NETWORK CONFIGURATION IMPACT ON DURING-FAULT VOLTAGE IN DISTRIBUTION SYSTEM

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ABSTRACT

The changes in the supply network configuration can significantly influence the voltage at individual sites during fault events. The main mitigation method against interruptions is the installation of redundant components (parallel feeders, loop system, multiple sources). But the redundant components can worsen conditions during voltage dip events mainly caused remote faults. The paper deals with an impact of the network configuration on the voltage dip magnitude, especially with the impact of a network operated in a radial way, a network with loop lines or parallel lines, and the impact of a spot network or an on-site (local) generator.

1. INTRODUCTION

The first step for connecting of new dispersed source to a distribution network is, besides building and territorial licence, the assessment of its effect on a distribution network. The study of connection of the dispersed source has to respect network operator guidelines, ensure the suitable parallel operating in distribution network and comply with limits of power systems disturbances and power quality.

Besides interruptions the voltage dips belong to most monitored events in power system from view of power quality. A voltage dip is a momentary decrease in the RMS voltage magnitude lasting between a half-cycle and 1 min. Voltage dips are characterised by their magnitude (remaining voltage, i.e. the voltage during the fault) and duration [1]. Dip magnitude ranges from 1% to 90% of the nominal voltage. Most of dips usually last less than 1 s.

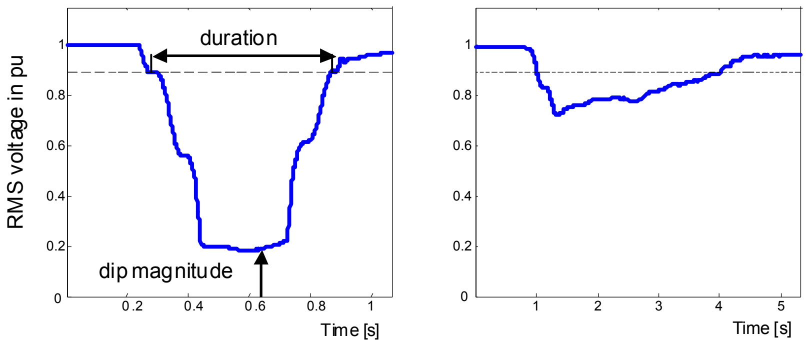

Figure 1 – Characteristics of a voltage dip caused by a) remote short-circuit fault and b) motor starting

Voltage dips are mainly caused by short-circuit faults in power system and reaction of protection system and automatic reclosing, overload and starting of large motors. Their effect on the operation of sensitive equipment is the same like the effect of short supply interruptions. Unlike interruptions voltage dips originate not only in the local distribution network, but they can be caused by fault hundreds of kilometres away in transmission system. Voltage dips are thus much more of a global problem than interruptions.

There are the various ways of mitigation of voltage dips [2]:

- Reducing the number of short-circuit faults (replace overhead lines by underground cables, use covered wires for overhead lines, improving maintenance etc.)
- Reducing the fault-cleaning time (using current-limiting fuses, faster static circuit breakers, inverse-time overcurrent protections etc.)
- Changing the power system such that short-circuit faults result in less severe events (change in network configuration, installing the local generation near sensitive load, feeding the sensitive load from two or more substations etc.)
- Connecting mitigation equipment between the sensitive load and the supply network (UPSs, voltage source converters VSCs etc.)
- Improving the immunity of the equipment.

2. EFFECT OF POWER SYSTEM DESIGN

Two improvement methods in power system design are parallel operation of components and switching to an alternative supply. The first one will be discussed in detail, especially the effect of supply network configuration and local generators on severity of voltage dips, i.e. dip magnitude.

