Low voltage, but high tension

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Abstract

A shift is taking place within low voltage (LV) networks. Electricity demand is growing, the amount of distributed generation is increasing, and more and more distributed generation (DG) techniques are being developed to fulfil the needs of end users. These developments are having a large impact on low voltage networks. The function of these networks changes and the installation of large scale DG present the operators of low voltage networks with additional challenges, mainly technical, but also concerning the control of the network. This paper describes the impact of installing large scale DG on low voltage grid operators.

The low voltage network is changing

The function of the LV network is subject to change. This change is initiated by several causes, but is mainly due to load growth and distributed generation (DG). Furthermore, the use of electricity by end-user consumers tends to increase steadily, and distributed power generation such as photovoltaics (PV) and combined heat and power (CHP) is expected to increase. This growth will lead to a shift; part of the end consumption will be locally generated instead of centrally at a power station and consumers will also become producers.

These trends change the requirements on low voltage networks. The necessity of changed protection, the increasing harmonics problems, the two-way power flow and the decreasing difference between public and private responsibilities create new challenges for the network operator. These trends were discussed recently [Thielens, 2005], as were several scenarios. For the most likely scenarios, it is expected that low voltage distribution networks will become more important and that the function of these grids will change in the near future.

For instance, in a large scale PV project, an entire suburb (Nieuwland, Amersfoort, The Netherlands) was massively equipped with PV. The utility company was faced with the challenge of accommodating the large share of renewable distributed generation in the grid while maintaining voltage limits and power quality in both the maximum generation case and the maximum load case. The utility company was worried about voltage regulation, harmonic amplification due to the many inverters and suspected islanding operation. For this new housing estate, the transition to a network with predominantly distributed generation could be performed in stages, and the utility company decided to equip the low voltage network with heavier wiring and a more meshed grid than would have been used if little or no PV generation had been installed, to deal with voltage fluctuation. After system studies the inverters were equipped with an update of the control software to prevent harmonic oscillations. From the system studies it also became clear that no special precautions were needed to prevent island operation.

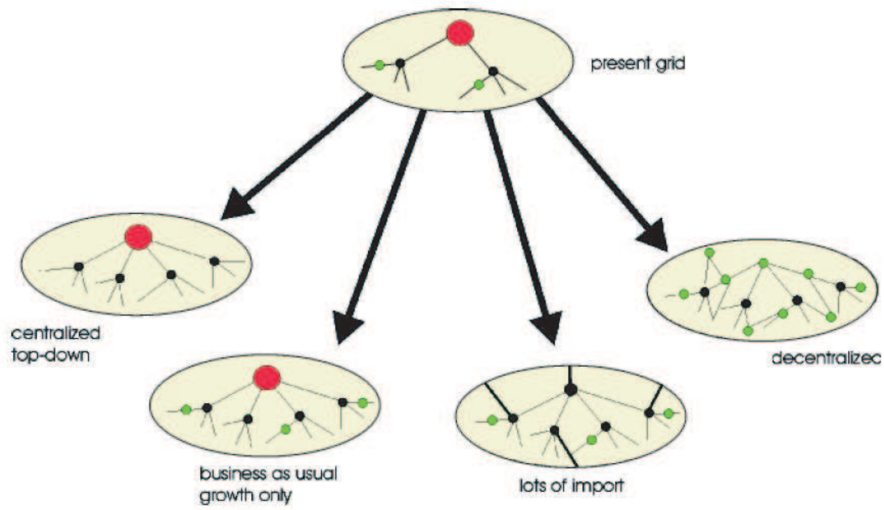

Figure 1: Transition to possible network concepts

Large scale DG projects are still in progress today. This paper aims to provide the reader with more information about the problems that may occur in LV grids, e.g. due to the integration of large scale DG and increasing electricity demand.

Developments and trends causing this change

The transformation of the low voltage network has many causes, such as a changed focus on energy supply, new DG technologies, and increased electricity demand.

