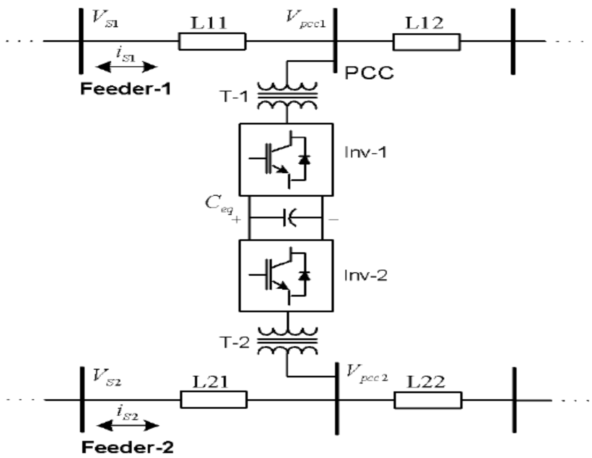

Fig.3 General single-line representation of proposed interline PV system.

In this project proposes a new droop control method called a "P -Q -V droop controller" for I-PV systems in which both active and reactive power are used to control the PCC voltage. The necessary active power for the compensation is drawn from the interconnected feeder via the PV solar plant inverter. The controller is designed to transfer the minimum active power between the two feeders. The active and reactive power droop coefficients are adjusted online through a lookup table based on the PCC voltage level.

III. Droop Control Method for I-PV Power System

Fig. 4 shows a two-feeder distribution system in which feeder-1 and feeder-2 are considered to be located close to each other. A large-scale PV solar power plant is connected at feeder-1. The PV plant inverters are reconfigured in such away that the two feeders could be interconnected with each other. This configuration is referred to as an 'Interline-PV' (I-PV) System

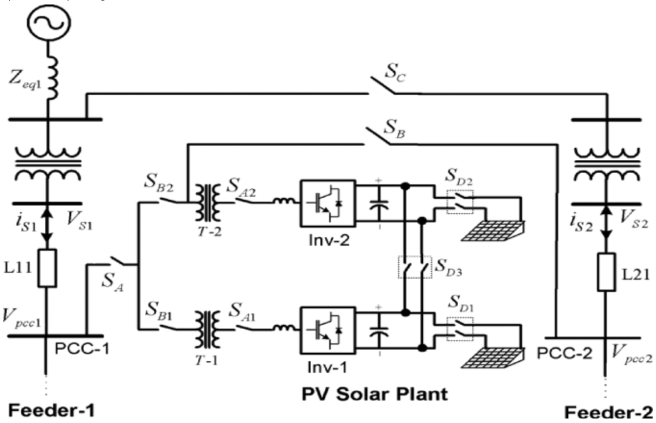

Fig. 4. Interline-PV (I-PV) power plant system configuration.

Table I shows the flexibility of I-PV power plants to inject the solar energy into feeder-1 only or feeder-2 only or to share it with both feeders. These operations can be achieved by opening and closing different switches, as illustrated in Table I. Switch is used for islanded/nonislanded operation of feeder-2. Based on the load demand on feeder-1 and feeder-2, the active power generated by the PV system can be delivered to one of the feeders fully or to both of the feeders partially. For example, when the switches S_A, S_C, S_{A1}, S_{A2}, S_{B1}, S_{B2}, S_{D1}, and S_{D2} are closed and switches and are open, the PV generated active power is delivered to feeder-1 only, whereas when S_B, S_C, S_{A1}, S_{A2},S_A, S_{B1}, S_{B2}, S_{D1} and S_{D2} are closed and S_A and S_{D3} open, the active power is delivered to feeder-2 only. During the night, when there is no power generation from the PV system, configuring the switches S_A, S_B, S_C, S_{A1}, S_{A2}, S_{B1}, S_A, S_{D3} as close and S_{B2}, S_D, S_{D2} as open, the active power exchange between feeder-1 and feeder-2 can be accomplished. Note that during all of the different operating modes (given in Table I), based on the system requirement, the respective feeder inverter(s) can inject or absorb reactive power as well.

