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Assessment of Net Energy Metering on Distribution Network Losses

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***Abstract*— This research paper highlights the impact of net metering solar PV sizing and its operating power factor on the total network active power loss. Digsilent Powerfactory is used to calculate the I^2R losses using load flow analysis based on steady state operation and Stability Analysis Function (RMS) simulation tool for dynamic network characteristic modelling. This approach was applied on a generic distribution network. The results verify that appropriate sizing and operating condition can contribute to significant reduction of active power grid losses while maintaining the bus voltage under permissible limit. Incorrect application or oversizing of solar PV are shown to aggravate the total grid technical losses.**

Keywords—grid loss, net metering, solar PV, distribution network

I. INTRODUCTION

Electric utilities are actively pursuing the agenda of grid power loss minimization. Network congestion and increase in load demand indicates that it is a necessity to improve the grid efficiency. Out of the total power supply in 2014, the average global power losses is 8.264 % [1]. Compared to transmission network, higher R/X ratio in distribution network causes substantial influence on grid losses and voltage drop [2].

Losses in distribution grid can be classified as the difference in the measurement of power entering and leaving the grid. The two general losses are technical and non-technical losses. Some factors of non-technical losses are inaccurate meter reading, power thefts, and incorrect power assignments or load management [3]. Distribution technical losses are also identified as I^2R losses [4] which occurs in the branches between the conventional generators and consumers. Small power consumption by metering devices, resistance from conductors, and transformer impedances are some of the contributors to distribution technical losses [5].

II. DISTRIBUTION POWER SYSTEM LOSSES

The three principle methods in distribution grid loss reduction are DG allocation, network restructuring and capacitor placement. Optimal DG allocation is considered to be one of the most reliable method to improve the network efficiency. However, improper sizing, displacement or operating conditions of DG can cause negative effect on the grid loss instead. Hence, this paper will demonstrate the effect of rooftop solar photovoltaic distributed generator (PVDG) on grid active power losses under Net Energy Metering (NEM) mechanism. Unlike gross metering which sells electricity directly into the grid, net metering consumers generate power mainly for self-consumption before feeding any surplus to other neighbouring load.

III. IMPLEMENTATION OF NET METERING PVDG IN AN EXISTING DISTRIBUTION POWER SYSTEM

Net metering was introduced in Malaysia in November 2016 to replace Feed-in Tariff (FiT) and to encourage self-consumption among consumers. Fig. 1 illustrates the mechanism of net metering scheme. Rooftop PVDG is the most popular option for NEM scheme due to ample sunlight, decline in solar PV technology prices, and simplicity of the system. The grid loss analysis will be evaluated using Digsilent Powerfactory and this approach will be assessed on a generic distribution power grid. The calculations of losses with PVDG requires several load flows for each analysis.

Fig. 2 represents a distribution network consists of a Main Intake Substation (132 kV / 33kV) which supplies power to four Main Distribution Substation (33 kV / 11 kV). These 4 substations then provides electricity to the industrial consumers or voltage is step down further to 0.4 kV to allocate power to residential and commercial consumers. The

