IMPACT OF VOLTAGE FLUCTUATION ON PETERSEN-COIL CONTROL AND RESULTS OF A TUNING METHOD WITH EVALUATION OF SIDE FREQUENCIES

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ABSTRACT

Petersen coils are installed in distribution networks in order to compensate for the capacitive ground fault current in case of a single phase earthfault. Neutral to Ground Voltage fluctuations nowadays often disturb the correct tuning of such coils or lead to very frequent coil adjustments. A new tuning method, using frequencies different from the operating frequency of 50 Hz, has been successfully tested at the Swedish railway operator and has proven that it is quite robust against such voltage fluctuations.

INTRODUCTION

The adjustment of the coil must be done before the occurrence of the fault, when the network is still healthy. Today this tuning procedure is usually performed by an electronic control device.
The simplest, traditional control strategy uses the measured voltage at the neutral point (V_o) by evaluating the resonance curve of V_o against the coil position, searching for the resonance voltage maximum ($V_o$max). It is assumed that still about 50 % of all installed controllers operate according to this simple method.

The impedance of the parallel resonance circuit, formed by Petersen coil inductance and network capacitance towards ground, is quite high (up to several kOhm) in tuned condition. Therefore already relatively weak interferences can cause V_o - voltage fluctuations in the range of $V_o$max. Traditional control strategies will possibly fail to tune the coil under conditions with such persisting interferences. Additionally the increasing degree of cabling in the networks leads to enhanced phase symmetry and lowers the voltage maximum as well.

When the Petersen coil controller is in error state, the coil is possibly not tuned correctly. In order to meet standards for maximum allowed touch voltage the operating staff is obliged to follow up these problems quickly. Such unplanned actions may cost important time to solve other possibly more important problems in the network.
Reasons for interferences on the neutral voltage are:

- Parallel lines of different networks (either other power lines or lines for traction purpose)
- Coupling from the overlain HV network or the underlain LV network
- Thunderstorms / windy weather conditions
- Load current fluctuations due to coupling from positive sequence system to zero sequence system (heavy industry, big drives, electrical furnaces, …)
- Interferences between different networks caused by common grounding systems.

As case example this paper deals with tuning problems at the Scandinavian railway operator “Trafikverket”. That company operates 50 Hz supply lines and 16 2/3 Hz traction lines mounted on the same poles, what leads to quite high mutual coupling between the two systems. Even though the controller effectively filters out the railway’s base frequency (16 2/3 Hz), the third harmonic, which is 50 Hz as well, leads to disturbances.
Similar problems have been observed in Austria, Germany, Switzerland as well, where 16.7 Hz are used for traction systems at locations with 50 Hz distribution lines and 16.7 Hz railway lines close to each other.

A more sophisticated tuning method with pulsed injection current was intensively tested. Generated side frequencies are evaluated to calculate resonance point (I_{res}) and other network parameter (k, v, d) of the zero sequence system. Since these frequencies are usually not contained in the natural frequency spectrum they will be less disturbed by interferences. It is assumed that this new method will make the adjustment of Petersen coils more reliable also under special conditions. Additionally enhanced strategies for the trigger of a new tuning process in order to recognize switching operations in such networks are required.

CONTROL METHODS

Standard method

The coil position is changed and measured couples of coil position and zero sequence voltage (I_{pos}, V_o) are evaluated to fit to the chosen mathematical model of the resonance circuit and to calculate the model parameters. Independent from evaluation method and mathematical model this standard method always requires a certain adjustment of the coil inductance (motor movement in case of a plunger core coil). The accuracy of the parameter calculation is usually better if the coil adjustment is evaluated close to the resonance point and increases with the amount of the inductance change.

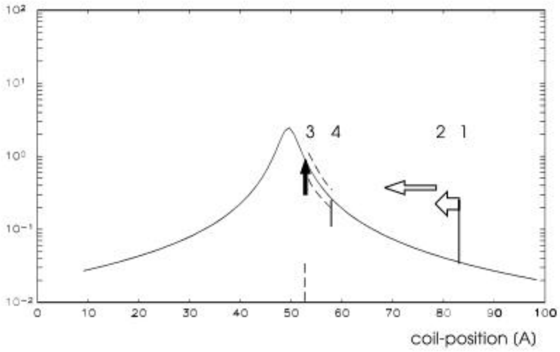

Fig. 1: Standard control method by coil adjustments in order to calculate resonance curve and network parameters.

