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Flexible electricity grids

Report of Work Package 1

EOS-LT project FLEXIBEL

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Voorwoord

Dit is het eerste rapport van het project FLEXIBEL (FLEXibele elektriciteitsnetten voor de Integratie van duurzame Bronnen van ElektriciteitsLevering) welke loopt van medio 2005 tot medio 2008. Het vat de resultaten samen van een inventarisatie van relevante informatie benodigd voor het formuleren van architecturen van toekomstige, flexibele elektriciteitsnetten. Deze studie wordt uitgevoerd door ECN, KEMA en de TU Eindhoven, en wordt mogelijk gemaakt door financiële ondersteuning via EOS-LT programma van SenterNovem (project nummer EOSLT01021).

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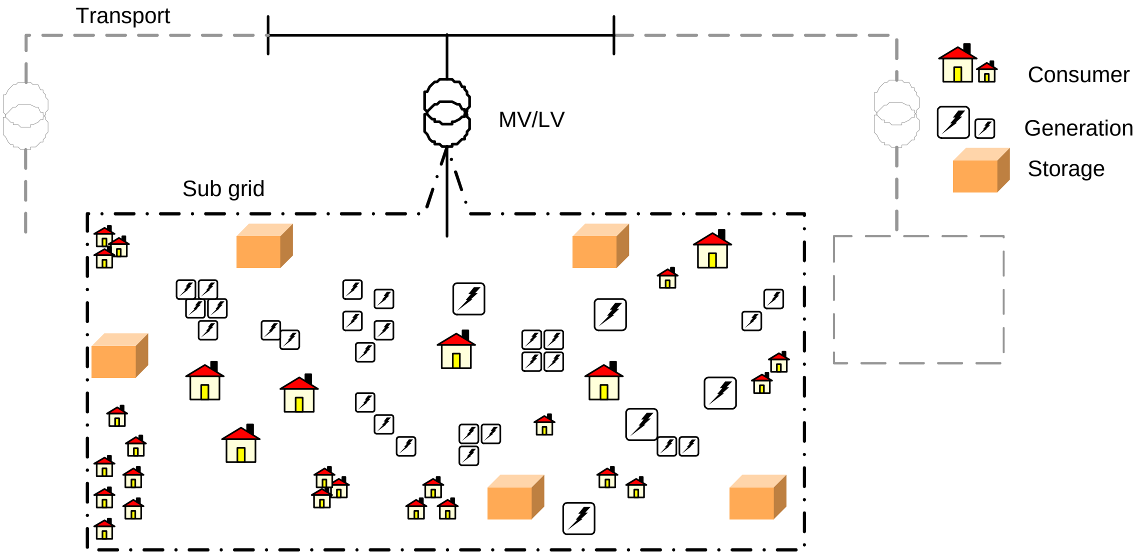
Acronyms and abbreviations

AMR	Automated Meter Reading
APX	Amsterdam Power eXchange
BUSMOD	BUSiness MODels in a world characterised by distributed generation
CHP	Combined Heat and Power generation
CRISP	distributed intelligence in CRitical Infrastructures for Sustainable Power
DG-RES	Distributed Generation with Renewable Energy Sources
DNO	Distribution Network Operator
DRR	Demand Response Resources
DSM	Demand Side Management
GSM	Global System for Mobile communications
ICT	Information and Communication Technology
IEC	International Electrotechnical Commissions
ISO	Independent System Operator (~ TSO, USA context); International Standards Organisation
IEA	International Energy Agency
LV	Low Voltage
MV	Medium Voltage
OLE	Object Linking and Embedding
OSI	Open Systems Interconnect
OPC	OLE for Process Control
PPI	Primary Process Interface
PRP	Programme Responsible Party
PV	Photo-Voltaic
PLC	Power Line Carrier or Programmable Logic Controller
RM-ODP	Reference Model for Open Distributed Processing
SDM	Supply and Demand Matching
SCADA	Supervisory Control And Data Acquisition
SMI	Settlement and Metering Interface
TSO	Transmission System Operator
UDDI	Universal Description, Discovery and Integration
UML	Unified Modelling Language
WSDL	Web Service Definition Language
XML	eXtended Markup Language

