OPERATIONAL EXPERIENCES WITH THE NEW METHOD TO CONTROL PETERSEN COILS BY INJECTION OF TWO FREQUENCIES

Gernot DRUML
A.Eberle GmbH&CoKG
g.druml@ieee.org

Stefan STEGER
E.ON Netz GmbH
stefan.steger@eon-energie.com

Olaf SEIFERT
Siemens
olaf.seifert@siemens.com

Andreas KUGI
Saarland University
andreas.kugi@lsr.uni-saarland.de

ABSTRACT

In this paper we present field experiences of several installations with the new method for the calculation of the zero-sequence network parameters and the control of Petersen coils in resonant grounded networks.

The major problems for the correct calculation of the line-to-ground capacity, respectively of the resonant-point, are the missing or very low zero-sequence voltage and the non negligible crosstalk of the varying load currents to the zero-sequence-voltage. As a consequence, the number of tuning operations and non correct tuning operations increases in today's networks.

The new method uses the injection of two currents with frequencies unequal to 50 Hz into the zero-sequence system for the calculation of the network parameters. Therefore it is possible to supervise complete symmetrical networks and to suppress the 50 Hz crosstalk of the load current. In consequence, the number of coil movements and also the number of wrong tuning positions are drastically reduced.

INTRODUCTION

The tuning of the Petersen-Coil is a preventive operation already done in the healthy network. With the existing methods it is not possible to determine the network parameters during a solid earthfault. The fault location and the resistance at the fault location are unknown and are not accessible for a measurement. In case of a solid earthfault the zero-sequence voltage is impressed and the measurement of the zero-sequence current at the fault location is impossible. The zero-sequence voltage and current can only be measured at the substation or, in some cases, at some dedicated switching-stations.

In the past different control algorithms were developed [2]. Most of these algorithms are based on the necessity to move the Petersen-Coil. The development of today's distribution networks is characterized on one side by an increase of symmetrical cables, which results in smaller usable zero-sequence-voltages and, on the other side, in an increase of the crosstalk of the positive sequence of the load current to the zero-sequence system [2]. With the decreasing zero-sequence voltage the controller must be set much more sensitive. Due to the crosstalk of the load current to the zero-sequence voltage each change of the load current can release a tuning operation, which is, in most of the actual algorithms, combined with a physical movement of the Petersen-Coil. Due to the disturbances the parameter estimation of the network is much more difficult and results in a necessary movement of the Petersen-Coil over a longer distance. Nevertheless, sometimes a correct tuning is impossible.

With the new method it is possible to calculate the correct tuning position without moving the Petersen-Coil, even if the natural zero-sequence voltage is zero, respectively if the disturbances in the zero-sequence voltage are not negligible. The result of the calculation is used to check if the actual coil position is within a tolerance field or if it is necessary to move the coil to a new tuning position. Therefore the number of moving operations of the Petersen-Coil and possible detuned situations are minimized.

PRINCIPLE OF THE NEW ALGORITHM

All the existing algorithms are based on the fact, that the residual voltage is generated either by the natural unbalance of the network or by an artificial 50 Hz current injection. These methods are assuming, that there is no change in the network respectively no change of the crosstalk of the load current during the calculation period. Please pay attention that the calculation period can last from several seconds up to several minutes.

In reality there are a lot of situations where these assumptions are not valid, for example in the sphere of heavy industry with symmetrical networks but heavy changes of load. The new CIF-algorithm (Control by Injecting Frequencies) suppresses the 50 Hz crosstalk from the load current by using frequencies unequal to 50 Hz for the measuring and for the parameter estimation.

The simplified equivalent circuit with a current injection according to *Fig. 1*

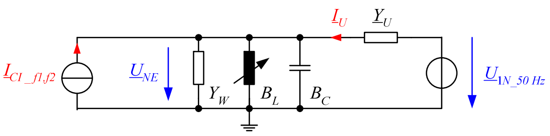

Fig. 1: Simple equivalent circuit with current injection

results for the frequencies unequal to 50 Hz to *Fig. 2*

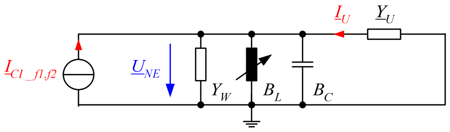

Fig. 2: Simple equivalent circuit with current injection unequal to 50 Hz

For the frequency *fn* the admittance, seen from the current injection, can be described for a network with a small $\underline{Y}_U$ as:

$$\underline{Y}_{CI\_fn} = \frac{\underline{I}_{CI\_fn}}{\underline{U}_{NE\_fn}} \approx Y_W + j(\omega_n C - \frac{1}{\omega_n L}) \qquad (1)$$

Using two different frequencies one gets two complex equations with three variables, which can be solved very easy.
Assuming a linear system enables the current injection of two frequencies and evaluation of the corresponding $\underline{Y}_{CI\_fn}$ at the same time. This results in very fast measurement possibilities and is usually in the range of 240 ms.

