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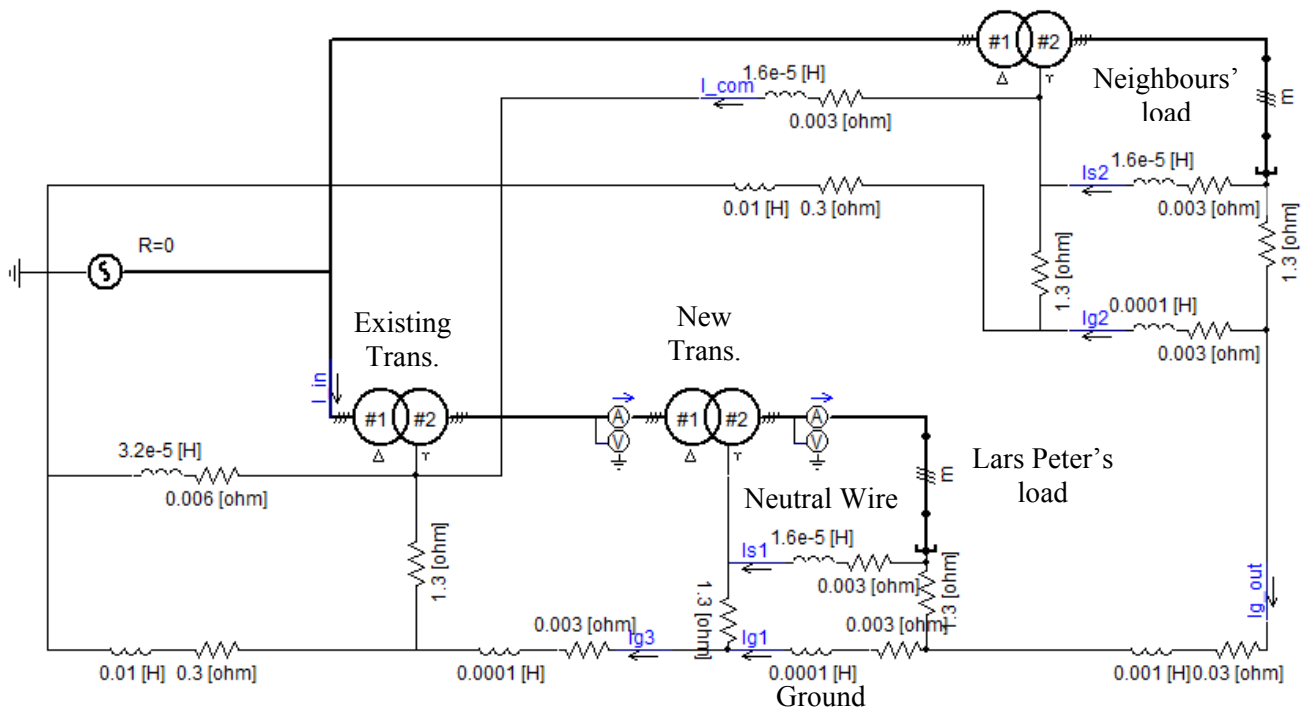
Transformer in series

Filipe Miguel Faria Da Silva and Claus Leth Bak



System

- The system includes Lars Peter's load and a virtual load that corresponds to a neighbour transformer. Both loads are 3-phase loads, which can be unbalanced to generate return currents.
- The leakage currents are simulated by considering a connection between one phase and the ground throughout a $10\text{k}\Omega$ resistance (lower than expected, so that the currents are larger).
- The harmonic content of the return current is simulated by injecting a current in the neutral of the farm. The harmonics are generated inside the farm, thus, the current source is grounded at the transformer's neutral.
- The new transformer is in series with the existing transformer feeding Lars Peter's farm. The connection between them is considered as being ideal.
- The reference ground is putted at the voltage source located at a generic distance of 5km (using the earth impedance as reference).
- The neutral on the star side of the two existing transformers is connected by an impedance representing the screen of the 10kV cable, which is also connected to the reference ground.
- The value of the earth impedance is lower than expected in order to make the phenomenon worse.



