MITIGATION OF FLICKER IN RURAL LV NETWORK

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ABSTRACT

This paper presents a technical solution for the increasing problem of voltage flicker in rural LV network, called the Power Quality optimizer (PQO). After a brief description of the problem and the main considerations to prefer this solution over traditional ones, the technical approach used is described. Test results show what has been achieved to date and point a route to further improvements. These are to be implemented and tested in early 2007. Available results up to now show the potential of the PQO but indicate that proper tuning of a PQO, to best resolve the local PQ issues, is required to obtain full benefit in a given situation.

INTRODUCTION

For historical reasons LV networks in rural areas often have relatively high impedances. Values of more than 0.5 ohm per phase may occur. Excessive voltage drops due to increasing loads have in the past been mitigated by inserting automatic voltage controllers based on autotransformers. Whereas this is a suitable solution for the steady-state voltage level and for three-phase loads, transient phenomena and voltage asymmetries are not compensated. They are even aggravated because the transformers add additional transient impedance to the system. Such a system is relatively sensitive to flicker.
Flicker has been a fact of life in rural areas for decades. It was taken for granted because the availability of electricity by itself was a massive improvement compared with not having electrical power at all. Modern electronic equipment is however making its way into these areas as well. This equipment, in particular PCs and electronic controls used by farmers for process or climate control, are sensitive to voltage drops and spikes. Temporary failure of such equipment could mean anything between a nuisance and significant economic losses.
Apart from this increased susceptibility, customers are becoming increasingly aware of the quality of power which they have lived with for a long time, is less than what they are entitled to according to the local network code.
A third cause for the increase of flicker problems is the proliferation of loads which take intermittent currents from the network, such as small welding appliances and photocopiers.
The traditional method of mitigating the flicker is to replace long LV cables by an MV cable plus a new distribution transformer, or to replace the LV cable by a cable having a larger cross-section. Both methods are very uneconomic if compared to the income obtained from delivering electricity through the network.
Technically, these methods have the effect of decreasing the local system impedance by lowering the series impedance of the feeder. An alternative approach is to add a low parallel impedance. This must be done locally and is thus a local cure.
This approach is attractive because it avoids having to invest in the network by upgrading long lengths of cable. In particular in the Netherlands, even in rural areas most of the LV network is cabled. The cost of replacing 1 km of cable could well exceed € 100,000.
The PQO discussed in this paper has a peak rating of approx. 50 kVA and would have a commercial price which is as fraction of that amount. Moreover, if for other reasons the network is upgraded after some time, the unit can be re-deployed at another location. The business case for installing a unit is therefore less sensitive to considerations of payback times than a re-cabling project.

PRINCIPLE OF OPERATION

Creating a low impedance in parallel to the network is relatively easy using power electronics. A three-phase inverter similar to the inverters that are used for PV systems and other forms of decentralised power generation, can be controlled in such manner that it behaves like a voltage source in parallel with the network. The principle is similar to the well-known Static VAR Compensators and is illustrated in figure 1. The inverter is built up with IGBTs operating in Pulse Width Modulation (PWM). The inverter is coupled to the network by means of a filter to avoid injection of PWM harmonics into the network. This filter is

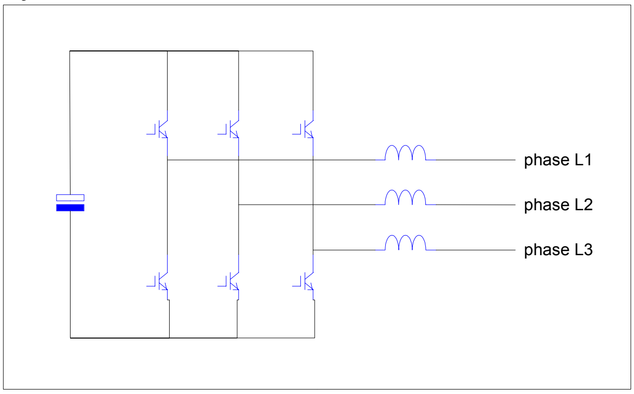

Figure 1. Basic principle of the PQO.