The following items list the main advantages of this new CIF-algorithm:

- Very fast measurement
- Suitable also for symmetrical networks
- Insensitive to the 50 Hz open-delta VT error
- Suppression of 50 Hz crosstalk

Details, how the frequencies are generated can be found in [3] and [1].

REALIZATION

The major task for the realization is the question, how to inject the two frequencies in the zero-sequence system. The first idea is to use the Petersen-Coil as a transformer, to inject a current of about 10 A on the low-voltage side via the 500V Power-Auxiliary-Winding (PAW) and to measure the zero-sequence voltage via the 100V Measurement-Winding (MW) of the Petersen-Coil.

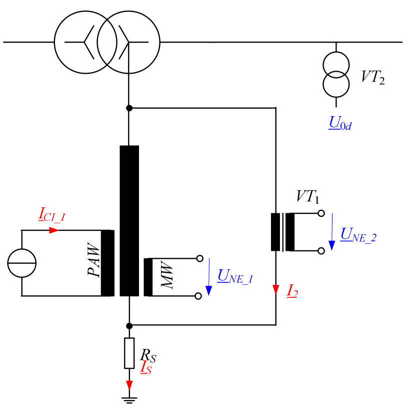

Fig. 3: Petersen-Coil and external VT's

Up to now, it was not necessary to specify the Petersen Coil for their use in combination with a current injection. Therefore no special requirements for the CIF are taken into consideration by standard coil designs.

Due to the changing air-gap in the Petersen-Coil the coupling from the primary-side to the secondary side depends on the coil-position [4]. The PAW is designed to allow the connection of a resistor to the PAW to increase the wattmetric part of the fault current for the earthfault-protection relays. The accuracy of this winding is usually in the range of ± 10% and depends on the coil position. In some cases, for example if the wattmetric increase is not used, the PAW does not exist.

The realization of the Measurement Winding (MW) depends on the manufacturer and the Petersen-Coil specification. In the simplest version this is a concentrated or distributed third winding. The accuracy depends on the location and distribution of this winding, but is normally also in the range between 5% and 10%. If a higher accuracy is specified, an additional instrument voltage transformer is installed on the primary side of the Petersen-Coil. This transformer can be mounted internal under oil or external for example on the top of the coil.

Usually there is no specification of the coupling between the PAW and the MW. This can lead to problems when a current is injected in the PAW. The MW should reflect the voltage on the primary side and not the voltage on the PAW.

Due to the fact, that the Petersen-Coil is not an ideal transformer, the most accurate version is, to use an external single phase transformer connected in parallel to the Petersen-Coil (*Fig. 3*: VT_1), to measure the injected current on the primary side of this transformer (*Fig. 3*: $\underline{I}_2$) and to measure the primary voltage via an extra VT. To reduce the costs, the VT can be replaced by the MW of the Petersen-Coil. This version could also be used in cases, where no PAW exists.

The previous version needs a single phase transformer for about 10 A on the low voltage side. These costs can be reduced by exchanging the components, by injecting the current via the PAW and to measure the voltage on the primary side via an extra voltage transformer in parallel to the Petersen-Coil (*Fig. 3*: VT_1) or via the open-delta winding on the bus-bar (*Fig. 3*: VT_2).

If all three windings in the Petersen-Coil are on the same core, the coupling from the PAW to the MW is normally too high. This version should not be used. But in practice there exist a lot of Petersen Coils with a good arrangement of PAW and MW working without problems, but with reduced accuracy. In these cases the controller needs only more steps to find the correct tuning position.

In the following samples of real installations the injection was done via the PAW and the measurement on the primary side or via the open delta winding.

FIELD EXPIERENCES

In the first net with a resonant point at 108 A a Petersen Coil with 210 A was installed. For the under-compensation an absolute value of -5A was selected. As shown in *Fig. 4* the amplitude of the zero-sequence-voltage U_0 is relative low and not stable.

