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Reactive-Active Power Control for Grid-Connected PV Arrays to Enlarge the Hosting Capacity in A Low Voltage Distribution System

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ABSTRACT

The stochastic behavior of solar radiation is one of the challenges faced by increasing the hosting capacity of the photovoltaic (PV) power. At times of exceptional high PV power output, unacceptable voltage rise could happen at PV system terminals. Violating the voltage threshold adversely affect the power quality and security at the customer sides. In order to avoid this, the PV system is normally disconnected during high PV power output, thus causing losses in power generated. Local control approaches have been introduced as a measure to overcome this issue by using only the inverter. One of these approaches is to control the reactive power output of a PV unit in order to suppress the voltage rise without ceasing the PV system. The results from this paper have shown that the existing reactive power control (RPC) approach is unable to suppress this voltage rise effectively in case of low X/R ratio. Active power curtailment (APC) is another approach that results in remarkable power losses. Hence, this paper proposes a methodology that combines both RPC and APC approaches to limit the voltage rise in a low voltage distribution feeder. The effectiveness of the proposed methodology have been examined and demonstrated in this paper. The obtained results show the superiority of the proposed methodology over the conventional approaches, which enlarges the hosting capacity for PV power penetration in a low voltage distribution system.

Keywords: Reactive Power Control; Active Power Control; Photovoltaic; Voltage Rise

ABSTRAK

Tingkah laku stokastik sinaran suria merupakan salah satu cabaran yang dihadapi dengan meningkatkan daya tampung kuasa fotovoltaik (PV). Pada saat pengeluaran kuasa PV tinggi yang luar biasa, kenaikan voltan yang terlampau akan berlaku pada terminal sistem PV. Melanggar ambang voltan akan menjejaskan kualiti dan keselamatan tenaga di sisi pelanggan. Untuk mengelakkan ini, sistem PV biasanya terputus semasa output kuasa PV tinggi yang luar biasa, sehingga menyebabkan kerugian dalam kuasa yang dijana. Pendekatan kawalan tempatan telah diperkenalkan sebagai langkah untuk mengatasi masalah ini dengan hanya menggunakan penyongsang. Salah satu daripada pendekatan ini ialah untuk mengawal output kuasa reaktif unit PV untuk menekan peningkatan voltan tanpa menghentikan sistem PV. Hasil dari kertas ini menunjukkan bahawa pendekatan kawalan kuasa reaktif (RPC) yang sedia ada tidak mampu menaikkan voltan ini dengan berkesan sekiranya nisbah X / R adalah rendah. Pengurangan kuasa aktif (APC) adalah pendekatan lain yang mengakibatkan kerugian kuasa yang luar biasa. Oleh itu, kertas ini mencadangkan satu metodologi yang menggabungkan kedua-dua pendekatan RPC dan APC untuk mengehadkan kenaikan voltan dalam pengantara pengedaran voltan rendah. Keberkesanan metodologi yang dicadangkan telah diperiksa dan ditunjukkan dalam karya ini. Hasil yang diperoleh menunjukkan keunggulan metodologi yang dicadangkan berbanding dengan pendekatan konvensional yang membesarkan kapasiti hosting untuk penembusan kuasa PV dalam sistem pengedaran voltan rendah.

Kata kunci: Kawalan Kuasa Reaktif; Kawalan Kuasa Aktif; Fotovoltaik; Peningkatan Voltan

INTRODUCTION

The use of sustainable energy sources has grown significantly due to the worldwide concern of global warming, climate change and environmental sustainability (Pazheri et al. 2016). Not with standing the benefits of other renewable sources, solar energy offers huge potentials for electricity generation and this is mainly driven by the increasingly mature technology of the photovoltaic (PV) system (Pinto et al. 2016). As a result, the demand for PV systems has been rising lately (Parida et al. 2011) Apart from this, as the demand for electricity continues to rise (Teh et al. 2018), the initiative to replace conventional distributed generations with PV distributed generation has also become more commonplace (Yilmaz and Özçalik 2015). However, the generated PV solar power may exceed the load of the feeder due to its uncertainty behavior (Jabir et al. 2018). This can cause a sudden voltage rise and reverse power flow in the distribution network (Abunima et al. 2018). This voltage violation possibility limits the hosting capacity of power systems to integrate high penetration level of PV.

The issue of high voltage rise can be avoided if the excessive injected power by PV generators is reduced. However, this contradicts the objective of shifting from a conventional to a solar-based generation and this presents a major obstacle for increasing the participation of grid-tied PV systems (Jung et al. 2014). Besides unwanted voltage rise, there is also the issue of voltage dip caused by inadequate PV power output. The higher and the lower end of a voltage rise and dip, respectively, create the voltage range that should not be exceeded as a result of replacing conventional generators with PV generators (Sayeef et al. 2012; Noone 2013). In Australia for example, this voltage range is set to be between +6% and -2% (Noone 2013).