Within the last ten years the focus on the energy supply in Europe has changed. The current focus on economic efficiency has replaced the earlier focus on technological reliability [Jaarsma, 2003]. Figure 1 shows the changed ranking of the three most important energy supply characteristics: environmental quality, economic efficiency and technological reliability. In the future, the focus will be more on the environmental quality. This will lead to an increasing demand for environmentally friendly energy generation; this will often be distributed generation such as PV, micro CHP and wind power.

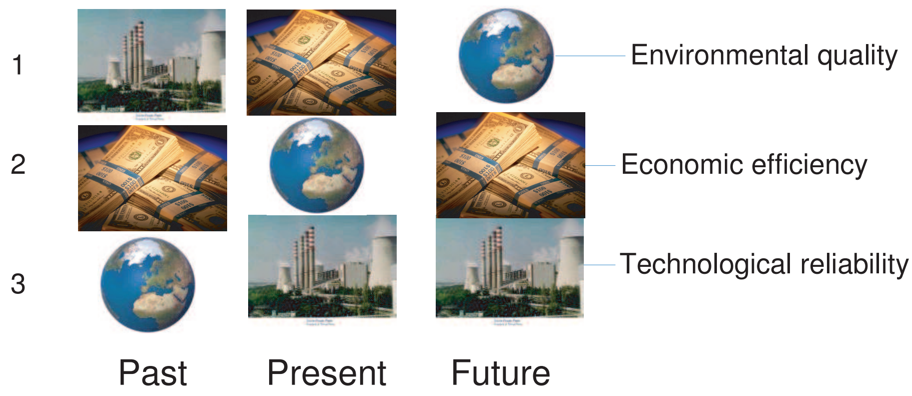

Figure 2: Shift between most important characteristics of energy supply

Problems in the low voltage grid may be caused by distributed generating units. The appearance of DG technologies in the market is dependent on the development state of the technology. The market volume influences the impact of a new technology on the market. Both the market entry and the market volume of the distributed generation technologies under development are shown in Figure 2. The figure gives an overview of the expected market volume and the expected development time of a number of distributed generation technologies. The figure shows that an increasing market volume will be expected in the near future [ECI, 2005].

Most of these technologies will not be market-worthy within the next ten years, but within 20 years a lot of new technologies will enter the market. Due to the large expected market volume, the grid operator will experience problems.

Another reason why the low voltage network is changing is the increase in the annual installed distributed generation connected to the low voltage grid. The quantity of installed DG within the European countries will grow from around 9% of the total installed European capacity, to 12% in 2010, and to approximately 20% in 2020. Figure 3 gives an overview of the expected growth of distributed generation in the European Union.

A comparison of the percentage of distributed generation between the European countries shows large differences [4]. In France, the percentage of DG compared to the total installed capacity is 6.6%, in Germany 19.8%, in Poland 28.4% and in the United Kingdom 6.2%.

Even though, as Figure 3 shows, there was only a small amount of DG in 2004, the idea of large scale distributed generation, also called micropower, is not new. The placement of many small power plants near the consumers was envisaged by Thomas Edison. His idea was to set up networks of DG near the consumer, but replacing the existing grid with micropower will be very cost inefficient. The combination of the low voltage grid

