HIGH-SPEED BUS TRANSFER FOR DISTRIBUTION NETWORKS WITH DG CONNECTED

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Abstract- Bus transfer has been widely accepted in power industry to improve system reliability. However, the blooming of DGs in distribution networks makes bus transfer a diverse issue. This paper addresses this issue from an actual example of petrochemical industry with DG-connected. Thus, the literature reviews, on typical bus transfer methods, are raised by explaining the benefits to introduce high-speed transfer technology in such networks. Accounting for the bus characteristics, with or without DG-connected, this paper then quantitatively analyzes the impact of DG on bus transfer following numerically simulation. According to the analysis, some design codes are finally summarized, to counteract the negative impact of DGs on bus transfer in distribution networks.

I. INTRODUCTION

Power continuity is a critical power quality issue, which nowadays attracts increasing concerns from both the utility and customer side. Disturbance that occurs in the distribution network leads to discontinuity, and even causes severe damages in some delicate facilities, such as personal computer and active current contactor[1]. Thus, distribution networks are commonly designed with two power supplies, so that bus transfer takes place between them, during a scheduled maintenance or an unexpected fault occurring in either of them[2-3].

The present bus transfer methods, depending on the open circuit time required for transferring, are generally categorized into three types: fast transfer, in-phase transfer and residual transfer[4]. The former two are considered as high-speed bus transfer, which are priority options for high-quality-requested industries, in target to achieve the shortest transfer time[5]. In contrast, the residual transfer is more commonly adopted for normal industry networks, in trade-off between transfer speed and cost[6].

However, with the installation of DG in distribution networks[7], bus transfer has to be adjusted comparing without DG-connected case[8]. This is because that the decay of the bus voltage and frequency slows down after DGs are connected. To resolve this problem, under residual transfer case, once the working source is lost, DG must be disconnected as soon as possible. Thus, residual transfer is able to work in the same way as without DG-connected[9]. This proposal is merely passable for low-quality-requested system. For higher requirements, it becomes an attractive subject to discuss the application of high-speed technologies on distribution networks with DG-connected, achieving a more advanced continuality and reliability.

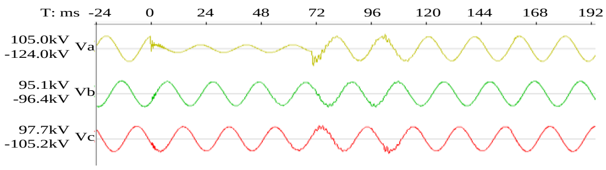
Around this topic, this paper firstly raises the question from an actual petrochemical system with DG-connected in section II. Then, in section III, 3 bus transfer methods are reviewed, to explain the benefits by introducing high-speed solution. Next, in section IV, the high-speed performances are numerically simulated, and then benchmarked comparing with residual transfer. The results are interpreted according to the characteristic of bus with DG connected. Finally, in section V and VI, this paper concludes some design codes for high-speed bus transfer, to benefit the quality of distribution networks with DG-connected.

II. AN APPLICATION EXAMPLE OF HIGH-SPEED BUS TRANSFER IN A PETRO-CHEMICAL PLANT WITH DG

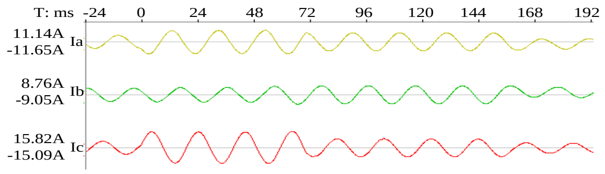
This industry example is from the petrochemical of Maoming, China. Maoming Petrochemical Company plant has seven 110kV substations, with a total capacity of 663MW. There are five DGs (co-generation types) installed, and the rated power are 2×25MW, 2×62.5WM, and 1×50MW, respectively. DGs efficiently reduce the cost, ￥15-20 per ton estimated, and save energy in the mean time., which is more than ￥*200M* each year.

However, even high efficiency achieved, power continuity is still an issue for Maoming Company. After a rough technology reviewing, high-speed bus transfer is selected in target for a more reliable system. Coincidently, these sorts of equipments work quite well during actual producing proces.