Conventionally, techniques such as increasing conductor size, managing load demand (Jabir et al. 2018) and integrating some equipment such as on-load-tap-changer, autotransformer, voltage regulator and switched capacitor have been used to mitigate voltage rise in a PV integrated distribution network (Su et al. 2014). Static Series Compensator and shunt-connected voltage source converter are also introduced to mitigate voltage dip (Bongiorno & Svensson 2007). While these solutions are effective, they are also costly and require a considerable amount of infrastructure upgrades, time, and maintenances to ensure their efficiency. Due to that, several local control approaches such as reactive power provision, fixed active power limitation, and dynamic active power control for grid-connected PV inverters have been proposed (Von et al. 2013). These techniques use an inverter that can control the active and reactive power output of the PV arrays so that the terminal voltage level stays within an acceptable range (Hoke et al. 2013).

The schematic of a PV generator connected to a grid is shown in Figure 1. V_S and V_{PV} are the utility grid source and the PV output voltage, respectively. During high solar irradiation, V_{PV} may increase to higher than V_S which causes reverse power flow from the PV-side to the utility grid. Then, the voltage drop ΔV, across the line is expressed in Eq. (1) to Eq. (3).

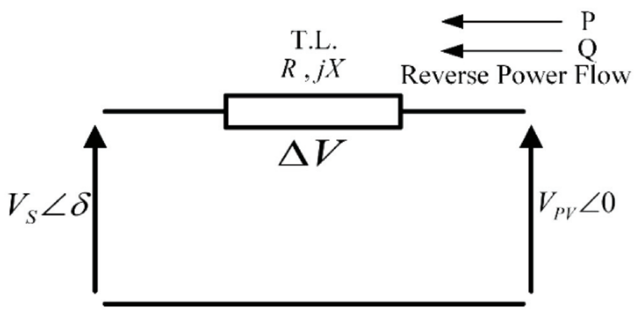


FIGURE 1. Schematic of a PV generator connected to a grid section during reverse power flow condition

$$\Delta V = V_{PV} - V_S \tag{1}$$

$$= \frac{(P_{PV}R + jQ_{PV})^*}{V_{PV}\angle 0}(R + jX) \tag{2}$$

$$= \frac{P_{PV}R + Q_{PV}X}{V_{PV}} + j\frac{P_{PV}X + Q_{PV}R}{V_{PV}} \tag{3}$$

Where ΔV is the voltage drop across the transmission line terminals. V_S and V_{PV} are the primary substation voltage and voltage at the PV system inverter, respectively, and δ is the angle between these two voltages. P and Q are the active and reactive power generated by the *PV* system, respectively. R and X are the resistance and reactance of the transmission line, respectively.

In Figure 2, the phasor diagram of reverse power flow situation shows that the imaginary part of ΔV can be ignored due to the low X/R ratio. Therefore, the voltage drop can be approximated as shown in Eqs. (4, 5). From Eq. (5), a positive XQ term represents the PV system is exporting reactive power and vice versa. Hence, the inverter of a PV array system can control the voltage value of the terminal where the PV array is connected. When the terminal voltage exceeds its upper limit, the inverter consumes reactive power to reduce the voltage. On the other hand, when the terminal voltage drops below its lower limit, the inverter injects reactive power to support the terminal voltage (Momeneh et al. 2016). The ability of the inverter to generate and absorb reactive power is limited by its apparent power capacity as describe by Eq. (6) below (Paaso et al. 2014; Hashemi and Østergaard 2016; Sunderman et al. 2014).

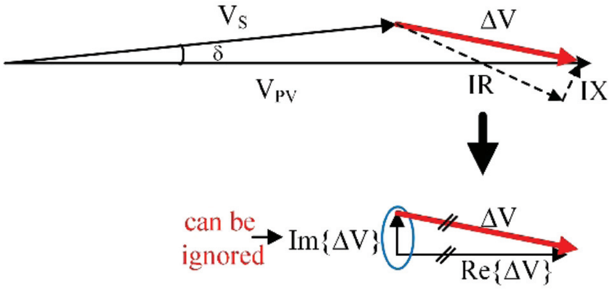


FIGURE 2. Phasor diagram of the system shown in Figure 1 during reverse power flow condition considering V_{PV} as a reference voltage

$$\Delta V \approx \mathrm{Re}\{\Delta V\} \tag{4}$$

$$\Delta V \approx \frac{P_{PV}R + Q_{PV}X}{V_{PV}} \tag{5}$$

$$|Q| \leq \sqrt{S^2 - P^2} \tag{6}$$

Where Q is the reactive power capacity of the inverter, S is the rated apparent power of the inverter, and P is the active power generated by the PV arrays. From Eq. (6), it shows that the reactive power capacity of the inverter is limited by its apparent power capacity. In practice, the inverter has a fix apparent power capacity and it is constrained by the current carrying capability of its semiconductor switches (Hashemi and Østergaard 2016; Yusof and Rahim 2011).