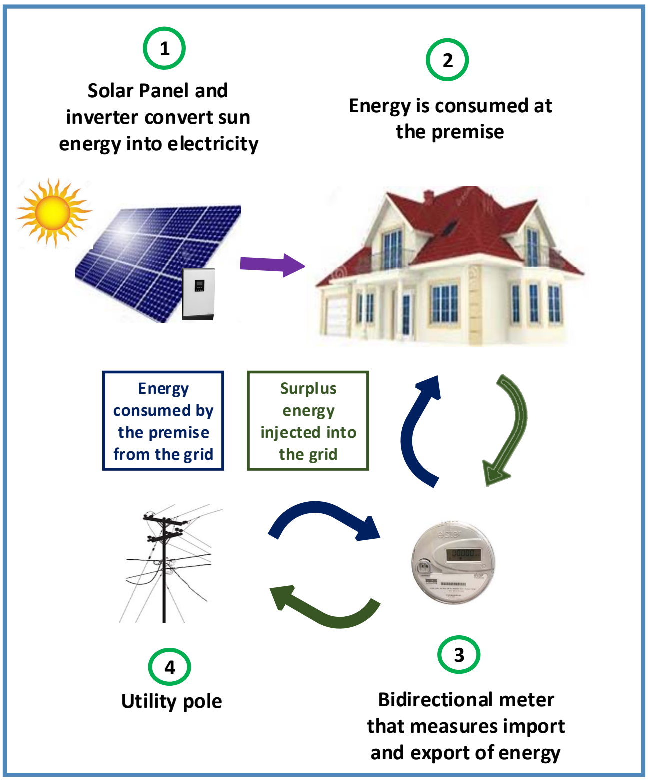


Fig. 1. Simple illustration of Net Energy Metering (NEM) Scheme

solar PV are connected one at a time for each of the analysis into the internal network of an 11 kV industrial consumer premises via indirect connection to emulate net metering scheme as shown in fig. 2.

IV. RESULTS AND DISCUSSIONS

In order to assess the active power loss minimization, there are several scenarios considered for this paper. The ideal results of each of the case studies will be determined when the total active grid loss is at the lowest while the constraints of voltage profiles are satisfied.

A. Impact of Sizing and Placement of PVDG

This study calculates the active grid loss without any PVDG as the base case. Load flow calculations will be applied again by adding the PVDG at three pre-determined busses labelled as 'Bus 1', 'Bus 2' and 'Bus 3' in fig. 2. Each of the location integrated with net metering have different load demand and cable length from the Main Intake Substation. The capacity of PVDG is varied from 0 to 2 MW at a step size of 0.05 MW at unity power factor (PF). Fig. 3 demonstrates the active power loss variation at three separate busses with varying penetrations. Table 1 summarizes the results of the PVDG placements. The lowest active power losses at each of the locations are labelled in fig. 3.

