Technical Constraints of Integrating Net Energy Metering from the Malaysian Perspective

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***Abstract*—This paper evaluates the technical issues due to net metering from the Malaysian distribution network perspective. Simulations of Malaysian distribution network with net metering implementation for residential consumers were carried out in DigSILENT PowerFactory. The simulation results demonstrate that net metering at high capacity can cause power quality issues to the distribution network such as voltage rise, fault level increment, and contribution to harmonic distortions. The case studies signify the severity of power quality issues with increasing penetration of the solar photovoltaic. Mitigation measures for the technical issues and proposed sizing were also discussed to ensure the solar PV does not violate any permissible boundaries of the grid.**

Keywords—net metering, power quality issues, solar PV, distribution network, distributed generation

I. INTRODUCTION

As one of the fast-developing nation in Asia-Pacific, Malaysia fulfils the high demand of energy by relying heavily on fossil fuels to generate electricity. Presently, Malaysia is aggressively pursuing effective approaches to utilize the abundant renewable sources such as solar and hydro. Therefore, high capacity of Renewable Energy Systems (RES) are connected to the distribution network. In conjunction, Net Energy Metering (NEM) was initiated in Malaysia on November 2016 to replace Feed-in Tariff (FiT) and to promote self-consumption among consumers. Net metering in Asia revolves mainly around solar photovoltaic (PV) due to the system's simplicity and abundance of sunlight. Despite all the advantages provided by net metering practice, rapid and unsystematic implementation can cause serious issues to the grid.

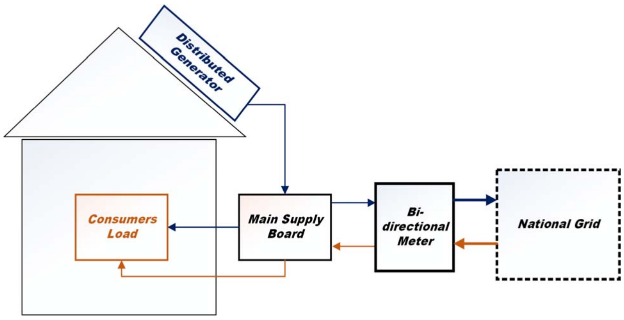

Fig. 1. Indirect connection of net metering scheme

A. *Concept of Net Energy Metering in Malaysia*

Fig. 1 represents an overview of the indirect type connection from the consumer's RE installation to the Distribution Licensee's system. The energy produced by the distributed generator (DG) will be consumed first, while any excess will be exported to the grid at displaced or blended generation cost depending on the utility. Therefore, the grid or distribution licensee acts as a storage system which removes the need of expensive battery installation. Net power export and import are measured by a single bi-directional meter as opposed to gross metering which requires two separate meters. Hence, the consumer only need to pay the difference in net import. If there is net export instead, credits will be rewarded which can be carried forward to the next billing cycle. The validity of credit in Malaysia is up to 24 months.

B. *Purpose of Technical Assesssment*

The distribution networks are radial in nature to accommodate a single direction power flow. Implementation of DG in the system promotes power supply reliability, reduces grid losses, and load demand. However, schemes like net metering which allows reverse power flow due to expanded penetration and intermittent traits of DG could alter the grid's regulation and technical aspects. Feeding active power to the residential network induces voltage rise, cable overloading, fault current increment, and other technical implications causing protection system failures and instability [1].

Residential network is ideal for technical investigation of consumer related DG due to the lack of control strategies in low voltage (LV) network. Influence of extended PV penetration on the grid can be investigated by replicating the high number of consumer units. Also, overloading due to smaller cables and transformer capacity prompts the LV network to be more vulnerable to the high entry of distributed generation compared to the high or medium voltage systems. Determining the effect of net metering can maintain the reliability and stability of the grid despite the various energy mix and reverse power flow into the power system.