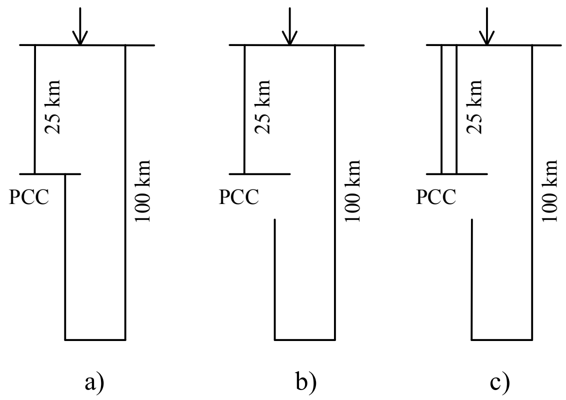

Figure 2 – Three alternatives of supply network: a) looped operation, b) radial operation and c) parallel operation

2.1. Loop system

Consider the system shown on Fig.2a. Two feeders of different length originate from the same substation and supply the point of common coupling (PCC). Suppose that Z_1 a Z_2 are the impedance of the feeders, that Z_Z is the source impedance. The load current before as well as during fault is neglected, the pre-fault voltage is exactly 1 pu and the fault impedance is zero. The fault occurs on feeder 1 in relative length *p* from the source. The equivalent circuit for faulted loop system is on Fig.3.

Total circuit impedance is given:

$$Z_K = Z_Z + \frac{pZ_1 \cdot \left[(1-p)Z_1 + Z_2\right]}{pZ_1 + (1-p)Z_1 + Z_2} \tag{1}$$

The voltage at PCC during the fault (i.e. dip magnitude) is then given:

$$u_{PCC} \cong \frac{p \cdot (1-p)Z_1^2}{Z_Z(Z_1 + Z_2) + pZ_1Z_2 + p(1-p)Z_1^2} \tag{2}$$

The voltage (dip magnitude) at the PCC, as a function of relative distance from source to fault, has been calculated for 110 kV grid with fault level of 2000 MVA, and 25 km and 100 km feeders of the 185 mm^2 overhead line. The faults on 25 km feeder cause deeper voltage drop at PCC in comparison with the faults on the longer feeder (Fig.4). The graph is completed by the alternative with radial feeder of 25-km overhead line and adjacent 100-km feeder (brown line). Consider the fault occurs on adjacent 100-km feeder in relative distance p from source. The voltage at PCC in network operated in a radial way is then given:

$$\bar{u}_{PCC} = \frac{p\bar{Z}_2}{\bar{Z}_Z + p\bar{Z}_2} \tag{3}$$

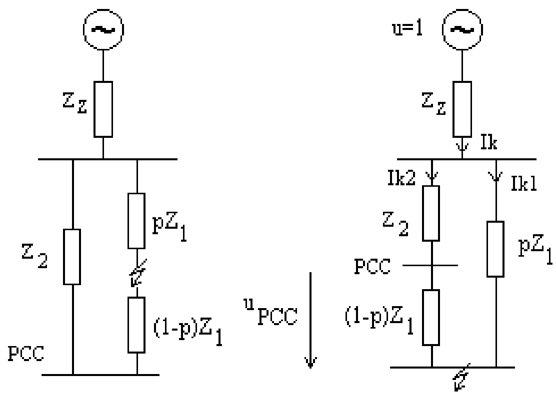

Figure 3 – Equivalent circuit for a looped network

Comparing the voltage at PCC in supply system operated in a looped and radial way respectively (Fig.4) it is evident that the faults on 100 km feeder cause more severe voltage dips at PCC when the supply system is operated as looped one.