For distribution systems, the resistive values of the feeders (Z_{eq1}, L_{11} , L_{12} , L_{21}, L_{22}, and Z_{eq2}) are taken into account with respect to the reactance values of the feeders, and considered as low X/R ratio feeders.

Power injected to	Switch status	
	Closed	Open
feeder-1 only, day time	S_A, S_C, S_{A1}, S_{A2}, S_{B1}, S_{B2}, S_{D1}, S_{D2}	S_B, S_{D3}
feeder-2 only, day time	S_B, S_C, S_{A1}, S_{A2}, S_{B1}, S_{B2}, S_{D1}, S_{D2}	S_A, S_{D3}
feeders-1 and -2, day time	S_A, S_B, S_C, S_{A1}, S_{A2}, S_{B1}, S_{D1}, S_{D2}	S_{B2}, S_{D3}
feeders-1 and -2, night time	S_A, S_B, S_C, S_{A1}, S_{A2}, S_{B1}, S_{D3}	S_{B2}, S_{D1}, S_{D2}

DIFFERENT MODES OF PV POWER INJECTION

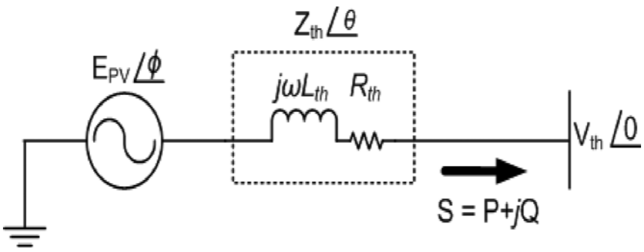

Fig. 5. Equivalent circuit for the shunt-connected inverter.

The active and reactive power flow (S=P+jQ) from inverter-2 (the power source) to feeder-2 are controlled through the following equations:

$$P = \frac{V_{th}}{Z_{th}}[(E_{PV}\cos\phi - V_{th})\cos\theta + E_{PV}\sin\theta\sin\phi]$$

$$Q = \frac{V_{th}}{Z_{th}}[(E_{PV}\cos\phi - V_{th})\sin\theta - E_{PV}\cos\theta\sin\phi].$$

Usually the phase difference between the PCC-2 voltage and grid voltage is very small, that is, cos ϕ =1 and sin ϕ = ϕ. Hence, (1) and (2) become

$$P = \frac{V_{th}}{Z_{th}}[(E_{PV} - V_{th})\cos\theta + E_{PV}\phi\sin\theta]$$

$$Q = \frac{V_{th}}{Z_{th}}[(E_{PV} - V_{th})\sin\theta - E_{PV}\phi\cos\theta].$$

Equations (3) and (4), show the dependency of delivered active and reactive power on the impedance angle θ and the phase difference angle ϕ.

Different Droop Control Methods

Two conventional droop methods to regulate the PCC voltage are P-V and Q-V methods.

PV- Droop Control Method

This method is convenient for electrical power systems that contain feeders/lines with predominant resistive values where the reactance of the lines can be neglected with respect to the resistance of the lines. This makes the impedance angle equal to zero. Hence, (3) yields that the active power delivered by the inverter is proportional to the voltage difference (Epv–Vth), that is, proportional to the inverter . The reactive power of inverter-2 is proportional to the phase difference ϕ, that is, proportional to the frequency ω of the system.

Fig. 6 shows the polar plot for (3) and (4) with pure resistive impedance for different values of the voltage magnitude Epv and phase difference angle ϕ . The polar radii denote the values of active and reactive power, whereas the polar angles denote the values of the phase difference angle ϕ . It should be noticed that is ϕ varying within small range as stated before.