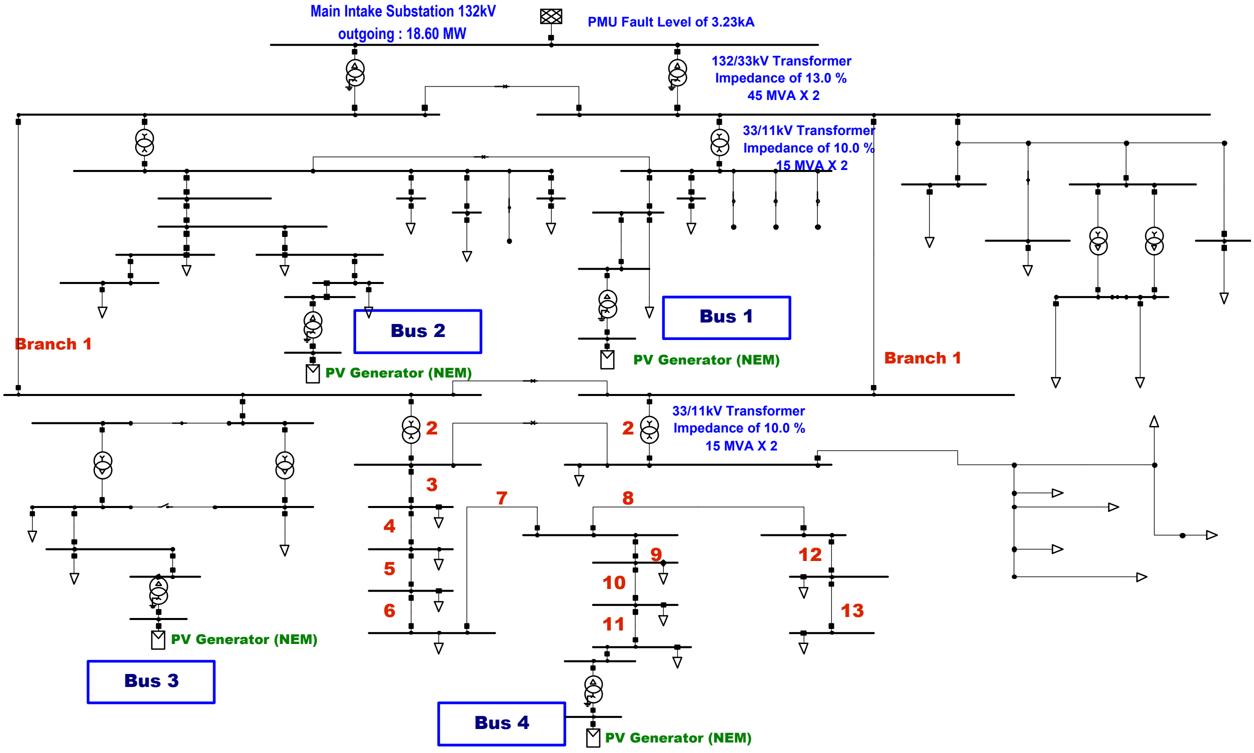


Fig. 2. Single line diagram of a generic distribution grid with NEM

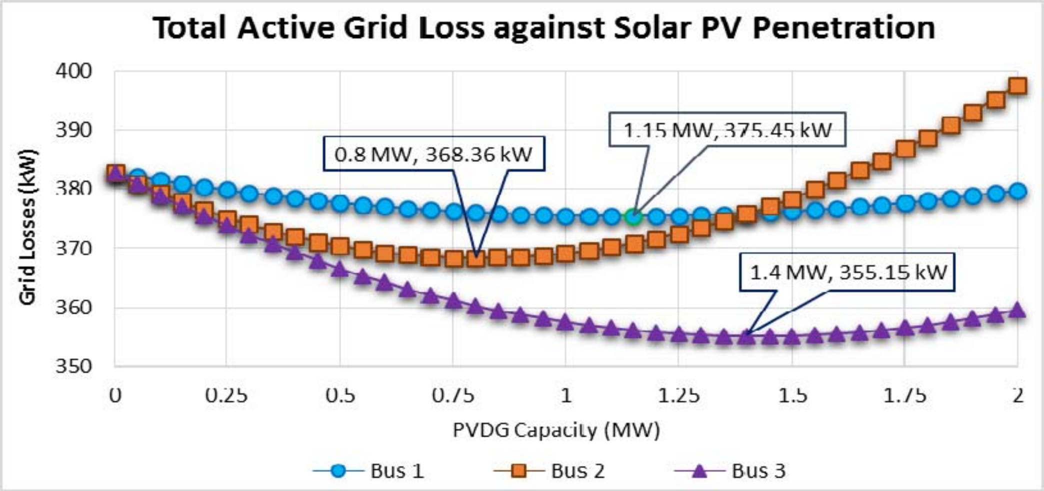


Fig. 3. Comparison of active power losses at several locations with different capacities

TABLE I. COMPARISONS OF SIZING AND PLACEMENT OF PVDG AT EACH LOCATIONS

Characteristic	***Base Analysis***	***Bus 1***	***Bus 2***	***Bus 3***
Distance from Main Intake Substation	-	1.1 km	11 km	27.5 km
Lowest Grid Losses (kW)	382.85	375.45	368.36	355.15
Optimal PVDG Capacity (MW)	-	1.15	0.80	1.40
Loss Reduction (%)	-	1.933	3.785	7.235
Bus voltage improvement (%)	-	0.283	1.430	0.434