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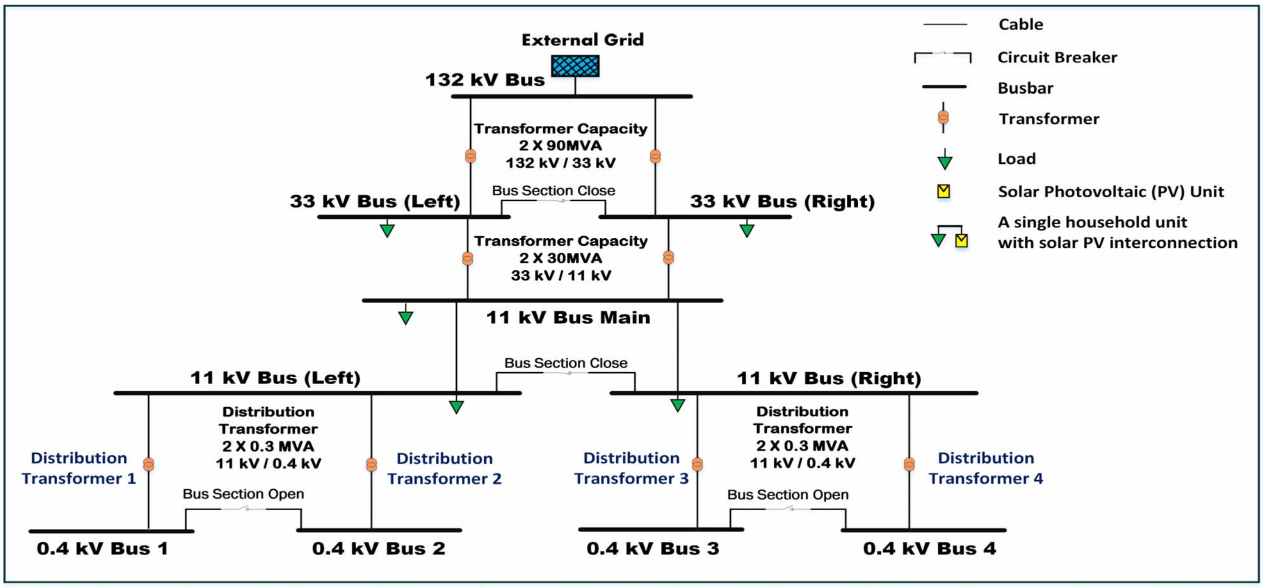

Fig. 2. Main network configuration of the distribution system

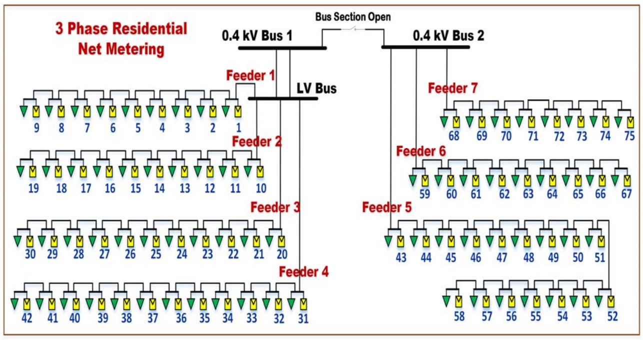

Fig. 2 (a). Three phase residential network (Left-hand side)

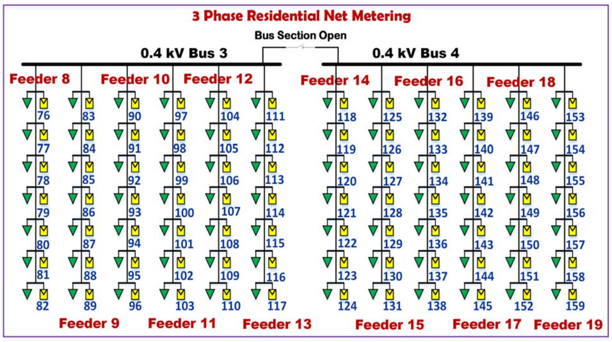

Fig. 2 (b). Three phase residential network (Right-hand side)

II. METHODOLOGY

A. Distribution Network Modelling

A Transmission Main Intake Station (132 kV / 33 kV) located in Kuala Selangor, Malaysia was designated as the main network for the technical studies. The main network and residential system were developed in DigSILENT Power Factory.

