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Impact of Solar Photovoltaic System on Transformer Tap Changer in Low Voltage Distribution Networks

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Abstract

This paper investigates the impact of solar resource variability on the operation of a low-voltage On-Load-Tap-Changer (OLTC) in a generic distribution network from the Malaysian grid. The OLTC's operation is studied in two different weather conditions—sunny and cloudy days. The aspects analysed are the OLTC's time delay setting, PV penetration levels and PV installation location. The results suggest that the number of tap changes in a cloudy day is approximately 1.5 times higher than in a sunny day. In addition, at 50% PV penetration level on a cloudy day, the OLTC operation increases by 38% and it is doubled at 100% penetration.

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Keywords: Solar Photvoltaic; OLTC; LV distribution network

1. Introduction

Intermittent renewable generation in the distribution network can lead to severe adverse effects such as power fluctuation, voltage fluctuation and reverse power flow [1]–[5]. Furthermore, large PV penetration is expected to significantly affect the voltage regulation for operational devices such as the transformer's On-Load Tap Changer (OLTC). This is because the variation of voltage can increase the operation of transformer OLTC to bring the voltage back to the normal range. [6], [7]. Present studies on the effect of passing cloud on the operation of OTLC appears to be inadequate. Previous work in [8] indicates that passing-cloud may potentially cause more frequent operation of the control devices. This may reduce the

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effectiveness of the control setting, consequently reducing the OLTC's lifetime. However, there is no conclusive results on how the weather condition affects the transformer's OLTC tap changer. In this respect, there is a need to investigate the tap changer operation of voltage regulator devices such as OLTC, particularly during high PV penetration level [9]. In addition, the intermittency of PV generation may cause voltage fluctuation problem, especially during a cloudy day. This may result in a high number of tap changes in OLTC to regulate the voltage level. This paper simulates the PV impact on the distribution side based on irradiance variability, OLTC's Time Delay (TD) setting, penetration levels and PV installation locations. The finding of the case study is expected to benefit the distribution network operators and power utilities that incorporates substantial amount of distributed PV systems.

2. Methodology

A generic distribution network model in Malaysia has been considered in this study. The network was modeled in OpenDSS [10] interfaced with MATLAB. The control element (regulators), PV generation and loads have been modelled and implemented for various scenarios. A total of four scenarios were considered in the case study, namely (a) Effect of weather condition, (b) Effect of TD setting, (b) PV penetration levels, and (c) Effect of PV installed location.

First, two day types, namely sunny day and cloudy day profiles were utilized to analyze the effect of weather conditions (direct correlation with PV generation output) on the number of tap changes on a transformer. For the second case, simulations were carried out in OpenDSS with different TD settings on transformer OLTC. TD settings used in this study were varied from 15s until 3600s. Comparisons of the number of transformer tap changes were made between different TD settings and different percentage of penetration level for both sunny and cloudy day.

The last scenario studies the installation of PV system on different locations for the fixed feeders and scattered feeders. The first part has all the PV system installed at feeder D, while the second part considers random allocation of PV system between feeders A, B, C, and D. All the details are discussed in Subsections 2.1 to 2.4.

2.1. Distribution network modeling

All the PV integration studies were performed at the LV side of the generic distribution network in Malaysia. The generic network has four main feeders at the LV side of the distribution network with the total connected load of 349 kW, as shown in Figure 1. The LV distribution network parameters include cable types, cable rating, the number of feeders, and transformer rating. The 1000kVA (11/0.4 kV) distribution transformer was connected at the LV side. There are 18 consumers at the LV side where the PV system is installed.

A regulator is located at the Reg. bus (Bus 20) to study the effect on the number of tap changes before and after the PV integration. The controller base voltage of 120V with a bandwidth of 2V was used in this study and the default time delay was 15s.

2.2. Transformer OLTC control setting

There are three main control settings for the OLTC operation which are voltage set-point, bandwidth and TD [7]. Figure 2 illustrates the relationship of the basic OLTC control settings. As can been seen, voltage profile A goes beyond the lower voltage boundary for a period longer than the TD setting (t_{delay}). The OLTC will operate, which then results in a step change for voltage profile A to bring the voltage within the bandwidth. Meanwhile, voltage profile B exceeds the bandwidth upper threshold but re-enters the bandwidth within the TD setting. In this circumstance, the OLTC will not operate.

The time series simulation by utilising OpenDSS [7] was carried out to model and analyse the number of OLTC tap changes. The voltage set-point of the OLTC control in this study was 120V. The measured voltage from the simulation was compared to the specified voltage set-point. The bandwidth for this control mode is 2V, meaning only ½ BW for each side of the voltage set-point as the range of the voltage level setting. The transformer OLTC provides the secondary (output) voltage to be regulated within the range of 0.90p.u. (90%) to 1.10p.u. (110%) of the voltage at primary (input). Therefore, this type of regulation will result in total of 33 steps, counting the neutral tap from -16 to +16. It has 32 discrete steps with 0.625% voltage per step. The TD setting for case studies 1, 3 and 4 was 15s. However, in case study 2, the TD was varied from 15s until 3600s. A tap change would be triggered if the voltage level was out of the bandwidth. If the sequential control mode did not result in a tap change, this would be due to the resetting of TD when the voltage had surged back within the desired band.