As a proof, Fig.1 shows the field-recorded response of fast transfer after a line-to-ground fault, on the incoming line of the working source in the factory on 13th, Aug, 2010. This fault lasted 20ms, which activates the high-speed bus transferring. In consequence, the working source breaker opened at 70ms, and the auxiliary source was then connected at 135ms by fast transfer. The whole system therefore recovered from fault within a short time, and DGs kept stable after transferring.



(a) Bus voltage



(b) Co-generation current

Fig.1 Characteristic of the petrochemical plant with DG connected during fast transfer

Given the previous sketch, the high-speed bus transfer has been proved to be reliable in distribution networks with DG-connected. Nevertheless, there is still lack of evidences to support a slow version, e.g. residual transfer, does not fit for such networks, bidding for a better price-performance ratio. A deeper study is requested to answer the question: Why the existing experiences show only high-speed bus transfer is applicable for distribution networks with DG-connected? Section II begins the answering by reviewing the different features of current bus transfer methods.

III. BUS TRANSFER METHODS

Based on the bus voltage and phase curve, post-fault bus transfer methods are categorized as following three in the distribution networks without DG-connected:

1) Fast transfer
2) In-phase transfer
3) Residual voltage transfer.

First two of them are given the name as "high-speed transfer", while residual transfer is a slow but low-cost alternative. The special features of these methods are discussed as following:

Fast Transfer

Fast transfer attempts to transfer the load bus to the auxiliary source as fast as possible, in order to shorten the time that the load bus is disconnected with either source. To review published literatures [2-4], there are two schemes proposed.

A. Simultaneous transfer: two commands are sent exactly at the same time: to open the working source breaker and to close the tie breaker. Therefore the open circuit time is merely the lag time, which are around 1~2 cycles (20~40ms), as the close action usually takes longer than the open.

B. Sequential transfer: the command to close the tie breaker is sent, only if the load bus has been securely detected to be disconnected with the working source. In this case, the open circuit time is expected to be longer, that is about 5~7 cycles (100~140ms). However, the sacrifice of transfer time avoids sources paralleling due to the open action failure of the working source breaker.

In practice, sequential transfer is used if fault occurring on the working source, while simultaneous transfer is preferred for scheduled bus transfer.

In-phase Transfer

In-phase transfer attempts to transfer the load bus to the auxiliary source, at the first moment that the phase angle between the bus and the auxiliary source goes to zero. Therefore, in-phase transfer minimizes the cross-voltage over the tie breaker, so as to reduce the negative impact on facilities during transferring. Considering the duration of breaker-close action, the zero phase angle must be forecasted in advance. Therefore, the bus phase angle is expected to not change too fast within transferring, to achieve an accurate forecast.

In-phase transfer is an important complement for fast transfer, and is mostly used in some specific situations, for instance, the initial phase difference is so large that fast transfer is not capable to be implemented.

Residual Transfer

In theory, residual transfer is not as effective as high-speed ways. It transfers the load bus to the auxiliary source by waiting that the bus voltage magnitude falls to 20%~30% of rated, without considering the voltage phase between the bus voltage and the auxiliary source voltage. No doubly, residual transfer takes the longest time, so that the motor inrush current probably rises beyond the rotor-locked limitation. Besides, transfer interruption is more likely to happen accounting for the possible disconnection of motors due to a protection of low voltage.

Comparing the two formers, due to a reasonable cost, the residual transfer is more commonly adopted by industry, under zero DG penetration case. However, nowadays, the number of DGs are rapidly incresing in distribution networks. With DG-connected, the bus characteristics are significantly changed. Thus high-speed transfer becomes a smarter choice, which is to be discussed in the next section.

IV. IMPACT OF DG ON BUS TRANSFER

To discuss the bus characteristics with DG-connected duing transferring, this section numerically simulates the impacts of voltage and frequency characteristics due to DG-connected by ETAP software package.

Voltage and frequency characteristic of bus with DG connected during transferring

In real world, different types of DGs have their own dynamic characteristics during transferring. Nevertheless, there are still common rules: the reactive power of DGs support the bus voltage, slowing the bus voltage decay; meanwhile the active power of DGs meets part of the loads, slowing the bus frequency decay.

Fig.2 shows a typical distribution system with DG connected. In Fig.2, S1 and S2 are two independent sources, which respectively supplies energy to load M1 and M2. CB1 and CB2 are breakers, normally closed, while the bus tie is normally open. Two scenarios are designed for case study.