• *Effect of changing ϕ on P and Q :*

i) P remains constant irrespective of any change in ϕ (represented by an arc which has the same radius).

ii) Q significantly changes with different polar angles ϕ

.• *Effect of changing Epv on P and Q :*

i) P significantly increases with increase in Epv (represented by arcs with different radii for different values of Epv).

ii) There is hardly any change in due to the changes in Epv as shown in the zoomed part of Fig9.

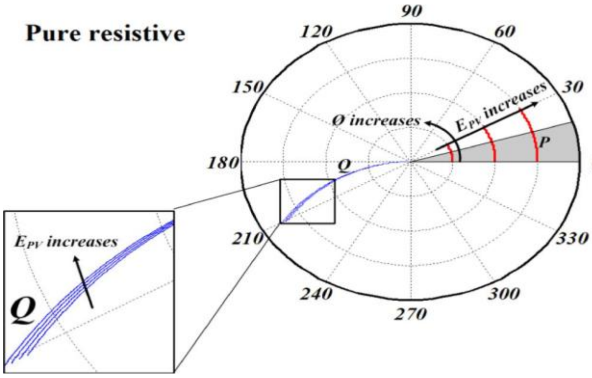

Fig. 6. Polar plot for the inverter and injected to the system with pure resistive impedance. Real power is red. Reactive power is blue.

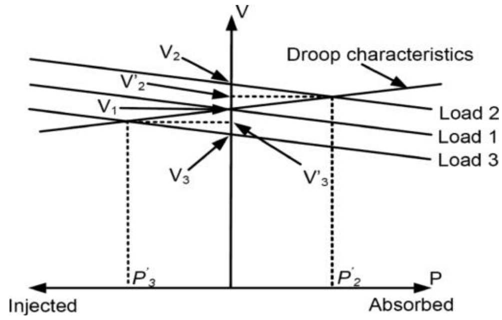

Fig. 7. - droop characteristics for the system with pure resistive impedance.

Q-V Droop Control Method

For high X/R ratio systems, where the reactance of the line is predominant over the resistance, impedance angle goes to 90 . The reactive power of the inverter is proportional to the inverter voltage Epv and the active power is proportional to the frequency . The polar plot for (3) and (4) for pure inductive impedance is shown in Fig. 8.

• *Effect of changing ϕ on P and Q :*

i) P significantly changes with different polar angles ϕ

.ii)Q remains constant regardless of any change in angle ϕ (represented by an arc which has the same radius).

• *Effect of changing Epv on P and Q :*

i) There are hardly any changes in P due to the changes of Epv as shown in the zoomed part of Fig. 10.

ii) Q significantly changes when Epv increases (represented by arcs with different radii for different values of Epv).

The Q-V droop control method is one of the widely used methods for voltage regulation. Unlike the - droop method where additional provision for real power is required;Q - Vdroop method does not need such a source of real power for generating the necessary Q for compensation.

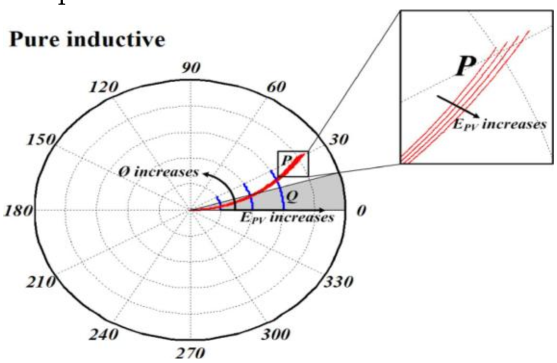

Fig. 8. Polar plot for the inverter P and Q injected to the system with pure inductive impedance. Real power is red. Reactive power is blue.

Proposed P-Q-V Droop Controller:

The power distribution networks may contain feeders with complex impedances, where neither reactance of the line nor the resistance can be neglected with respect to each other. In some cases, the resistance of the line may equal or be even higher than the reactance of line, giving a low X/R ratio feeder system. Such a kind of situation where the X/R ratio is small (close to 1), neither the - nor the - droop method may be sufficient to regulate the PCC voltage. Fig. 9 shows the polar plots for active and reactive power with a complex impedance system. It is shown that both active and reactive power are affected by the changes in voltage magnitude Epv and the phase difference angle ϕ.