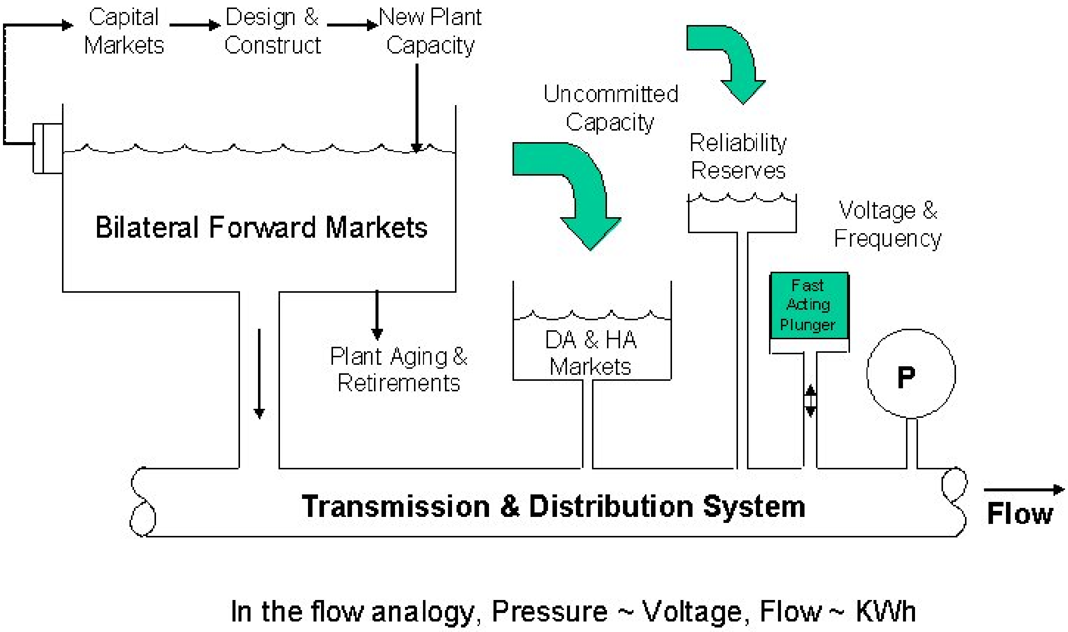
Samenvatting

Inleiding
Recente veranderingen in de elektriciteitssector worden vooral gedreven door de liberalisatie golf, door milieu aspecten en in mindere mate door de brandstofinzet. Van de drie kernactiviteiten, opwekking, transmissie en distributie heeft vooral de eerste grote organisatorische veranderingen ondergaan. Centrale inzet van eenheden is in korte tijd vervangen door een marktmechanisme. Daarentegen bestaat distributie nog steeds primair uit het verspreiden van grootschalig opgewekte elektriciteit onder een groot aantal aangesloten klanten, vooral op het laagspanningsnet. Maar door een groeiend aandeel decentrale opwekking met warmtekracht eenheden en intermitterende duurzame energiebronnen zal de functionaliteit van het laagspanningsnet wijzigen, van primair distributie op dit moment naar een combinatie van transmissie en distributie in de toekomst. Opwekkers en gebruikers van elektriciteit zullen naar verwachting een actievere rol krijgen in het leveren van systeemdiensten, waardoor flexibele netten ontstaan. Vanwege de grote impact van deze veranderingen op laagspanningsniveau ligt hier de focus van het FLEXIBEL project.



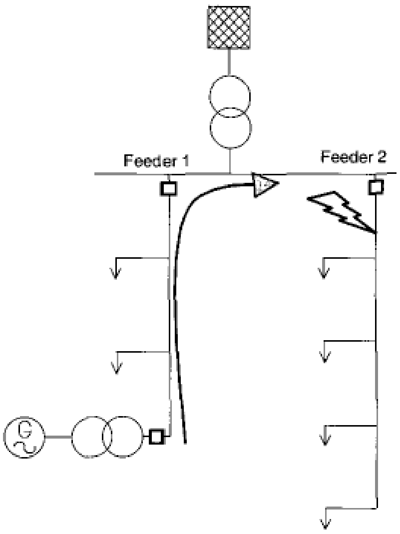
Figuur A.1 *Het FLEXIBEL project beperkt zich tot laagspanningsnetten en de koppeling met het middenspanningsnet*

Regelgeving en markten voor elektriciteit in Nederland
Liberalisatie van de elektriciteitsmarkt was het belangrijkste doel van de Elektriciteitswet van 1998. Opwekking, handel en levering van elektriciteit zijn aan de markt overgelaten terwijl het natuurlijke monopolie van de aan netten gekoppelde transmissie en distributie sterk gereguleerd bleef. In Nederland wordt het merendeel van de elektriciteit verhandeld via bilaterale contracten. Het korte-termijn surplus wordt op de APX verhandeld (day-ahead market). Ook voor de systeemdiensten welke leveringszekerheid moeten bewerkstelligen zijn markten gecreëerd. De belangrijkste hiervan is de onbalansmarkt waar het regel- en reservevermogen verhandeld worden. Zowel de markten voor elektriciteit (commodity markets) als die voor de systeemdiensten (ancillary services) zijn primair geënt op grootschalige opwekking gevolgd door transmissie en distributie. Het is aannemelijk dat voor toekomstige, flexibele netwerken, de spelregels van deze markten aangepast moeten worden. Ook voor spanningskwaliteit is het mogelijk dat regelgeving over kwaliteitsnormen gecomplementeerd zal worden met marktconforme instrumenten.



Figuur A.2 *Analogie met de watervoorziening. Links de twee productmarkten (bilaterale contracten en de APX), rechts de systeemdiensten voor betrouwbaarheid en de regeling van voltage en frequentie (DA=Day Ahead, HA = Hour Ahead)*

Functionele eisen aan netten met gedistribueerde opwekking
Toepassing van decentrale opwekking in distributienetwerken kan problemen opleveren op het gebied van beveiliging. De niveaus waarop beveiligingen aanspreken worden beïnvloed door de bijdrage aan de kortsluitstroom van decentrale opwekkers. Bescherming van decentrale opwekker en het net moeten dan ook op elkaar afgestemd worden. Overige problemen zijn de synchronisatie bij het opnieuw aankoppelen, ongepland eilandbedrijf en afstemming van de wijze van aarding van decentrale opwekker.