Simulations

In the simulations there are measured the current in the ground for four different conditions:

- Both loads balanced;
- Lars Peter's load unbalanced;
- Neighbours' load unbalanced;
- Both loads unbalanced;
- Loads balanced and connection to the ground (leakage current)
- Return current with 3rd harmonic

Both loads balanced

During the measurements there was measured a current in the return wire of a 30A peak. Thus, the loads are unbalanced in such a way that there is a return current of at least 90A peak.

The simulations are first done considering a load represented by means of lumped parameters, meaning that only the fundamental is present.

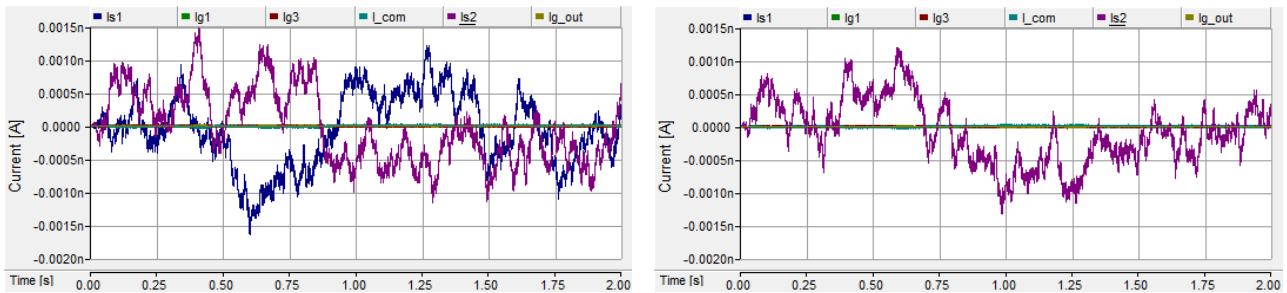


Figure 1 – Currents in the ground, return wires and screen of the 10kV cable

As expected there are no problems in this case and no current flows in the ground.

Lars Peter's load unbalanced (current in the neutral wire: 120A peak);

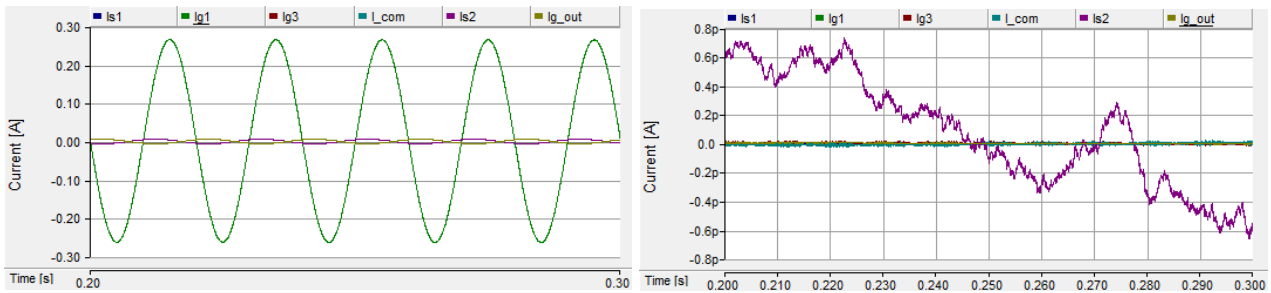


Figure 2 – Current in the ground and screen of the 10kV cable. Left: New transformer grounded; Right: New transformer ungrounded;

In this case there is a current in the ground between the load and the new transformer, if its neutral is grounded. This current disappears if the neutral is open, however, the current in the phases is also changed (it has to return somewhere) which may rise other issues, as the voltage is also affected and it becomes more unbalanced.