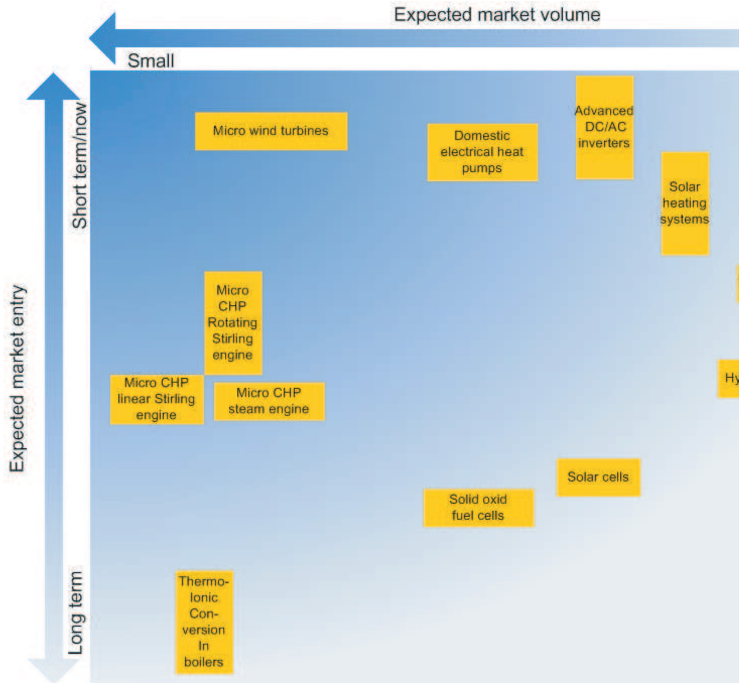

Figure 3: Overview of new distributed generation technologies

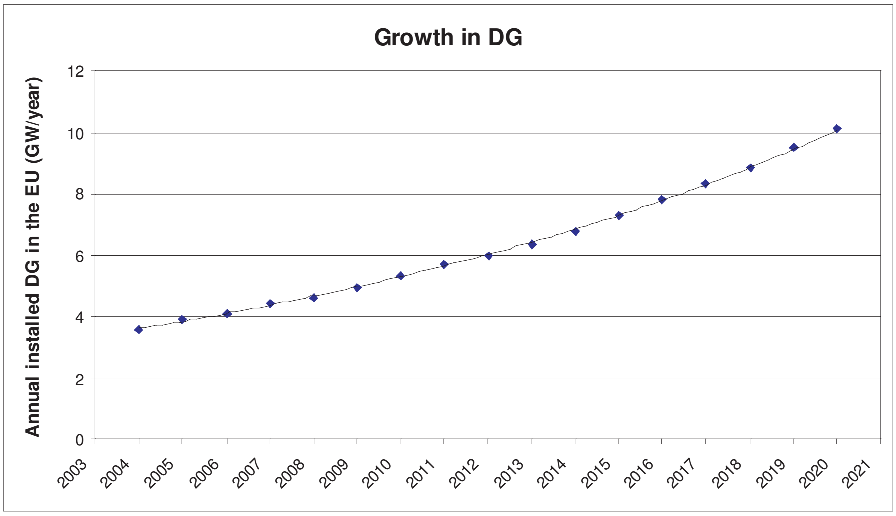

Figure 4: Overview of installed distributed generation in the EU (GW/year)

and distributed generation increases the possibilities for the consumer. The energy supply will become more like a digital network, with multidirectional power flows. This will cause problems for the grid operators. [WADE, 2005]

What will change? The impact of the changing LV network

A changing low voltage network has impact on five types of issues: technical, economical, fuel-related and safety. Furthermore, the necessity of a low voltage grid will be discussed.

Technical issues due to a changed LV network

Some of the best known technical issues for LV networks are the stability of the network and the power quality. These problems will intensify when more DG is installed at the LV networks.

Power quality disturbances are divergences from the ideal sine wave and they can affect the customer equipment or the electricity grid. The effect of DG on the power quality of the grid largely depends on the type of generating unit and its accompanying interface with the grid. Depending on the business model, the network operator may or may not be able to influence the type of generating unit and might be highly dependent on the customer. A solution to reduce the dependability of the network operator on the operator of the DG unit is to create a lease construction for leasing the DG units.