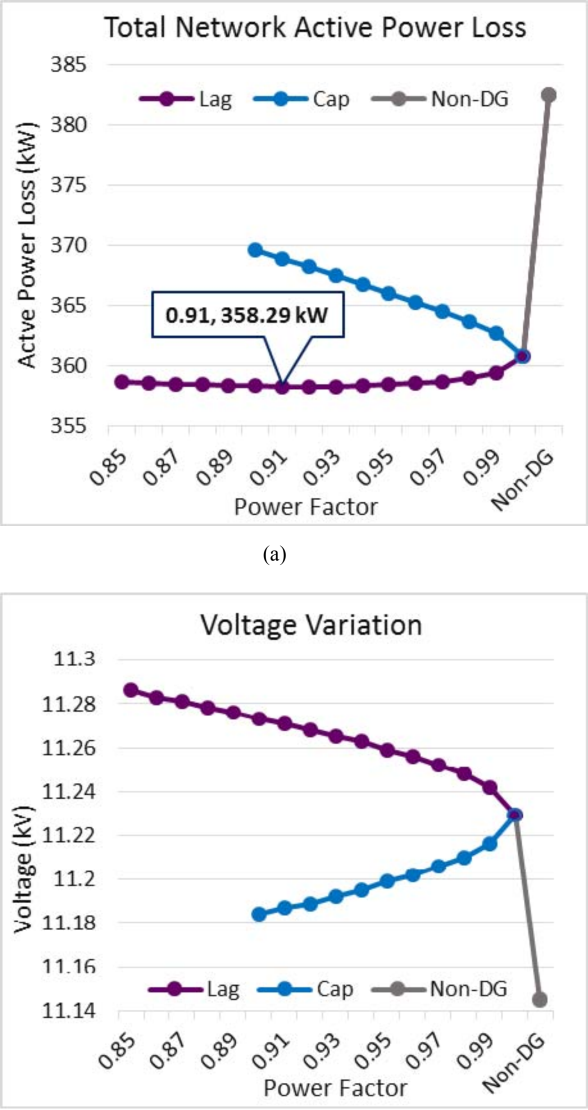
Based on the DG sizing simulations, the optimal capacity is determined at the lowest value of active power distribution loss. At a predetermined location, fig. 4 clearly shows that the active grid loss curves are reduced to a minimum value and tend to increase further as the PVDG output increases which illustrates a 'U' trajectory which is similar to results in [6]. By oversizing the DG, it is possible for the losses to exceed that of the loss without PVDG due to reverse power flow into the upstream busses.

The loss reduction result in table 1 suggests that PVDG integrated at a distance further away from the Main Intake Substation is more effective in minimizing network losses. However, choosing the best location to implement DGs are not necessarily possible in practical scenario. Generally, most of the placement of the NEM PVDG are predetermined since the scheme is consumer related. From the end results obtained from the three predetermined PVDG locations, it can be concluded that substantial reduction in loss are achieved by proper sizing and placement. The voltage profile improvement due to solar PV integration is an added benefit.

B. Influence of Power Factor at Constant Output

Many studies have assumed that PVDG units can only operate at unity power factor. However, the Malaysian grid code requires grid connected PVDG to provide a power factor control in a specified range of 0.85 lagging to 0.9 leading. Hence, the power factor is applied along this range to analyse the influence of operating power factor of PVDG on active power system loss. It should be acknowledged that PVDG operating in lagging mode denotes that the PVDG is supplying reactive power and leading mode indicates that reactive power is being absorbed. This convention is the exact opposite of load power factor.

With the reference of fig. 2, the PVDG is implemented at the consumer site labelled as 'Bus 4' with a rated output of 1 MW. Fig. 4 a) and b) present the effect of varying range of power factor on active power loss and voltage profile variation (with and without PVDG) respectively. In this case analysis, the ideal PF operation for this network configuration is found to be at 0.91 lagging mode since it results in the lowest active power loss in the whole network with substantial voltage support at 11 kV consumer bus. This study proves that both real and sufficient reactive power are required for optimal grid loss.