Figuur A.3 *Decentrale opwekkers beïnvloeden beveiliging in laagspanningsnetten. In dit voorbeeld wordt de beveiliging van 'feeder 1' aangesproken door een kortsluiting in 'feeder 2'*

Functionele eisen zullen geformuleerd worden op het gebied van belasting, voltage niveaus en eliminatie van kortsluiting. Hierbij zal rekening gehouden moeten worden met de veranderende functionaliteit van laagspanningsnetten, met name ten gevolge van bi-directionele vermogens-transport, actieve regeling van lokale opwekkers en actieve regeling van voltage niveaus in het netwerk.

ICT ontwikkelingen

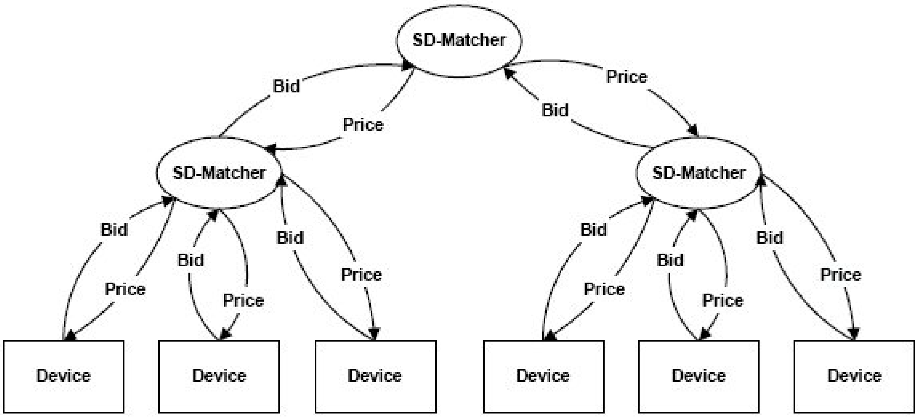
De huidige laagspanningsnetten zijn in essentie statische systemen waarbinnen weinig geregeld wordt. Ze zijn ontworpen vanuit het uitgangspunt dat de gevraagde vermogens onder alle omstandigheden geleverd moeten kunnen worden. Wanneer in de toekomst de omvang van decentrale opwekking zo groot wordt dat de functionaliteit van het laagspanningsnet essentieel verandert door de extra transmissiefunctie zal deze ontwerpfilosofie niet langer optimaal zijn. Actief beheerde, flexibele, netwerken zullen nodig zijn, waarbij lokale opwekkers, en ook een deel van de elektriciteit consumerende apparaten, een actieve rol spelen in het leveren van systeemdiensten. Hierdoor ontstaat een betrouwbare en kosteneffectieve infrastructuur. Om dit mogelijk te maken is toepassing van Informatie en Communicatie Technologie (ICT) nodig.

Informatie en communicatie technologie maakt het mogelijk dat grote aantallen actoren met elkaar verbonden kunnen worden en informatie kunnen uitwisselen. Dit is een essentiële randvoorwaarde voor actieve netwerken. De combinatie van verbindingen, communicatie, hardware en software biedt een platform voor een architectuur voor een aantal cruciale toepassingen in elektriciteitsnetwerken. Dit zijn met name: meten en afrekenen, energiebeheer, netbeheer en de bewaking van de vermogenskwaliteit. Verder kunnen installaties op afstand gemonitored en beheerd worden, wat onder meer het ontstaan van virtuele centrales mogelijk maakt welke gebaseerd zijn op grote aantallen kleinere eenheden.

Commerciële concepten voor afstemming vraag en aanbod van energie

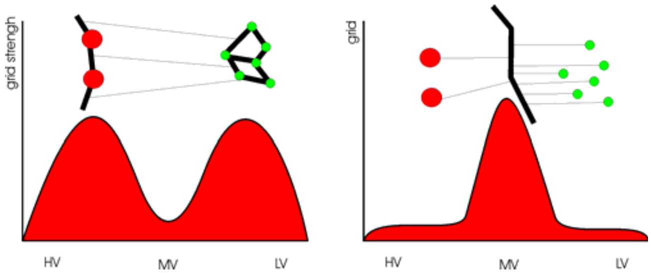
Om problemen met piekbelasting te voorkomen is er de afgelopen decennia veel belangstelling geweest voor 'demand side management' (DSM). Een deel van energieconsumerende processen in industrie en gebouwde omgeving lenen zich er toe om tijdelijk geheel of gedeeltelijk afgeschakeld te worden, waardoor verbruik uitgesteld wordt tot momenten waarin het beslag op de infrastructuur minder is. Dit zijn met name niet-kritische processen met motoren, verwarming, koeling of verlichting. In recente Demand Response Resources (DRR) programma's is de nadruk uit het verleden op activiteiten in de controle kamer van nutsbedrijven verschoven in de richting van marktconforme activiteiten van aangesloten klanten. DRR kan hierbij gezien worden als het terugverkopen van elektriciteit welke niet geconsumeerd hoeft te worden in het licht van nieuwe informatie. De belangrijkste drijfveer hiervoor is meestal de marktprijs.

DRR richt zich op de vraagzijde. In toekomstige netten zullen grote aantallen kleine vragers en aanbieders van elektriciteit op korte afstand van elkaar aanwezig zijn. Dat kan plaats vinden in een individueel kantoorgebouw of woning, maar ook op de schaal van een wijk of een laagspanningsdistributienet. In een recent project [CRISP, 2004b] is het concept van lokale afstemming van vraag en aanbod van energie uitgewerkt in de vorm van een elektronische markt waar onafhankelijke 'agents' voor het aansturen van apparaten zorg draagt (Power Matcher).