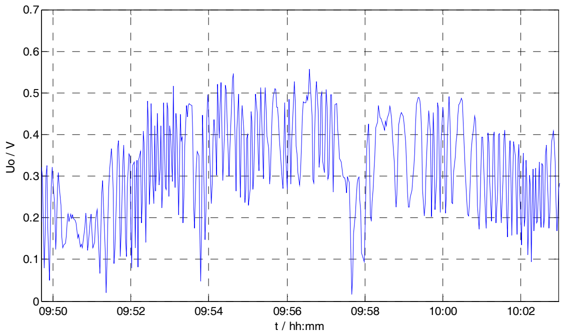

Fig. 4: Disturbed U_0 without switching operation

Slow and statistic variations of U_0 can be explained as the crosstalk of the load current to the zero-sequence-system [2].

In this net from the zoomed view in *Fig. 5* a periodic behaviour can be recognized for the amplitude of U_0 with a varying period between few seconds and 30 s.

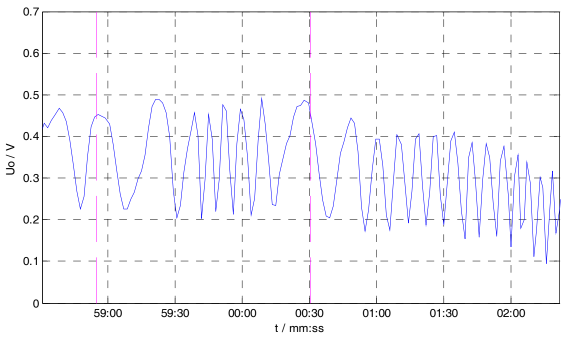

Fig. 5: Zoomed view of U_0

In *Fig. 6* the locus diagram of the selected range between the two cursors of the previous figure is shown.

Further investigations confirmed that the crosstalk was a result of the 3rd harmonic of the 16.7 Hz 110-kV-railway-network, which runs parallel to the 20-kV-lines over a longer distance. The 16.7 Hz network is not synchronised to the 50 Hz system, therefore a varying beat can be detected on the 50 Hz component.

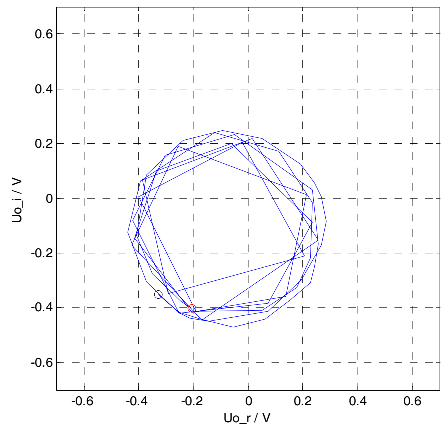

Fig. 6: Locus diagram of $\underline{U}_0$

Due to this crosstalk the resonance curve is disturbed, as it is shown in *Fig. 7*. For a standard Petersen-Coil controller with a standard search algorithm it is not possible to find the correct tuning position in such a network. Additionally this controller would more or less continuously move the Petersen-Coil to find the resonance point. The number of detuned situations is increasing.

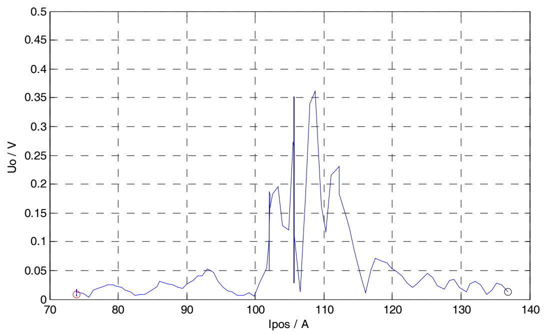

Fig. 7: Disturbed resonance curve

In the following figure the controller was enabled to make a **continuous estimation** and recording of the resonance point using the CIF method. During this recording the Petersen-Coil was moved from the upper coil-position to the lower coil-position. From the record can be noticed, that the estimation of the resonance point is very accurate, also in detuning positions of about ±100 A.