(a)

(b)

Fig. 4. Power factor influence on: a) real power losses and b) voltage variation

C. Implication of Different Set of Power Factor with varying PVDG Capacity

A PVDG is connected at the same consumer site labelled as 'Bus 4' with a set of power factor ranging from 0.6 lagging to 0.6 leading mode at varying output. The losses from the wide range of PF are then compared to highlight the importance of operating power factor with respect of to PVDG capacity. The outcome in fig. 5 outlines that the total active power loss is lowest at 0.9 lagging mode with an

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output of 1.2 MW. Since PVDG system are capable of supplying both real and reactive power, suitable operating PF along with appropriate sizing of a DG are crucial in deciding the most significant power loss reduction. Nevertheless, the results always varies depending on the network characteristics.

In this case, the active power loss is measured in each of the elements along the distribution feeder connected with PVDG. A PVDG rated at 2 MW is connected at the same location tagged as 'Bus 4'. This feeder consists of two 33 kV main incomers (branch 1), two 33 kV / 11 kV distribution transformers (branch 2), and 11 distribution lines of 11 kV (branch 3 to 13) as labelled in fig. 2. Fig. 6 quantifies the impact of varying PF against active power losses in each of the branches. The losses in branch 9 and 10 are the lowest without PVDG due to the absence of losses from power export from surplus PVDG generation. Fig. 7 depicts the total active power loss of the entire feeder at different PF.

The results in fig. 6 and fig. 7 signifies that PVDG operating at 0.8 lagging mode yields the least active power losses for this feeder. It validates that power factor control is vital in active power loss reduction. Reactive power compensation satisfies a portion of local load requirement which decreases the current along a section of distribution branches. This also enhances the voltage magnitude along the 11 kV distribution feeder.

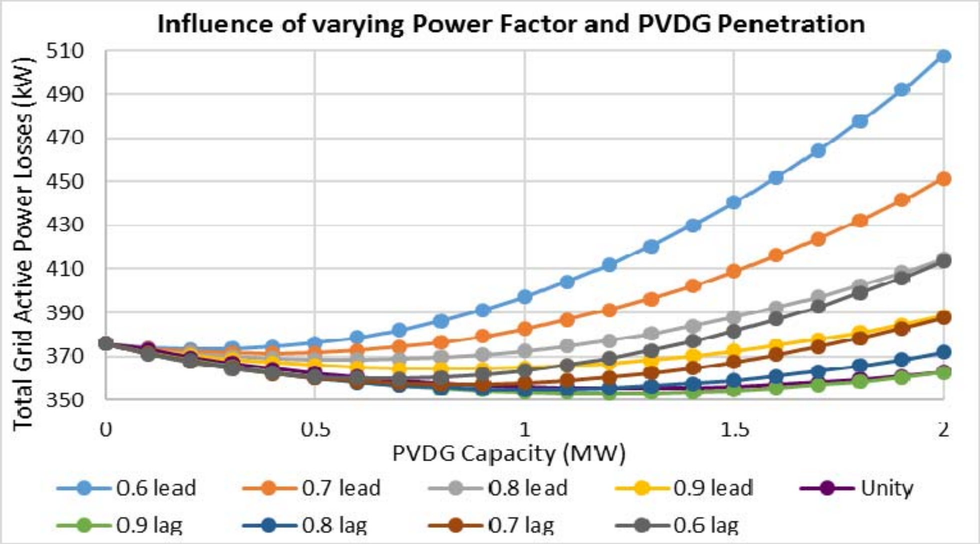

Fig. 5. Comparison of real power losses at different PF with increasing PVDG capacity

