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Performance analysis of distribution networks under high penetration of solar PV

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Abstract

Integration of solar photovoltaic (PV) resources into distribution networks changes the normally expected network behaviour by injecting real power into the point of connection. Depending on the characteristics and setup of the PV inverter, reactive power could also be injected into the network. The impact will depend on the control strategy adopted for reactive power injection. Typically, solar PV units are installed at low voltage (LV) level in distribution networks. Cluster based installation of numerous PV inverters in the LV level will impact the operation of both the host LV network and the upstream medium voltage network. With random variations in load and PV output throughout the day, the behaviour of distribution network needs to be studied so that any unexpected operational behaviour of the network arising from PV integration can be avoided. In this paper, the distribution network performance under high penetration of solar PV resources is studied. Novel indices are developed to analyse network performance in terms of voltage deviation from nominal value, average feeder loading, substation capacity and feeder power losses. Variations of the indices for increasing level of PV penetration are investigated under different types of power control strategies. Day long behaviour analysis is performed in terms of the performance indices by adopting the most suitable control strategy for the PV inverters. A practical distribution feeder from Australia is used to examine the applicability of the developed indices and control strategies.

Keywords

distribution, networks, under, high, penetration, performance, solar, analysis, pv

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Performance Analysis of Distribution Networks under High Penetration of Solar PV

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SUMMARY

Integration of solar photovoltaic (PV) resources into distribution networks changes the normally expected network behaviour by injecting real power into the point of connection. Depending on the characteristics and setup of the PV inverter, reactive power could also be injected into the network. The impact will depend on the control strategy adopted for reactive power injection. Typically, solar PV units are installed at low voltage (LV) level in distribution networks. Cluster based installation of numerous PV inverters in the LV level will impact the operation of both the host LV network and the upstream medium voltage network. With random variations in load and PV output throughout the day, the behaviour of distribution network needs to be studied so that any unexpected operational behaviour of the network arising from PV integration can be avoided. In this paper, the distribution network performance under high penetration of solar PV resources is studied. Novel indices are developed to analyse network performance in terms of voltage deviation from nominal value, average feeder loading, substation capacity and feeder power losses. Variations of the indices for increasing level of PV penetration are investigated under different types of power control strategies. Day long behaviour analysis is performed in terms of the performance indices by adopting the most suitable control strategy for the PV inverters. A practical distribution feeder from Australia is used to examine the applicability of the developed indices and control strategies.

KEYWORDS

Solar PV Cluster, Distribution Network Performance, Inverter Control, Active and Reactive Control, Feeder Voltage Rise, Performance Indicators.

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1.0 INTRODUCTION

Customers in the low voltage (LV) distribution networks are increasingly installing Solar PV resources in the form of rooftop PV units in residential households. In conventional distribution networks, electric power is supplied to the customers from upstream networks. The normal direction of power flow is therefore from the source (substation) towards the load (customers). With an increasing level of solar PV penetration, there is a possibility that the total power generation from the PV resources connected to the low voltage distribution feeder may exceed the total load demand. This situation could typically arise in distribution feeders with high PV penetration during midday, when generation from PV resources is typically highest and may be greater than the load level. The surplus power resulting from the mismatch of load and generation would flow to the upstream networks, and this will produce reverse power flow and voltage rise in the feeders. Changes in voltage and power flow created by PV resources will impact the normal behaviour of distribution networks as discussed in [1-3].

Rooftop PV units typically operate at unity power factor. That is, only real power is produced by the PV units. If the PV resources were allowed to inject reactive power as well, different situations may arise depending on the control strategies adopted for reactive power injection. Control strategies such as IEEE 1547 control, voltage control, maximum reactive power control, and power factor control could be adopted [4-7]. For example, if the PV units intend to control voltage at the connection points, then the resulting reactive power injection from PV inverters would be different than the reactive power injection arising from the PV inverters if the objective is to control the power factor. The magnitude and direction of reactive power flow through the feeder will, therefore, be different for each of the control strategies. The impacts on the feeder in terms of voltage variation, feeder loading and power losses will also be different for each of the control strategies.

A small number of PV units scattered over a large distribution area may not impact the network severely, as the generation from PV units may not exceed feeder load. However, when numerous PV units are connected to the same distribution feeder in a small area, the impact of the PV cluster [8] may impose the threat of violating the system operation limits, such as upper and lower voltage limits, current limit, etc. With random variations of feeder loads, and PV active and reactive power injection throughout the day, network performance would also vary in a random fashion. It is therefore essential to investigate the potential impacts of solar PV clusters with random output variations on the distribution networks to achieve the target level of solar PV penetration.

