POWER QUALITY IMPROVEMENT IN RURAL AREAS WITH STATIC UPS TECHNOLOGY

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SUMMARY

A major part of the LV distribution network in the Netherlands is located in rural areas. Due to the low population density, many users are connected via relatively long LV underground power cables with a radial grid topology. Because of the long power cables with relatively small conductor sizes the impedance of the circuits is typically high causing the following problems:

- Voltage drops and variations
- Influence of higher harmonics
- Protection problems

For a distribution service operator (DSO) it becomes more and more challenging to comply with the European grid standards (EN 50160), since the distances are relatively long, density of connections low and cost per connection high.
The DSO can solve power quality problems i.e. by the use of larger cable conductor sizes, more MV/LV transformer stations, more LV step up transformers or a different type of grid topology (i.e. meshed grids). This, however, is very costly and it is therefore very interesting for the DSO to investigate alternative technologies, which can solve these types of problems and which are economically attractive from a costing point of view.

Thanks to many improvements over the years in power electronics, modern uninterruptable power supplies (UPSs) provide *'natural'* features which improve power quality. This gave us the following idea: Since static UPS's (SUPS) have been successfully applied in Data Centers to back up the power supply and protect the load from common power problems, it would be interesting to investigate if these technologies could also be applied to LV distribution grids. The result of this is that SUPS's have been applied in the rural area in the eastern part of the Netherlands in order to prove that typical power quality problems can be solved in a sound and economical way.

Description of the problem:

In the east of the Netherlands a part of the LV grid of DSO Cogas consists of an underground LV power cable with an aluminum conductor with a size of 95mm^2 and a length of 600m. The cable is fed by a 250kVA 10/0,4kV transformer. On the LV cable multiple households are connected. Load changes are causing fast voltage variations of more than 15% in this cable. Two households are complaining that they suffer voltage quality problems. They are connected on the end of the cable as can be seen in the picture below.

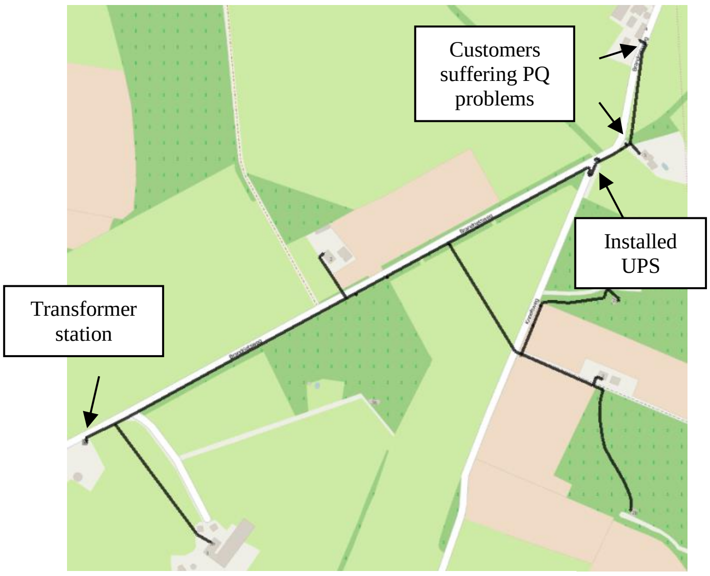

Fig. 1 Location plan

How the problem was addressed:

The technological development of past years have made the UPS an interesting and potential solution for a wider range of applications. A modern UPS is no longer based on SCR (silicon controlled rectifiers) introducing a high content of harmonic currents to the mains, resulting in a low power factor. Instead, the use of IGBT (insulated gate bi-polar thyristors) based rectifiers with advanced controls accomplish low overall input current harmonics, near unity power factor and symmetrically loading all three phases of the mains supply. Improvements in power density have resulted in smaller and lighter equipment, reducing the space required. But maybe the most important improvement has taken place in the overall efficiency, where power conversion losses from AC to DC and back to AC can be below 4% with the latest products. The reduced losses and improved efficiency reduce the required cooling, make practical implementation easier and most of all improve the Total Cost of Ownership (TCO).