Fig. 2 illustrates the main distribution network which consist of:

- External grid which represents the transmission grid.
- A Transmission Main Intake Station (132 kV / 33 kV) with 2 step down transformers with a capacity of 90 MVA each.
- Main Intake Substation (33 kV / 11 kV) with 2 step down transformers with a capacity of 30 MVA each.
- 2 distribution substations (11 kV / 0.4 kV), each substation with 2 step down distribution transformers capacity of 0.3 MVA in each distribution substation.
- Four 0.4 kV busses which accommodates several feeders of three phase residential units.
- The loads in 33 kV and 11 kV busses was based the real time substation's transformer loading.
- Actual cable specifications and distances, bus voltage, short circuit level, and impedances were used to configure the main grid.

Fig. 2 (a) and (b) represents a generic model of a residential system which consist of:

- 13 feeders of three phase housing units with a total of 159 households.
- The type of cable used for feeders 1 to 4 and 8 to 19 is 1 kV Aerial Bundled Cable (ABC) 95 mm^2, while 1 kV ABC 185 mm^2 was assigned to feeder 5 to 7.
- The cables for the residential units are rated at 1 kV XLPE 095 mm^2 cable with a distance of 0.035 meters in between each households.

- This residential network is assumed to be a newly developed area with pre-installed solar PVs and zero load to portray the worst case scenario.

B. *Case Studies for Technical Analysis*

In order to explore how present-time residential system will cope with rapid growth of rooftop solar PV, steady-state analysis of system reliability must be carried out to ensure that the grid is operating within the limits set by the Malaysian Distribution Code. Therefore, the three technical analysis that will be considered in this paper are load flow analysis for voltage profile measurement, short circuit calculation and harmonic load flow. Firstly, these analysis will be carried without the integration of net metering. Then, the same procedures will be performed using different capacity of solar PV integration. For voltage and short circuit analysis, the solar PV penetration ranges from 0 %, 20 %, 40 %, 70 %, and 100%. As for harmonic distortion analysis, the delegated penetration are 0 %, 33 %, 66 %, and 100%. Each of the solar PV loading have different harmonic current injection. In this study, the PV penetration is calculated as:

$$\text{PV\%} = \text{Solar PV output} / \text{Total Size of Solar PV} \qquad (1)$$

The solar PV implemented in each of the housing area is assumed to be sized to produce a maximum capacity of 10 kW each. For example, each solar PV system at 40 % or 100 % capacity can generate 4 kW and 10 kW respectively.

III. RESULTS AND DISCUSSIONS

A. *Voltage Profile*

Load flow analysis was carried out in conjunction with the solar PV penetration at unity power factor using Newton Raphson method in DigSILENT. To emulate net metering, the solar PV units installed are in parallel with the consumer's load where the Main Supply Board (MSB) acts as a point of common coupling. The results denote that the voltage of LV busses have significant rise as the solar PV output increases. However, the active reverse power flow does not influence 11 kV and 33 kV busses voltage level due to the insignificant size of residential-scaled solar PVs and robustness of the upstream busses in terms of control strategies, cable size, etc. Fig. 3 depicts the voltage profile of the residential busses with increasing solar PV penetration. Although the voltage rise is significant, but the voltage of the main busses in the LV residential network are within the limit. The upper and lower boundary for LV voltage are +10 and -6% respectively of the nominal voltage [2]. However, household units in the end feeders experience overvoltage at high solar PV penetration. Feeder 5 accommodates 16 units of household with NEM, the most compared to the other feeders in the residential network. In regards to this, the nodes in the end of feeder 5 will be the first to violate the permissible voltage limit. Fig. 4 shows that overvoltage occurs along feeder 5 at 70 % and 100 % of solar PV capacity. There is a drop in voltage at 0 % solar PV penetration due to cable impedances.

