Control Range of Photovoltaic Systems to Eliminate Voltage Regulation in Power Distribution Systems with End-of-Line Large-Capacity PV Installations

Tomoki Aoyama[1], Kazuto Yukita[1], Toshiya Nanahara[1], Akihiro Tsusaka[1] and Toshiro Matsumura[2]
[1]Aichi Institute of Technology,
[2] Nagoya Industrial Science Research Institute.
v24701vv@aitech.ac.jp

Introduction

In recent years, the spread of photovoltaic (PV) power generation has caused voltage fluctuations due to reverse power flow in power distribution systems. We have investigated the voltage profile and reverse power flow along the power distribution line with a large-capacitive PV system at the end [1-3]. This paper reports on conditions under which the voltage at the PV connection point and the voltage profile along the power distribution line might be maintained at appropriate levels by adjusting the power factor and reverse current of PV devices.

Power distribution system model

Fig. 1 shows the single-phase equivalent circuit of the power distribution system assumed in this study. PV is connected to the end of the line at a distance D from the distribution substation (DS). The PV connection point voltage vector, the DS output voltage vector, the line impedance, and the reverse current from PV are $\boldsymbol{V}_r$, $\boldsymbol{V}_s$, R+jX, and $\boldsymbol{I}$, respectively.

Conditions under which voltage adjustment on power distribution lines is not required

In this paper, the output voltage (V_s) of the distribution transformer is set to 6600 V, and the voltage of the distribution line is maintained within the range of 6300 V to 6900 V. Regarding the power factor cosϕ at the connection point, we refer to the "Guidelines for System Connection Technical Requirements to Ensure Power Quality" and consider operating within the range of 0.85 to 1 (from the perspective of the distribution transformer, within the range of lagging phase).

Fig. 2 shows the voltage circle diagram for R:X=3:4, where the vector trajectories of $\boldsymbol{V}_r$ with an increase in the reverse current $\boldsymbol{I}$ are illustrated by solid half-circles for the power factor of 0.85, 0.9, 0.95, 0.99 and 1 [1-2]. The arcs corresponding to voltages V_{min}=6300 V, V_s=6600 V, and V_{max}=6900 V are also drawn with quarter-circles. To facilitate understanding, for an example, the relation between the voltage vector of $\boldsymbol{V}_r$ and voltage drop $R\boldsymbol{I}$+j$X\boldsymbol{I}$ is represented for operating point of "b" in Fig. 2.

When the following three conditions are simultaneously satisfied, whose area is shaded in Fig. 2, no other voltage regulations are required:

1. The tip of $\boldsymbol{V}_r$ must be between the half-circles corresponding to power factors of 0.85 and 1.
2. The tip of $\boldsymbol{V}_r$ must be between the quarter-circles corresponding to V_{max} and V_{min}.
3. The voltage profile along the power distribution line is represented by the straight line connecting the tips of $\boldsymbol{V}_r$ and $\boldsymbol{V}_s$ [1]. In Fig. 2, the straight line that is tangent to the V_{min} circle is drawn from the point "a" of the tip of $\boldsymbol{V}_s$, and the intersection point of the tangent straight line and the V_{max} quarter-circle is denoted by "B". The tip of $\boldsymbol{V}_r$ must be on the right side of the straight line "aB"

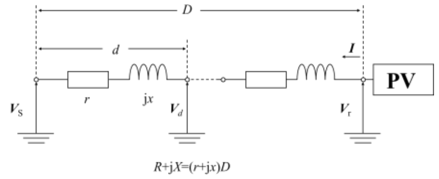

Fig. 1. Single-phase equivalent circuit of the assumed distribution system.

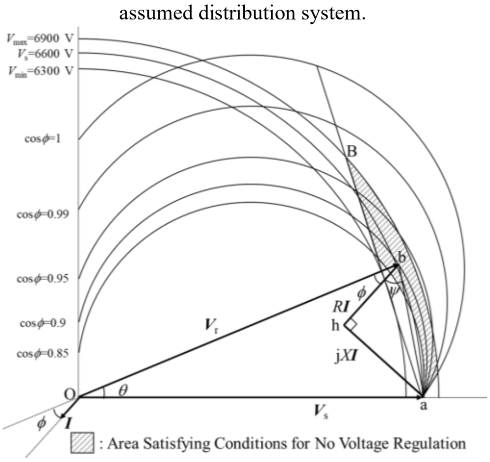

Fig. 2. Area Satisfying Conditions for No Voltage Regulation on the voltage circle diagram.

Conclusion

It is clarified that no other voltage regulation may be required by the operation of PV system in which the tip of $\boldsymbol{V}_r$ exists in the shaded area in Fig. 2.

References

[1] Toshiro Matsumura et al., Hindawi International Journal of Photoenergy, Volume 2019, Article ID 1263480, 8 pages (2019)
[2] Akihiro Tsusaka et al., IEEJ Trans 2021; Vol.16, Issue 3, pp.392–401 (2021)
[3] Tomoki Aoyama et al., ICEE2024,ID P-019 (2024)