DETERMINATION OF FLICKER CONTRIBUTIONS BASED ON SYNCHRONISED MEASUREMENTS OF RAPID RMS CHANGES

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ABSTRACT

This paper proposes a method for the determination of flicker contribution based on synchronised measurements of RMS voltages and currents. The advantage of this approach is the avoidance of time aggregation which is present in the analysis based on the short or long term flicker coefficient. The applicability of the method is demonstrated using PMU measurements from a 50 kV network and compared to the results of an analysis based on instantaneous flicker coefficients.

INTRODUCTION

To connect new customers, or to extend existing networks, network operators need to consider the impact on the Power Quality (PQ) levels among other aspects. In this process, the planning levels of phenomena are used as a reference, and headroom is allocated to new connections based on the current levels of phenomena and expected increases in disturbance levels.

For voltage flicker, the short- and long-term flicker coefficients (*Pst* and *Plt*) are evaluated, which are measured only for the voltage signals. The method is not applicable to the current signals, as shown in [1], so the emission of a device or installation is usually estimated based on magnitude and frequency of the expected current RMS variations, e.g. due to motor starting.

To determine the impact of a network user or a part of the network on flicker levels, several methods are proposed. In [2] it was proposed to use the sign of voltage and current RMS variations to determine if the flicker source is upstream or downstream from the measurement point. In [3] it was proposed to use measurements of inter-harmonics to determine the propagation of flicker. In [4] and [5], simultaneous measurements of *Pst* are used to determine the transfer of flicker in networks with arc furnaces.

In this paper, it is proposed to use synchronised single-cycle RMS voltage and current measurements from neighbouring substations to determine the contribution of individual substations. The expected advantage of this approach is the increased sensitivity for networks with relatively low levels of *Pst* and *Plt*, as the effect of 10 minutes and 2 hour aggregation is avoided, which is not the case with the mentioned flicker coefficients. Additionally, it is analysed whether voltage measurements alone are sufficient in this case, as the location of the flicker source can be determined based on the magnitudes of voltage variations on nearby bus-bars, given that their measurements are synchronised as it is the case with Phasor Measurement Units (PMUs).

TEST SYSTEM

As a test system, a 50 kV network of Enduris in the Netherlands is used, with six PMU's with PQ installed in five consecutive substations, as explained in [6]. A diagram of the test network is shown in Fig. 1. At each of the 50 kV busbars from the figure, a 10 kV network is connected via 50 kV/10 kV transformers. Except for a single 50 kV overhead line in the connection of the 50 kV Goes station to the 150 kV net, all connections in the analysed part of the network are cables.

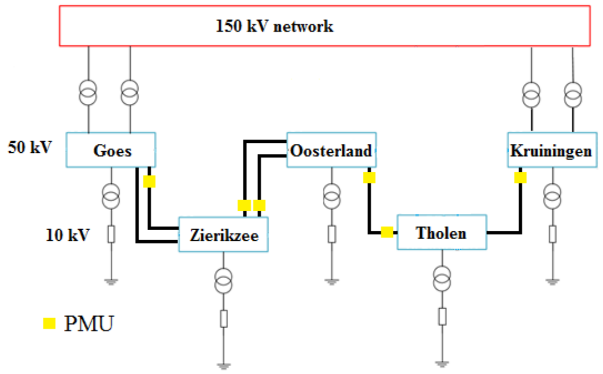

Fig. 1. Topology of the Enduris 50 kV test network and locations of PMUs

Next to the standard PMU measurements of single-cycle magnitudes, phase angles and powers, the PMU units used for monitoring the 50 kV network also measure some of the PQ parameters, such as the flicker coefficients [7]. Except for the short and long term flicker coefficient, a one second value is also available, as the instantaneous flicker coefficient (P_{inst}).

Derivation of current pseudo-measurements

To analyse the contributions of individual substations based on current changes, the 50 kV / 10 kV transformer currents are needed. As only some of the 50 kV cable currents are monitored, these transformer currents need to be calculated based on the currents of all incoming and outgoing cables, busbar voltages and cable parameters. This methodology was proposed in [8] in a different form, where line parameters were calculated based on both voltages and currents measured.