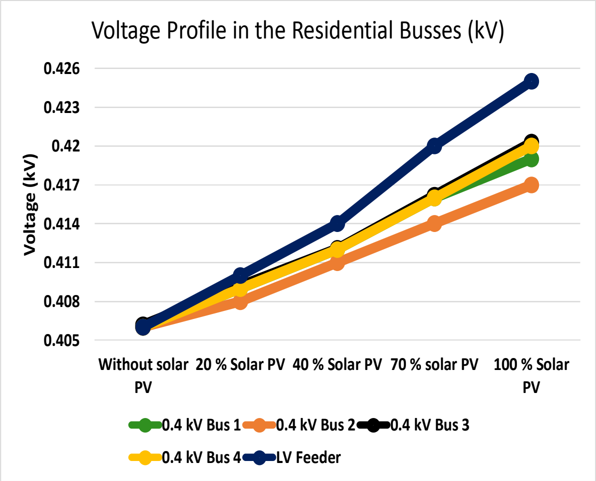

Fig. 3. Voltage profile of the residential busses with increasing solar PV penetration

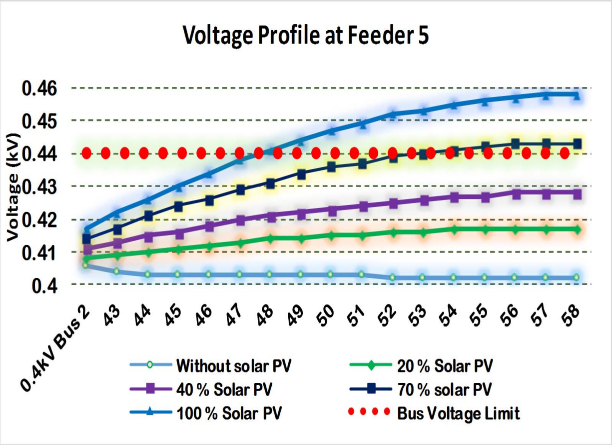

Fig. 4. Voltage profile measured at feeder 5 at each nodes / household with increasing solar PV output

Load flow analysis for cable and transformer loading are carried out to ensure that the cables and transformers are able to withstand the solar PV installed by making sure the cable ampacity rating and transformer loading capacity are not exceeded. Cables and transformers are meant to operate for certain period while operating at its rated capacity. Exceeding the capacity limit reduces its overall lifespan due to thermal degradation or ampacity overburden. The line used for the residential network is 1 kV ABC 095 mm2 cable with cable ampacity of 0.19 kA. Few cables in the beginning of feeder 5 and all of the four 0.3 MVA distribution transformer are slightly overloaded at 100 % solar PV generation. No overloading occurs up to 70 % PV.

Based on the results, 40 % solar PV penetration or 4 kW solar PV system in each household unit is the recommended sizing for this residential network. At 40 % capacity, a cumulative solar PV system of 0.636 MW can be generated safely without violating the grid code. Overvoltage can reduce the life span of cables, transformers and over-strain electrical equipment. It is uneconomical to curb reverse power flow into the grid. Thus, devices such as AVR and STATCOM can help to regulate the voltage rise. Another practical mitigation is storage system [3]. Storage system can increase the value of self-consumption by utilizing the excess energy stored in the battery during peak irradiance. Therefore, the reduction in back feed during excess generation can reduce the voltage rise contribution.

