INTELIGENT DISTRIBUTION NETWORK DESIGN

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Summary

Distribution networks (medium voltage and low voltage) are subject to changes caused by re-regulation of the energy supply, economical and environmental constraints, more sensitive equipment, power quality requirements and the increasing penetration of distributed generation. The latter is seen as one of the main challenges for today's and future network operation and design. In this thesis it is investigated in what way these developments enforce intelligent distribution network design and new engineering tools. Furthermore it should be investigated how a new design and control strategy can contribute to meet the power quality and performance requirements in distribution networks in future.

This thesis focuses on network structures that, typical for the Netherlands, are based on relatively short underground cables.

Managing current and voltage in such networks both during normal and disturbed operation, requires a good network design and an adequate earthing concept. The limited size of Dutch distribution networks has a positive effect on power quality aspects and reliability. The use of impedance earthing for medium voltage (MV) cable networks reduces the risk of multi-phase faults that cause large fault currents and deep dips. It also reduces the risk on transient over-voltages due to re-striking of cable faults. A TN earthing system for the low voltage (LV) network reduces the risk of damaged apparatus and it maintains safety for people. However, care must be taken for the earthing of devices of other service providers, which requires a co-operative solution.

The fast developments of computation techniques and IT equipment in the network opened the possibility to perform many calculations in short time based on both actual and historical data. Examples are the on-line distribution load-flow and the short-circuit calculation for protection coordination and intelligent fault location. In LV and MV network calculations the accuracy of the models and the availability of data are the main obstacles. Because of the unsymmetrical nature of load and generation in LV networks a multiple conductor model is needed. For safety calculations also the earth impedances have to be modelled as well as the neutral and protective earth impedances and their mutual interactions.

The protection philosophy in MV networks must take into account the changing requirements regarding safety and power quality. An overall philosophy concerning both network and generator protection is necessary.

New developments in substation automation benefit future upgrade and refurbishment of substation control and protection. As a result, also cheap, accurate and fast fault location becomes feasible, reducing the outage time of the customers.

Next the influence of distributed generation on the above subjects is investigated. The increasing magnitude of short-circuit currents and the increasing voltage variations in the network are seen as a major challenge for the network planners. Conventional measures for reducing voltage problems may introduce problems with the short-circuit current level and vice versa. In networks which contain a large amount of both load and distributed generation, adverse voltage problems may occur, especially when the generation is located in the LV network. In order to reduce this, specific control strategies need to be developed.

The last part of the thesis is related to these control strategies as a solution for operating future distribution networks. By introducing storage and power electronics, networks can be transformed into autonomously controlled networks. These networks remain an inseparable part of the electricity network but may behave in a fairly autonomous manner, both internally and externally, with respect to the rest of the network. The focus in this thesis is on maintaining an optimal voltage for all customers during all combinations of load and generation. Because of the autonomous behaviour of the control systems, their operation must be based on local measurements. A suggested approach is to replace the normal open point between MV feeders by a so called “intelligent node”. This node is able to control the power flow in several feeders by means of power electronics and, if provided, by electricity storage. The voltage profile can be improved further, by introducing an intelligent voltage control on the HV/MV transformer feeding the distribution network.

The simulation studies in this research have been performed on a realistic model of a typical Dutch MV/LV distribution system. Based on the results the following conclusions are drawn:

- The HV/MV transformer control must be based on line drop compensation. This compensation must use the load situation instead of the measured exchange signal. The compensation factor must differ between cases of high load and of high generation.
- The optimal control of the intelligent node is a voltage control, based on a linear dependence of the voltage at the node and the power flow towards that node. This method can be improved when the voltage of the MV bus bar in the substation is taken into account.
- Methods to obtain a perfect voltage profile will lead to a storage device that is not available for this voltage level yet.

- A voltage control based on a fixed value at both terminals of the intelligent node and at the MV bus bar of the HV/MV substation does not result in the optimal voltage profile, although guarantees a good voltage quality and might therefore be a good alternative.

Contents

1 Introduction

The main objective of an electric power system is to transfer the electrical energy from the generators to the consumers. A power transmission network connects large-scale power plants to multiple substations near a populated area. A power distribution network connects the customers to the substations. Electric power transmission allows distant power plants to be connected to consumers in population centres.

Since the electric power cannot be stored in large amounts, the electricity generation must always be balanced with the momentary consumption and losses. Multiple sources and loads can be connected to the transmission system and they must be controlled to provide orderly transfer of power. In the long term this process is dominated by the electricity market, that affects the purchase and sale of electricity, using supply and demand to set the price.

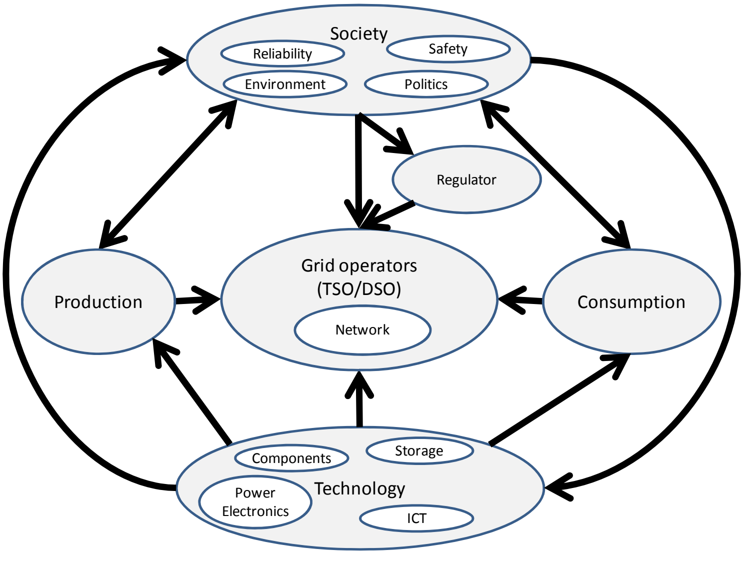

Figure 1.1 Players in the field of electricity supply

Operating an electric power system is a complex business with a large number of players involved, as shown in Figure 1.1. A central position is played by the grid operator, owning and operating the network.

All players have wishes and set requirements affecting the behaviour of the electric power system:

- Generators need to be connected to the network at all times in order to be able to generate the electric power. They need the network to be operated within technical limits to ensure the proper working of their generating units. Their relation to the society is often on the field of politics, where it concerns the environment and economy. This also affects the policy for constructing new generating units.
- The consumers also need to be connected to the network at all times for their processes. These processes include conversion of electric energy into labour, heat and light, as well as electricity generation. The consumers are related to society because society determines safety and reliability requirements.
- The society sets requirements to generation, grid operator and consumption players. The requirements for the generation players are mainly in the environmental field. The requirements towards the grid operator are in the field of reliability, environment, politics (economical) and safety. The requirements towards the consumption players are mostly in the field of the environment and safety. Very often the regulator is used to set the requirements.
- The grid operators must enable the transmission and distribution of electrical energy. This must be done in a reliable, safe and economical way, while at the same time the environment must be saved. They will adopt new technological features to be able to cope with new requirements.
- Technology players develop new components, processes and ICT-solutions for generation, grid operator and consumers. Driven by economical, environmental and sociological signals, they carry out research and development. Players are, amongst others, universities, technological institutes, manufacturers and engineering consultants.

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