The I-PV system can circulate active power between two adjacent feeders through back-to-back connected inverters. Furthermore, these inverters, with proper control, can also inject reactive power while transferring active power. Thus, the I-PV system configuration may be considered as one of the possible solutions for voltage regulation in low X/R ratio feeder systems. In order to achieve the desired PCC voltage regulation, a new droop control method is proposed in this paper in which both active and reactive power are used. Since both active and reactive power are utilized for voltage regulation, the proposed droopmethod is called as “P -Q -V droop control.” Two different droop coefficients, namely,n_d for active power and m_d for reactive power, are thus estimated according to PCC voltage levels to achieve the P-Q -V droop controller objectives. However, in this approach, the desired performance should be achieved with the least possible active power transfer to insure minimum voltage variation on the other feeder. In the proposed method, a lookup table approach is used to transfer the minimum active power between two feeders.

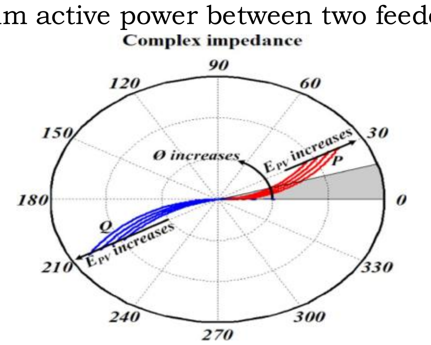

Fig. 9. Polar plot for the inverter P and Q injected to the system with complex impedance. Real power is red. Reactive power is blue.

IV. Simulation Study

In this section, a simulation study based on the given I-PV power system and its control to compensate the unbalanced PCC voltage is discussed.

A. System under consideration

Fig. 4 shows the power distribution network that is used for the simulation study. The system consists of two feeders, while the study is performed on just one feeder (i.e. feeder-1).

The voltages of the two feeders are considered as 11 kV. The loads on the feeders are normalized as PQ loads, located at the ends of each feeder. The loads have different values on each feeder and are programmed to emulate balanced and unbalanced conditions. The simulation results are taken with base voltage of 11 kV and base MVA of 1. Appendix-I contains the detailed data for the system under simulation for balanced and unbalanced conditions. Fig.4 shows System under consideration for simulation.

B. Simulation Results

Fig.6 shows the voltage, current, real power and reactive power waveforms of feeder-1 without PV plant. Fig.7 shows the voltage, current, real power and reactive power waveforms of feeder-1 with PV plant. Fig.8 shows the voltage, current, real power and reactive power waveforms of feeder-1 and feeder-2 with PV plant. Following are the important simulation timelines: Time - 1 = 0.45 sec: unbalanced loads are connected to the feeder without any compensation. Time - 2 = 0.50 sec: Inv-1 starts to compensate for the unbalanced loads The PCC three phase voltage waveforms are shown in Fig. 5(a). It is noticed that the waveforms of the voltages are unbalanced in magnitude (without compensation). When the IPV system Inv-1 is controlled to compensate, this unbalance in the PCC voltages is mitigated achieving a balance set of PCC voltages. The load voltage waveforms are similar to the PCC voltage, due to the small voltage drop on the impedance between the two buses. Load three phase voltage waveforms are shown in Fig 5(b). Fig.9 shows simulated output voltage waveform in which the feeder voltage is regulated at the point of common coupling (PCC) at the time period of 0.5 sec