Figuur A.4 *Hiërarchische structuur van een elektronische markt voor afstemming van vraag en aanbod*

Mechanismen voor het verhogen van netstabiliteit
Een kernvraag voor de toekomstige netten is de vraag hoe de uitwisseling van vermogen zich zal ontwikkelen tussen grootschalige opwekking en de grote aantallen decentrale opwekkers. Twee modellen hiervoor zijn geschetst in figuur A.5. Het kameel model heeft een relatief zwak middenspanningsnet welke de min of meer zelfvoorzienende laagspanningsnetten met elkaar verbindt. In het dromedaris model is aangenomen dat het grootschalige vermogen en de mini-netten met elkaar verbonden zijn door een relatief sterk middenspanningsnet. Als het kameel model werkelijkheid zou gaan worden, zullen er meer lokale investeringen nodig zijn (misschien bij de aangeslotenen zelf) om de spanningskwaliteit voldoende hoog te houden. In een dergelijk netwerk zal meer behoefte zijn aan informatie technologie en regelsystemen.



Figuur A.5 *Kameel en dromedaris model voor uitwisseling vermogen HV en LV*

In een elektriciteitsnet moeten zowel het actieve als het reactieve vermogen in balans zijn voor een stabiel bedrijf van het net. Reactief vermogen wordt in transmissiesystemen gebruikt voor het regelen van voltages. In tegenstelling tot transmissielijnen domineert bij kabels de weerstandscomponent over de reactieve component. De mogelijkheden voor voltage regeling met reactief vermogen zijn bij kabels dan ook veel beperkter omdat de ohmse verliezen de overhand krijgen.

1. Introduction

Society critically depends on a secure supply of energy. Currently, electricity networks in the Netherlands show a high level of reliability compared to other European countries. But the electricity sector is changing fundamentally and this change is likely to affect future reliability. Three main drivers of change in the electricity sector can be identified. These are market liberalisation, environmental aspects and security of supply. Liberalisation has affected the operation and organisation of the sector already and is supposed to result also in improved cost efficiency. Environmental objectives have stimulated a growth in distributed generation with efficient cogeneration units and renewables such as solar photovoltaics and wind power. Security of supply has influenced the choice for fuel diversification.

The changes in the past decade have affected the three main functional components of the electricity sector: generation, transmission and distribution, to a different extent. Generation has seen the most fundamental change due to the liberalisation. Centrally planned dispatch has been replaced by a market mechanism where different actors base their decisions mainly on cost-benefit arguments. The original fear that the market mechanism would not provide sufficient incentives for new investments in large generation capacity appear unfounded since several plans circulate for new large power plants. Furthermore there has been a trend in the past decades of an increasing share of distributed generation. This was mainly cogeneration in industry and agriculture. We expect this trend to continue further, mainly due to introduction of small cogeneration units at the level of households and offices, which are currently in a demonstration stage.

The transmission system is gradually being strengthened. Interconnections with neighbouring countries were originally designed for mutual assistance to attain sufficient reliability of supply and to achieve frequency stability. Besides this security function, there is an increased cross-border trade that contributes to further integration of the markets in the individual countries. New technologies (such as e.g. FACTS) will contribute to more efficient utilisation of transmission infrastructure investments.

Distribution networks have seen the least change in the recent past. They are still primarily designed for unidirectional power flows towards the connected consumers. However, the increased role of small-scale distributed generation will strongly affect the operation of distribution networks. An increasing importance of the transmission function in low voltage grids (LV) is likely to introduce new technical problems such as larger voltage fluctuations, local power quality, and possibly even stability issues. Very little concrete preparations have been made already for the future development towards flexible LV grids, where active management of both local generation and consumption, has a role in operation of the LV grid. One of the few exceptions is the development to introduce intelligent meters. However, current interest is mainly on remote metering of electricity use. In the traditional structure of the electricity sector, large-scale generation plants feed the grid mainly at High Voltage level, followed by transmission at High Voltage and Medium Voltage, followed by distribution, mainly at Low Voltage level. Future LV grids will have a more complex function since they will also include generation and transmission. Large-scale generation, e.g. biomass co-fired with coal, is still expected to have a role in the future. High Voltage transmission lines and interconnections with neighbouring countries will continue to form the backbone of the electricity network, providing security, reliability and the possibility to match inter-country differences in supply and demand. But the most fundamental changes are expected at the Low Voltage level where the function of the distribution grid will change.

In this FLEXIBLE study, our focus is primarily on distribution grids since the largest impact of future changes in the electricity networks are to be expected at the LV level. Future electricity grids will still consist of connections (transmission lines and cables) and nodes (sub-stations and transformers). But the differences with current grids will be in the field of management, control and security of the grid, since power flows will become different. New components will be added that will match fluctuations in supply and demand, achieve power control and voltage stability. Furthermore, future systems are expected to become more compact.

The basic objective of this FLEXIBLE study is to create conditions for integration of small generation and loads instead of just connecting them to the grid. Through an integral assessment of network requirements, dispatch of distributed generation units and demand side management, a more optimal solution can be achieved than simply increasing network capacity and adding more regulating power to meet the growing mismatch between supply and demand due to co-generation.