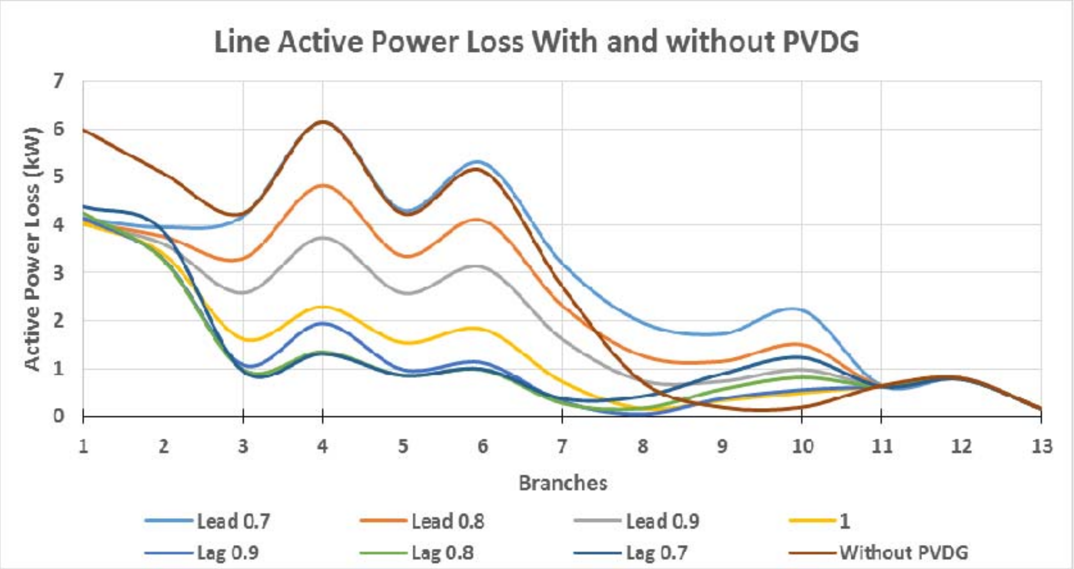

Fig. 6. Active power losses in each of the branches as a function of varying power factor

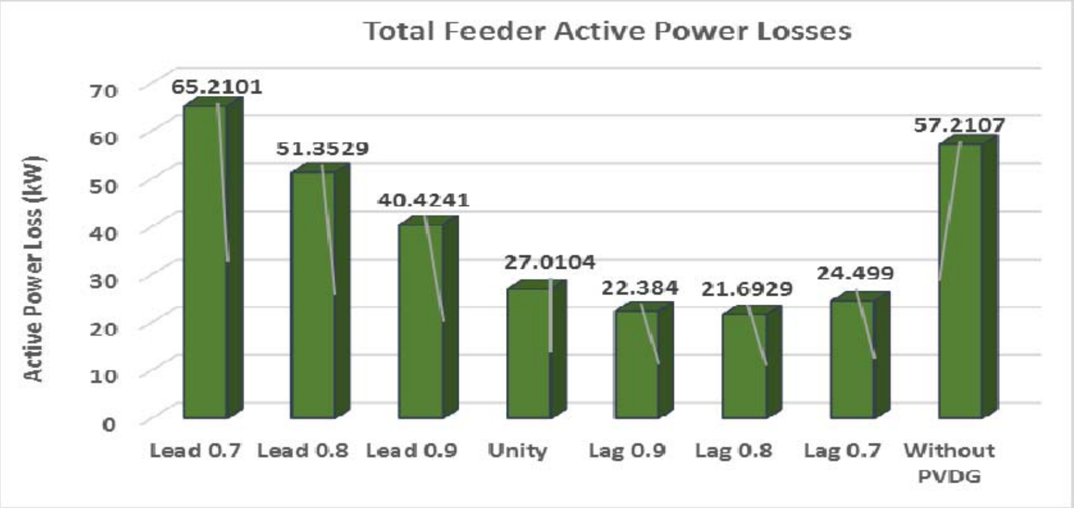

Fig. 7. Comparison of real power losses along the distribution feeder

D. Effect of Irregularity of PVDG Generation

Although steady state characteristic analysis is extensively utilised for power system studies (PSS), this approach only accommodates the rated power or a single PVDG output. In order to evaluate the technical losses in time-varying with intermittent characteristic of PVDG, a 12 hour (7am to 7pm) Malaysian irradiation data which was taken once every 3 minutes is incorporated in the configuration of solar PV system. The PVDG is installed in the same location labelled as 'Bus 4'.