This paper studies the performance of distribution networks with a high penetration of solar PV resources which are connected in clusters and with random output levels. Feeder voltage, feeder loading, substation capacity and feeder power losses are used to develop performance indices to assess network performance for networks with a fluctuating level of PV penetration level throughout the day. The performance of the network under different reactive power control strategies also is compared to establish a guideline for selection of the most suitable PV operation strategy.

2.0 SOLAR PV IMPACTS ON DISTRIBUTION NETWORK PERFORMANCE

The primary task of distribution network is to supply electrical energy to the customers while maintaining the voltage level within acceptable limits. Voltage profile along the feeder decreases depending on the line impedances and the level of loads being served [4]. The solar PV resources connected to distribution networks change the loading conditions of the grid at the points to which they are connected, namely, the points of common coupling (PCC) as shown in Fig. 1.

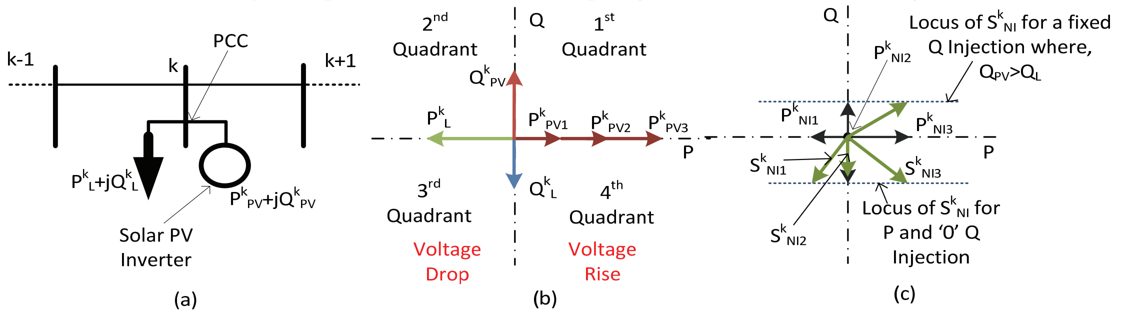

Fig. 1: Variation of net PQ injection (a) simple system diagram of an arbitrary phase of three phase LV feeder (b) four-quadrant PQ model for kth system node (c) net P-Q injection for kth system node

Changes in power flow and voltage profile for a fixed set of line impedances and load levels in the network are a function of the net power injection from PV resources after the PV resources serve the local demand.

Schematic diagram of a simple feeder shown below in Fig. 1(a) is used to discuss how the net injection from PV changes with varying level of PV output.

It is assumed that a solar PV inverter is connected to the *k*-th node of an arbitrary phase of a three phase LV distribution feeder shown in Fig. 1(a). The load connected at the k-th node is $P^k{}_L+jQ^k{}_L$ and the power injection from solar PV inverter is $P^k{}_{PV}+jQ^k{}_{PV}$. From an injection perspective, loads are shown in the negative P and Q axes and different levels of PV injection (e.g. $P^k{}_{PV1}$, $P^k{}_{PV2}$, $P^k{}_{PV3}$) are shown in the positive P and Q axes in Fig. 1(b). The net PV injection at the k-th node is defined in Equation (1),

$$S^k{}_{NI} = P^k{}_{NI} + jQ^k{}_{NI} = \left(P^k{}_{PV} - P^k{}_L\right) + j\left(Q^k{}_{PV} - Q^k{}_L\right) \tag{1}$$

For a PV injection with $P^k{}_{PV} < P^k{}_L$, the net *P* injection, $P^k{}_{NI}$, is negative as shown in Fig. 1(c); with increasing level of $P^k{}_{PV}$, the net *P* injection becomes zero when $P^k{}_{PV} = P^k{}_L$ and eventually changes to a positive value when $P^k{}_{PV} > P^k{}_L$. If the *Q* injection from PV inverter is *zero*, then the net *Q* injection always remains negative and the locus of net apparent power injection, $S^k{}_{NI}$ from the PV inverter is a straight line parallel to the *P* axis and intersects the *Q* axis at $-Q^k{}_L$. With increasing $P^k{}_{PV}$, the PV operation at *k*-th node changes position from 3rd to 4th quadrant. If the PV inverter injects reactive power with $Q^k{}_{PV} > Q^k{}_L$, then the PV operating point shifts to 1st quadrant where the net *P* and net *Q* injection, both are positive. As shown in Fig. 1(b), PV operation at the 1st and 4th quadrants may create voltage rise and reverse power flow in the feeder, and as a result it may impact distribution network performance.