Control methods that determine whether the inverter should inject or absorb reactive power are the maximum-VAR-support mode, static-VAR mode, passive-VAR mode, scheduling-VAR mode and Volt/VAR mode (Hashemi and Østergaard, 2016). Volt/VAR mode is most commonplace as it allows the inverter to monitor its own terminal voltage and respond with a custom VAR response determined by the local utility (Smith et al. 2011). Its mechanism is described in Figure 3a (Sunderman et al. 2014). The figure shows that the inverter neither absorbs nor generates reactive power when the terminal voltage is between V2 and V3 – the dead band. Other than that, the inverter absorbs or generates reactive power when the voltage is more than V3 or less than V2, respectively.

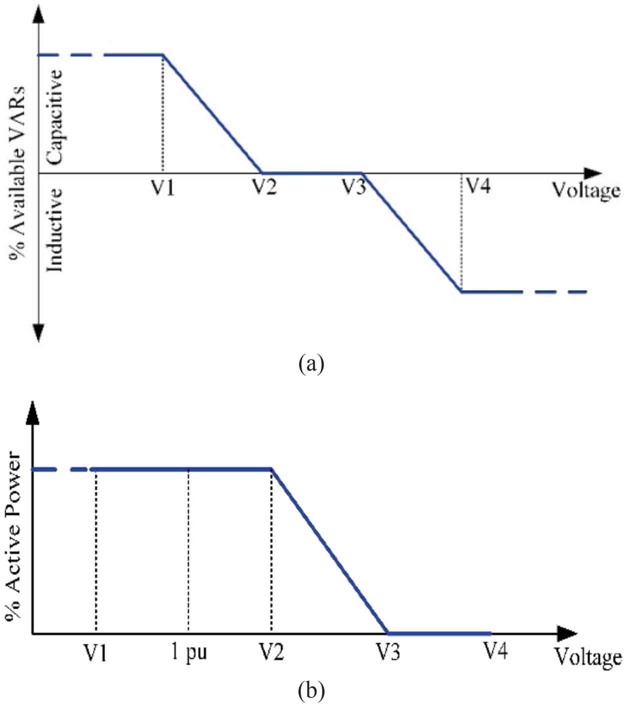
In the situation where cables have low X/R ratio, the reactive power control (RPC) is not effective due to the low sensitivity of ΔV towards Q as shown in Eq. (5). The situation is made worse during high solar irradiation, that is, high active power production, as this can reduce the reactive power capacity of the inverter as given in Eq. (5). In addition, voltage rise is also more probable during high power production by the PV arrays (Orchi et al. 2013). In the case when RPC cannot maintain the terminal voltage to stay within its limits, the PV system is disconnected to maintain the grid voltage constraints and power quality. It is stated in the IEEE 1547 standard that the PV system should cease operation when its terminal voltage exceeds the specified limits. According to the Italian standard CEI 0-21, it is recommended that the PV source should be disconnected within 3s if its terminal voltage exceeds 1.1 p.u.. However, frequent disconnections cause reduction of power generation, financial investment loss, damage to equipment, potential loss of lives, and disruption in the main grid (Ghiani and Fabrizio 2015).

An alternative to RPC is to control the PV arrays active power through the active power curtailment (APC) technique (Tonkoski Lopes 2011). This technique allows the injection of the power generated by the PV arrays as long as the terminal voltages are below its upper limit. Above the limit, the inverter curtails the active power generated by the PV arrays so that the terminal voltage is kept within its acceptable range (Tonkoski Lopes 2011). This control method is illustrated in the Volt/Watt relationship curve as shown in Figure 3b (Sunderman et al. 2014). The figure shows that the active power of the PV arrays is curtailed linearly according to the terminal voltage when it exceeds V2.

Although APC avoids terminal voltage rise, it also limits the injection of PV power output. In other words, the installed PV is not fully utilized to meet financial profit and to aid in the reduction of the greenhouse gasses. Moreover, the APC technique is less flexible than RPC method as it can only deal with the problem of violating the terminal voltage upper limit.

This paper demonstrates that RPC is ineffective in the case of low X/R ratio, and significant losses result from APC approach. The drawbacks of RPC and APC approaches present a gap that this paper intends to fill. Hence, in this paper, a new control methodology that combines RPC and APC is proposed. Applying RPC together with APC approach can effectively mitigate the voltage rise, which in turn increases the hosting capacity for more PV solar power injection. The proposed method has the flexibility of RPC and utilizes the effectiveness of APC when RPC has reached its control limit. It is able to prioritize the RPC and APC functions in order to maintain the voltage limits with lower power losses. A more detailed description of the proposed method will be given in the methodology section. The results in this paper have also shown that the proposed methodology is effective in maintaining the limits of the terminal voltage.

Considering the above, this paper proposes a reactive-active power control approach to increase the PV hosting capacity of distribution systems, especially those with low voltage level. The paper is organised as follows: An overview on the most common local control approaches is presented in Section 1. In Section 2, the proposed approach is discussed. Section 3 describes the system and the data used for demonstrating the functionality of the proposed control approach. The simulation results and discussion are presented in Section 4, and the conclusion is drawn in Section 5.