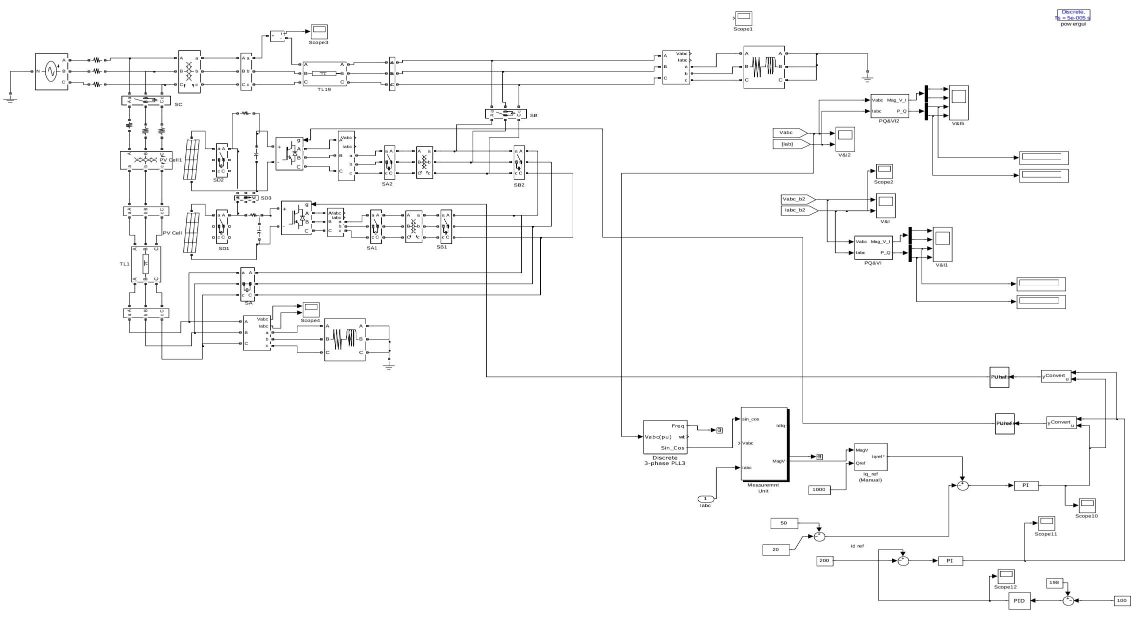

Fig 10Simulation Circuit of proposed I-PV

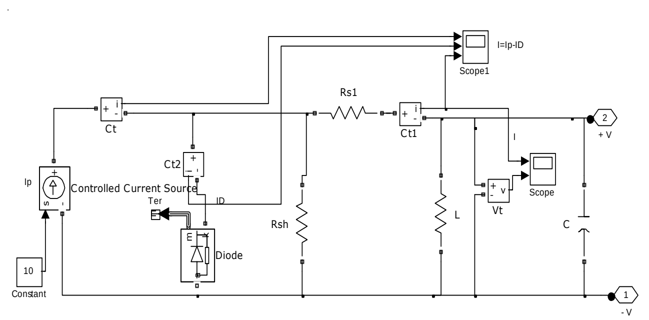

Figure 11: Simulation Circuit of PV Circuit

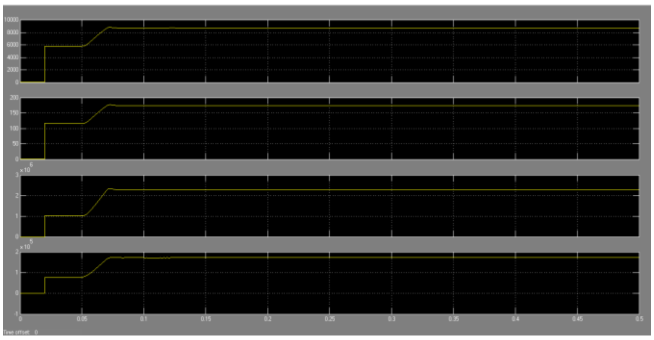

Figure 14: Active Power, Reactive Power, Voltage and Current at Feeder 2

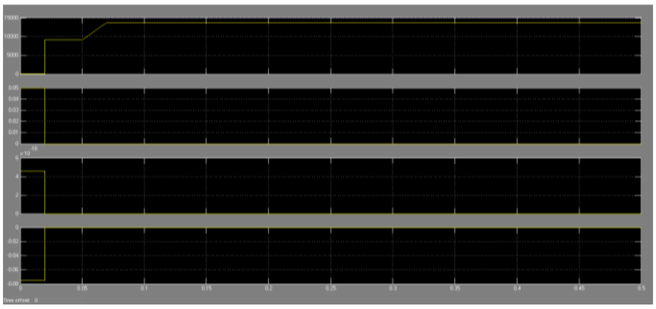

Figure 12: Active Power, Reactive Power, Voltage and Current at Grid.

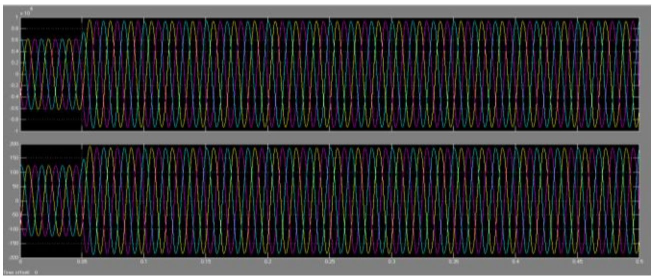

Figure 13: Voltage and current at Feeder 2

V. Conclusion

A new concept of using a PV solar power plant as interline PV system is introduced in this paper. As the name suggests, the interline PV system interconnects two (possibly more) transmission/distribution lines by reconfiguring existing PV solar plant inverters. This newly developed system thus can act as a FACTS device providing a flexible control over both active and reactive powers on multiple lines simultaneously. The interline PV system can be implemented during night hours when PV solar plant produces no real power. The configuration can possibly be realized during daytime hours too. The interline PV system can be used to regulate the transmission/distribution line voltages, to support inductive load VAR requirements, to improve the system performance during dynamic disturbances, manage real power flow between two or more interconnected lines and so on. A MATLAB/SIMULINK based case study is discussed in the paper to demonstrate the control concept of interline PV system. A detailed study however is essential and authors expect to conduct a thorough analysis and in-depth study in the near future.