This can be done for three out of the five monitored substations (Zierikzee, Oosterland and Tholen). For example for the cable between substations Tholen and Kruiningen, the equations are set based on the diagram given in Fig. 2.

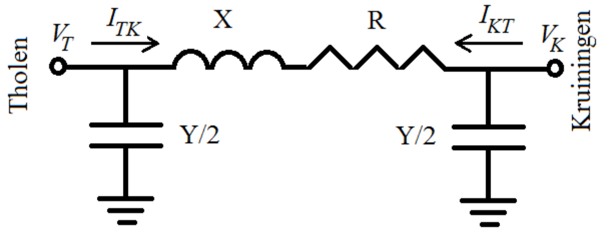

Fig. 2. Diagram for the calculation of transformer current at substation Tholen

In this case both busbar voltages in Tholen en Kruiningen (V_T and V_K respectively) and currents between Tholen and Oosterland I_{TO} (not in diagram) and between Kruiningen and Tholen I_{KT} are measured. The transformer current for substation Tholen (I_{tT}) is then calculated as:

$$I_{tT} = -I_{TO} - I_{TK} \tag{1}$$

where:

$$I_{TK} = \frac{Y}{2}(V_T + V_K) - I_{KT} \tag{2}$$

and Y is the shunt admittance of the cable, as shown in Fig. 2 (all variables in (1) and (2) are complex representations). After the current is calculated, the powers can also be calculated based on the measured voltages and pseudo-measured currents.

The validity of (2), based on three measured values and cable capacitance, can be checked on the example of currents on the two ends of the cable Oosterland – Tholen, where both currents are measured. The histogram of differences between the measured and calculated magnitude of the current Tholen – Oosterland (I_{TO}) during one six-hour time interval is shown in Fig. 3. In this case the difference never exceeds 1.5 % for the magnitude, while for the phase angles the differences are even lower. Based on this, here it is assumed that for other cables (where current is not measured on both ends) the differences are comparable and that calculated currents can be used as well for the three analysed busbars.

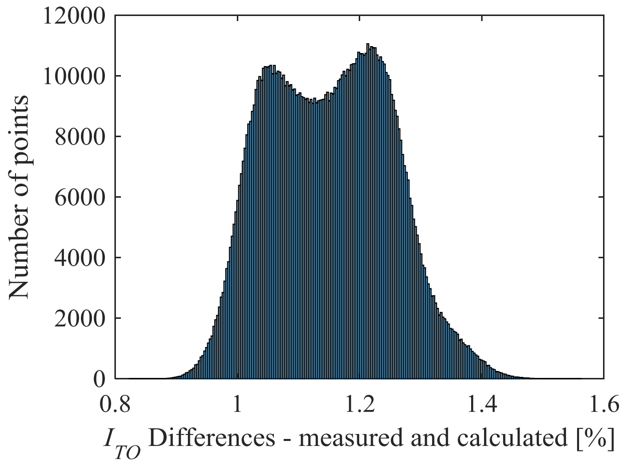

Fig. 3 Difference between measured and calculated current

METHOD

As mentioned in the Introduction, in the literature it has been proposed to determine the contribution of voltage flicker based on the simultaneous measurements of the flicker coefficient or based on the sign of current and voltage changes.

The latter of the two methods is based on the concept of rapid voltage change (RVC), which is an event-type phenomenon with magnitude changes which do not cause dips or swells, but are a common source of flicker [9]. By analysing if the current change follows the voltage change or causes it (by having the opposite sign), the method checks if the RVC originates upstream or downstream from the point of evaluation [2].

In this paper an alternative RVC based method is also checked, using synchronised rapid changes of the voltage RMS alone, as provided by the PMUs, as a basis to distinguish the origin of individual RVCs. If consecutive busbars are monitored, the highest of the magnitudes of individual RVCs are used to determine if the event originates from one of the monitored substations, or from the rest of the network (if the magnitude is highest on the first or the last substation).