Neighbours' load unbalanced

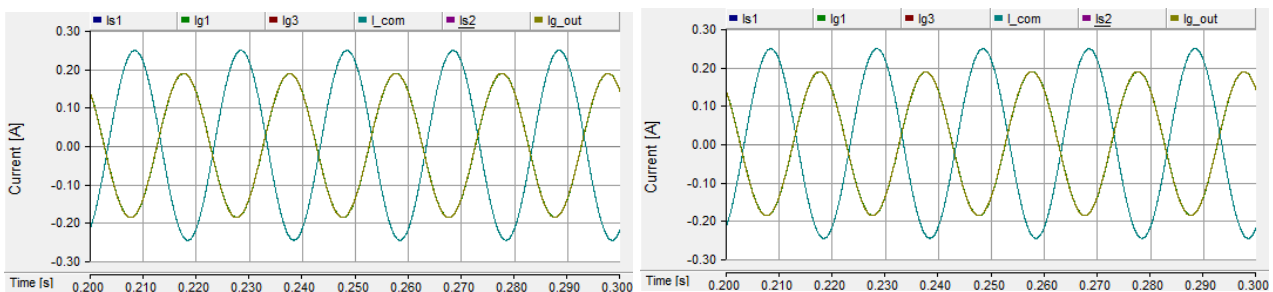


Figure 3 - Current in the ground and screen of the 10kV cable. Left: New transformer grounded; Right: New transformer ungrounded;

In this case there is a current flowing in Ig_out and I_com, where the first represents a possible ground path in the farm area and the second the current in the screen of the 10kV cable. As it can be seen, the new

transformer does not help reducing these currents. This makes sense as the old transformer is still grounded and the current can flow in the ground to that neutral.

However, there is a solution. If the transformers' neutrals are not connected the current in the ground is much reduced as seen in the next figure. The reasons were those that I explained in the last meeting.

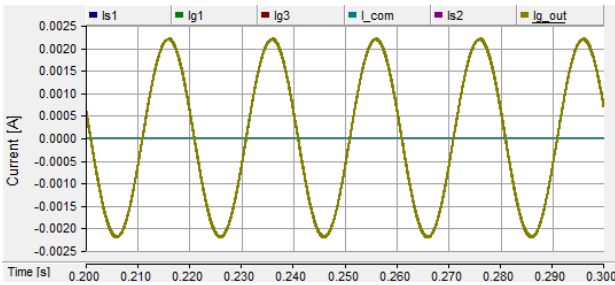


Figure 4 - Current in the ground and screen of the 10kV cable.

Both loads unbalanced

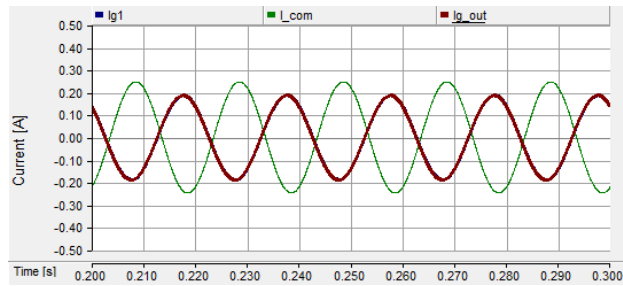
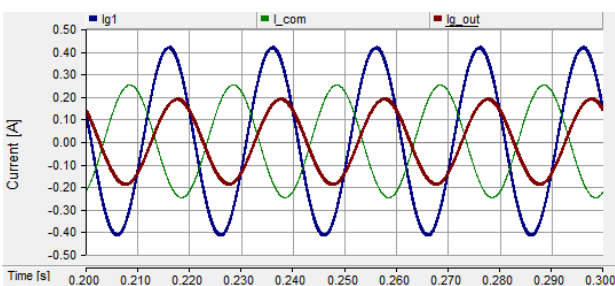


Figure 5 - Current in the ground and screen of the 10kV cable. Left: New transformer grounded; Right: New transformer ungrounded; (at bold the currents in the ground)

This case is a combination of the previous two. It can be seen that the results are also like before. The new ungrounded transformer helps if the problem has an internal origin, at the cost of a larger phase unbalance, but does not help if the cause is external to the farm.

Leakage Current

For this case it is consider that there is a 10kΩ impedance between one of the phases and the ground. This impedance is lower than expected in order to have a larger current in the ground making it easier to see if having transformers in series can help.