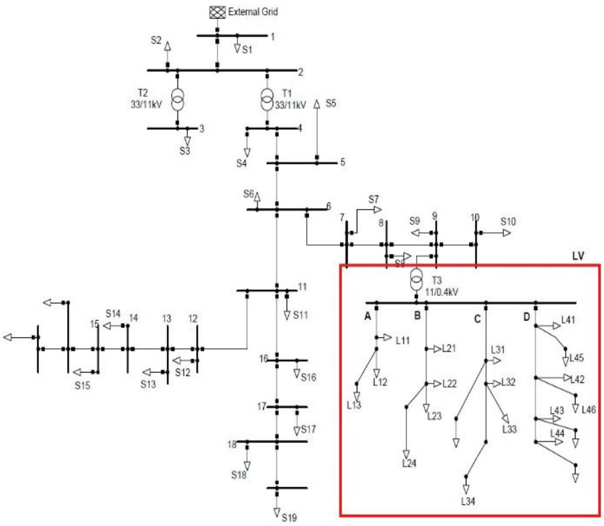

Fig. 1. Generic distribution network in Malaysia

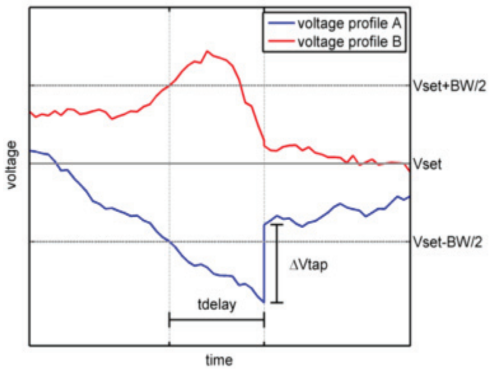

Fig. 2. Relationship of three basic OLTC control setting [7]

2.3. Load demand

A five-minute time resolution load shape was used in this study. This load demand was adopted from Malaysian domestic load profile, which presents high demand from the evening (at approximately 5.00pm) until midnight [11]. This situation is representative since the residential consumers go out for work in the morning and return home in the evening. Therefore, this contributes to high demand during the night hours.

2.4. PV system

In this study, five-minute resolution profiles for a sunny day and cloudy day were used for PV generation as shown in Figure 3. The PV generation profiles used in this paper were collected from the PV system installed in UTeM's Solar PV System and Smart Grid Research Laboratory. This PV system is rated 2.08 kW_p capacity, thin-film model which located facing to the south and 15º tilt angle. The PV's output generation is highly fluctuated on a cloudy day compared to a sunny day, which can potentially cause voltage fluctuations. Subsequently, this could lead to more tap changes of the OLTC transformer which can be observed in Figure 4.

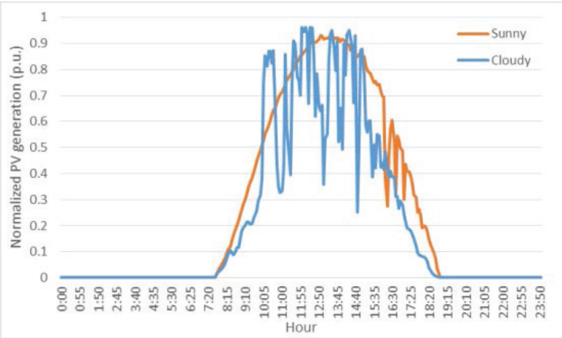

Fig. 3. PV generation profiles on a sunny and a cloudy day

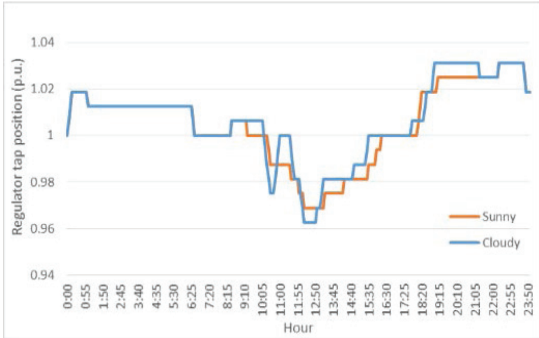

Fig. 4. Tap position for a sunny and a cloudy day

3. Results and discussion

Four scenarios were carried out for this paper. The results shown here are for full PV generation penetration, except for Section 3.3 (with different PV penetration level).

3.1. Effect of the weather condition

By using full PV penetration, two PV profiles were used to study the effect of the weather condition on the number of tap changes. Figure 4 illustrates the changes of the regulator tap position for a sunny and a cloudy day. The numbers of tap changes for sunny and cloudy day are 33 and 53 respectively. For this data sample, the number of tap changer operates is 60% more during a cloudy day compared to a sunny day to regulate the voltage level.