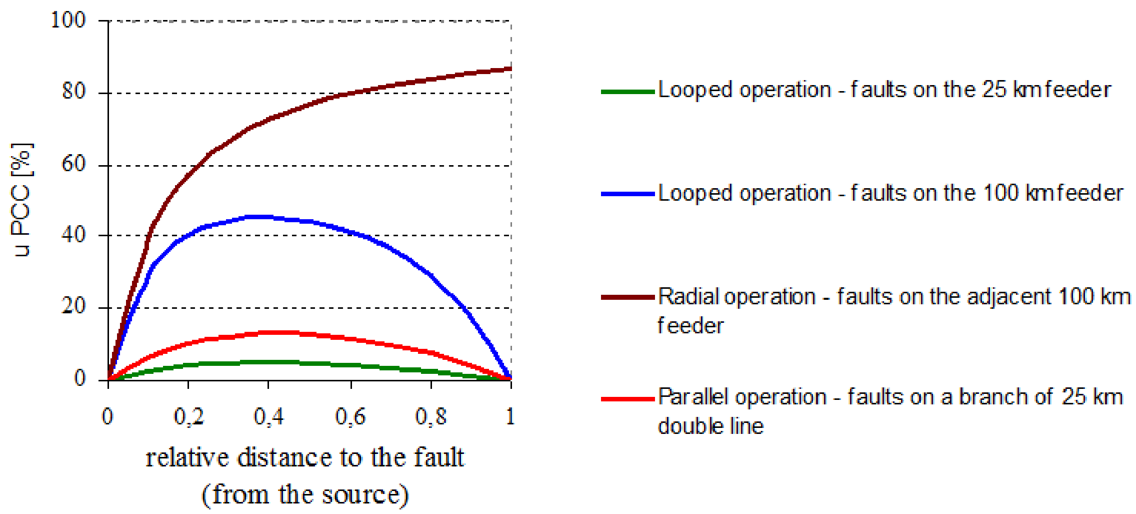

Figure 4 – Voltage at the PCC as a function of fault position on the feeders for various ways of network operation

2.2. *Parallel feeders*

Parallel feeders in radial systems improve power supply reliability. The fault between the source and the PCC do not cause any interruption, but only deep voltage dip. The voltage at the PCC can be expressed by using equation (2), both feeders have the same length (Z_1=Z_2) (Fig.2c). The voltage (dip magnitude) at the PCC as a function of the relative distance from source to the fault has been calculated for 25-km parallel feeders (Fig.4 – red line).

The faults on the parallel feeders of common length cause the voltage at the PCC not exceeding several tens of nominal voltage Un, i.e. severe voltage dips. The number of severe voltage dips at the PCC is higher in comparison with a network with radial feeders. Improving of reliability of supply by using parallel feeders is controversial, because the effect of severe voltage dips on sensitive equipment can be the same as the effect of interruption.

2.3. Local generator

The local generator connected near by load bus not only increases the fault level but also damps the voltage dips caused by remote faults. During such a fault the generator keeps up the voltage at its local bus by feeding into the fault. The equivalent circuit is on Fig.5, Z_4 is the impedance of the local generator during the fault (transient impedance), Z_1 is the source impedance at the PCC, Z_3 is the impedance between the generator bus and the PCC.

The total circuit impedance is given:

$$Z_K = Z_2 + \frac{Z_1(Z_3 + Z_4)}{Z_1 + Z_3 + Z_4} \tag{4}$$

The voltage at the load bus is calculated as $u_{load} = Z_2 I_{k1} + Z_3 I_{k2}$ and is expressed by using branch impedances:

$$u_{load} = \frac{Z_2(Z_1 + Z_3 + Z_4) + Z_1 Z_3}{Z_1(Z_3 + Z_4) + Z_2(Z_1 + Z_3 + Z_4)} \tag{5}$$

The voltage at PCC is calculated as $u_{PCC} = Z_2(I_{k1} + I_{k2})$. This voltage is related to the voltage at the load bus according to following equation:

$$\left(1 - u_{load}\right) = \frac{Z_4}{Z_3 + Z_4} \cdot \left(1 - u_{PCC}\right) \tag{6}$$

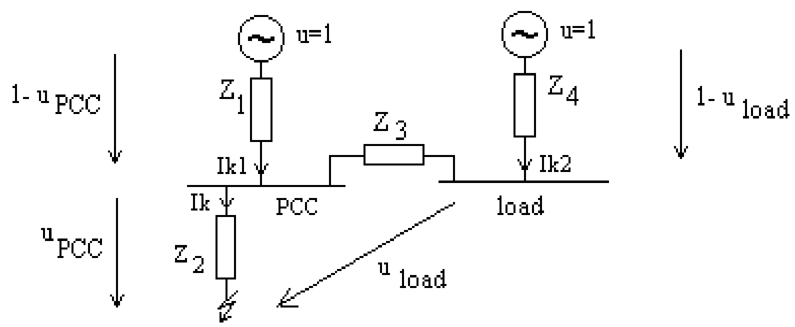

Figure 5 – Equivalent circuit for system with local generator

The voltage drop at the load (generator) bus is $Z_4/(Z_3+Z_4)$ times the voltage drop at the PCC. Because of $Z_4/(Z_3+Z_4) <1$ the connection of the local generator mitigates voltage dips due to remote faults. The voltage drop thus becomes smaller for larger electrical distance to the PCC (larger impedance Z_3) and for larger local generator (smaller impedance Z_4). The more remote fault is, the more damped voltage dip. The larger the generator, the more the reduction in voltage drops (Fig. 6).