represented by the three inductors in figure 1. The fundamental-frequency impedance of the IGBT inverter is very low. This means that the input impedance of the system as observed from the network, is more or less equal to the impedance of the inductors.
In fact the dynamic control system of the inverter can even compensate for the impedance of the inductors, so that the effective output impedance at the fundamental frequency is further reduced.
The inverter is programmed to produce a purely sinusoidal voltage (plus high-frequency harmonics which are not relevant because the filter prevents them from entering into the network). Therefore it acts as a low-impedance sink for any disturbance in the network. Such disturbance could be:

- A rapidly changing voltage amplitude. The PQO is programmed to follow slow voltage variations, because the average power exchanged with the network has to remain zero. Rapid voltage variations have the effect that the PQO will inject or absorb power in such a way that the voltage variations are reduced. This property is the main topic of our paper.
- Harmonics. The PQO absorbs local harmonics because of its low input impedance. This translates directly into an improved voltage quality and into lower losses in the network. Harmonics originating further away in the network will be absorbed as well, but to a lower extent because of the network impedance. A typical illustration of this property is shown in figure 2. The three traces in the figure are the three phase currents of the PQO during steady-state operation. The 7th harmonic component is very prominent.
- Voltage asymmetry. The PQO is programmed to follow the phase of the positive-sequence voltage at the three phase terminals. Negative-sequence voltages will lead to negative-sequence currents absorbed by the PQO, leading to an improved local voltage symmetry. This property is evident as well from figure 2, because the phase currents have different amplitudes. Apparently the PQO is compensating a relatively low or high voltage in the "green" phase by loading the two other phases.

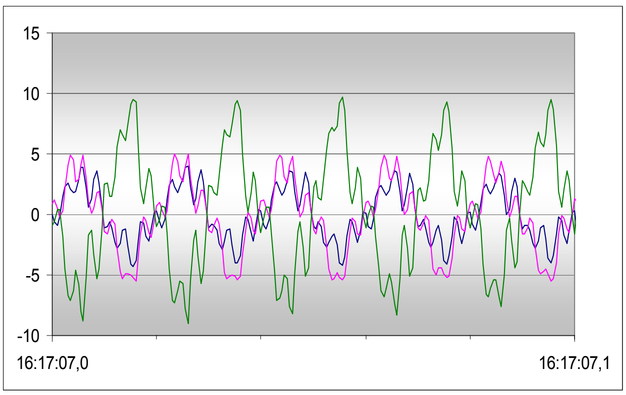

Figure 2. Example of measured currents in the three phases during steady-state operation. Vertical scale in A.

TEST LOCATION

The prototype was ordered by ENECO to test its capability to reduce flicker in its network at a rural location near Bodegraven, the Netherlands. This network node originally served only a few residential customers and farms. One of the farm owners has leased parts of his shed to small businesses. These businesses are sub-metered from the farm owner, so that they do not have a contract with ENECO. From the measured consumption it can be estimated that at least one of these businesses uses electrical tools like welding equipment.
The flicker level at this node exceeds the limits of EN50160 considerably. The highest values recorded are Pst=5 and Plt=2.8 and the highest 95% value is Plt=2.2.
For some time already, ENECO was considering improvement of the network situation. The average load at this node is however 10-15 A per phase, which means that the cost of network reinforcement is much higher than the value of the electricity supplied at the node. A more economic solution was therefore highly necessary.

