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The Impact of Multiple Single-Phase Power Generation Systems on the Three-Phase Voltage Imbalance of Low-Voltage Distribution Systems

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***Abstract*—This paper shows the impact of multiple single-phase power generation systems on the three-phase voltage imbalance of low-voltage distribution systems. If the low-voltage power distribution system is interconnected with multiple single-phase power generation systems, its operation will become very complicated. The research results show that if multiple single-phase power generation systems can be appropriately interconnected to each phase of the distribution feeder of the low-voltage distribution system, the unbalanced three-phase voltage situation will be improved. On the contrary, if the interconnection is concentrated to the phase with light load of the distribution feeder of the low-voltage distribution system, the three-phase voltage imbalance of the low-voltage distribution system will be worsened.**

***Keywords*—Voltage imbalance, low-voltage distribution system, single-phase power generation system.**

I. INTRODUCTION

Governments around the world have been promoting green energy power generation policies for many years, and the construction of large-scale wind power generation and photovoltaic power generation systems has gradually become saturated. In order to sustain this green energy power generation policy, the governments have begun to encourage companies and the public to develop small wind power generation, photovoltaic power generation and hydropower systems, hoping to increase the proportion of green energy power generation and achieve environmentally sustainable use. [1,2].

Based on technical and cost considerations, some small power generation systems are made into single-phase power generation devices[3,4]. These small power generation systems can operate alone to generate electricity for the public to use, or they can be added to the low-voltage distribution system of the electric power industry and operate together to generate electricity for the costmers to use.

The low-voltage power distribution system is downstream of the entire power system[5]. In addition to supplying power to three-phase customers, it also supplies power to a large number of single-phase customers. Since there are many single-phase loads in the system, the three-phase voltage imbalance is generally not good. Nowadays, a large number of small single-phase power generation systems are interconnected with the low-voltage distribution systems. How will they affect the three-phase voltage imbalance problem of the low-voltage distribution system? It is necessary to discuss it.

This research adopts a three-phase low-voltage power distribution system as an example system. Three single-phase power generation system is connected to its distribution feeder, and then its connected phase and power generation are changed to obtain the three-phase voltage imbalanced data of the low-voltage power distribution system. This research then further analyzes the impact of the connected phase and the power generation of the multiple single-phase power generation systems on the three-phase voltage imbalance of the low-voltage distribution system. The research results have been presented in this paper and can be used for reference and application by power utility personnel.

II. THE EXAMPLE SYSTEM

The structure of the example system is shown in Fig. 1. It contains a main transformer, a circuit breaker, a distribution feeder and 6 load tap points (LTP). The capacity of the main transformer is 150kVA, and the nominal voltages of the primary and secondary sides are 11.4kV/380-220V respectively. The distribution feeder is also called a example feeder. Its length is 60 meters and the load tap points are 10 meters apart from each other. The example feeder has three phases: A, B and C. The total load of phase A is 24kVA, phase B is 30kVA and phase C is 36kVA.

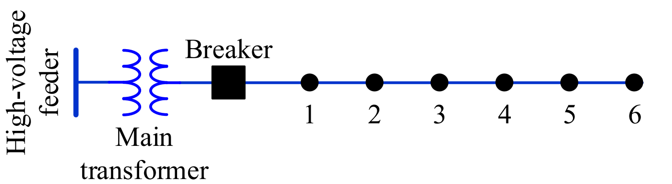

Fig. 1. The structure of the sample system employed in this paper.

Three single-phase power generation system will be connected to the distribution feeder of the example system. The connected location, phase and power generation of these single-phase power generation system are determined by the simulation scenarios. The power generation capacity of these three single-phase power generation systems is 3.3kW.

III. SCENARION SIMULATION

This reseach defines 10 simulation scenarios to show the impact of small single-phase power generation systems on the

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three-phase voltage imbalance of low-voltage distribution systems. The definitions of these 10 simulation scenarios are explained below. The formula of voltage unbalance rate (VUR) is also defined as shown in (1) [6].

S0: No small single-phase power generation system interconnected with the example system.

S1: Three single-phase power generation systems connected to phase A of LTP6 with an output power of 9.9kW.