This first report of the FLEXIBLE project is primarily an inventory of the state of the art on a number of different aspects of future, flexible grids. It doesn't cover all relevant subject but illustrates on which areas the project team intends to focus during the rest of the project until the middle of 2008.

2. Regulations and markets

2.1 Current market structures - centralised - liberalised context

In order to be able to scale back load control from high level grid control to bottom-up control in flexible power grids, it is mandatory to have a description of the normal process of energy metering, trade, balancing and distribution pricing as well as a picture from current demand side and supply side management techniques. In this chapter a functional overview of a number of aspects of electricity markets operating at this moment and possibly future variants will be given. This provides the context within which a more bottom-up load control in flexible power grids may be developed.

Liberalisation has paved the way to a market, where the roles in the delivery of power have been decoupled. This is illustrated in Figure 2.1.

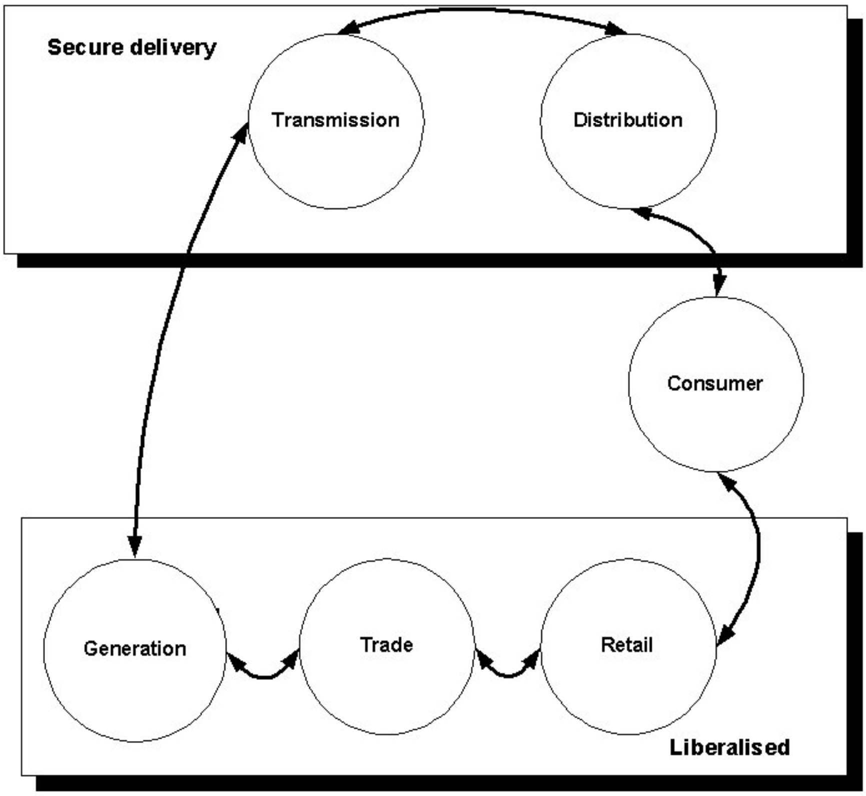


Figure 2.1 *Roles in the electricity delivery chain*

The transmission system operator (TSO) managing the high-distance, high voltage network and distribution network operators (DNO's) are focussed on secure delivery with a minimum of outages. In power trade, bilateral contracts, open day-ahead markets with multiple commercial parties for supply and demand and balancing markets with one party demanding/supplying and multiple parties supplying/demanding exist. These three mechanisms together constitute a mechanism for operating a power grid in a liberalised, unbundled setting. The legislator defines these roles in order to maintain a sufficiently high reliability level in delivering power.

On the other hand in the liberalised, re-regulated market a power generation trade and retail business (displayed in circles in the lower rectangle) has evolved operating from a distance of the physical power delivery process. A description of detailed mechanisms for this process for a number of European country settings has been the subject of one of the BUSMOD-deliverables [Busmod, 2003].

Bilateral forward market
In most European liberalized electricity markets the planning of the amount of electricity demanded is done on the basis of time-of-year, meteorological prospects and feedback of historical consumption data. Based on this predicted amount, producers and consumers ensure their basic loads in long-term contracts. In the Flexibel project this market type will not be considered.

Day-ahead market
After establishing the base load, the surplus is traded on a central market, the power exchange. This market also gives foreign producers the ability to import/export their electricity through the interconnection (import/export) lines. An independent net authority (TSO: Transmission System Operator[1]) manages the process that the projected amounts can be transported and that sufficient transmission capacity is present.

Hour-ahead market
One hour before delivery of the electricity, delivery programme changes are accounted for and changed to adapt to the present situation. In some countries of Europe an hour-ahead market is operating for trading surpluses and deficits in capacity and demand.

Ancillary Services
The market for ancillary services pertains to background power in the form of providing of capacity for a spinning reserve (supply of electricity if the grid has an unexpected need for more power on short notice) and for regulation (correction for short-term changes in electricity use that might affect the stability of the power system). This can be organised as a day-ahead (or hour-ahead) ancillary market, on which potential suppliers submit reserve capacity bids to be utilised by the TSO.

Other market concepts
Derived markets, hedging positions of market players, are evolving in some countries as well. Such a derived market operates as an option market in traditional stock exchanges and allows risk management for different market parties.