2.1 Reactive Power Control Approach for Solar PV Inverter

Solar PV inverters typically operate at unity power factor and therefore the reactive power capability is kept ideally at *zero* so that whole capability of the inverter can be used for real power generation. However, if the PV inverters are allowed to inject reactive power as well, the capability has to be increased in such a way that the inverters are capable to inject a certain amount of reactive power even at the time of maximum real power generation. The rating of the PV inverter needs to be increased to supply this additional output [7]. In this case, the additional capacity factor, α, can be defined as a fraction of the maximum real power generation, $P_{pv}{}^{max}$, where α varies from 0 to a user defined value (typically less than 1).

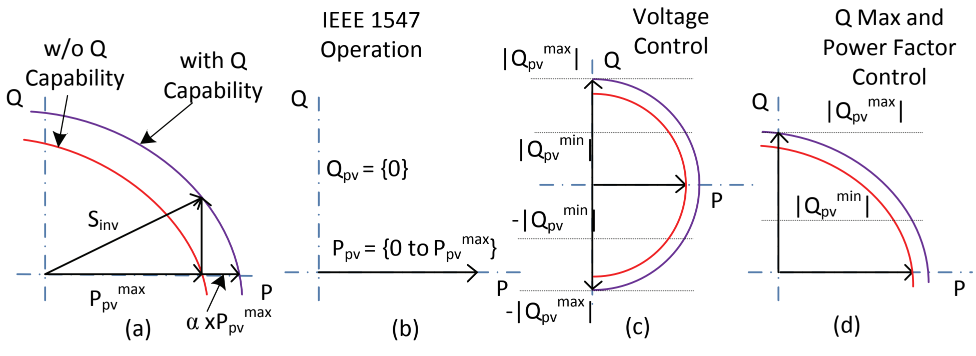

Fig. 2: PV inverter capability with different control strategies (a) Increase of PV inverter size for reactive capability addition (b) IEEE 1547 control (c) Voltage control (d) Q max and power factor control

The reactive power generated at the time of maximum active power generation is the minimum value of reactive power, $Q_{pv}{}^{min}$, whereas the maximum reactive power, $Q_{pv}{}^{max}$, is obtained using the total inverter capacity when active power production is *zero*; these values can be obtained for different values of α using the relation shown in Equation (2).

$$Q_{pv}^{\min} = P_{pv}^{\max}\left(\sqrt{\alpha^2 + 2\alpha}\right) \text{and} Q_{pv}^{\max} = (1+\alpha)P_{pv}^{\max} \tag{2}$$

The reactive capability obtained by increasing the inverter size can be used according to different control strategies [4, 6-7]. Network performance under different types of reactive power control strategies followed by the PV inverters would be different and needs to be explored. The control approaches discussed in [6-7] are used to formulate the active and reactive power control strategies for rooftop solar PV inverters, and are briefly described below.

2.1.1 IEEE 1547 Approach:

In this approach the inverter does not actively participate in voltage regulation. This means that the inverter would not respond to change in voltage by changing reactive power production in a closed loop approach [2]. Although in this control approach the inverters may be able to generate reactive power, in this paper only the real power generation by the inverter is considered. As shown in Fig. 2(b), the real power production ranges from *zero* to P_{pv}^{max}.

2.1.2 Voltage Control:

This approach is similar to the one for a conventional power generating unit that controls the voltage by manipulating reactive power output within its reactive capability limits; active power production remains in the same range of (0, P_{pv}^{max}). As the PV inverters will control the feeder voltage, operation of voltage regulators is deactivated [6]. The amount of reactive power generation or consumption will depend on the voltage set-point and the operating point will vary depending on the amount of reactive power, as shown in Fig. 2(c). If the limit in either direction is exceeded, then voltage control is lost and reactive power generation or consumption becomes fixed at the limit value.

2.1.3 Q Max Control:

This mode allows the feeder to export reactive power to upstream network, as well as the active power in the range of (0, P_{pv}^{max}). In other words, if the reactive power production is higher than the reactive power demand, this will create reverse reactive power flow in the feeder. Solar PV inverters provide maximum reactive power based on their remaining capability after generating active power, as shown in Fig. 2(d). The amount of reactive power generation at any given active power generation, P_{pv}, and, additional capacity factor, α, can be obtained using the following expression in Equation (3)

$$Q_{pv} = \sqrt{\left\{(1+\alpha)P_{pv}^{\max}\right\}^2 - \left(P_{pv}\right)^2} \tag{3}$$

2.1.4 Power Factor Control:

In this approach, active power generation is same as before. Reactive power generation from the PV is controlled such that the power factor at the PCC remains slightly capacitive. This means the reactive power production needs to be higher than the reactive demand at the PCC; however, if the reactive demand at PCC is higher than the remaining capability of the inverter, the reactive power production is set to this limit value. The control approach can be expressed as shown in Equation (4).