It must be noted that plunger core coils are not designed for permanent movement [1], [6]. Too frequent adjustments may lead to early damage of the adjustment mechanism (spindle, core nuts) of a plunger core coil and repairs will be relatively difficult and time consuming.

Control with 50 Hz current injection

A 50 Hz current is injected into the neutral point. Depending on the impedance of the resonance circuit this leads to a change of the zero sequence voltage V_o. Phasor measurement allows to calculate actual network parameters and resonance curve without any adjustment of the coil position.
(Remark: Alternatively to the injection in the neutral point also an injection into a single phase, respectively the use of single phase unbalancing elements is feasible – however the injection in the neutral is the simplest approach – if the injection is done into the power auxiliary winding of the plunger core coil low voltage device components can be used.)

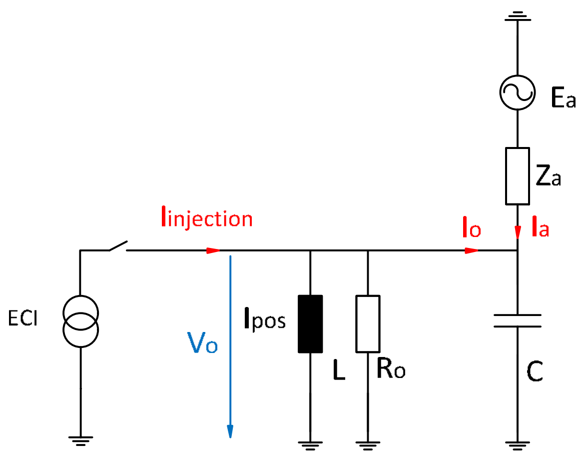

Fig. 2: Control method with 50 Hz current injection for calculation of network parameters.

A comparison (done by an Austrian utility about 15 years ago) of the standard control method with the current injection method showed significant reductions in the motor adjustment time of the coils from several hours down to only several minutes p.a. This statistical evaluation demonstrated that the number of control operations caused by voltage fluctuations can dominate over the control operations caused by real switching operations.
The method with the 50 Hz current injection however still has the disadvantage that the voltage change caused by the injection current can be disturbed by network interferences. Accurate measurement can therefore only be achieved if the network is sufficiently stable during the measurement. A simple check for such stability is to compare the voltage before and after the measurement. A current injection with too high difference is regarded as invalid and will therefore be repeated. However in networks with permanent disturbances a valid calculation will never be achieved and after a certain time an error message has to be generated.
Further improvement can be achieved by longer measurement intervals in order to average out the interferences, but the periodicity of such interference is usually not well known and probably also not well predictable. A further disadvantage is that averaging increases the necessary tuning time. Less sensitivity in order to enhance the probability of a valid injection on the other hand leads to less tuning accuracy and is limited by the maximum acceptable tuning mismatch.

Control with multifrequency current injection

Methods overcoming these problems use frequencies different from the 50 Hz operation frequency [2], [3], [4], [5].
Such frequencies can for example be generated by pulsing a 50 Hz injection signal like shown in the following pattern.

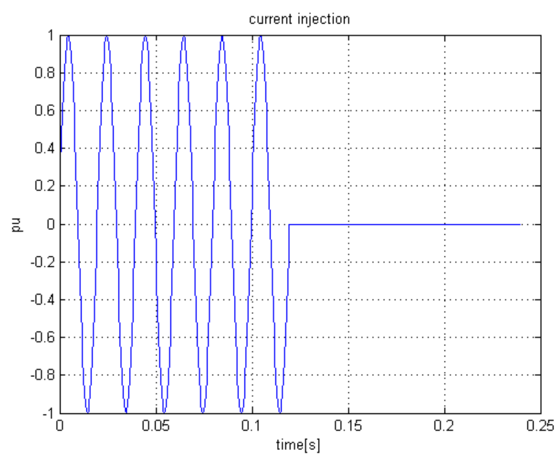

Fig. 3: Current injection pattern for generation of side bands to the 50 Hz main frequency.