The schematic view of action of the power delivery system is shown in Figure 2.2. A basic load contracted bilaterally between generating and trading companies is shown on the left. The day-ahead and hour-ahead markets act as multi-party, open markets with a larger number of players. In some countries, an auction-like balance market is operating in which bids for demand and supply are exposed to a limited number of parties.

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[1] In the USA an ISO (Independent System Operator) in a different context fulfils this role.

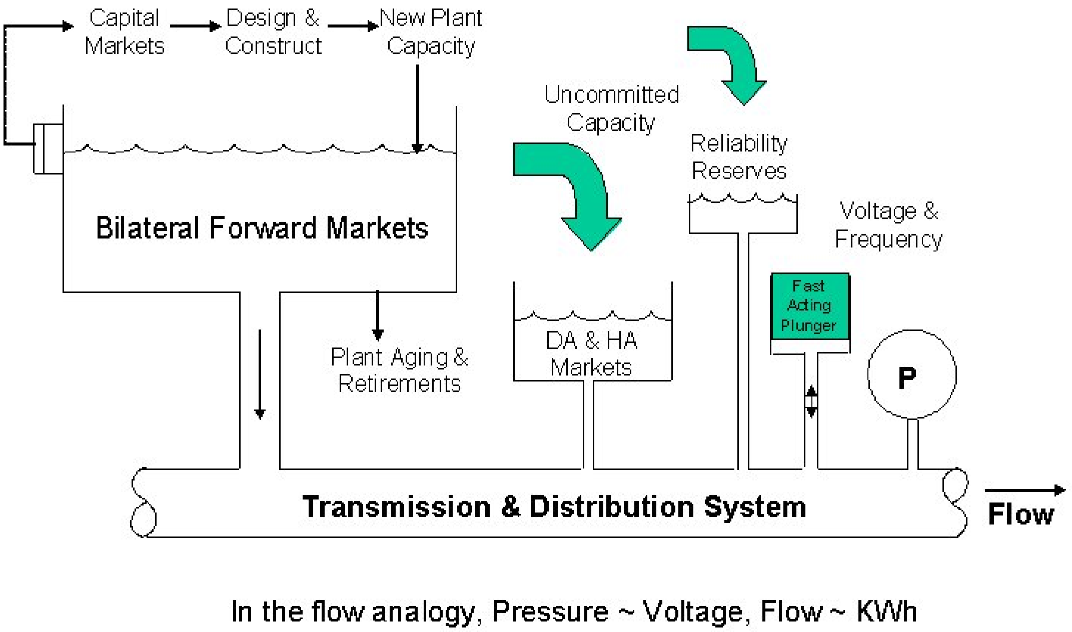

Figure 2.2 *Water flow analogy of electricity supply adjustment*

Power reliability and security of delivery is an item separated from the market aspects by law. The market and trading mechanism may in no way impair these aspects. For large customers, the financial transactions of the market mechanism based on the actually measured productions and consumptions are done on the basis of measurements on a short time-basis (minutes). For small consumers and producers financial implications are lumped and accounted in annual adaptations of contractual unit prices.

The electricity market on one hand is liberalised, on the other hand the distribution and balancing aspects are strongly regulated in order to retain a high level of security of delivery. In the liberalised part of the market, a large amount of transparency is achieved. In the perception of individual customers the new balancing scheme of the electricity infrastructure is difficult to imagine and it is not always easy to identify the separate roles of distributor or trader. Only the appearance of new energy trading companies on the market is the item a customer sees. The transparency of price formation and accounting also has the effect, that aggregation of consumer and producer alliances or brokers is possible with little reference to their locations in the physical power distribution grid.

2.2 System balancing and power quality

Introduction

To prevent overloading of the distribution network, and to maintain power quality and the balance between supply and demand, consumers and suppliers of electricity are expected to contribute to ancillary services in the future. Current regulation does not take this into account. New regulations have to be designed that fosters business models in which these services can be provided through market mechanisms. First part of this chapter summarises relevant existing regulations focussing on the provision of ancillary services. In the second part possible new regulations are discussed.

Ancillary services are activities that facilitate a reliable operation of the transmission and distribution system with a sufficiently high quality level. A division can be made into three main categories: system balancing (matching instantaneous supply and demand of power), power quality (voltage levels, reactive power balance, flicker, harmonics, dips and surges) and reliability of supply. System balancing in the Netherlands is the responsibility of the Dutch Transmission System Operator TenneT. Contributions with reserve-, regulating-, and emergency power are partly regulated, but primarily left to a market mechanism. Sufficiently high power quality levels are mainly attained through regulations that have to be met by all parties involved (TSO, DSO and connected customers, generators as well as consumers). Maintaining the reactive power balance is also the responsibility of TenneT, although DSOs are supposed to be responsible for voltage levels and reactive power in their networks. Additional distributed generation affects reliability in the network. Although contributions to reliability are difficult to value this can be a relevant ancillary service even when provided by small generators.

Program responsibility; the role of TenneT

This paragraph describes in short the situation in the Netherlands for system balancing, as performed by [TenneT].

Program Responsibility can be defined as the responsibility for market parties to keep their own energy balance within each settlement period[2], i.e. provide energy programs (E-programs) to the TSO and act accordingly. Deviations on energy programs during realizing are settled by the *imbalance pricing system*.