$$\begin{aligned}&\text{if } \beta Q_{PCC}^{demand} \le \sqrt{\left\{(1+\alpha)P_{pv}^{\max}\right\}^2 - \left(P_{pv}\right)^2} \text{ for } \beta > 1, \text{then } Q_{pv} = \beta Q_{PCC}^{demand} \\ &\text{else } Q_{pv} = \sqrt{\left\{(1+\alpha)P_{pv}^{\max}\right\}^2 - \left(P_{pv}\right)^2}\end{aligned} \tag{4}$$

With this control approach, reactive power flow through the feeder would decrease and this, in turn, would reduce the feeder loading and power losses.

2.2 Impact of Solar PV Cluster with Random Output

Multiple numbers of solar PV units connected to the same distribution feeder in a small area resulting to a high density of PV installations is typically defined as a PV "cluster" [8].

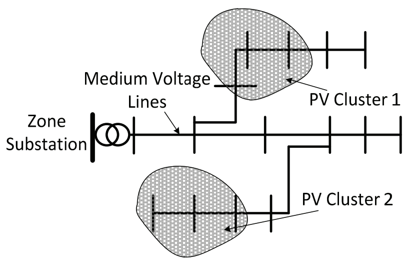

Fig. 3: Location of PV clusters in distribution feeders

When numerous small solar PV units are introduced in multiple LV feeders within a small distribution area in a "cluster" form, as shown in Fig. 3, the cumulative impact could be detrimental to maintaining normal system operation. Moreover, the outputs of each of the PV units in the cluster and the loads would vary randomly throughout the day, and the impacts would also vary accordingly. In this paper, the results of network performance studies considering these issues are presented.

3.0 DEVELOPMENT OF PERFORMANCE INDICES

The level of PV impact will vary depending on the impedance, loading level, and PV output in any given feeder. Development of indices is therefore beneficial to analyse and compare the impacts on different feeders in a distribution network under varying system conditions. The following sub-sections discuss the formulation of performance indices.

3.1 Maximum Voltage Deviation Index (MVDI):

Fig. 4 shows the voltage deviation from the nominal value with and without PV integration. It is seen in Fig. 4(a) that a significant voltage drop can occur without PV integration. PV inclusion can introduce voltage rise in the network. For any phase p, where $p \in \{a,b,c\}$, of the three phase feeder shown in Fig. 4(b), if the maximum voltage deviation is found at node k, then the maximum voltage deviation index, *MVDI* can be obtained from the expression given in Table I, where V_{nom} is the nominal voltage and V^{kp} is the voltage at k-th node of phase p. The change in voltage profile caused by PV integration, as shown in Fig. 4(a), can be supportive to the system as long as it is within the voltage limit bandwidth. As per the definition of MVDI, it will become negative when the node voltage at k exceeds the nominal voltage level.

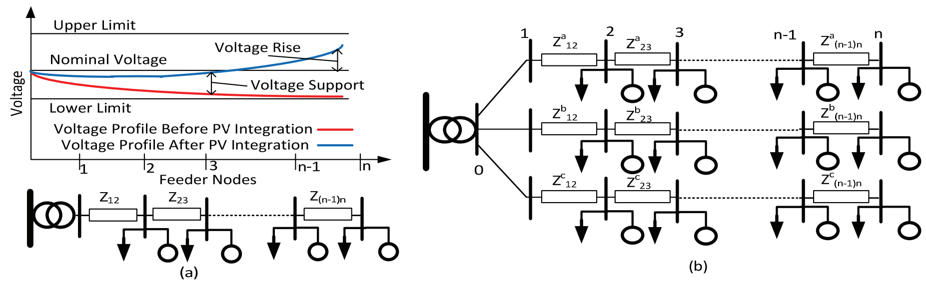

Fig. 4: Change in feeder voltage profile due to PV integration (a) a per phase feeder diagram with the voltage profile along the feeder (b) three phase diagram of the LV feeder

3.2 Average Feeder Loading Index (AFLI):

Distribution feeders are typically operated in a way not to exceed their rated capacities in normal operation. The average loading of a feeder therefore could be used as an indicator to determine how far the feeder is from being overloaded. Different segments of a feeder may have different levels of loading. An average feeder loading index, *AFLI*, can be defined based on the weighted average of percentage length of the feeder segments, as shown in Table I, where $l^p_{k(k+1)}$ is the length of the segment at phase p from k-th node to the (k+1)-th node, L_f is the total feeder length, $S^p_{k(k+1)}$ is the apparent power flow in the segment under consideration and $C^p_{k(k+1)}$ is the rated apparent capacity of the segment. Average loading would decrease by serving local loads by solar PV, however, may increase as well, due to excessive reverse power flow..