(a)

(b)

FIGURE 3. (a) Volt/VAR curvefor RPC mode; (b)Volt/Watt curve for APC mode

METHODOLOGY

PHOTOVOLTAIC ARRAY MODEL

A free power flow package known as OpenDSS is used to model the PV systems and the inverter controller. The PV system in OpenDSS can be identified as the simplified block diagram shown in Figure 4 using PV System model. The

P-V and I-V curves of the PV system are shown in Figure 5. OpenDSS assumes that the inverter is able to track the maximum power point (MPP) of the PV arrays quickly and smoothly (Sunderman et al. 2014). This model is identified using the rated power (P_{mpp}), temperature profile, irradiance profile, kVA rating, inverter efficiency, and temperature coefficient of the PV module.

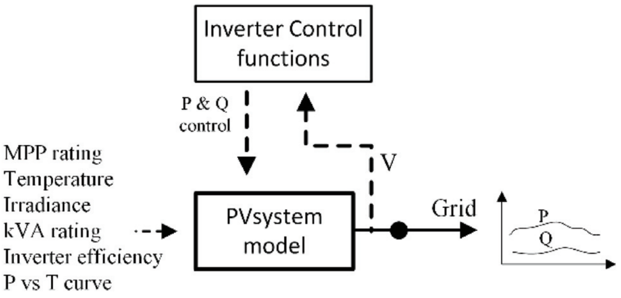


FIGURE 4. Simplified block diagram of the PV system model and inverter control model

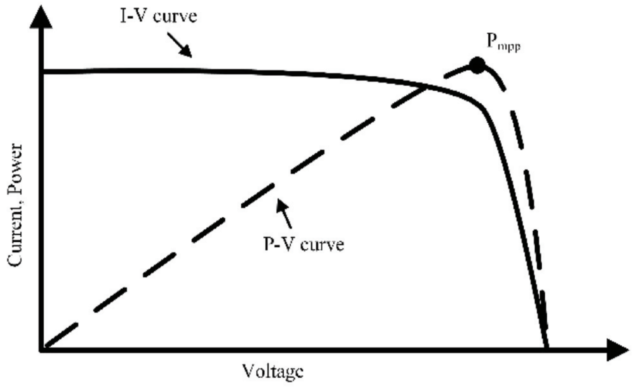


FIGURE 5. Typical current-voltage and power-voltage characteristics

THE PROPOSED CONTROL APPROACH

The two most common control approaches, RPC and APC, are used to alleviate the overvoltage issues. RPC can inject or absorb reactive power, however, it is limited by the inverter kVA rating. APC approach has the ability to mitigate voltage rise but with considerable power losses incur towards the amount of integrated PV power and it is unable to maintain the lower voltage limit. The proposed control approach is described in Figure 6. The controller is modeled using "InvControl" model in OpenDSS.

The proposed control approach is effective in low voltage distribution systems where the X/R ratio is low. The approach consists mainly of two stages. The first stage of the control approach is to control the reactive power according to the Volt-VAR function in Figure 3(a) – known as the 'Q control'. This control function is repeated as long as the reactive power capacity of the PV system inverter is available and the terminal voltage is kept within its limits. When the inverter reactive power output reaches its available capacity and the terminal voltage is still above its upper limit, the second stage of the proposed control method is triggered. If the terminal voltage is below its lower limit, it is raised by injecting reactive power.

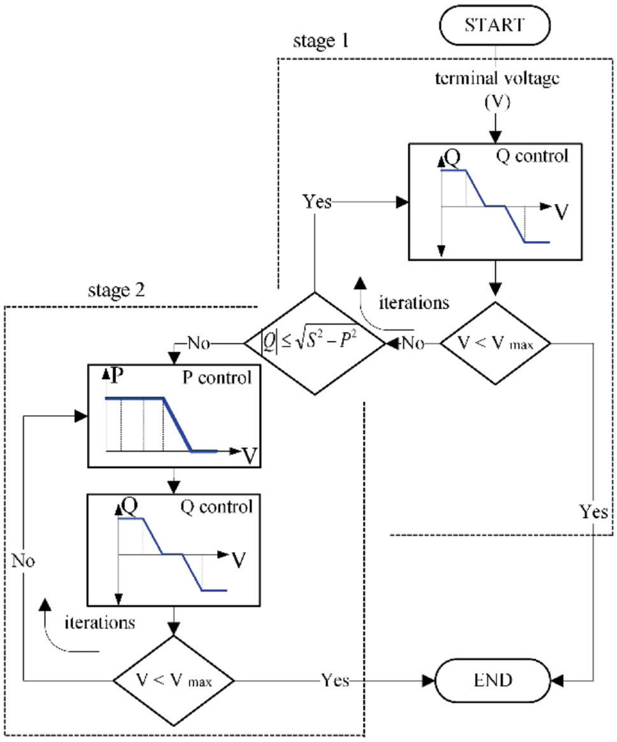


FIGURE 6. Flowchart of the reactive/active power control process

Output reaches its available capacity and the terminal voltage is still above its upper limit, the second stage of the proposed control method is triggered. If the terminal voltage is below its lower limit, it is raised by injecting reactive power.