One type of power quality issues is the tripping of the DG unit due to a fault in the network, e.g. earthing faults and short circuit current. The difficulty is that when fault levels are exceeded this may lead to plant damage, plant failure and accompanying risks of injury to personnel and disturbance of supply. Furthermore the network operator has to prevent the DG unit from damage by disconnecting the DG unit after faults. The start-up of the DG units after the disturbance weakens the network stability. The connection of the distributed generator must be designed in a way that an unstable operation does not occur. Another option is to use temporary microgrids to reduce the loading on the system after a fault, which can prevent this power quality issue. Solutions to manage fault levels are uprating or upgrading network components (e.g. increase the circuit breaker ratings), increasing the impedance of generators or transformers, reconfiguring the network or sequential switching.

Another consequence of the changing LV network is a growing level of (high-order) harmonics. The impact of these harmonics is still under investigation and experts call for caution. The high frequency disturbances may affect the DG interfaces, e.g. the interaction with the electronic controls. One way to solve this (potential) problem is to limit the high frequency emission of the interfaces. This can be done either by the grid operator or with the interface. Limiting the emission by the network might be the cheapest option, but the flow over long distances will cause additional problems due to inductive coupling.

Yet another important issue concerning the network stability is the short circuit current and the accompanying fault detection. An increasing number of DG units makes it more time-consuming and difficult to trace faults in a network. Figure 4 illustrates the nominal and the short circuit current in a LV grid with a number of distributed generation units after a fault. Due to the large number of DG units, the directions of the current flows become unpredictable.

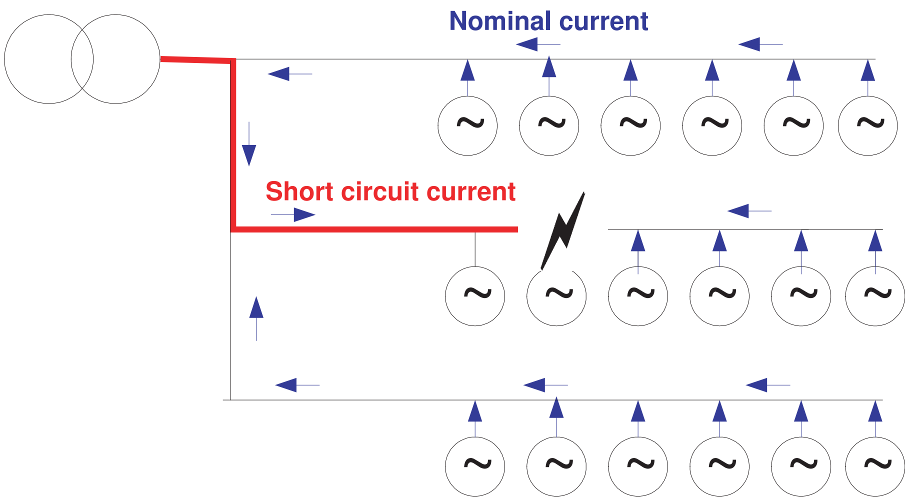

Figure 5: Nominal and short circuit current flows after fault

The increasing demand for electricity and the increase in the number of DG units create problems in the low voltage network. Connecting DG to a low voltage network may cause the fault level limit to be exceeded due to the fact that the network was already close to its limits. These problems mainly occur in older low voltage networks; the connections and the transformers in these networks are not designed for an increase in demand and generation in the LV network.

A comparable issue occurs with reverse power flows through transformers. As a rule of thumb, the generation of and demand for electricity have to be lower than the transformer power. When large amounts of DG units are installed, the local generation will increase, the transformer exceeds its specifications and it needs to be uprated or upgraded. Two parties can pay for this operation: the grid operator, for anticipating the increased generation, or the owners of the DG units.

Most problems caused by the changing LV network can be solved either by the network operator (centrally) or by the owners of the generation units (decentrally). This shows that the connection point is shifting from the customer site towards the public grid. The network operator loses control and is becoming more dependent on the generating customers. Figure 5 gives a simplified overview of the relation between the grid operator and the owner of the DG units.