3.3 Substation Reserve Capacity Index (SRCI):

The remaining capacity of a substation transformer can be determined from its loading level. A measurement index can be developed to assess the distribution feeder performance in terms of substation reserve capacity. To determine the loading level of the three-phase LV substation shown in Fig. 4(b), the apparent power flowing through the segment connecting from substation node (node 0) to the first node of the feeder (node 1) can be used, which consists of the total loads and losses in the feeder. Ratio of the sum of apparent power flows, S^a_{01}, S^b_{01}, and S^c_{01} over the three phases, to the capacity of the substation, S^{sub}, will provide the loading level of the substation; this ratio can be used to determine the reserve capacity index, *SRCI*, as given in Table I. *SRCI* may increase with PV integration, but may decrease as well, with high PV penetration and reverse power flow.

3.4 Feeder Loss-to-Load Ratio (FLLR):

Ratio of feeder losses to the total loads being served by the feeder could be used as an index to measure the performance of the feeder in terms of power losses. For the three phase feeder in Fig. 4(b), if the total load in phase p is P_p and the total real power loss incurred in phase p of the feeder is P_{loss}^p, then feeder loss-to-load ratio, *FLLR* for phase p can be expressed as per the ratio given in Table

I. Power loss is expected to reduce with reduction in feeder power flow from the substation. However, with excessive level of solar PV penetration, feeder loss may increase with reverse power flow.

TABLE I: EQUATIONS OF PERFORMANCE INDICES

Max. Voltage Deviation Index (MVDI)	Average Feeder Loading Index (AFLI)	Substation Reserve Capacity Index (SRCI)	Feeder Loss-to-Load Ratio (FLLR)
$MVDI^p = \frac{V_{nom} - V^{kp}}{V_{nom}}$	$AFLI^p = \sum_{k=1}^{n} \left(\frac{I^p_{k(k+1)}}{L^p_f} \right) \left(\frac{\lvert S^p_{k(k+1)} \rvert}{C^p_{k(k+1)}} \right)$	$SRCI = 1 - \frac{\lvert S^a_{01} \rvert + \lvert S^b_{01} \rvert + \lvert S^c_{01} \rvert}{S^{sub}}$	$FLLR^p = \frac{P^p_{loss}}{P^p} = \frac{P^p_{loss}}{\sum_{k=1}^{n} P^{kp}}$

4.0 NETWORK PERFORMANCE UNDER PV PENETRATION

Changes in network performance indices caused by the changes in PV penetration and load in the feeder are presented in this section. PV inverters of up to 2.5 kW size per household are considered.

4.1 Test Network:

An Australian distribution feeder in the South-East part of New South Wales has been used for this study. This is an 80 km long rural feeder, serving several sparsely populated areas. This 11 kV rural feeder contains several types of conductors and the R/X ratios of lines are different for different segments of the feeder. It contains three series voltage regulators as shown in Fig. 5(a) below.

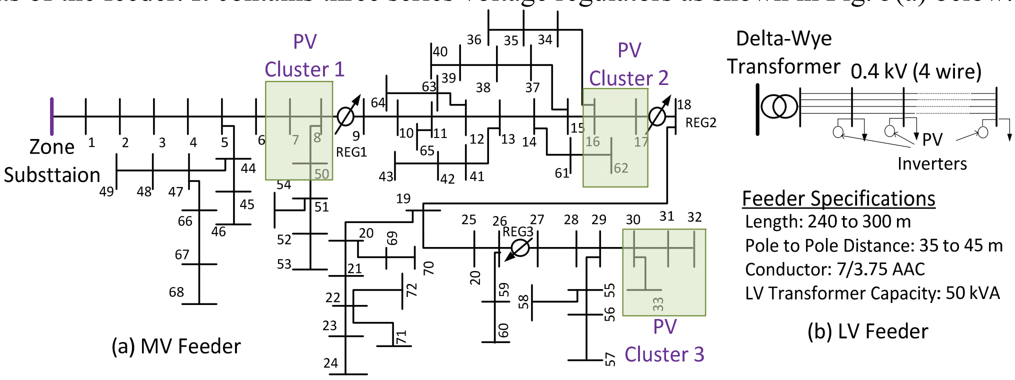

Fig. 5: Test feeder (a) 11 kV network (b) 0.4 kV LV feeder

4.1.1 LV Feeder and Transformer:

The LV feeders are of four wire configuration, as shown in Fig. 5(b). The MV/LV transformers serving the LV feeders are delta-wye connected; the delta side is connected to three wire MV lines and wye side is connected to four wire LV lines. Feeder specifications are shown in Fig. 5(b).