PROTOTYPE DESIGN CONSIDERATIONS

Typically a PQO will be installed at a node in the network serving a small number of residential customers or farms with a relatively light electrical load. The local peak load is 25..50 kW. Flicker is created by instantaneous load changes or inrush currents of equipment. Such changes or inrush currents are of the order of 50..100 A. The prototype PQO is based on a standard IGBT module which can handle currents up to 75 Arms for 0.1 s. The rated continuous current is much lower because during steady-state operation the input current is a few Amps only.
Initially it was assumed that the PQO did not have to provide a neutral connection, because nearby in the network a balancing transformer is installed creating a defined neutral.
During testing however it was observed that, at this particular location, the most important flicker phenomena occur at single phases only and the impedance of the balancing transformer is not sufficiently low to absorb the flicker currents in the neutral. A modification of the PQO to include a neutral connection is now in preparation.
The prototype PQO was designed and assembled by EMPEQ as an open-frame unit and then mounted into a cabinet provided by ENECO.
Figures 3 and 4 show the PQO in its cabinet, installed at the test location. The cabinet was placed next to the customer's connection point and connected in parallel to the network by means of a short cable.

OPERATING EXPERIENCE

Tables 1 and 2 show the accumulated data of two consecutive weeks of power quality measurements. The data of table 1 have been obtained in the first week, during which the PQO was not in operation. This can be

considered as the "base case" situation. The data of table 2 have been collected in the second week, when the PQO was connected to the network.
This was actually the first week ever for the PQO to be in operation. Therefore the results are unpolished indications of what the PQO can do. Both on 7th harmonic, and on asymmetry, and on flicker value Plt, the numbers in table 2 are lower than in table 1. However the reduction is not as big as anticipated. The same holds for the Pst values, which are available but in a less presentable form.
There are two reasons for this:

- For some categories of flicker events, the response of the PQO is not optimal yet. Further tuning of the control systems wil improve on this point. This reason explains why there is a slight improvement only on the maximum Plt values, wheras the 95% values show considerable improvement.
- The considerable difference between the values for the three phases indicates that single-phase phenomena are responsible for the most severe flicker events. Therefore the PQO must offer a neutral connection as well.

Both the optimization of the control system and the addition of a neutral connection are in preparation, but were not ready for test before the deadline of this paper. Results of these tests are to be presented during the conference.
Figure 6 shows a typical response of the PQO to a voltage dip caused by an inrush current. The figure indicates that the dip cannot be fully compensated. The lack of a neutral connection plays in important role in this respect.

CONSIDERATIONS FOR INSTALLATION

As discussed, the PQO absorbs both flicker and harmonics and asymmetries. In particular with respect to the latter, this may have unwanted side effects. For example, the steady-state situation depicted in figure 2 was followed by the connection of some large single-phase load leading to asymmetry between the phases. In an attempt to compensate for this asymmetry, the PQO has to supply so much current that its overcurrent protection is triggered and switches the PQO off.
In most cases, the voltage symmetry is not so critical that it warrants such a compensation effort. Moreover, voltage asymmetry may originate higher in the network, so that the PQO creates large circulating currents in the network. Therefore it may be more practical to accept voltage asymmetries and program the PQO in such a way that it compensates each phase voltage independently without trying to maintain symmetry between the phases. For each specific location considerations like these have to be made again and the local priorities for compensation have to be defined acurately. Therefore a PQO is not just a plug-and-play device; if one wants to obtain maximum benefit, the modes of operation should be made explicit and programmed into the PQO.

CONCLUSIONS

The PQO is proving itself as a suitable component to reduce flicker in rural LV networks. Flicker events in such networks often have a single-phase nature. The PQO must be able to compensate each phase independently to deliver a maximum benefit. In each application the operational parameters should be tuned to best resolve the particular PQ issues at that location.

Figure 3. Close-up of the PQO cabinet.

Figure 4. PQO cabinet next to the customer's interconnection box.