TABLE I. SHORT CIRCUIT CURRENT CONTRIBUTION FROM NET ENERGY METERING

Bus name	Circuit breaker rating	Fault Level (kA) without solar PV plant	Fault Level (kA) with 20 % Solar PV Penetration	Fault Level (kA) with 40 % Solar PV Penetration	Fault Level (kA) with 70 % Solar PV Penetration	Fault Level (kA) with 100 % Solar PV Penetration
132 kV Bus	35 kA	8.0	8.002	8.003	8.005	8.008
33 kV Bus	25 kA	13.584	13.591	13.597	13.607	13.616
11 kV Bus	20 kA	17.915	17.935	17.954	17.982	**[a]18.010**
11 kV Bus (Left)	20 kA	17.824	17.844	17.863	17.891	17.919
11 kV Bus (Right)	20 kA	17.824	17.844	17.863	17.891	17.919
0.4 kV Bus 1	35 kA	8.654	8.786	8.923	9.135	9.355
0.4 kV Bus 2	35 kA	8.654	8.757	8.865	9.031	9.202
0.4 kV Bus 3	35 kA	8.654	8.784	8.917	9.119	9.325
0.4 kV Bus 4	35 kA	8.654	8.784	8.917	9.119	9.325
LV Bus	35 kA	6.856	6.981	7.112	7.316	7.528

[a] Fault level violation in the permissible rating of the 11 kV busbar

B. *Short circuit Analysis*

Grid connected distributed generation are susceptible to inject current into the grid. However, current contribution from small-scaled generators are fairly insignificant. Nevertheless, overwhelming incorporation of net metering can cause inflation in the fault level of the power system. Some of the effect of elevated fault level are [4], [5]:

- overheating of electronic equipment, lines and transformers
- the need for recalibration of protection devices
- unintended shutdowns due to circuit breaker tripping

Table I. tabulates the fault level injected into the network due to net metering implementation in the residential network. At 100 % solar PV penetration, the permissible limit of circuit breaker rating is exceeded. Despite the rating of the circuit breaker at 11 kV bus is 20 kA, but the Malaysian utility, Tenaga Nasional Berhad (TNB), states that the fault level should not exceed more than 90 % of the breaker's rating [6] which is 18 kA. Fig. 5 demonstrates the fault level increment of the residential busses. Based on TABLE I, 70 % solar PV penetration and below will not disrupt the protection system. There are no modest mitigations to overcome this issue other than costly upgrading of protection network and cables.

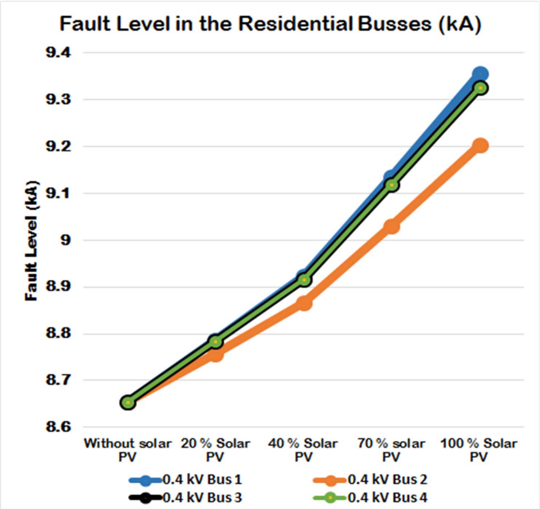

Fig. 5. Fault level of the residential busses with increasing solar PV penetration

TABLE II. TOTAL HARMONIC DISTORTION

Bus name	THDv without solar PV	THDv at 33% Solar PV (THDi = 2.070 %)	THDv at 66% Solar PV (THDi= 1.386 %)	THDv at 100 % Solar PV (THDi = 2.923 %)
132 kV Bus	0.258	0.259	0.258	0.260
33 kV Bus	0.260	0.262	0.260	0.265
11 kV Bus	0.264	0.268	0.264	0.277
11 kV Bus (Left)	0.265	0.270	0.265	0.278
11 kV Bus (Right)	0.265	0.270	0.266	0.278
0.4 kV Bus 1	0.261	0.427	0.448	0.837
0.4 kV Bus 2	0.261	0.382	0.396	0.702
0.4 kV Bus 3	0.261	0.427	0.448	0.837
0.4 kV Bus 4	0.261	0.427	0.448	0.837