4.1.2 Feeder Load:

Residential feeder loads comprise of end-use electrical appliances related to household activities like such as lighting, cooking, washing and drying, entertainment, computer and telecommunication technologies etc. Modelling of these appliances is a complex task that involves finding the voltage dependencies of each of the appliances in a typical household. Voltage dependency of loads can be modelled by using ZIP parameters that are the proportions of constant impedance (Z), constant current (I) and constant power (P) type of load in any given load model. Standard ZIP parameters of typical household appliances have been aggregated using weighted average of load to obtain the ZIP parameters of the total household. Each of the individual households in a feeder would have different type of daily load variations. The daily load variation of a number of households in an Australian LV residential feeder was studied and these load patterns were used for daylong load variation of the feeder.

4.1.3 Solar PV System:

Solar PV systems used in the residential households are typically rooftop PV installations that consist of the PV modules on the roof and the voltage source inverter converting DC power from PV modules to AC power and feed into the AC mains of the household. The DC power produced by the PV modules obtained from the I-V characteristics of the modules depend on the ambient temperature and sun insolation level. Losses in conversion from DC to AC through the inverters have been considered. Other factors include mismatches among panels and loss due to dirt. Parameters of the solar PV units used for simulation are given in the Table II below.

TABLE II: SOLAR PV MODULE SPECIFICATIONS AT STANDARD TEST CONDITIONS

Manufacturer and Model	Kyocera, KC200GT
Current and Voltage at Maximum Power Point	26.3 V and 26.3 V
Maximum Power	200.143 W
Nominal Short Circuit Current and Open Circuit Voltage	8.21 A, 32.9 V
Voltage / Temperature and Current/ Temperature Coefficient	-0.1230 V/K and 0.0032 A/K
Series and Parallel Resistance	0.222 Ohm and 420.3 Ohm
Inverter Model	Sunny Boy SB2000
Maximum Efficiency	96%

4.2 Network Performance Indices under High PV Penetration

In this study, network performance indices are observed for a fixed load level in the feeder with an increasing level of PV penetration. As the PV penetration typically reaches a peak level at noon time, the feeder load at noon time has been used as the feeder load for this analysis. The Australian households studied for residential load variation showed that the average load per household drops down to about 1 kW at midday. The ratings of PV inverters per household were varied from 0 kW to 2.5 kW. Using the definition of feeder PV penetration as the ratio of total PV generation in the feeder to the total feeder load, this means a penetration from 0% (without PV) to 250% (with 2.5 kW PV). As the reactive power control strategies would mainly impact the reactive power flow through the feeders, a study was performed to understand the changes in reactive power flow as a result of the control strategy adopted. Reactive capability was included in the PV inverter by increasing its rating by 10% of the active power capacity, as shown in Fig. 6(a). Results of this study are presented in Fig. 6(b).

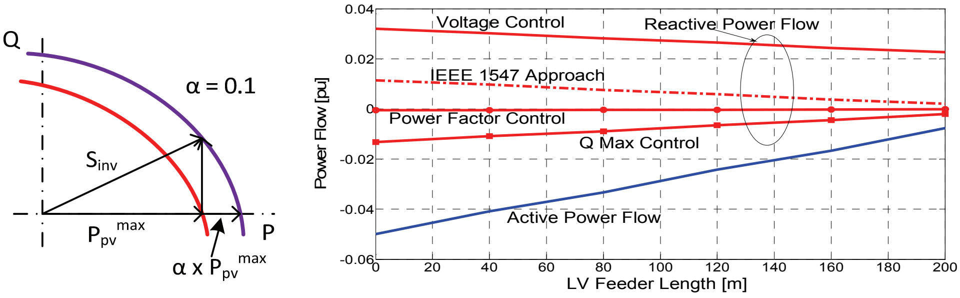

Fig. 6:Application of control strategies: (a) PV inverter capability (b) Reactive power flow in LV feeder