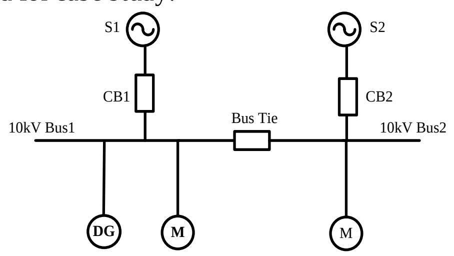


Fig.2 Simplified bus with DG connected

Case1 (With DG): In this case, DG meets 80% of the load M1. Fig.3 shows the characteristic of Bus due to the open-breaker event of CB1.

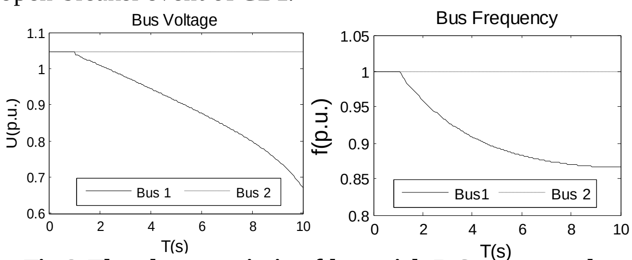


Fig.3 The characteristic of bus with DG connected

Case2 (Without DG): In this case, DG is out of service, so that Bus1 becomes a traditional load bus. The characteristic of Bus1 responding the same event of Case1, is plotted in Fig.4.

Comparing Fig.3 and Fig.4, the simulations show that with DG connected, both the bus voltage and frequency decay are slow down.

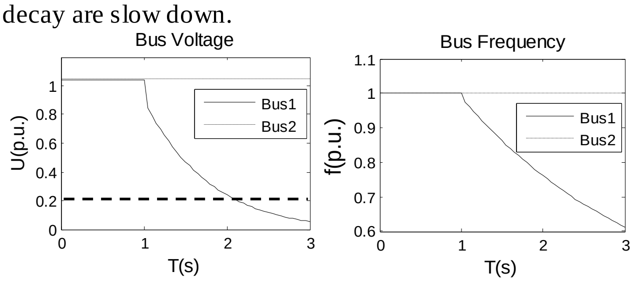


Fig.4 The characteristic of motor bus without DG

Simulation analysis of bus transfer for distribution networks with DG connected

Residual transfer

Fig.3 shows that 9 seconds after CB1 opens, the voltage Bus1 falls to 70% of rated, comparing without DGs, it takes only about 1 second to decline to 20% of rated, as shown in Fig.4. As mentioned above, 20% is a common criterion to activate the residual transfer. Therefore, the motor and DG itself suffer a longer time under low voltage and frequency, due to the "unintentional" support of DGs. It of course increases the possibility of power-interruption.

Therefore, once DGs are connected, the residual transfer has the instinct drawback to be applied in high-quality-requested industry. Faster transfer therefore becomes essential to build up a more reliable distribution system. Following simulations demonstrate both in-phase transfer and fast transfer are applicable for such system.

In-phase transfer

Suppose CB1 opens at 1s. Fig. 5 a) shows that the in-phase time with DG is 1.943s, which is much shorter than the decay time studied in Fig.3. Therefore the system reliability is significantly enhanced. Comparing with Fig.5 b), though the transferring time is only slightly longer than 1.336s without DG, the dynamic of motor is still excited. It is clear to read the transient from the right subplot in Fig.5 a).

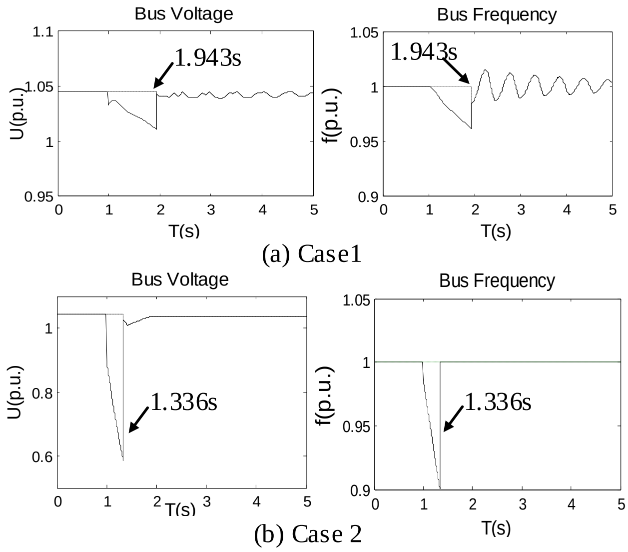


Fig.5 Characteristic of bus with DG–In-phase transfer

If one system does not accept this dynamics, for example containing extremely-delicate equipment, the fast transfer method is recommended, preferably.