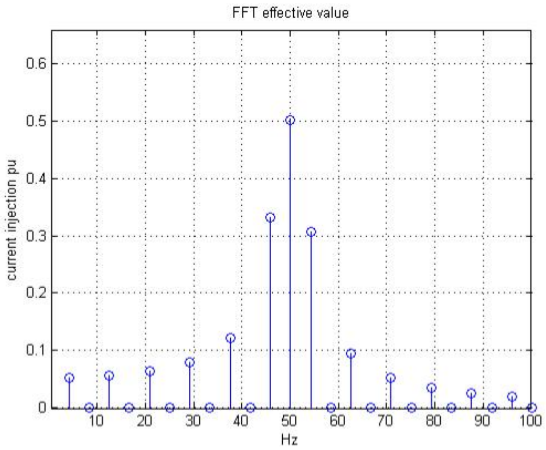

Fig. 4: Frequency spectrum caused by pulsed injection pattern.

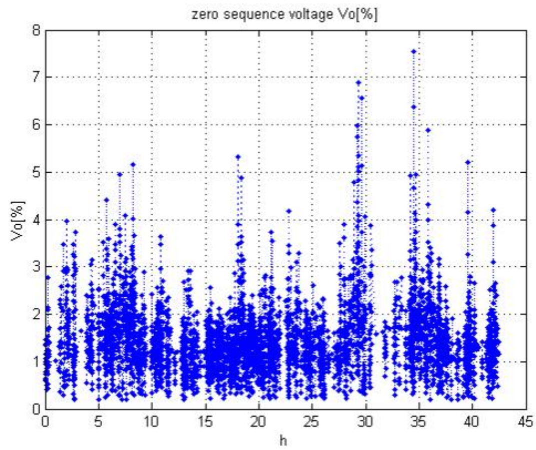

Fig. 5: Voltage fluctuations in station Järna

Evaluation of the side frequencies allows the calculation to become less dependent from 50 Hz fluctuations. In order to calculate the resonance at 50 Hz the split of capacitance and inductance in the zero sequence system must be known. Therefore at least two different frequencies need to be evaluated. The measurement accuracy of injected current and voltage must be higher than for 50 Hz injection signals [6].
As a side result also the total inductance in the zero sequence system is derived including eventual parallel fixed coils and distributed coils.

EXPERIENCE AT TRAVIKVERKET

The Swedish railway operator Travikverket (former Banverket) operates 50 Hz networks which supply the energy for the traction system at 16 2/3 Hz. Power frequency conversion is done by static or rotating inverters. The power lines of the 50 Hz and the 16 2/3 Hz network are often guided on the same poles in close vicinity. The 50 Hz network is resonance grounded by plunger core Petersen coils.

At the beginning these coils were controlled by means of the standard control method, using coil adjustment. However it turned out in many stations that the V_o fluctuations were so high and persistent that a successful tuning was hardly possible. Motor maximum run time was quickly exceeded, the controllers changed into error state.

Therefore in several stations 50 Hz current injection units were installed. Extensive motor movement was avoided and the rate of successful tunings was improved. Nevertheless still too many invalid current injections happened and the customer received too often error messages.

Since it wasn't to expect that individual parameter optimisation (averaging time, sensitivity) for each station would completely overcome the problem it was proposed to use a controller with multifrequency current injection, which Trench already had under development at that time.

Test of multifrequency current injection

The customer wrote a new specification for the Petersen coil controller, which also included lab tests with simulated interferences in order to prove the robustness of the tuning method.

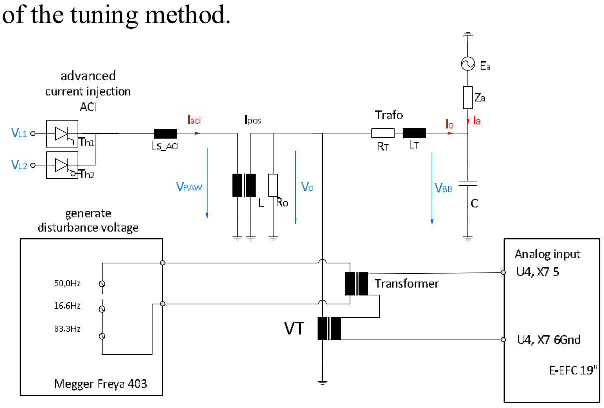

Fig. 6: Test arrangement for interference test

Fig. 7: E-EFC19i

Nevertheless the tests were performed in a real station with a test arrangement as shown in fig. 6. The aim was to test worst case situations for the controller algorithm, starting the tuning procedure from the upper or lower end-switches of the Petersen coil.