In the second stage, the active power is curtailed according to the Volt-Watt curve in Figure 3(b)– known as the 'P control'. Subsequently, more reactive power can be absorbed (refer to Eq. (6)). The inverter continues to adjust P and Q to maintain the voltage standard provided that the lowest active power is curtailed concurrently with absorbing the available reactive power. Due to the manipulations of reactive and active power in our proposed control approach, this method is known as the 'Q-P control'.

TEST SYSTEM

The IEEE European low voltage test feeder is used as a test system to investigate the proposed control technique and it is as shown in Figure 7. The IEEE network is supplied by a main power source connected at bus 1 through a delta-wye connected transformer rated at 800 kVA (11/0.416 kV). The test network contains 55 load points. The load data are expressed chronologically over 24 hours with a 1-minute resolution. They are modelled as constant PQ loads with 0.95 power factor and total peak demand of 24.3 kW. For the purpose of this study, the network was modified by adding two identical 5 kW PV systems, connected at bus 639 through two inverters with a rated capacity of 5.55 kVA each.

Each PV system consists of 20 PV modules (ND-R250A5) manufactured by SHARP. P_{max} and temperature coefficient of the module at standard test conditions (STC) are 250 W and -0.44%/°C, respectively. The PV systems were added using the OpenDSS software based on database of the PV modules. The meteorological data such as average solar irradiance and average temperature from Perth, Australia was obtained via METEONORM and they are plotted as shown in Figure 8. In this study, we also adopt the Australian standard for bus operating voltage, which specifies that the bus voltage should range from -2% to +6% of 1 p.u. (Noone 2013). Hence, the PV systems will be disconnected from the grid if the bus voltage exceeds the upper limit.

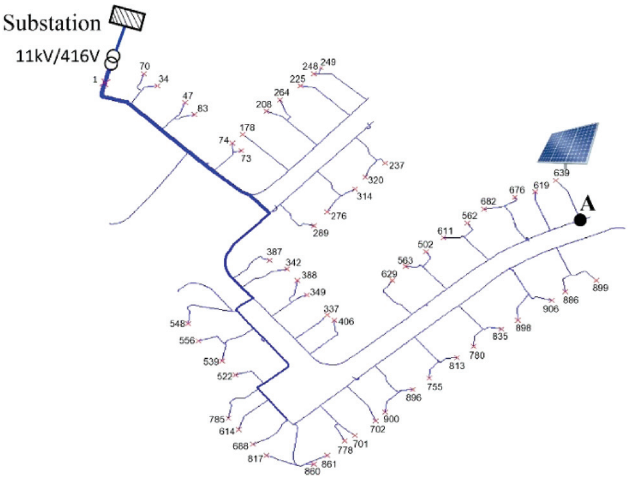


FIGURE 7. One line diagram of the low voltage test feeder and the PV system at bus 639

RESULTS AND DISCUSSION

This section, firstly, presents the three terminal voltage control approaches: 'Q control', 'P control' and the proposed 'Q-P control'. The results are then discussed.

THE COMMON LOCAL CONTROL APPROACHES

In order to identify the power output of the PV system that causes terminal voltage violation in the test system, the PV systems capacity was increased as shown in Figure 9. The figure shows that the voltage exceeds its upper limit of 1.06 p.u. when the maximum power output of the installed PV systems was more than 8 kW under the No-control approach. The active and reactive power output and the terminal voltage of the PV systems when operating without any control function are shown in Figure 10(a). The figure shows that the terminal voltage exceeds its upper bound at various intervals throughout the day from 10:27 to 15:19. The maximum terminal voltage is 1.0675 p.u. at 11:58.

In order to mitigate the voltage rise, two common local control approaches were applied and investigated; 'Q control' and 'P control'. The active and reactive output power and the terminal voltage of the PV systems under the Q control approach are shown in Figure 10(b). The figure shows that the available reactive power was insufficient to maintain the terminal voltage under the upper limit of 1.06 p.u. The recorded highest terminal voltage is 1.0649 p.u at 11:58.

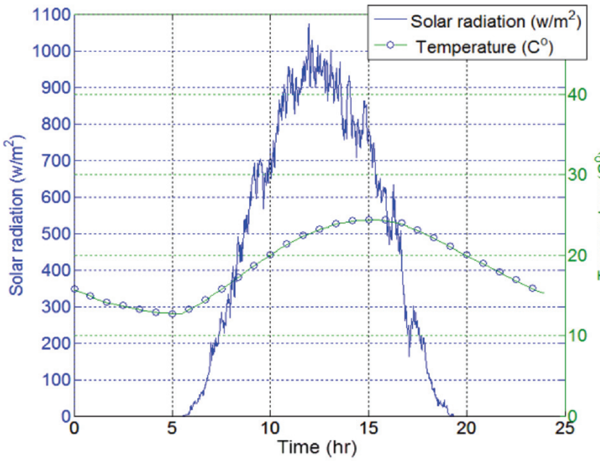


FIGURE 8. Average temperature and average solar irradiance in Perth city for panel tilt angle of 32°