3.2. Effect of the Time Delay (TD) setting

TD setting is a factor which could affect the number of tap changes of the regulator. Figure 5 shows the number of tap changes by varying the TD setting. It shows that the number of tap changes is same at the beginning until TD increased to 300s due to the 5-minute resolution load demand. By using longer TD setting for the OLTC, there is a longer amount of time control after a change in the voltage occurs before the OLTC operates. Therefore, the longer the TD setting, the less number of tap changes will occur. However, the number of tap changes on a cloudy day is less than the tap changes on a sunny day during the longer TD setting. This may due to the period of fluctuation occurs in cloudy day is within the TD setting caused by the passing-cloud.

3.3. Effect of the PV penetration level

In this study, different PV penetrations were used to study the number of tap changes of OLTC as shown in Figure 6. The PV penetration level was increased from 0% (base case) until 100% (full) with the 15s TD setting. High PV penetration could lead to high power fluctuation which would cause more violation of voltage. The number of tap changes are proportional with the percentage of PV penetration level. However, there was a small reduction in the number of tap changes when 40% of PV penetration on sunny day. This might be caused by the variation in feeder load for the selected feeder operation. The intermittency in generation on cloudy day clearly showed a big difference for the OLTC operation, compared to on sunny day. On the other side, the stochastic behavior on a cloudy day would limit the PV penetration in power systems to respond adequately to PV's output fluctuation. It would then result in higher number of tap changes compared to the sunny day [12].

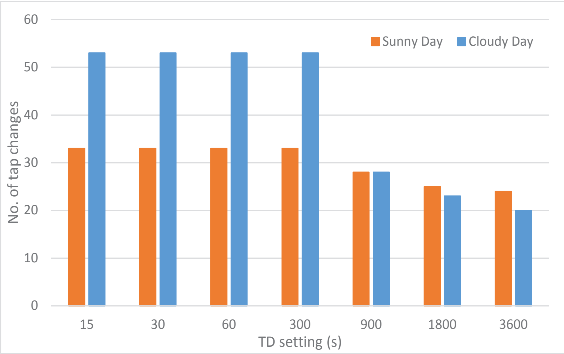

Fig. 5. Number of tap changes with different TD setting

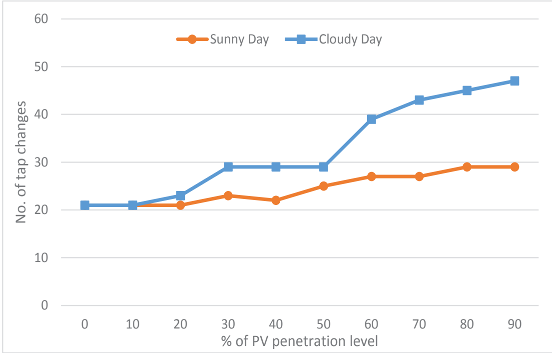

Fig. 6. Number of tap changes with different penetration level

3.4. Effect of PV installed location

Two different case studies for the effect of location were conducted by fixing the PV system at feeder D and randomly placing the PV system among the four feeders at LV side. Table 1 shows the number of tap changes for both cases on a sunny and a cloudy day. The total load consumption on feeder D is 133kW$_P$. When distributed PV are at a specific feeder, the number of tap changes on a cloudy day is higher than sunny day. However, when the PV randomly installed between feeders A, B, C, and D with the total load of 102.6 kW$_P$. It showed that there was a decreased number of tap changes on a sunny day, but slightly increased on a cloudy day which might due to high number of voltage variation on a cloudy.

The load consumption of the randomly selected feeders was lower than the load demand on the fixed feeder. However, the generation was poorly correlated with the demand consumption. Thus, it caused the voltage to rise at the regulation bus, which forced the OLTC to operate more frequently compared to the low load consumption. For the sunny day, it shows a decrease on the number of tap changes. This may be due to the generation being divided to the other feeders before the reverse power flowed to the regulation bus. In other words, the OLTC would frequently operate only when the load consumption was higher than the generation power to step up the voltage on the grid.

Table 1. Number of tap changes for randomly selected feeders

	PV located at feeder D		PV located randomly between feeders A, B, C and D	
PV profiles	Sunny	Cloudy	Sunny	Cloudy
No. of tap changes	25	27	23	29

4. Conclusion

This paper highlights the effects of weather conditions on the operation of tap changer for both sunny and cloudy days. To achieve this, time-series analyses have been carried out to evaluate the impact of PV integration on a specific Malaysian LV distribution network. TD settings, PV penetration levels and PV installed locations were amongst the parameters that have been considered in performing the analyses. More importantly, real Malaysian PV generation profiles have been used in this study. As expected, OLTC operates more frequently when PV penetration increases as well as with a short TD setting. In addition, the OLTC is easily influenced by the weather condition especially on cloudy day with high PV variability.

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Biography

Chin Kim Gan received his B.Eng and M.Sc degrees both in Electrical Engineering from Universiti Teknologi Malaysia (UTM) and PhD degree from Imperial College London, UK. Currently, he is an Associate Professor at Universiti Teknikal Malaysia Melaka (UTeM), Malaysia. His research interests are distribution network design, integration of renewable energy and smart grid.