The more the network is detuned, the lower is the network impedance Z_o (=X_L || R_o|| X_C) and the response of the zero sequence voltage V_o is therefore a minimum for the injected current I_{aci}, what means that the highest inaccuracy in network parameter calculation is to be expected.
The goal of the test was to prove, that the controller finds the correct tuning point also in case of massive disturbances in the voltage signal.
In order to be independent from random voltage fluctuations during the tests, a disturbance voltage generator was connected in series to the voltage transformer and the voltage, disturbed in such way, was measured by the controller. The tests were performed at 4 different network configurations and the following combination of disturbance voltages (voltage values in the table are secondary values):

Table 1 :
Network configuration 1, network capacitance I_{res}=12A

Test case	$V_{disturbance}$[V] 16 2/3Hz	$V_{disturbance}$ [V] 50Hz	$V_{disturbance}$ [V] 83 1/3Hz
1	0	0	0
2	1	0	0
3	1	0	0
4	1	2	0
5	1	2	0
6	0	4	0
7	0	4	0
8	2	4	2
9	2	4	2

Table 2 :
Network configuration 2, network capacitance I_{res}=27A
Network configuration 3, network capacitance I_{res}=50A
Network configuration 4, network capacitance I_{res}=65A

Test case	$V_{disturbance}$ [V] 16 2/3Hz	$V_{disturbance}$ [V] 50Hz	$V_{disturbance}$ [V] 83 1/3Hz
1	0	0	0
2	1,5	0	0
3	1,5	0	0
4	1,5	10	0
5	1,5	10	0
6	3	10	3
7	3	10	3

At Fig. 8, test 2 one can clearly identify the resonance curve and in this test case also standard method and 50Hz injection method would work properly. As expected the tests showed that the 16 2/3 Hz disturbance has a negligible influence due to filters applied in the controller.

The disturbance voltage generator was not synchronised to the network frequency, therefore it was expected that the 50 Hz disturbance causes a beat frequency which can be observed in figure 8, test 5.

Obviously the standard method would have troubles to find the correct tuning point due to the additional local maxima of the zero sequence voltage V_o.

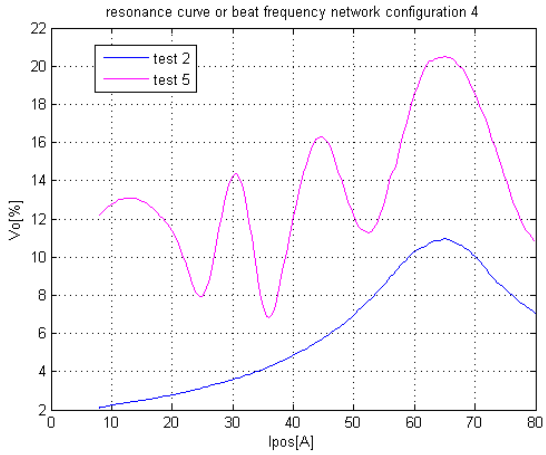

Fig. 8: Network configuration 4, test 2 and test 5 measured voltage over coil position

The method with 50 Hz current injection could fail if the validation of a current injection finds a too high voltage difference before and after the injection. In this case the current injection is regarded as invalid and must therefore be repeated, if the maximum number of allowed injections are exceeded the controller goes into error state.
The multifrequency tuning method still finds the correct tuning point. The slow 50 Hz voltage changes (FFT) due to the beat frequency have only a minor influence to the used side frequencies, the window for averaging the side frequencies can be kept shorter compared to the 50Hz method.

Superimposing a not synchronised disturbance voltage gave good evidence of the robustness of the controller algorithms especially against disturbances of the 3rd harmonic of 16 2/3 Hz used by traction systems.

The disturbance with 83 1/3 Hz (5th harmonic) was only used in combination with the 2 other disturbance frequencies. No special influence of this frequency could be observed during the tests.