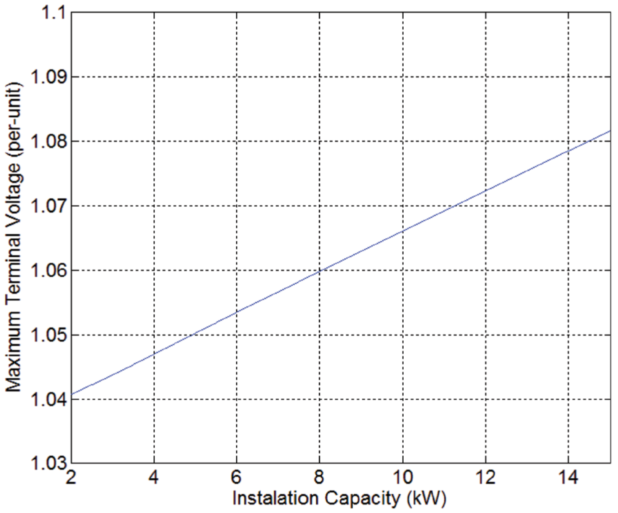
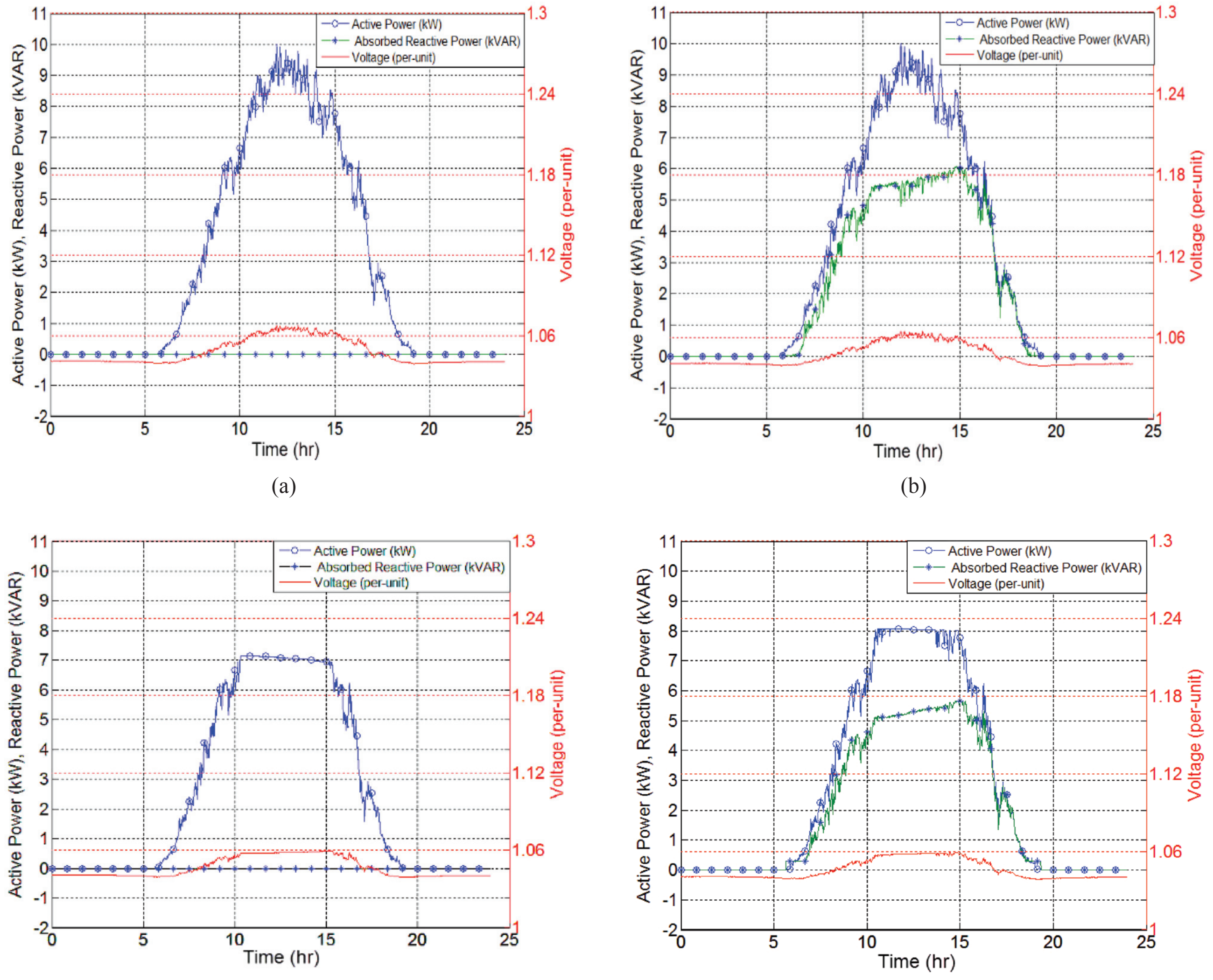


FIGURE 9. The terminal voltage at different capacities of a PV systems connected to the bus 639

In case of APC, the outputs were plotted as shown in Figure 10(c). The figure shows that the terminal voltage is kept under its upper limit throughout the simulation period. However, this was achieved by reducing the output power of the PV systems.