The solar PV is set to be rated at 2 MW at different sets of power factor to evaluate the impact of output variation of PVDG on active power loss. Fig. 7 displays the summation of active power loss of 'Branch 1' labelled in fig. 2. Based on the performances of the operating power factors, the lowest average active power loss for a period of 12 hours irradiation is at the constant power factor operation of 0.8 lagging followed by 0.9 lagging. Since the intermittent characteristic is considered in this analysis, the reduction of active power loss is less substantial because the variation of the actual power generation is lower than the rated nominal capacity.

V. CONCLUSION

Lack of reactive power compensation, highly resistive distribution lines, and load increment are the major causes of technical active power losses and voltage drop. Despite the main purpose of DGs are meant for active power generation, however the results demonstrate that optimal application of power factor operation and sizing of PVDG have been successfully applied to provide several technical benefits such as minimization of active power distribution loss and voltage profile improvement.

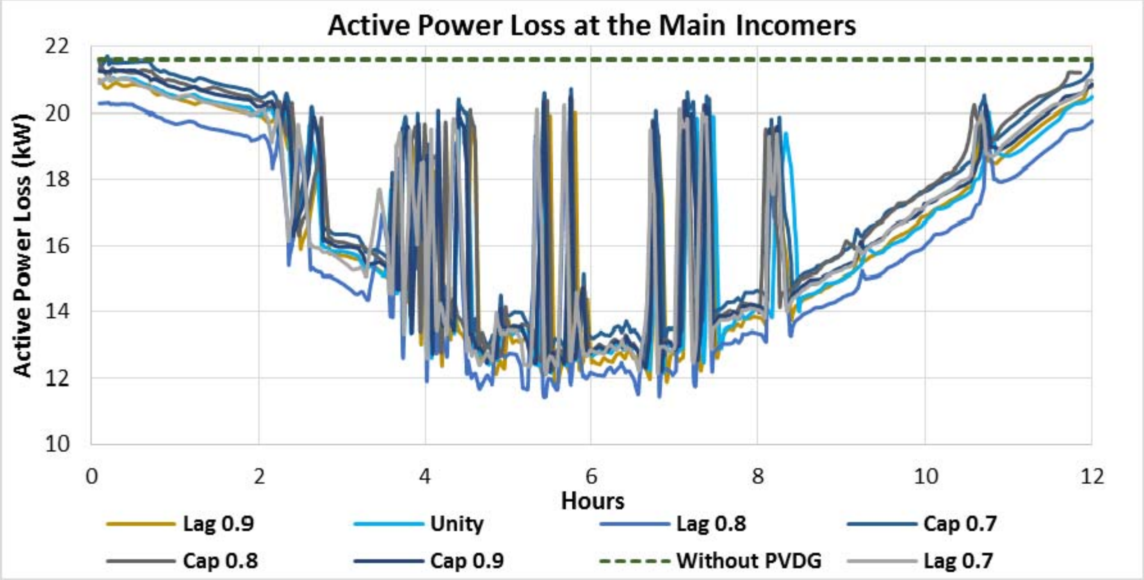

Fig. 7. Comparison of real power losses in the Main Incomers at different PF with intermittent output

On the contrary, oversizing and improper power factor operation can jeopardize the desired objectives of loss reduction and voltage support. This circumstances can also lead to other technical grid issues such as overvoltage and fault level elevation. Furthermore, the application of DG for loss reduction differs according to the grids configuration and characteristics of DG integrated. Considering that the distribution network are meant to be passive for unidirectional power flow, the results are evident that implementation of DGs can modify the power loss. Therefore, determining appropriate DG penetration and PF with respect to load demands and grid structure are crucial for loss curtailment and overall grid reliability. This scope of studies can also contribute to peak demand reduction, lowers environmental impacts, and significant cost cutbacks by electrical utilities

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