The voltage at the load bus (Fig.6), as a function of the distance from PCC to the fault, has been calculated for 110 kV grid with fault level of 900 MVA. Transient reactance of generator is 15% and the transformer connecting the generator has impedance of 11%, distance between source and local generator is 30 km.

From (6) and Fig. 6 it is clear that there is a non-zero minimum voltage at the load bus. The local generator keeps up the voltage at the load bus:

$$u_{load\ \min} = \frac{Z_3}{Z_3 + Z_4} \tag{7}$$

The similar effect as the local generation has feeding from two substations or different busbars. The equivalent circuit is identical to Fig. 5. In case of two substations with identical fault level, the voltage drop due to fault will be reduced to about half its original value. Contrary to the previous case, the alternative supply (second substation) introduces new dips due to faults originated in connected system. In reality two substations are seldom totally independent, so that faults in higher voltage levels cause the voltage drop in both substations and thus the mitigation effect of double infeed is somewhat less. Before deciding about a double infeed it is necessary to find where most of the disturbing dips originate.

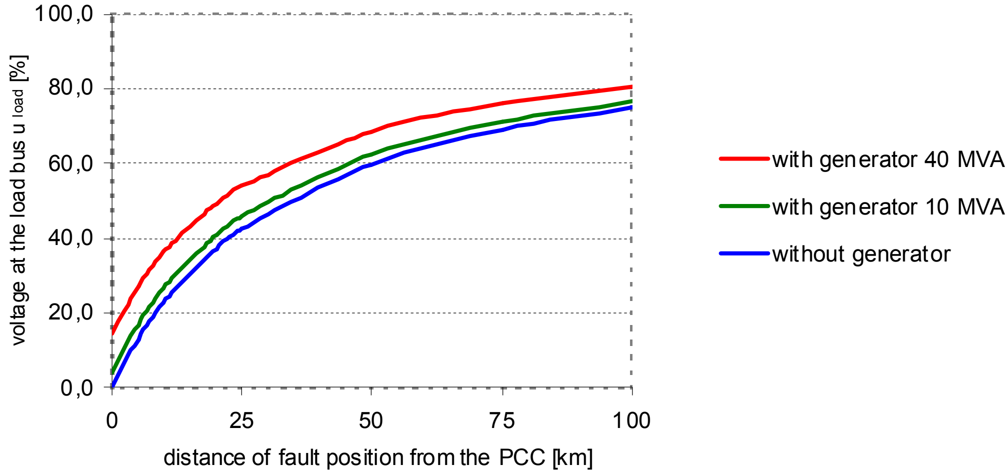

Figure 6 – Voltage at the load bus as a function of fault position for system with and without local generator

3. CONCLUSIONS

By implementing changes in the supply system, the severity of the voltage events can be reduced. The cost on mitigation of voltage dips by changing the power system could be very high. Generally, the cheapest mitigation solution is installation of less sensitive equipment.

Changes of the supply system configuration can cause the reduction in voltage drop during the fault. In contrast to requirement for reliability of power supply, the radial operated system is more convenient from point of less severe voltage dips. However, radial operation of supply system can worsen voltage condition during fault at some buses.

The installation of a local generator near by the sensitive load will keep voltage up during remote faults. The reduction in voltage drop is equal to the percentage contribution of the generator to the fault current. In case of a combined-head-and-power station it is worth to consider the position of its connection to the supply system.

Feeding the sensitive load from two or more substations has similar mitigation effect as installation of local generator. The more independent substations are the more the mitigation effect. Introducing the second infeed increases the number of voltage dips, but reduces their severity.

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