THE PROPOSED REACTIVE/ACTIVE POWER CONTROL APPROACH

The active and reactive output power and the terminal voltage of the PV systems when operating with the proposed 'Q-P control' approach are shown in Figure 10(d). The results demonstrate that the proposed approach is able to maintain the terminal voltage below and at its upper limits with lower curtailed active power. This is possible due to the mechanism of the proposed method as discussed earlier. It is also noted



(a) (b)

(c) (d)

FIGURE 10. The terminal voltage, active and reactive power output of the PV systems under: (a) No control approach; (b) Q control approach; (c) P control approach; (d) Q-P control approach

that the active power output in ‘Q-P control’ approach is higher than that in ‘P control’ approach.

DISCUSSION

Hourly active and reactive power of the three control approaches are shown in Table 1. The symbol (-) was given to the hours when the PV systems were disconnected due to voltage violation.

Table 2 shows a comparison between the three control approaches in terms of energy not utilized while satisfying the voltage constraints. It shows that the system under both the ‘No-control’ and the ‘Q control’ approaches are unable to satisfy the terminal voltage constraints. Moreover, these two methods also have a higher amount of energy not utilized as compared to ‘P control’ and ‘Q-P control’ due to the disconnections of the PV system during overvoltage. More importantly, the results in Table 2 show that although the ‘P control’ approach is able to satisfy the terminal voltage standard, it incurs more losses as compared to our proposed ‘Q-P control’ approach. This is evidenced by the higher energy not utilized due to the execution of ‘P control’ in comparison to the proposed ‘Q-P control’. Hence, the comparison shows that the proposed control approach outperforms both the ‘No-control’ and the ‘Q control’ approach in terms of being able to satisfy the terminal voltage standard and at the same time able to minimize the PV energy not utilized.

CONCLUSION

Voltage rise is one of the concerning issues of installing solar PV into the distribution networks. Many existing networks are unable to match a high injection level of grid-connected PV systems. Therefore, it is considered as a significant obstacle to the solar power industry. Voltage rise occurrence can be mitigated using several measures. Some of these

TABLE 1. Hourly active and reactive power injected to the grid of the three control approaches

Hour	No control		Q control		P control		Q/P control	
	P kW	Q kVAR	P kW	Q kVAR	P kW	Q kVAR	P kW	Q kVAR
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0.19	0	0.19	0.02	0.19	0	0.19	0.3
8	1.45	0	1.45	0.84	1.45	0	1.45	0.99
9	3.20	0	3.20	2.35	3.20	0	3.20	2.38
10	5.12	0	5.12	3.80	5.12	0	5.12	3.69
11	6.66	0	6.66	4.83	6.66	0	6.66	4.61
12	-	-	-	-	7.18	0	8.07	5.11
13	-	-	-	-	7.16	0	8.06	5.21
14	-	-	-	-	7.10	0	8.04	5.36
15	-	-	-	-	7.08	0	8.03	5.45
16	-	-	7.77	6.02	6.99	0	7.77	5.65
17	5.23	0	5.23	4.76	5.23	0	5.23	4.52
18	2.27	0	2.27	2.02	2.27	0	2.27	2.07
19	1.12	0	1.12	1.01	1.12	0	1.12	1.14
20	0.27	0	0.27	0.02	0.27	0	0.27	0.3
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0

TABLE 2. Comparison between the control approaches

	No -control	Q control	P control	Q/P control
Daily energy generated (kwh)	28.09	44.71	61.55	65.57
Energy not utilized (kwh)	40.27	23.64	6.08	2.79
Maximum terminals voltage (Vpu)	1.067	1.065	1.06	1.06
Satisfies the standard condition Vpu ≤ 1.06	No	No	Yes	Yes

measures require an upgrade to the existing distribution network, and others are limited by some physical or technical constraints.

In this paper, a control approach has been proposed aiming to maintain the voltage within the allowable limits and therefore increasing the hosting capacity in a low voltage distribution system. The approach includes controlling both reactive power and active power injected by the inverter following a priority scheme. The results in this paper have also shown that the proposed method allows the injection of PV power output without violating the terminal voltage standard and at the same time minimizes the PV energy not utilized. Hence, the proposed control approach could be a promising method to compensate the deficiencies of the widely used RPC approach. This also means that the proposed control approach can increase the hosting capacity of the distribution networks for PV systems.

FUTURE STUDY

Despite the effectiveness of the proposed control approach, further studies are required to assess the economic limitations resulting from curtailing the active power.

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REFERENCES

Abunima, H., Teh, J., Lai, C.M. & Jabir, H. 2018. A aystematic review of reliability studies on composite power systems: A coherent taxonomy motivations, open challenges, recommendations, and new research directions. *Energies* 11(9): 2417.