To get an open market for the price setting of imbalance, the regulation market was introduced. The System Code foresees in the obligation to all suppliers (with connection capacity > 60 MW) to offer all available reserve capacity to TenneT at a market energy price but without capacity payment. Additional bilateral contracting with suppliers of regulating power obliges these suppliers to bid (all together) at least 250 MW of regulating power on the daily regulation market.

There are two imbalance prices, for *shortage* and *surplus* separately. The imbalance price for shortage is linked to the regulation price for positive power, whereas the imbalance price for surplus is linked to the regulation price for negative power.

Another important aspect of right pricing is the different kind of contributions to system balance that market parties can have. Two kinds are identified: *passive contribution* and *negative contribution*. A passive contribution is an imbalance with an opposite sign to system imbalance and a negative contribution is an imbalance with the same sign as the system balance. These differences can only be identified if during one settlement period there is dispatch of regulation and reserve power in one direction only. Then passive contributions are awarded the regulation price minus the incentive component whereas negative contributions pay the regulation price plus the incentive component[3].

In case of bi-directional dispatch during a settlement period passive or negative contributions can not be identified in which case imbalance price for surplus is directly linked to the dispatch price for negative regulation and reserve power whereas imbalance price for shortage is linked to the dispatch price for positive regulation and reserve power

For 2001, 250 MW of the required regulating power is contracted. The rest of the required regulation power and all of the required reserve power is procured on a day-to-day basis. To have a fall back in case insufficient power can be procured through this system TenneT has additionally contracted 300 MW of dedicated emergency capacity. This emergency power is thus in effect taken out of the market as well as the regulating power.

Reduction of imbalance versus reduction of imbalance cost

The imbalance pricing system is aimed at encouraging market players to operate efficiently:

- the imbalance on the part of Program Responsible Parties and their underlying market players should be kept to a minimum;
- the imbalance on the part of Program Responsible Parties and their underlying market players should be accidental.

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[2] TENNET has set the settlement period to 15 minutes

[3] TENNET has put the incentive component to zero.

Imbalance caused by the intermittence of DG-RES resources supplied on a liberalized market therefore brings about a main financial risk. The Program Responsible Party can try to avoid his imbalance in two ways:

- Minimizing the overall imbalance by counteracting on the intermittency of the wind park using buffer capacity.
- If the imbalance direction is known or predictable at short notice, the Program Responsible Party may consider not to act, if the portfolio imbalance is in the opposite direction of the system imbalance. It then creates a passive contribution to the system imbalance. The commodity prices (APX or contractual) will play a role in the decision.

Reactive power

In principle, every DSO is responsible for the reactive power balance in its own network. Under normal conditions there will be no exchange of reactive power at the connections points with the transmission grid. However, in practice, limited exchange is allowed of up to 50-100 MVAr per substation without financial compensation. Only the additional amounts will be charged to the DSO. Exchange of reactive power with consumers is not charged when the power factor remains higher than 0.85. Contracted producers receive a contractual tariff for reactive power, which is partly dependent on the number of production hours[4]. It can be concluded that the reactive power balance can be maintained relying mainly on regulations, with a only a limited role for the market mechanism.

Tariffs[5]

The tariffs that DNOs are allowed to charge their customers (both generators and consumers of electricity) influence the development of distributed generation. Since electricity distribution activities constitute a natural monopoly, pricing of the network services is subject to regulation.

Price-cap system

In the first regulation period from 2000 to 2004, DNO tariffs were regulated under the 'price-cap system', which establishes maximum tariffs. Initial tariffs in 2000 were set based on the tariffs of 1996. In subsequent years the maximum tariff P_t was reduced, assuming a certain rate of efficiency improvements over the previous period (t-1), by using the following formula:

$$P_t = \left(1 + \frac{CPI - X_t}{100}\right) P_{t-1}$$

CPI is the inflation rate based on the Consumer Price Index. The X-factor is different for each DNO, and is based on controllable costs, consisting of both operational and capital expenditures. Including both components provides incentives for DNOs to reduce operational costs, and at the same time prevent over-investments.

Price-quality regulation system

A basic flaw in the price-cap system is the lack of binding quality regulations regarding transactions between the DNO and its customers. Technical quality aspects are covered by grid code and system code (e.g. frequency and voltage fluctuations). Minimum performance standards have been formulated by DTe regarding to responses to metering problems, queries on charges and payments and execution of certain works.

Active management of distribution networks

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[4] Bedrijfsvoeringsconcept TenneT, BS-NES 02-064, 23 mei 2002, http://www.tennet.org

[5] This section is based on the SUSTELNET report Review of current electricity policy and regulation, Dutch Study Case, ECN Report February 2003, http://www.ecn.nl/docs/library/report/2003/i03005.pdf

Present distribution networks are generally operated independently from distributed generation [Busmod final report]. This results in inefficient use of the distribution network and limits the capacity of the distributed generation that can be connected. Active management of the distribution network allows the DSO to maximise the use of existing circuits by integrated control of transformer taps and reactive compensation devices as well as active and reactive power dispatch. [Busmod]