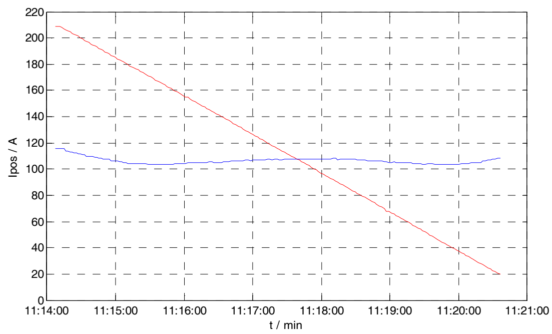

Fig. 8: Estimated resonance point during coil movement

The second 20-kV-network had its resonant point at 67 A under standard conditions. In this network a Petersen-Coil with 188 A was installed and an under-compensation of -5 A was used. Due to ground currents in a solid grounded 50 Hz 110 kV network in the same substation, the zero-sequence voltage of the 20 kV network varies by 200% as shown in *Fig. 9*

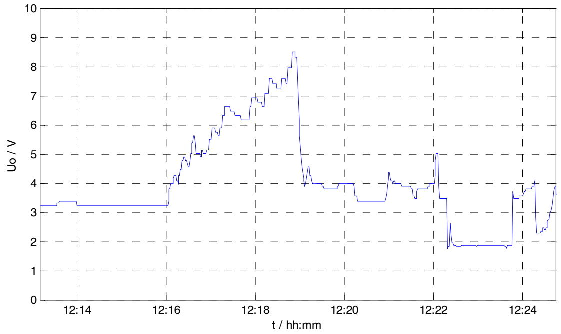

Fig. 9: Disturbed U_0 without switch-operation or coil movement

Although the zero-sequence-voltage in this network was relatively high, the crosstalk does not enable a standard Petersen Controller to find the correct tuning. In *Fig. 10* the disturbed resonance curve is shown. It must be noticed, that this curve is complete different during the next search operation.

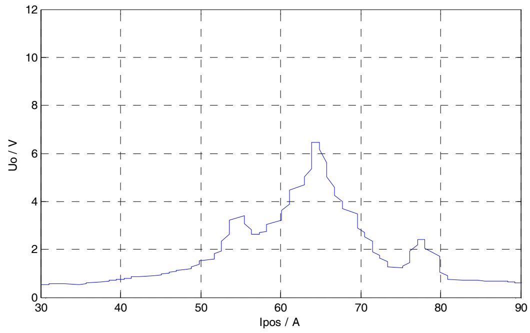

Fig. 10: Disturbed resonance curve

The next two figures show the zero-sequence voltage and the coil position using the automatic tuning operation with the current injection method CIF. The intended switch operations in the network were detected correctly and compensated. In *Fig. 12* it is easy to identify the coupling with the second also by -5A under-compensated network (+5A), the switchover of a line with I_{CE} of 10 A to the second network, the reconnecting and the re-establishing of the original state.

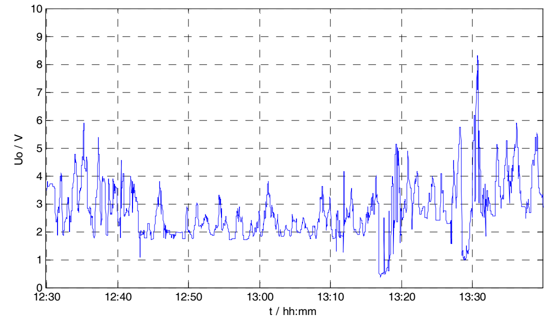

Fig. 11: U_0 with switch operation and successful tuning

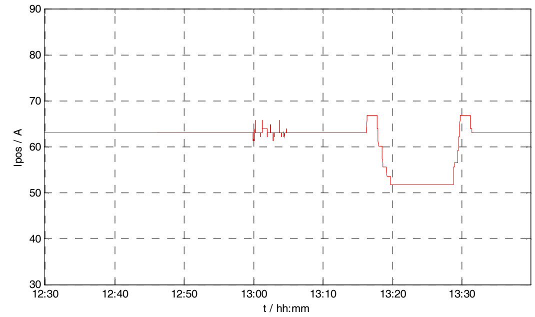

Fig. 12: Coil position

CONCLUSION

In this contribution we have shown two network examples with low and high natural unbalance and with high crosstalk from load current respectively from other power-systems. Compared to standard Petersen-Coil controllers, which are not able to make a successful tuning in these networks, using the new Control by Injecting Frequency (CIF) algorithm there was no problem to find the correct tuning operation point. The CIF algorithm is faster and more accurate and combines this feature with an essential reduced number of coil movements.

The performance of the CIF algorithm in these two examples was very convincing in every respect. Even the installations in many other substations show the effectiveness of this new concept for the control of Petersen-Coils.

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