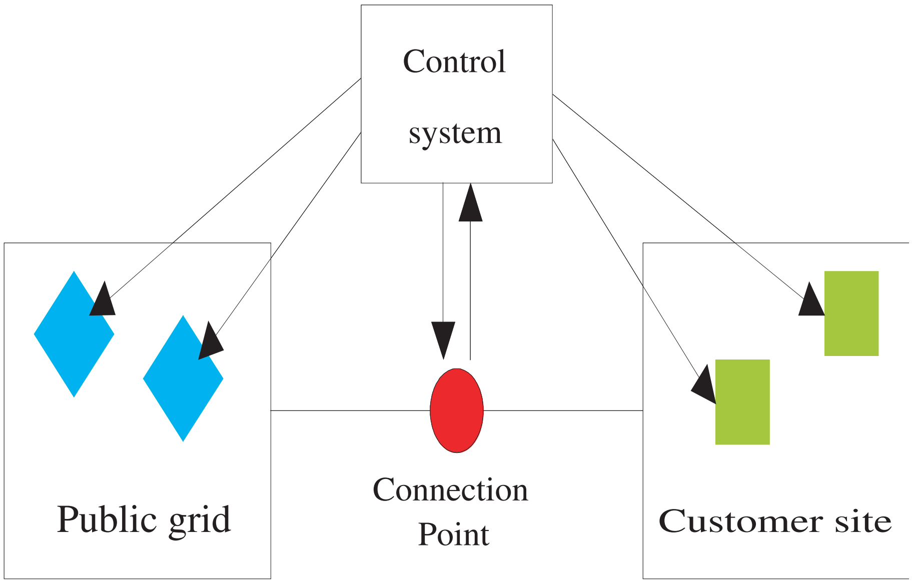

Figure 6: Control system public grid and customer site

Economic effects

One of the most difficult economic barriers to overcome is the connection charging. For the network operator it is important not to discriminate between centralised generation and distributed generation. But on the other hand, the registration of the costs and benefits of the connection of DG has to be appropriate and open access to the network (under certain conditions) has to be guaranteed. There are two types of connection charging: deep charging and shallow charging. Deep charging means that all the costs and benefits associated with the connection to the generating unit are charged to the generating party. An example of deep costs is the extra costs for placing a new transformer to connect the generating unit. This type of connection charging is difficult and requires very detailed expertise. Shallow charging is a lot easier; only the direct connection costs are charged to the generating party. The network operator has to decide how he charges the connecting generating units: shallow or deep.

Another economical issue is the intensity and the speed of the connection of generating units. A customer who wants to connect a DG unit to the grid can experience problems due to bureaucracy. This bureaucracy occurs when the new customer asks the network operator for a connection. The DNO makes a proposal for the specific connection, but getting the permission can take several years. In the meantime, the legislative situation and the network situation may change. Furthermore, the DG technology may be changed during the process of getting permission, which will cause new implementation problems for the network operator.

Fuel related issues

For the network operator, fuel related uncertainty causes planning problems and might cause financial problems for the customers. The DG unit (mainly a combined heat and power unit) has to be connected to a chimney and sometimes also to the gas grid. This can be a costly and time-consuming operation. The dependency on one type of fuel can make it unattractive to install DG units. If the price of this fuel type changes often, it is hard to predict the growth of the number of installed DG units in the future. Sometimes, the use of different fuels is an opportunity. For instance, for the micro-turbine, natural gas, town gas, biogas from landfill or sewage, oil, and methanol are some of the fuels that can be used.

Safety issues

In general, the maintenance of conventional low voltage grids does not cause large hazards for the maintenance personnel as long as they obey the rules. In a low voltage grid with a large amount of decentralized generation, the safety of the maintenance personnel cannot be assured. For the maintenance engineer it is too time-consuming to switch off all the separate generating units. When the local energy demand equals the local generated energy, the voltage remains at the low voltage grid and causes safety hazards. The matching of demand and supply within a gird is called islanding. Islanding has to be prevented, but distributed generation still has to be attractive. This causes an area of tension, which can be reduced by reducing the diameter of the electricity cables. Cables with a large diameter have a high capacity and create more reactive power. A reduction of the reactive power reduces the chance of islanding.