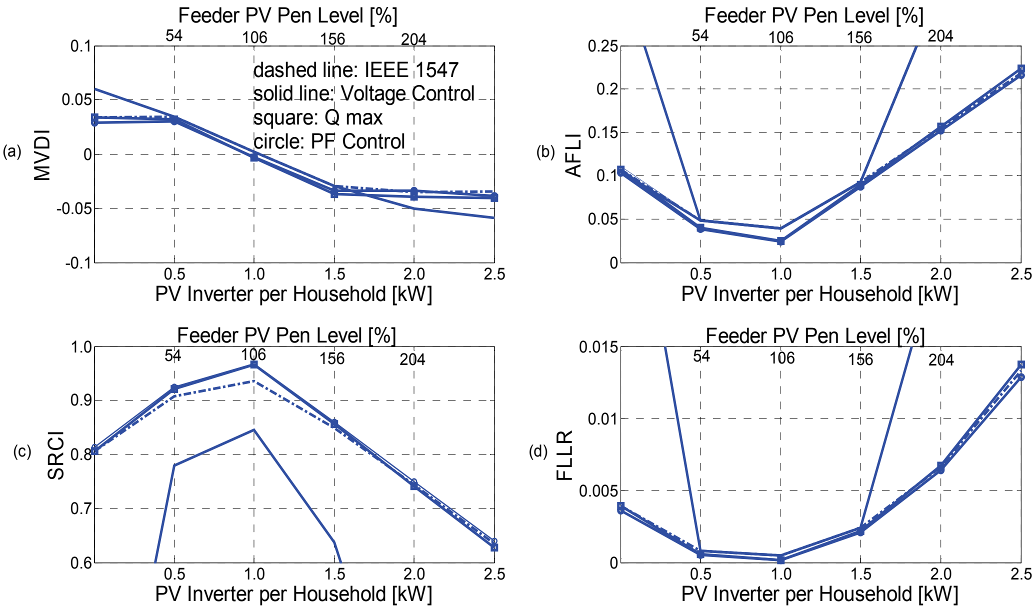

Fig. 7: Variations of network performance indices with increasing PV penetration: (a) MVDI, (b) AFLI, (c) SRCI and (d) FLLR

With the IEEE 1547 strategy, PV units only inject active power into the feeder and reactive power is taken from the feeder as shown with the dotted line in Fig. 6(b). With the voltage control approach, PV units absorb reactive power to control the voltage at the PV connection when the voltage rises above a threshold level. This results in high reactive power flow in the feeder as shown by the solid line in Fig. 6(b). With the Q Max approach, PV inverters provide maximum reactive power based on their capability, and surplus reactive power, upon meeting the load reactive demand, is exported back to the grid. With the power factor control approach, reactive power injection from the PV is controlled so that the power factor at the connection point is slightly capacitive.

In the IEEE 1547, Q Max and Power Factor control strategies, voltage regulators act to maintain the voltage within acceptable limits and the voltage deviation index, MVDI, remains nearly the same, with slight variation due to differences in the number of tap operations. For the voltage control approach, regulator operations are deactivated to study the effectiveness of PV inverters in controlling the feeder voltage. The MVDI, therefore, increases in the negative direction until it reaches to a threshold level, and then it starts to decrease due to control action of the inverters. This is done at the expense of increased reactive power flow and hence the feeder loading increases as indicated by the AFLI plot in Fig. 7(b).

In other control approaches, the average loading is less than the loading in the voltage control approach. Due to the increased loading of the feeder in the voltage control approach, the substation reserve capacity is also affected as shown in the SRCI plot in Fig. 7(c). In the voltage control approach, the amount of reserve capacity decreases sharply after it reaches a threshold level of PV penetration. Increased feeder loading also increases feeder loss as shown by the FLLR plot in Fig. 7(d). The average loading and feeder power loss is the minimum for the power factor control approach due to nearly zero reactive power flow through the feeder.

4.4 Daylong Variations of Network Performance

From the observations above, it is understood that the power factor control strategy adopted for reactive power injection performs better as the feeder loading and power loss are lower in this approach. Daylong variations of performance indices are therefore only presented for this strategy and compared with the IEEE 1547 approach. Load and PV output variation profile with 5-min resolution data was used for simulation; random variations are incorporated using pseudorandom numbers based on a uniform distribution. The MVDI plot in Fig. 8(a) shows somewhat similar type of voltage deviation behaviour with both control approaches. The average feeder loading is lower as shown in the AFLI plot in Fig. 8(b), and lower loading is also reflected in the reserve capacity profile of the substation as shown by SRCI plot in `Fig. 8(c) and in the feeder loss profile shown by the FLLR plot in Fig. 8(d).