Once the individual RVCs are assigned to substations (and the rest of the network), the frequency and percentile values of magnitudes of individual events can be used to determine the contribution of an individual substation to the flicker level over the observed time interval.

Regarding the magnitude, two parameters are defined by the standard [9]:

- the steady state change (ΔU_{SS}) – the difference between two quasi-steady state magnitudes based on one second averaging,
- the maximal change (ΔU_{max}) – the difference between the maximal single-cycle RMS value, refreshed at every half-cycle, to the previous quasi-steady state magnitude.

The threshold for detecting an RVC event is set as a percentage of the declared supply voltage, without a standardised value. However, a value of 0.2 % is mentioned as a similar parameter for flicker meter testing, based on standard [10]. In this paper several values of the threshold are considered, based on the link to the P_{inst} values.

The link between RVC events and flicker coefficients cannot be expressed analytically. An approximate formula which connects the frequency and magnitude of voltage changes to the P_{st} is sometimes used, however this formula assumes that the same magnitude change is occurring at a steady frequency, which generally is not the case. Therefore the threshold for the RVCs is tuned based on the results of the instantaneous flicker coefficients – to separate the events which cause significant levels of instantaneous flicker.

The source of every RVC event is then determined based on the the sign of the voltage and current changes. For this purpose, the transformer currents are calculated as explained in the previous section (pseudo-measurements).

RESULTS

The instantaneous flicker values measured on three substations are shown in Fig. 4 (the remaining two are omitted for clarity). The values on all five substations are very close throughout most of the time, and mostly lower than 1. One visible excursion – zoomed-in in the nested figure, has high flicker coefficient values and a more significant difference between the busbars.

The example in Fig. 4 shows a moment in which it is easy to conclude that the disturbance originates from a load connected to substation Zierikzee, as at the two neighbouring substations the measured level was significantly lower. However, for most of the time the instantaneous values are lower than one and with very similar values, which makes the determination by higher magnitude more uncertain.

To do the characterisation using single-cycle RMS values, the threshold for detecting RVCs is set first. The level of significant P_{inst} values is set to 0.2, as the standard [9] specifies that the uncertainty of flicker meters needs to be maintained starting from this value. By adjusting the voltage RMS threshold to detect events at times when this criterion is met, the value is set to 0.2 % of the nominal voltage. An example of the P_{inst} values and the detected moments of RVC event at substation Oosterland during a six-hour time interval is shown in Fig. 5. In this figure only the moments of RVCs are shown, without their magnitude.

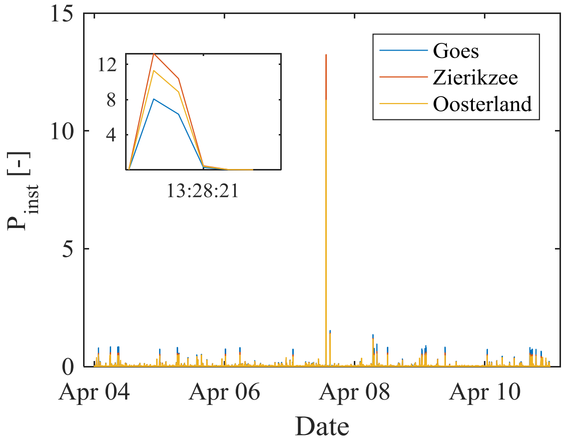

Fig. 4. Instantaneous flicker values on three monitored busbars

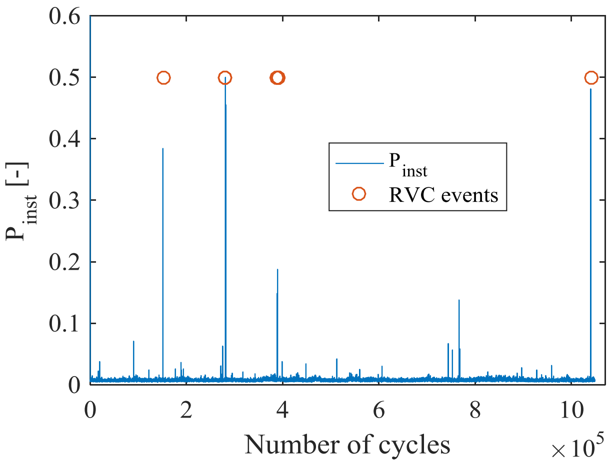

Fig. 5. Instantaneous flicker levels and detected RVC events at substation Oosterland