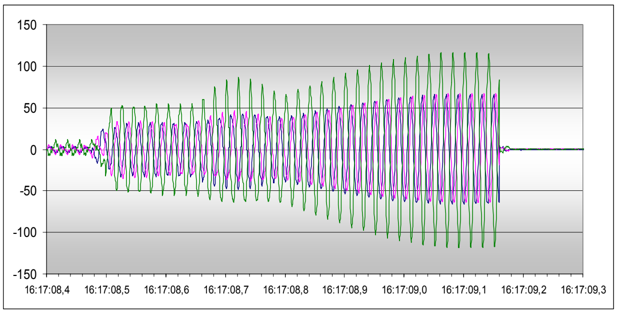

Figure 5. Large single-phase load leading to switch-off of the PQO.

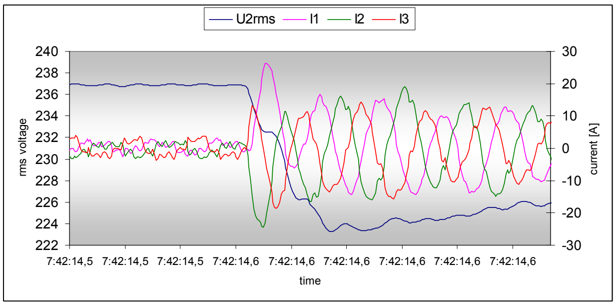

Figure 6. Response to a voltage dip. The steps in the voltage are a mathematical effect of the calculation of the rms value.

Parameter			Maximalwert			95%-Wert		
	Einheit	En50160-50Hz.gwd	L1	L2	L3	L1	L2	L3
Spannungsänderungen		230.00V						
Maximum 100% / 95%	% [Un]	+10.00/+10.00	2.68	2.65	3.89	2.07	2.29	3.12
Minimum 100% / 95%	% [Un]	-15.00/-10.00	-2.97	-4.06	-4.60	-2.18	-2.26	-2.92
Unterbrechungen < 1%	Anzahl	100	0	0	0		-	
Ereignis	Anzahl	100	9	12	7		-	
Spannungsharmonische								
7. Harm.	% [Un]	5.00	2.02	1.81	1.99	1.61	1.59	1.59
Flicker Plt	Plt	1.000	1.480	2.787	1.449	1.214	2.174	1.246
Unsymmetrie U	%	2.00		1.82			1.24	
Signalspannungen							99%-Wert	
1600 Hz	% [Un]	5.00	1.00	1.00	1.00	1.00	1.00	1.00
Frequenz		50 Hz					99.5%-Wert	
Maximum 100% / 99.5%	%	+4/+1		0.20			0.20	
Minimum 100% / 99.5%	%	-6/-1		-0.40			-0.20	

Maximalwert grösser als Grenzwert

95% (99.5%) - Wert grösser als Grenzwert

Table 1. Accumulated power quality data over a week with the PQO disconnected.

Parameter			Maximum value			95%-value		
	Unit	En50160-50Hz.gwd	L1	L2	L3	L1	L2	L3
Voltage variations		230.00V						
Maximum 100% / 95%	% [Un]	+10.00/+10.00	2.41	2.64	3.35	2.07	2.03	2.54
Minimum 100% / 95%	% [Un]	-15.00/-10.00	-2.55	-3.74	-3.31	-2.02	-2.07	-2.48
Interruptions < 1%	Number of	100	0	0	0		-	
Events	Number of	100	20	3	5		-	
Voltage harmonics								
7. Harm.	% [Un]	5.00	1.36	1.41	1.42	1.22	1.26	1.19
Flicker Plt	Plt	1.000	1.478	2.468	1.403	1.049	1.308	1.052
Unbalance U	%	2.00		1.57			0.85	
Signallingvoltages							99%-value	
1600 Hz	% [Un]	5.00	1.00	1.00	1.00	1.00	1.00	1.00
frequency		50 Hz					99.5%-value	
Maximum 100% / 99.5%	%	+4/+1		0.20			0.20	
Minimum 100% / 99.5%	%	-6/-1		-0.40			-0.20	

Max value above limit value

95% (99.5%) - value above limit value

Table 2. Accumulated power quality data over a week with the PQO connected.