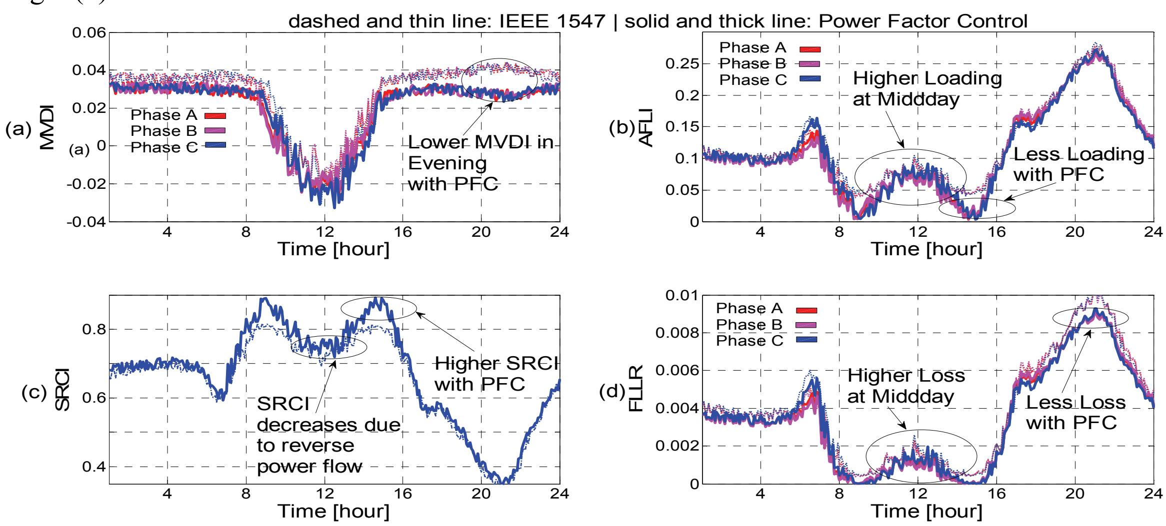

Fig. 8: Daylong variations of network performance indices with changing feeder loads and PV generations

4.3 Impact of PV Cluster on MV Distribution Network

The impact of cluster based installation of numerous solar PV units on the medium voltage distribution feeder is studied in this section. Fig. 9(a) shows the voltage profile and Fig 9(b) shows the active and reactive power flows through the feeder for different reactive power control strategies adopted by the PV units in the cluster. Voltage rise is experienced at three places in the feeder where the PV clusters are located. Reactive power flow is the minimum for the Power Factor Control strategy as shown by the circle marked in Fig. 9(b).

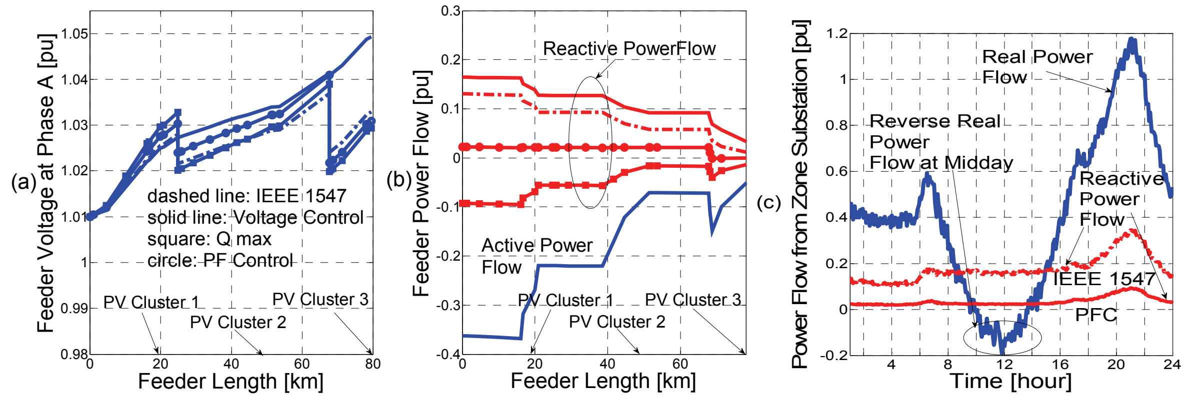

Fig. 9: Network performance: (a) Voltage profile along the 11 kV feeder; (b) Reactive power flows through the feeder for different control strategy (c) Daily variation of power flow from zone substation

The amount of power flow taken from the main HV/MV zone substation throughout the day is shown in Fig. 9(c). Active power flow is nearly the same for both the IEEE 1547 and Power Factor Control strategies. It is negative at midday due to reverse power flow. The reactive power flow is higher for the IEEE 1547 strategy and lower for Power Factor Control approach.

5.0 CONCLUSION

Distribution network performance under high solar PV penetration has been considered in this paper. Four performance indices have been developed to assess the network performance in terms of voltage deviation, feeder loading, substation capacity and feeder loss. Analysis shows that penetration of solar PV up to a certain percentage may be beneficial for supporting distribution systems; above this level network performance degrades in terms of feeder voltage deviation, feeder and substation loading and loss due to reverse power flow. Investigations were also performed for studying the participation of PV inverters in reactive power support. The Power Factor Control strategy was found to be more effective to reduce the reactive power flow in the network and therefore help to reduce feeder loading and power losses in the networks.

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