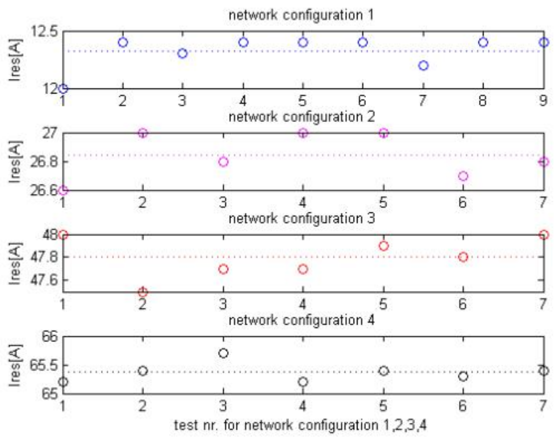

Fig. 9: calculated I_{res} [A] – circles indicate individual test result – dashed line corresponds to mean value

In total more than 30 different tests were performed, combining different levels of disturbance voltages and frequencies. In all situations the controller was able to find the correct tuning point. The deviation of the calculated network capacitive current I_{res} with or without disturbance was less than 0,5A at the whole test series.

TRAVIKVERKET FIELD RESULTS

The controller was set in normal service in order to collect practical experience in such networks. After 5 months the stored data was downloaded and evaluated.

- The controller was in automatic mode the whole time.
- No errors generated during this time. The total trigger time was about 25 h.
- The amount of trigger starts was 46978. (11times/h)
- 1192 trigger starts leaded to a recalculation of network parameters
- Effective running time of coil was only 20sec !

Result: Error – free operation during 5 months and coil adjustment only if switching operation demanded a change of compensation current.

COMMENTS ON THE TRIGGER PROCESS

A new tuning operation performed by the automatic controller should only be triggered by the 50 Hz zero sequence voltage, if the network capacitance changes after a switching operation.

If a voltage change higher than the trigger threshold (defined as percentage value of reference zero sequence voltage $V_o$ref) is detected for a time longer than an adjustable trigger delay time the tuning operation starts.

Detecting network changes is difficult in very symmetric networks. Due to low zero sequence voltages also the trigger level is very low and might become too sensitive. To overcome this problem an inverse mode (permanent current injection with 50 Hz) can be used to increase the zero sequence voltage. A change of the network capacitance then leads to a significant change of the zero sequence voltage again.

Another variant is to use a periodic recalculation of the network parameters. At the moment this is the preferred method for networks with permanent voltage fluctuations.

Additional improvements of the trigger criteria could be achieved by permanent pulsed 50Hz current injection which is equal to continuous network parameter calculation and monitoring.

SUMMARY

Voltage interferences have been observed in many networks. Using the standard tuning method (coil detuning for network parameter calculation is necessary) stresses the adjustment mechanism of the Petersen coil unnecessarily.
A big improvement was achieved by using the 50 Hz current injection method, but also this method has its limits and can cause unintentional error messages if validation of the injection fails too often in sequence. Often it is difficult afterwards to find out the root cause. A check of the counter records of the controllers is therefore recommended in order to recognise such behaviour and optimize parameter settings.
With the multifrequency method a very robust and reliable method was found to tune the Petersen coil also in case of permanent zero sequence voltage fluctuations.

REFERENCES

[1] Druml G., Kugi A., Parr B., "Control of Petersen Coils", *XI. International Symposium on Theoretical Engineering,* 2001, Linz

[2] Druml G., Kugi A., Seifert O., "New Method to Control Petersen Coils by Injection of Two Frequencies", CIRED 2005, Turin

[3] Druml G., Steger S., Seifert O., Kugi A., "Operational Experience with the New Method to Control Petersen Coils by Injection of Two Frequencies", CIRED 2007, Vienna

[4] Leikermoser A., Ortolani F., "New Techniques for Compensated Networks: Tuning the Petersen Coil, Determining the Network Parameters and Performing Earthfault Current Prediction and Reconstruction", CIRED 2007, Vienna

[5] Ortolani F., Calone R., Paulon P.,Leikermoser A., "Device for MV Network Inspection via Pulse Injection", CIRED 2011, Frankfurt

[6] Schlömmer M., König R., Mendrock O., Ivancic M., Druml G., "Innovationen im Bereich der Petersen-Spulen", 3rd *ETG-Fachtagung Sternpunktbehand-lung in Netzen bis 110kV (D-A-CH)*, 2014, Nürnberg