Due to their nature, UPS's can be used for a wide range of applications. It's designed to draw energy from the mains (or a DC source such as a battery) and provide clean sinusoidal voltage to critical loads. Meanwhile, the mains is optimally loaded with symmetrical three phase current close to the unity power factor and low current distortion. With improving efficiencies and bi-directional rectifiers, energy can be fed back to the mains or can share the load between mains and batteries (energy storage). Therefore in the future, UPS products will most likely be used to bring additional features and benefits outside their traditional use.

For the demonstration of the concept in the grid of Cogas, two Eaton 9355 15 kVA, dual-feed, double-conversion UPS's were installed in an external enclosure with a maintenance bypass breaker as can be seen in the picture below.

Fig. 2 Static UPS's in enclosure

The Outcome:

Power quality improvement:

- After installing the UPS in the LV grid of DSO Cogas, the power quality at the customer site improved considerably.
- The UPS is controlling the voltage to a stable and clean 230V sinusoidal voltage at the output of the UPS, where the voltage at the primary side is varying widely between 235V and 210V due to load variations on the LV feeder.
- The fast voltage variations are reduced
- The currents at the primary side of the UPS are symmetrical distributed resulting in lower cable losses and less voltage variations for the customers connected on the LV feeder that is feeding the UPS.

TCO scenarios considered and modeling approach:

To calculate the TCO's, all major costs were estimated for each year of the **economical** equipment lifetime and for following three alternatives:

1. The traditional solution being: 800m of 3x95 mm^2 Alu XLPE MV cable and a 250 kVA step-down distribution transformer substation (40 year lifetime).

2. A solution with traditional UPS technology being: 2x15 kVA Eaton 9355 UPS (20 year lifetime), maintenance bypass breaker and enclosure (40 year lifetime).

3. A solution with UPS with higher efficiency technology being: 1x30 kVA Eaton 93PM UPS (20 year lifetime), maintenance/bypass breaker and enclosure (40 year lifetime). The 93PM UPS was included in the TCO comparison to determine the effect of a modern UPS with a higher efficiency, all other costs were assumed identical with the traditional UPS's.

In a datacenter application, UPS's will typically be replaced by more efficient equipment in a period of under 10 years. However, in distribution grids, equipment is usually installed for a longer duration (>10 years). The presence of an integrated automatic static bypass switch, the possibility for maintenance and fast replacement (<2 h) made a reduction in requirements for availability acceptable. Based on these considerations, 20 years was selected as a conservative maximum lifetime for UPS's.

To correct the investments for the different lifetimes, the UPS investments (20 years) were extended to the Cables & Transformers' lifetime (40 years) by replacing the UPS investments at year 21. After this, all costs were adjusted to Present Values (PV) by using a Cost of Capital typical to Distribution System Operators. (3,6%).

TCO components (CAPEX, first year):

Equipment:
The following was included for the solution based on UPS technology:

1. Eaton 2x15 KVA 9355 UPS or an Eaton 30 kVA 93PM high efficiency UPS (same price for both UPS types).
2. Enclosure & maintenance breaker.

The following was included for the traditional solution:

1. 800 m. MV cable (ALU, XLPE, 3x95mm^2) including joints.
2. A 250 kVA distribution transformer station.

Assembly, Installation & commissioning:
The following was included for the solution based on UPS technology:

1. Assembly of UPS and the maintenance bypass switch into the enclosure.
2. Transport, site work, connection of cables and commissioning.

The following was included for the traditional solution:

1. 350m of drilling (due to trees).
2. 50m of digging.

TCO components (OPEX):

Service & maintenance:
For the UPS's, service and maintenance costs are estimated according to the following suggested schedule:

1. Years 6 & 16 of operation: Preliminary maintenance inspection, replacement of cooling fans ,part replacement and labour costs.
2. Year 11 of operation: Preliminary maintenance inspection, replacement of capacitors/PCBs , part replacement and labour costs.

The following was included for the traditional solution:

1. Years 10, 20 & 30 of operation: Preliminary maintenance for the transformer substation.

Operating losses:
First, an average load of 9,6 kVA (32% of 30 kVA nominal load for the UPS's) was calculated from current and voltage measurements before the UPS's were installed.