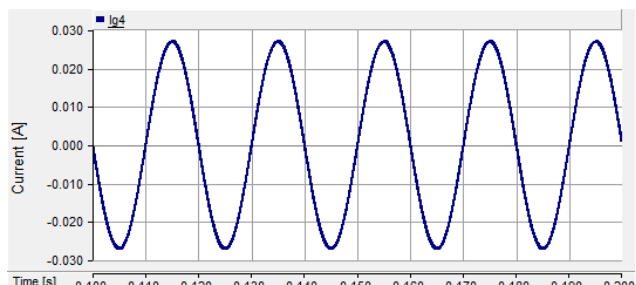
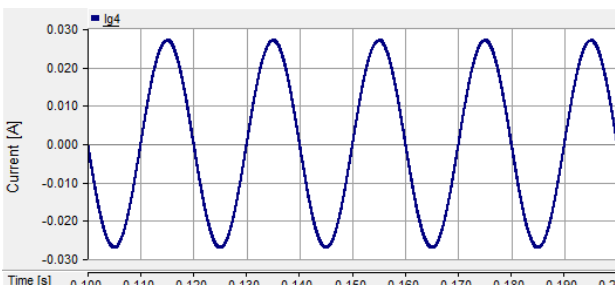


Figure 6 - Leakage current to the ground. Left: both farm and transformer are grounded; Right: Farm grounded, transformer ungrounded;

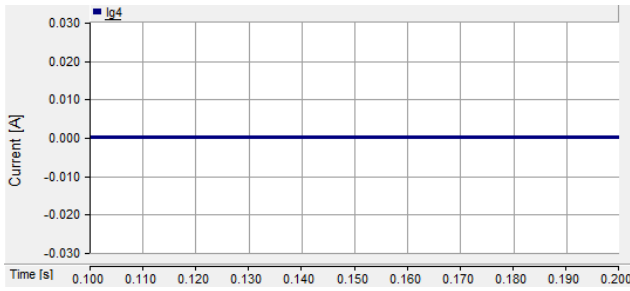


Figure 7 – Leakage current to the ground with both the farm and the transformer ungrounded

The simulations show that the new transformer may help as long as the farm is also not grounded. If the farm is grounded the current can flow from the farm's ground to the neutral wire and from there to transformer closing the circuit.

Return current with 3rd harmonic

A third harmonic current is injected in the farm's neutral and there are simulated the currents in the ground.

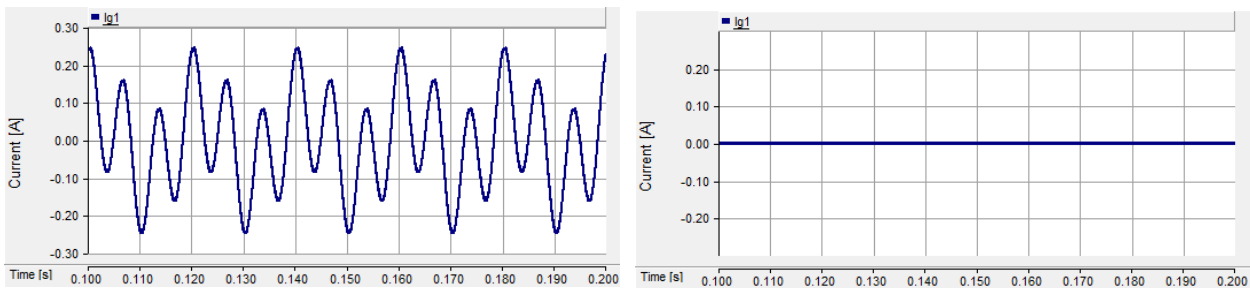


Figure 8 – Current in the ground. Left: Farm and transformer grounded; Right: Farm and/or transformer ungrounded

In this case it is enough to have the farm or the transformer ungrounded to not have the current in the ground. This happens because the simulation is made in such way that the harmonics are generated inside the farm, meaning that they have the neutral of the transformer as reference. Thus, they will always flow to that neutral and the only way of having this and current in the ground is by having two points connected to the ground.

Considering leakage current and a 10kΩ impedance between the farm and the ground there are seem come currents in the ground if either the transformer or the farm are grounded, but they are very small. The harmonic return currents would have to be in the order of kA for this be of concern or the leakage impedance very small.

Conclusions

The new ungrounded transformer may help under certain conditions.

- No leakage current, but unbalance in the farm or neighbour loads:
 - It helps in the unbalance is in the farm;
 - It does not help if the unbalance or currents to the ground are in neighbour areas;
- Leakage current in the farm:
 - It helps only if both the farm and the transformer are ungrounded;
- Return current with 3rd harmonic:
 - It helps;