Necessity of the low voltage grid

A robust low voltage grid will be an important part of the energy supply of the future. Although distributed generation is growing alongside the grid, the low voltage grid is still necessary for back-up power and utility companies can install power plants close to the consumers to avoid bottlenecks in the grid.

To solve the issues described above, the responsibilities between the grid operator and the owners of the DG units have to become clearer to keep the costs for both grid operation and DG as low as possible and to guarantee safety. It is expected that the influence of the network operator will shift towards the customer with DG units (Figure 6). This may change the role of the low voltage network into that of a back-up for the DG units, instead of being the main electricity supplier.

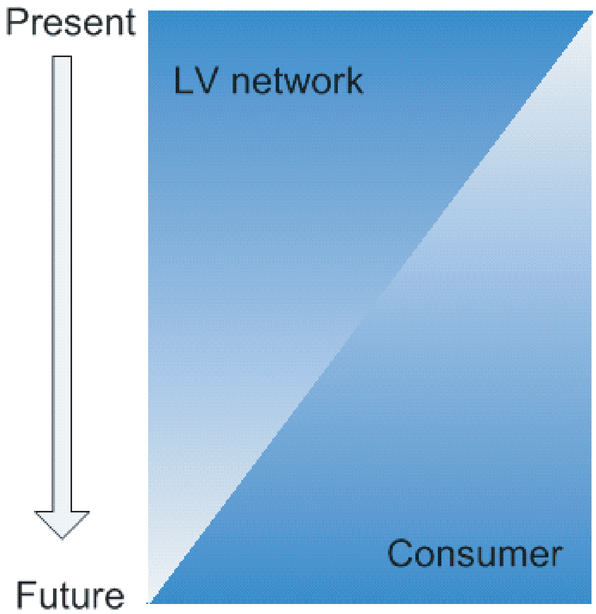

Figure 7: Influence shift from LV network towards consumer

Conclusion

Due to a growing electricity demand and an increasing amount of distributed generation, the pressure on the low voltage network is rising. Getting insight into the main causes of this growing pressure and its accompanying effects on the changing role of the low voltage grid operator is therefore indispensable.

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Femmy Combrink graduated with a Master of Science degree in Technical Business Aministration at the University of Twente (the Netherlands) in 2002, the same year she joined KEMA. Since then, she participated in numerous projects with a focus on consultancy on risk and process analysis. She was part of the team that valued the fixed assets of the Dutch utilities. She was also part of the team that discussed the valuation starting points and the results of the valuations with the representatives of the Dutch tax department. In the context of a cooperative initiative undertaken by the Energy Research Centre of the Netherlands and the Dutch Ministry of Economic Affairs, she joined the development team of FleXnet, a modeling and business simulation project investigating the impact of implementing flexible grid components within the power market. She is also a member of a research team that is looking for ways of reducing the risk impact of long-term grid investments. This team also conducts (mainlyTechnical) Due Diligence investigations. Within the assignments she is responsible for the valuation of the assets under consideration, review and assessment of the capital and operational expenditures.

Peter Vaessen studied electrical power engineering and graduated from Eindhoven Technical University in 1985, the same year that he joined KEMA. He held several research positions in the field of large power transformers and measurements in high-voltage networks. From 1991 to 1996, he managed several realization projects, among them construction of the Dutch 400 kV substations at Meeden and Eemshaven. As a consultant he has experience in the conceptual design of integrated electrical systems and innovative techniques and tools for transforming existing large-scale hierarchical systems into flexible dynamic structures, allowing economic utilization, competition and integration of RES and DG. He is actively involved in the technology strategy of KEMA and works for the Dutch Ministry of Economic Affairs on setting up scientific research programs in the areas of power electronics and the future long-term reliability of the Dutch electricity network.