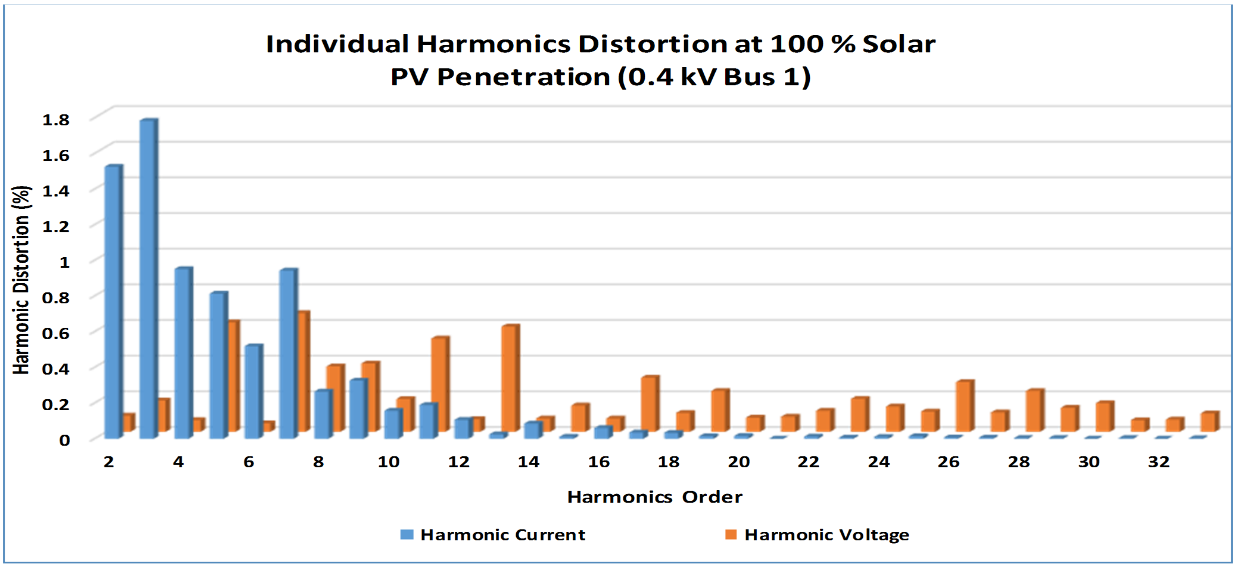

Fig. 6. Individual harmonics distortion in the residential network at 0.4 kV Bus 1

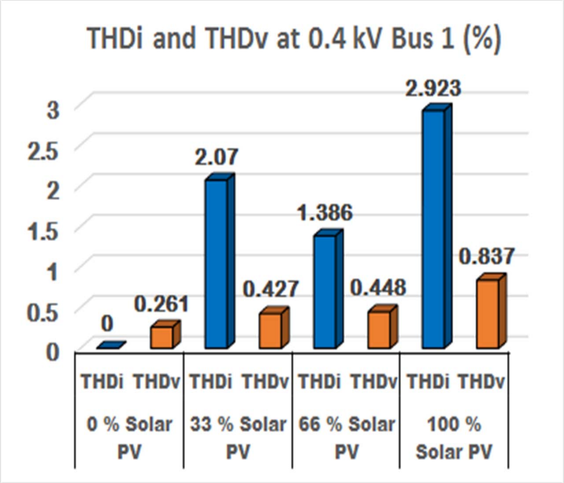

Fig. 7. Total harmonic distortion in the residential network at 0.4 kV Bus 1 with increasing solar PV penetration

C. *Harmonic Distortion*

Harmonic load flow analysis was performed by injecting individual harmonic currents. The harmonic current contributions is based on the solar PV loading which was referred to the inverter's manufacturer data sheet. The harmonic analysis on the residential network are conducted without solar PV and with solar PV at 33 %, 66 % and 100 % loading.