The magnitudes of RVCs, both maximal and steady-state, show a similar behaviour as the P_{inst}. At moments of large changes, such as the zoomed-in moment from Fig. 4, it is possible to determine the propagation of RVCs based on the voltage RMS values alone. For the majority of events, when the RMS changes are close to the threshold of 0.2 %, the magnitudes of changes at different busbars are very close, with differences often below the uncertainty level of voltage measurement. An example of the maximal and steady-state magnitudes of RVCs of substations Zierikzee, Oosterland and Tholen are shown in Fig. 6.

As for the determination of the location of the source, the voltage measurement alone can be uncertain for events with low magnitudes, and the sign of the voltage and current changes can be a better indicator of the source location. For an event which is detected based on the change of the voltage RMS, at the same moment of time the change of the current RMS is calculated, as proposed in [2]. In this work, the current RMS change is calculated with the same procedure as for the steady-state RVC magnitude, and is applied to transformer currents at substations Zierikzee, Oosterland and Tholen.

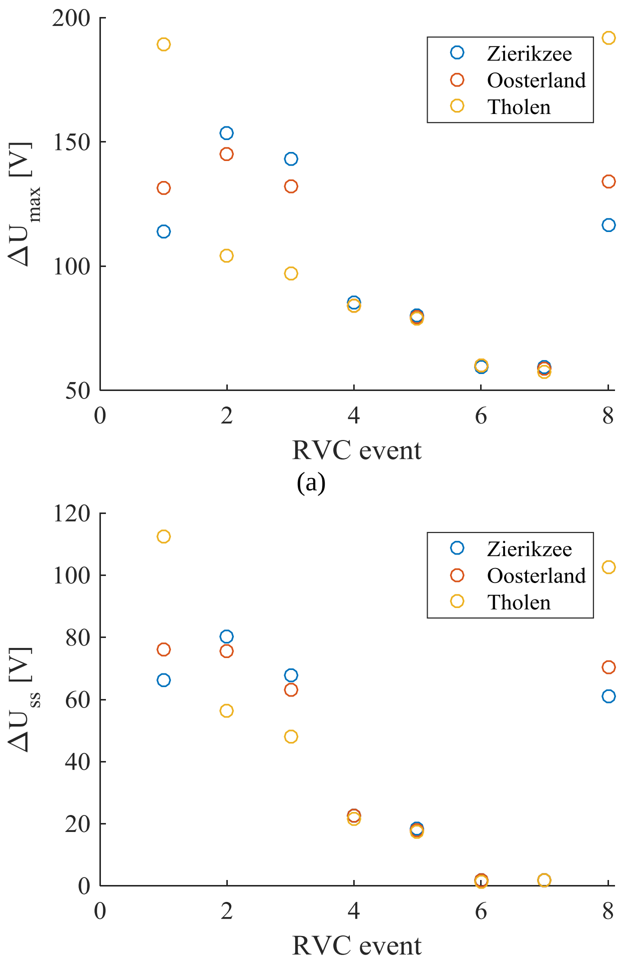

Fig. 6. Magnitudes of RVCs at three substations: (a) maximal Δ*Umax*, (b) steady-state Δ*Uss*

Regarding the reliability, this approach has the advantage that the averaging used for the steady-state magnitude change filters out a significant part of the noise, which makes it unlikely that the noise can change the sign of the change (both for the current and voltage).