S2: Two single-phase power generation systems connected to phase A of LTP6 with an output power of 6.6kW.

S3: A single-phase power generation system connected to phase A of LTP6 with an output power of 3kW.

S4: Three single-phase power generation systems connected to phase B of LTP6 with an output power of 9.9kW.

S5: Two single-phase power generation systems connected to phase B of LTP6 with an output power of 6.6kW.

S6: A single-phase power generation system connected to phase B of LTP6 with an output power of 3.3kW.

S7: Three single-phase power generation systems connected to phase C of LTP6 with an output power of 9.9kW.

S8: Two single-phase power generation systems connected to phase B of LTP6 with an output power of 6.6kW.

S9: A single-phase power generation system connected to phase B of LTP6 with an output power of 3.3kW.

$$VUR=\frac{\left(Max.\left(|V_A|,|V_B|,|V_C|\right)-Min.\left(|V_A|,|V_B|,|V_C|\right)\right)}{\left(|V_A|+|V_B|+|V_C|\right)/3}\times 100 \quad (1)$$

IV. RESEARCH RESULTS

The 10 simulation scenarios have been carried out by this research. The simulation results will be discussed in the following subsections.

A. Secnarios S0, S1, S4 and S7

In simulation scenarios S1, S4 and S7, these three single-phase power generation systems are interconnected to the same phase in the example feeder. The VUR of each load tap point of the example feeder is shown in Fig. 2. The simulation results show that the voltage unbalance rate of simulation scenarios S4 and S7 is greater than that of simulation scenario S0, which means that when the three single-phase power generation systems are interconnected to phase A or phase B of the example feeder at the same time, the voltage imbalance of the example system will be worsened. The reason is that the loads of phase A and phase B of the example feeder are not large, and the three single-phase power generation systems supply power to the loads of the two phases at the same time, which will expand the load difference between the three phases of the example feeder, resulting in a three-phase voltage more imbalanced.

But when these three single-phase power generation systems are interconnected to the phase C of the example feeder, the voltage unbalance rate of the example feeder will decrease. This is because the load of the phase C of the example feeder is very large. The power supply of the three single-phase power generation systems can reduce the load difference between the three phases of the example feeder, making the three-phase voltage more balanced.

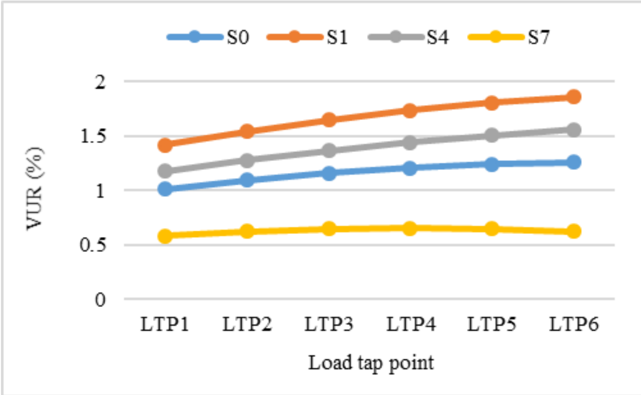

Fig. 2. The voltage unbalance rates along the sample feeder in scenario S0, S1, S4 and S7.

B. Secnarios S0, S2, S5 and S8

In simulation scenarios S2, S5 and S8, two single-phase power generation systems are interconnected to the same phase in the example feeder. The VUR of each load tap point of the example feeder is shown in Fig. 3. The simulation results show that when the two single-phase power generation systems are interconnected to phase A of the example feeder, the voltage unbalance rate will increase. This is because the total load of phase A of the example feeder is the least. When the two single-phase power generation systems are interconnected to phase A of the example feeder, the load difference between the three phases of the example system will increase, causing the voltage unbalance rate to also increase. .