References

[1] T. Ackermann, G. Andersson, and L. Soder, "Electricity market regulations and their impact on distributed generation," in *Proceeding on International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, 2000, pp. 608-613.

[2] T. Ackermann, G. Andersson, and L. Soder, "Distributed generation: A definition," *Electric Power System Research*, vol. 57, pp. 195-204, April 2001.

[3] M. Marie, E. El-Saadany, and M. Salama, "Flexible distributed generation: (FDG)," in *IEEE Power Engineering Society Summer Meeting*, 2002, vol. 1, pp. 49-53.

[4] C. Marnay and G. Venkatarmanan, "Microgrids in the evolving electricity generation and delivery infrastructure," in *IEEE Power Engineering Society General Meeting* 2006, pp.1-5.

[5] E. Gumerman, R. Bharvirkar, K. LaCommare, and C. Marnay, "Evaluation framework and tools for distributed energy resources," Lawrence Berkeley National Laboratory, LBNL-52079, February 2003.

[6] R. Lasseter and P. Piagi, "Microgrid: A conceptual solution," in *Proceedings of the 35th IEEE Power Electronics Specialist Conference*, Germany, 2004, pp. 4285-4290.

[7] R. Lasseter and P. Piagi, "Extended microgrid using (DER) distributed energy resources," in *IEEE Power Engineering Society General Meeting*, 2007, pp. 1-5.

[8] R. Dugan, M. McGranaghan, S. Santoso, and H. Beaty, *Electrical Power System Quality*, 2nd ed. New York, NY: McGraw-Hill, 2003.

[9] W. Kuehn, "Control and stability of power inverters feeding renewable power to weak ac grids with no or low mechanical inertia," in *IEEE/PES Power Systems Conference and Exposition*, 2009, pp. 1-8.