As mentioned in the previous section, an analytical connection between the P_{inst} values and magnitudes of RVC does not exist, due to the non-linearity of the flicker meter. In Fig. 7 a comparison of the maximal and steady-state magnitudes of RVCs to the P_{inst} values is shown. It can be noticed that they have the same trends, however, in both cases the ratio between the two is not constant. An approach to characterise flicker level purely on RVC parameters still needs to be researched.

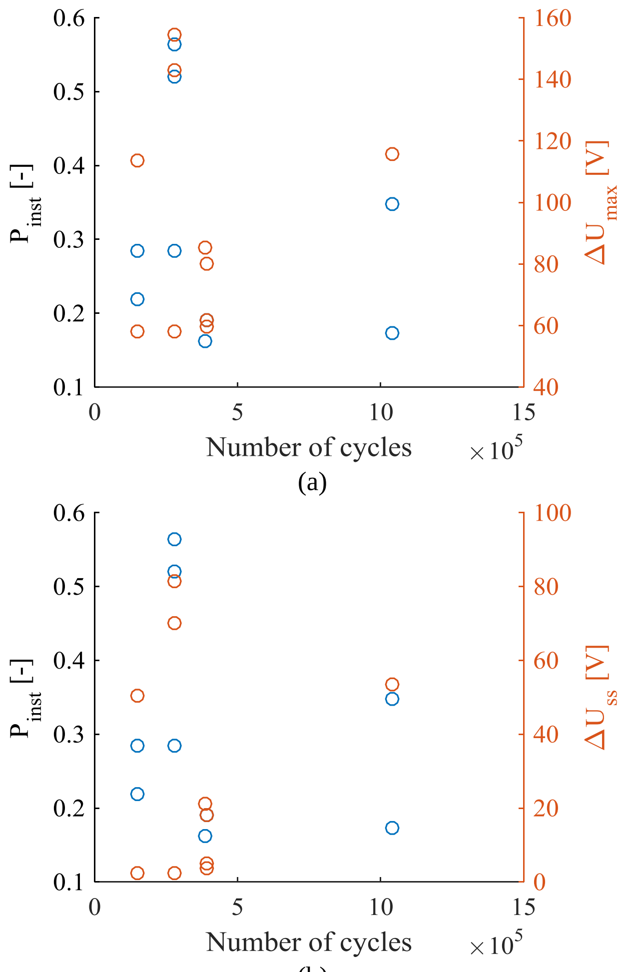

Fig. 7. Comparison of P_{inst} values and RVC magnitudes: (a) maximal Δ*Umax*, (b) steady-state Δ*Uss*

CONCLUSIONS AND RECOMMENDATIONS

A method for characterising flicker contributions is proposed in the paper, based on synchronised RMS changes. The method uses rapid voltage changes as the basis. The disturbance source can be determined either based on the magnitudes of the RMS voltage changes at consecutive busbars, or based on the sign of RMS voltage and current changes during these events. The latter of the two is found to be more appropriate due to higher sensitivity.

The performance of the method was demonstrated using measurement data from PMUs with power quality functionality in a 50 kV network. It was shown that the results are in good agreement with the characterisation based on instantaneous flicker coefficients.

The advantages of this method are:

- Due to the absence of time aggregation for individual events, the signal to noise ratio is better than with flicker coefficients, which is an advantage especially when the flicker coefficients are not relatively high.
- If current measurements are present, it is possible to define the emission based on RMS changes of the current, whereas it is not possible to define flicker emission based on current signals.

The disadvantages of this method are:

- RVC parameters cannot be directly translated into flicker coefficients. Therefore, the results require a certain assumption for the conversion into flicker coefficient if the frequency and magnitudes or RVCs are not sufficient.
- The RMS voltage measurements need to be well synchronised (at a sub ms level).

It is recommended that the instantaneous flicker coefficient is used in the future to further explore the connection between RVC parameters and aggregated flicker coefficients. In this way it might be possible to define an RVC-based flicker measurement alternative, for which it is easier to define the emission of devices and installations based on rapid RMS changes of the current (in an equivalent way as for the voltage).

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