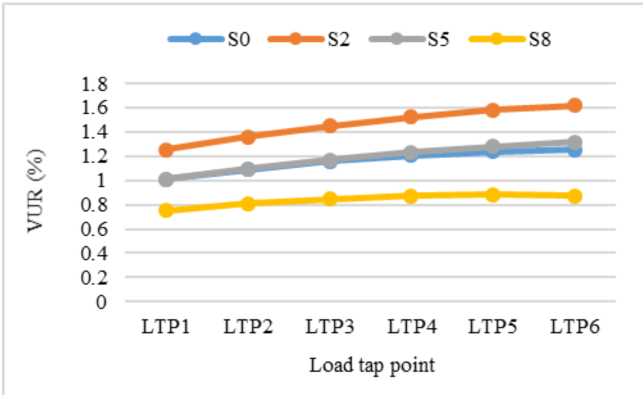

Fig. 3. The voltage unbalance rates along the sample feeder in scenario S0, S2, S5 and S8.

When the two single-phase power generation systems are interconnected to phase B of the example feeder, the voltage unbalance rate of the example feeder remains almost unchanged. This is because the load of phase B of the example feeder is larger than that of phase A. When the two single-phase power generation system are interconnected to phase B of the example feeder, the supply and demand are just balanced, so there will be no impact on the voltage unbalance rate of the example system.

When the two single-phase power generation systems are interconnected to phase C of the example feeder, the voltage unbalance rate will be reduced for the reasons explained in the subsection A.

C. Secnarios S0, S3, S6 and S9

In simulation scenarios S3, S6 and S9, only one single-phase power generation systems is interconnected to the same phase in the example feeder. The VUR of each load tap point of the example feeder is shown in Fig. 4. The simulation results are similar to Fig. 3, and the reasons are also as mentioned in subsection B, so they will not be repeated here.

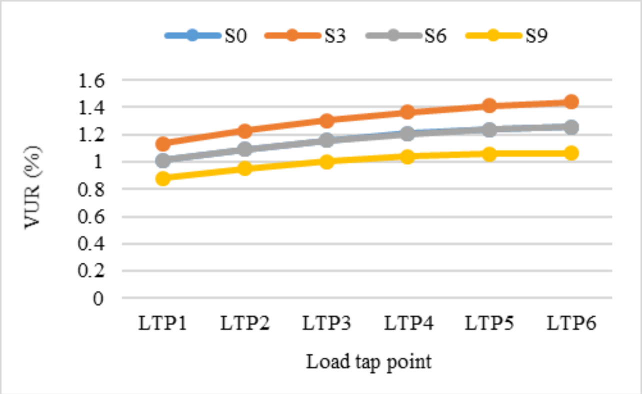

Fig. 4. The voltage unbalance rates along the sample feeder in scenario S0, S3, S6 and S9.

D. Secnarios S0, S1, S2 and S3

In this subsection, this research will observe the influence of the interconnection number of single-phase power generation systems on the voltage imbalance of the example system. The three single-phase power generation systems are all interconnected to the phase C of the load tap point 6 of the example feeder. The VUR of each load tap point of the example feeder is shown in Fig. 5.

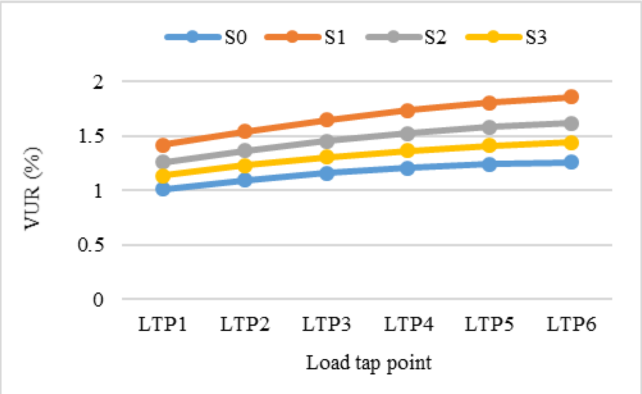

Fig. 5. The voltage unbalance rates along the sample feeder in scenario S0, S1, S2 and S3.

The simulation results show that as long as the single-phase power generation system is interconnected to phase C of the example feeder, regardless of the number of interconnections, the impact on the voltage imbalance of the example system will be unfavorable. The reason is that the load of phase C of the example feeder is relatively light. The greater the number of interconnections, that is, the greater the power generation, the greater the impact on the voltage imbalance problem of the low-voltage distribution system.