Fast transfer

By simulating the same open-breaker event at 1s, the open circuit time of fast transfer is 5cycles (0.1s). Fig.6. shows the characteristic of Bus1 during fast transfer.

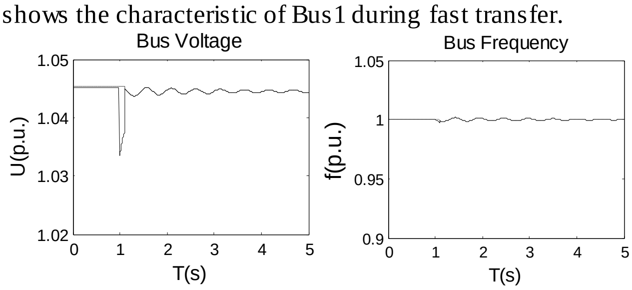


Fig.6 Characteristic of bus with DG-Fast transfer

It is shown from Fig.6 that fast transfer completes within a very short time (5~7cycles) with DG connected. There is lack of time to excite the transient of system due a short fault-clear time. All in all, comparing Fig.3~6, the fast transfer becomes the most suitable way to do bus transfer in distribution networks with DG connected.

V. DESIGN CODE DISCUSSION

From the angle of numerical simulation, section IV analyzes the impact of DG on bus transfer in distribution networks. Based on the knowledge from Fig.3~6, some design codes, which help the design of distribution system, can be summarized and further discussed in this section.

Appropriate DG capacity level setting

Taking DG capacity gradually decreases from 80% to 20%. The simulation results by ETAP indicate that, with fast transfer, the DG impulse current triples from 1.36p.u. up to 4.12p.u. , meanwhile the system goes through a longer transient process.

Therefore, if one distribution network needs fast transfer (within 0.1s, e.g.), the DG capacity and output should better not be less than 60% of the bus load. Then both the impulse current and system transient process resulted from bus transfer are acceptale.

Priority for Fast transfer in high DG penetration system

The simulations results clearly show in-phase transfer require longer open circuit time. The reason can be easily located by reviewing the characteristic of bus with DG connected (shown in Fig 3) , that the bus frequency decay is slow down after DG-connected. Thus it takes longer time to reach in-phase moment (zero phase), which may not meet some requirements of industries, such as petro-chemical industry.

On the other hand, with a slower decay of bus frequency, fast transfer becomes much easier to be implemented. Besides, the side effect of fast transfer is acceptable. Given all that, fast transfer obtains a priority in high DG penetration system.

Auto-reclosing forbidden for incoming line breakers

Auto-reclosing is widely used in power system, and the minimum reclosing time setting is around 0.15~0.5s. Without DG, the bus voltage always decays under 40% of the rated within the reclosing time. In that case, So auto-reclosing works well and increases the reliability of power system.

However, with the voltage support from DG, bus voltage decay is slow down. Within the setting time, the bus voltage cannot decline too fast. Thus auto-reclosing might fail to activate due to the non-voltage check. If the time of auto-reclosing is set longer, the same trouble as residual transfer also happens. Therefore the direct way is to forbid auto-reclosing for the incoming line breakers.

VI. CONCLUSION

This paper answers the question raised from a real example from petrochemical industry: why high-speed transfer method is essential for system with DG-connected. According the principle review and simulation study, a general rule is found for bus with DG-connected, that the decay of the bus voltage and frequency is much slow down due to the “unintentional” DG support. Thus residual transfer is not suitable to be applied in such system as power interruption risk gets too high. High-speed ways therefore become the only solutions. For a higher power quality, comparing fast transfer and in-phase transfer, the former one is preferably recommended, since system transient is capable to be significantly sustained.

Finally, this paper makes a further discussion on the design codes for bus transfer in distribution networks with DG connected. :

1) 60% is the a good setting level for DG capacity;

2) Fast transfer has a priority in high DG penetration system;

3) Auto-reclosing shall be forbidden for incoming line breakers.

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