Bongiorno, M. & Svensson, J. 2007. Voltage dip mitigation using shunt-connected voltage source converter. *IEEE Transactions on Power Electronics* 22(5): 1867-1874.

Ghiani, E. & Fabrizio, P.I.L.O. 2015. Smart inverter operation in distribution networks with high penetration of photovoltaic systems. *Journal of Modern Power Systems and Clean Energy* 3(4): 504-511.

Hashemi, S. & Østergaard, J. 2016. Methods and strategies for overvoltage prevention in low voltage distribution systems with PV. *IET Renewable Power Generation* 11(2): 205-214.

Hoke, A., Butler, R., Hambrick, J. & Kroposki, B. 2013. Steady-state analysis of maximum photovoltaic penetration levels on typical distribution feeders. *IEEE Transactions on Sustainable Energy* 4(2): 350-357.

Jabir, H., Teh, J., Ishak, D. & Abunima, H. 2018. Impact of demand-side management on the reliability of generation systems. *Energies* 11(8): 2155.

Jabir, H., Teh, J., Ishak, D. & Abunima, H. 2018. Impacts of demand-side management on electrical power systems: A Review. *Energies* 11(5): 1050.

Jung, J., Onen, A., Arghandeh, R. & Broadwater, R.P. 2014. Coordinated control of automated devices and photovoltaic generators for voltage rise mitigation in power distribution circuits. *Renewable Energy* 66: 532-540.

Mahfouz, M. M. & El-Sayed, M.A. 2016. Smart grid fault detection and classification with multi-distributed generation based on current signals approach. *IET Generation, Transmission & Distribution* 10(16): 4040-4047.

Momeneh, A., Castilla, M., Miret, J., Martí, P. & Velasco, M. 2016. Comparative study of reactive power control methods for photovoltaic inverters in low-voltage grids. *IET Renewable Power Generation* 10(3): 310-318.

Noone, B. 2013. PV integration on Australian distribution networks. The Australian PV Association, UNSW, Australia.

Orchi, T.F., Hossain, M.J., Pota, H.R. & Rahman, M.S. 2013. Impact of distributed generation and series compensation on distribution network. Industrial Electronics and Applications (ICIEA), *2013 8th IEEE Conference,* 854-859.

Paaso, E.A., Liao, Y. & Cramer, A.M. 2014. Formulation and solution of distribution system voltage and VAR control with distributed generation as a mixed integer non-linear programming problem. *Electric Power Systems Research* 108: 164-169.

Parida, B., Iniyan, S. & Goic, R. 2011. A review of solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews* 15(3): 1625-1636.

Pinto, R., Mariano, S., Calado, M.D.R. & de Souza, J.F. 2016. Impact of rural grid-connected photovoltaic generation systems on power quality. *Energies* 9(9): 739.

Sayeef, S., Heslop, S., Cornforth, D., Moore, T., Percy, S., Ward, J., Berry, A. & Rowe, D. 2012. Solar intermittency: Australia's clean energy challenge. Characterising the effect of high penetration solar intermittency on Australian electricity networks, CSIRO.

Smith, J.W., Sunderman, W., Dugan, R. & Seal, B. 2011. Smart inverter volt/var control functions for high penetration of PV on distribution systems. *Power Systems Conference and Exposition (PSCE), 2011, IEEE PES*; 1-6.

Su, X., Masoum, M.A. & Wolfs, P.J. 2014. Optimal PV inverter reactive power control and real power curtailment to improve performance of unbalanced four-wire LV distribution networks. *IEEE Transactions on Sustainable Energy* 5(3): 967-977.

Sunderman, W., Dugan, R.C. & Smith, J., 2014. Open source modeling of advanced inverter functions for solar photovoltaic installations. T&D Conference and Exposition, 2014, *IEEE PES*; 1-5.

Teh, J., Ooi, C.A., Cheng, Y.H., Atiqi M.Z. & Lai, C.M. 2018. Composite reliability evaluation of load demand side management and dynamic thermal rating systems. *Energies* 11(2): 466.

Tonkoski, R. & Lopes, L.A. 2011. Impact of active power curtailment on overvoltage prevention and energy production of PV inverters connected to low voltage residential feeders. *Renewable Energy* 36(12): 3566-3574.

Von Appen, J., Braun, M., Stetz, T., Diwold, K. & Geibel, D., 2013. Time in the sun: the challenge of high PV penetration in the German electric grid. *IEEE Power and Energy Magazine* 11(2): 55-64.

Yang, D.X. & Nie, P.Y. 2016. Influence of optimal government subsidies for renewable energy enterprises. *IET Renewable Power Generation* 10(9): 1413-1421.

Yusof, Y. & Abd, R.N. 2011. Functional simulation model for single phase Pulse Width Modulation-voltage Source Inverter (PWM-VSI) using switching function concept. *Jurnal Kejuruteraan* 23: 49-56.

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