E. Secnarios S0, S4, S5 and S6

In this subsection, this research will also observe the influence of the interconnection number of single-phase power generation systems on the voltage imbalance of the example system. The three single-phase power generation systems are all interconnected to the phase B of the load tap point 6 of the example feeder. The VUR of each load tap point of the example feeder is shown in Fig. 6.

The simulation results show that because the load of phase B of the example feeder is slightly heavier, it can just absorb the power generation of the single-phase power generation systems, so the voltage unbalance rate of the example system remains roughly constant. Of course, the greater the number of interconnections of single-phase power generation systems, that is, the greater the power generation, it will also have a negative impact on the voltage imbalance of the low-voltage distribution system.

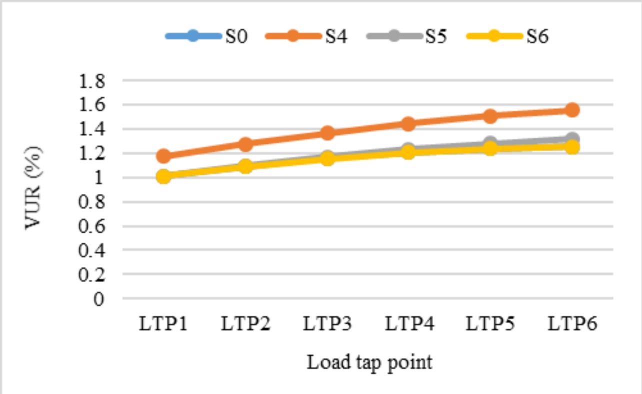

Fig. 6. The voltage unbalance rates along the sample feeder in scenario S0, S4, S5 and S6.

F. Secnarios S0, S7, S8 and S9

In this subsection, this research will also observe the influence of the interconnection number of single-phase power generation systems on the voltage imbalance of the example system. The three single-phase power generation systems are all interconnected to the phase C of the load tap point 6 of the example feeder. The VUR of each load tap point of the example feeder is shown in Fig. 7.

The simulation results show that because the load of phase C of the example feeder is very heavy, it can consume all the power generation of the single-phase power generation systems, making the load difference between the three phases of the example feeder smaller, so the voltage imbalance of the example system will be reduced. It can be seen that single-phase power generation systems should be interconnected to the heavier-loaded phases of low-voltage distribution feeders as much as possible. The greater the number of interconnections, that is, the greater the power generation, it will also have a good impact on the voltage imbalance of the low-voltage distribution system.

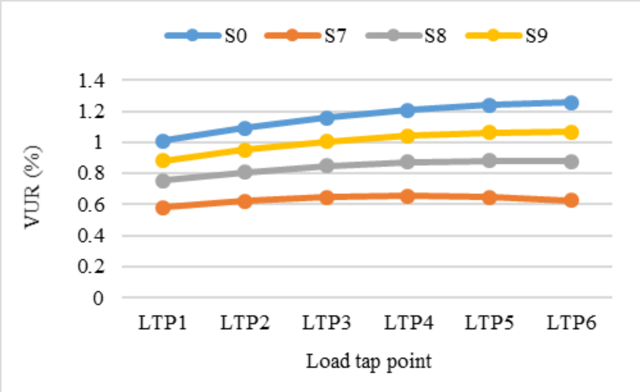

Fig. 7. The voltage unbalance rates along the sample feeder in scenario S0, S7, S8 and S9.

V. CONCLUSIONS

In this paper, this research explores the impact of the interconnection of multiple single-phase power generation systems on the three-phase voltage imbalance of a low-voltage distribution system. The research results show that the single-phase power generation system should be interconnected to the phase with the heaviest load of the low-voltage distribution feeder as much as possible, because this can reduce the load difference between the three phases of the distribution feeder, further reduce the three-phase voltage unbalance rate, and improve the power supply quality of the distribution system.

With the encouragement of the government, more and more single-phase power generation systems will be interconnected to low-voltage distribution systems in the future[7-9]. The selection of interconnection locations of single-phase power generation systems is very important. If power engineers can determine the load distribution of low-voltage distribution feeders, , appropriately interconnecting the single-phase power generation systems to a certain phase of the low-voltage distribution feeder, which will reduce the voltage unbalance rate and improve the power supply quality of the power system.

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