The total harmonic distortion current and voltage, (THDi) and (THDv), were then computed and tabulated in TABLE II. The THDv measurement obtained without net metering is actually the background harmonics present at the existing distribution grid. The THDv contribution from the residential net metering does not have distinct influence on the 132 kV and 33 kV busses due to the small harmonic contribution from residential solar PV. High network impedances and efficient harmonic distortion mitigation in the busses upstream also reduces the effect of harmonics contribution from the residential net metering.

Despite the small contribution of harmonic distortion in the high and medium voltage busses, the harmonic injection at residential side can affect the power quality at low voltage network. 0.4 kV Bus 1 was chosen to be the base case to present the effect of residential net metering. Fig. 6 illustrates the individual harmonic distortions in 0.4 kV Bus 1 at 100 % solar penetration as the worst case scenario. Fig. 7 summarizes the total harmonic distortion obtained from the harmonic analysis with and without net metering in 0.4 kV Bus 1. Fig. 7 shows that the THDv of 0.4 kV Bus 1 increases as solar PV capacity increase. Regardless, THD in all the busses are below 5 % and the individual harmonics in Fig. 6 complies with the limits set by IEC 61727-2003 [7]. Harmonic distortions above the recommended limits can prompt communication and sensitive devices to malfunction [8]. Passive harmonic filter is the simplest way to tackle this issue while active harmonic filters are used for unpredictable and dynamic cases for a more effective resolution.

D. *Other Possible Technical Constraints*

Other than the mentioned technical implications, unplanned and swift development of net metering can cause voltage deviations due to the intermittent characteristic of the renewable resources. This leads to sensitive lighting loads to flicker and inaccurate performance of high-tech devices. Storage systems and automatic voltage regulator (AVR) devices can smoothen the fluctuating voltage.

Net metering can also cause power factor to deteriorate. Active power demand is lower due to DG integration while the electric utility producing the same amount of reactive power. This leads to power factor reduction. Serious power factor issue can lead to voltage instability and potential grid collapse. Capacitor banks can compensate the reactive power needed for the motor loads especially in industrial sectors. This mitigation measure reduces the reactive power demand from the utility, hence improving the power factor. Other power factor correction (PFC) devices can be used to improve and restore the grids power factor.

Single phase net metering can precipitate voltage imbalance due to irregular supply of active power in each phase. Voltage stabilizers can resolve this problem.

I. CONCLUSION

This paper highlights the technical setbacks due to residential Net Energy Metering rooftop solar photovoltaic system. The voltage analysis denotes that the voltage profile at the residential busses increases rapidly and overvoltage occurs in Feeder 5 as the solar PV increase the export of active power to the grid. Due to their small rating, LV cables and transformer are also overloaded at high active power export. Distribution network is vulnerable to high application of solar PV due to the high R/X ratio as compared to transmission network. Short circuit analysis also proves that unsupervised implementation of residential net metering can cause the fault level to exceed the circuit breakers and other protection designation limit at substations with high faults. The constraints of net metering on harmonic distortions was also performed. The solar PV integration has contributed harmonic distortions into the distribution network but there will not be any apparent implications as all the results are within the satisfactory boundary.

Overall, the findings conclude that only 40 % solar PV penetration or 0.636 MW can be allowed for commissioning in the residential network to maintain a safe operation at the worst case scenario. Basic steady-state power system studies need to be carried out before any large pre-installation of net metering in newly developed area to evaluate whether the existing grid can cope with any additional distributed generation. Utilities can adopt preventive measurements from triggering any technical issues before hand. By doing so, net metering customers can enjoy the benefits of net metering without complications. Further research and studies can be conducted to maximize the allowed penetration level of DGs by implementing modest and practical methods such as power factor control, line drop method, and readjustment of tap position of distribution transformers without exceeding the thermal limits.

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