The following method was used to determine the UPS's operating losses:

1. Efficiency for 15 kVA 9355 was estimated using the nearest available stated efficiency (90% at 50% load) in its datasheet .
2. Efficiency for the 93PM was estimated using the nearest available stated efficiency (96,2% at 30% load) in the Eaton Efficiency Calculator.
3. Efficiencies were converted to UPS operating losses and upstream LV distribution cable losses at 9,6 kVA (42 W) were added to arrive at total losses using the following formula:
$$S_{l,total} = \left(\frac{S_{avg}}{\rho}\right) - S_{avg} + 0{,}042kW$$

For the traditional solution, the following method was used to calculate operating losses:

1. Transformer load losses were calculated as resistive copper losses at rated load (2460 W) using a quadratic ratio of average load to nominal load using the following formula:
$$P_{Cu,avg} = P_{Cu,N} * \left(\frac{P_{avg}}{P_N}\right)^2$$
2. Transformer no-load losses (300 W) were assumed to be constant and added to the load losses. Because of MV upstream of the transformer, currents and cable losses were negligible.

Finally, all operating losses were multiplied with the number of hours/year and a typical cost of electricity to DSO's of 0,068 € to obtain the following annual costs:

1. 2x15 kVA Eaton 9355 – 660 €/year
2. 1x30 kVA Eaton 93PM – 251 €/year
3. Transformer – 181 €/year

Results of the TCO comparison

Based on the previously presented approach and parameters, it was found that the TCO's of the UPS-based solutions were more cost effective than the traditional approach for both models (Fig. 3).

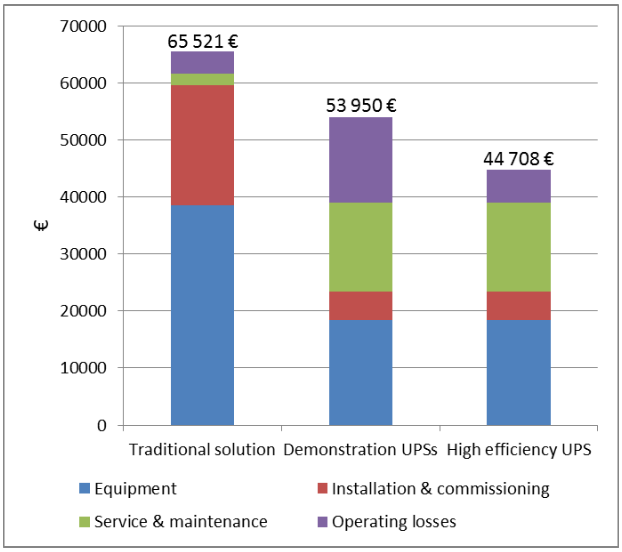

Fig 3. TCO comparison, adjusted for Present Value

From this, we can find the ratio of the UPS costs to the traditional solution:
2. 82,3% for Demonstration UPSs
3. 68,2% for the High Efficiency UPS.

Conclusions

Due to long power cables with relatively small conductor sizes, customers connected to the LV grid in a rural area can suffer voltage- and power quality problems.
For a distribution service operator (DSO) it becomes more and more challenging to comply with the European grid standards (EN 50160), since the distances are relatively long, density of connections low and cost per connection high.

DSO's can solve power quality problems i.e. by the use of larger cable conductor sizes, more MV/LV transformer stations, more LV step up transformers or a different type of grid topology (i.e. meshed grids). This, however, is very costly

The natural features (voltage regulation, separation between input and output) of Static UPS's allow its use in a wide range of applications.
Cogas initiated a case whereby static UPS's have been installed in the LV network to improve the power quality.

Studies have indicated that the TCO of UPS applications become very attractive, mainly since technology over the years has improved the efficiency losses of UPS solutions considerably. The latter is an important factor of the TCO.
Depending on the load and power, the purchasing- and operational cost can be lower, than with the earlier mentioned conventional methods.

Values of 20% improvement in TCO are easily achievable.
A proven concept which is used so far in traditional applications, becomes now a simple plug and play configuration for application in the LV distribution grids in rural areas.

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