[10] D. Klapp and H. Vollkommer, "Application of an intelligent static switch to the point of common coupling to satisfy IEEE 1547 compliance," in *IEEE Power Engineering Society General Meeting*, 2007, pp. 1-4.

[11] C. Marnay and O. Bailey, "The CERTS microgrid and the future of the macrogrid," Lawrence Berkeley National Laboratory, LBNL-55281, August 2004.

[12] P. Piagi and R. Lasseter, "Autonomous control of microgrids," in *IEEE Power Engineering Society General Meeting*, 2006, pp. 8-15.

[13] D. Feng and Z. Chen, "System control of power electronics interfaced distributed generation units," in *CES/IEEE 5th International Power Electronics and Motion Control Conference*, 2006, vol. 1, pp. 1-6.

[14] J. Liang, T. Green, G. Weiss, and Q. Zhong, "Hybrid control of multiple inverter in an island-mode distribution system," in *IEEE 34th Annual Power Electronics Specialist Conference*, 2003, vol. 1, pp. 61-66.

[15] T. Loix, K. De Brabandere, J. Driesen, and R. Belmans, "A three-phase voltage and frequency droop control scheme for parallel inverters," in *33rd Annual Conference of the IEEE Industrial Electronics Society*, 2007, pp. 1662-1667.

[16] C. Sao and P. Lehn, "Control and power management of converter fed microgrids," *IEEE Transactions on Power Systems*, vol. 23, no. 3, pp. 1088-1098, August 2008.

[17] P. Karlsson, J. Bjornstedt, and M. Strom, "Stability of voltage and frequency control in distributed generation based on parallel-connected converters feeding constant power loads," in *European Conference on Power Electronics and Applications*, 2005, pp. 10-19.

[18] M. Chandorkar, D. Divan and R. Adapa, "Control of parallel connected inverters in standalone ac supply systems," *IEEE Transactions on Industry Applications*, vol. 29, no. 1, pp. 136-143, January/February 1993.

[19] M. Illindala and G. Venkataramanan, "Control of distributed generation systems to mitigate load and line imbalances," in *IEEE 33rd Annual Power Electronics Specialists Conference*, 2002, vol. 4, pp. 2013-2018.

[20] G. Venkataramanan and M. Illindala, "Small signal dynamics of inverter

interfaced distributed generation in a chain-microgrid," in *IEEE Power Engineering Society General Meeting*, 2007, pp.1-6.

[21] K. de Brabandere, B. Bolsens, J. Van den Keybus, J. Driesen, M. Rodanovic, and R. Belmans, "Small-signal stability of grid with distributed low-inertia generators taking into account line phasor dynamics," in *18th International Conference on Electricity Distribution (CIRED)*, Italy, 2005, pp. 1-5.

[22] M. Chandorkar, D. Divan, Y. Hu, and B. Barerjee, "Novel architectures and control for distributed UPS systems," in *9th Annual Conference Proceedings Applied Power Electronics Conference and Exposition*, 1994, vol. 2, pp. 683-689.

[23] J. Guerrero, J. Vasquez, J. Matas, M. Castilla, and L. de Vicuna, "Control strategy for flexible microgrid based on parallel line-interactive UPS systems," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 3, pp. 726-736, March 2009

[24] A. Engler and N. Soultanis, "Droop control in LV-grids," in *2005 International Conference on Future Power Systems*, 2005, pp. 6-11.

[25] K. De Brabandere, B. Bolsens, J. van den Keybus, A. Woyte, J. Driesen, and R. Belmans, "A voltage and frequency droop control method for parallel inverters," *IEEE Transactions on Power Electronics*, vol. 22, no. 4, pp. 1107-1115, July 2007.

[26] J. Guerrero, J. Matas, L. de Vicuna, M. Castilla, and J. Miret, "Decentralized control for parallel operation of distributed generation inverters using resistive output impedance," *IEEE Transactions on Industrial Electronics*, vol. 54, no. 2, pp. 994-1004, April 2007.