2.3 Energy prices - tariff structures

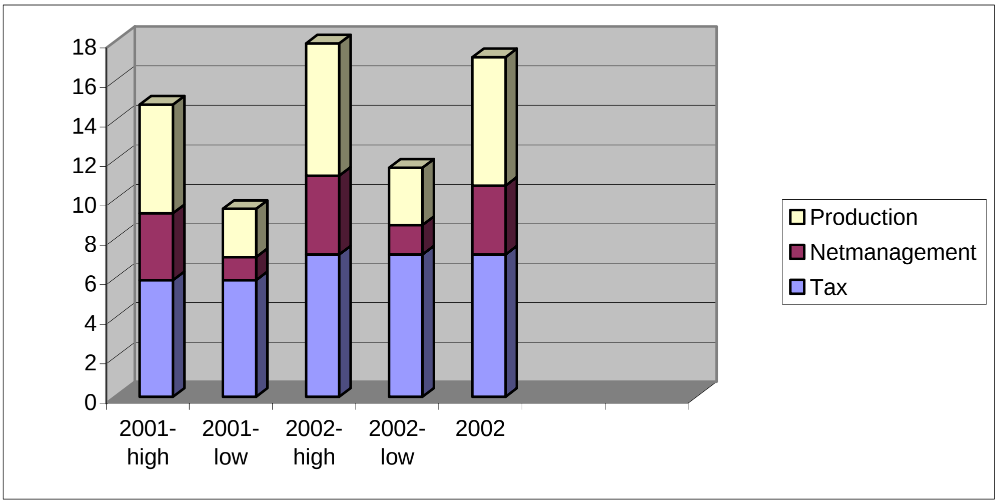

Figure 2.3 *Build-up of electricity prices (day(high) and night(low) tariff)*

When looking at the composition of prices for end users in 2001 and 2002 three elements are to be discriminated. Figure 2.3 illustrates the build-up of end user prices for the Dutch situation; the situation in other European countries however is not very much different.

Apart from a commodity price, based on production cost and partially market dependent, there is a time dependent grid management (mainly distribution) tariff (brown/dark) and a constant tax contribution (blue/grey). The net management tariff is capacity related In various European countries the distribution/transmission component is not 'shallow' but 'deep'; i.e in the tariff infrastructure components from high voltage transmission and distribution lines are included. The price constituents are discussed in the following paragraphs. The tax contribution may depend on the origin of electricity production (e.g. renewable versus fossil) and on type of consumer (industry, household).

Distribution network pricing
As can be seen in Figure 2.3, apart from market prices, there are two tariffs in the price build-up for the distribution price (net management in figure 2.3). This price accounts for transmission and distribution losses, investment cost and management of the infrastructures and metering and includes a profit margin. In high market price situations, the distribution component might increase due to added transport cost by import. Due to legislation, no market forces are operative on the distribution market. Although the situation on liberalised markets varies somewhat, typically, electricity market authorities set a fixed profit on distribution activities based on general five-year government bonds with 1.5 % added. The distribution prices have been increased with the introduction of the liberalisation typically by 4-7 %.

Retribution fee

In the Netherlands two basic systems exist for retribution cost / profit for redelivery of electricity by end-consumers:

- balancing: redelivered electricity is settled with electricity consumption;
- subsidy (MEP): the government pays a subsidy for redelivered electricity from renewable sources.

Balancing of retributed renewable electricity. On a yearly base the registered amount of redelivered electricity is substracted from the total registered consumption. Balancing is allowed up to a net consumption of 0 kWh.
At this moment own production is restricted to a certain amount (3000 kWh). A registered meter has to be installed in order to demonstrate this. Instead of a restriction on production in future a restriction on redelivery to the grid might be set.

MEP subsidy and retribution. If the electricity production from a renewable resource amounts to more than 3000 kWh on a yearly basis, one can request MEP subsidy. The MEP subsidy depends on the type of renewable resource and is given in €cts per kWh produced. On top of the subsidy one might get an extra retribution fee from the utility.
Registration of the resource as a renewable one is required, as is a certified electricity meter including production and retribution registration.

Energy monitoring and metering

In the liberalisation context, the process of metering is also decoupled. The market is open to independent certified metering companies. The projected revenues on simply selling electricity as a commodity with small margins are expected to decrease in the future. Therefore utility companies could also try to become more active on the metering market. In this respect, utilities might migrate from their traditional role of selling as much as possible of a commodity to advising their customers by using their metering data intelligently and in this way contributing to energy saving.

Currently the metering process strongly depends on customer size. Contracts range from simple lump sum power consumption over a year, via year-fixed time-of-day-dependent tariff groups, to very elaborate near real-time (15 minute resolution) pricing-schemes. This large variability is reflected in the metering process. Techniques range from meter reading and communication to the utility company by the end-user via the Internet using a web-browser interface to readings with a frequency of once every quarter of an hour with reporting via a Ram-mobile data network.

Apart from customers operating directly on the wholesale market, large (> 1 MW) and medium size customers (> 100 kW) have fixed metering procedures for their production and consumption of electricity. These procedures are supported by contract-defined mostly real-time prices. Metering typically takes place locally with one-hour resolution and daily data transfer to the metering company. Cost are 25-30 € per meter/month for AMR (Automated Meter Reading), data communication and balance statement.

In Italy at the moment intelligent meters are rolled-out to as many as 27 million customers. These meters use an Internet connection to transmit meter readings. Reasons for introducing these meters on such a large scale were prevention of tampering/revenue protection and contract management in areas with a weak grid. The last point pertains to the fact, that above a certain limit per day power consumption is charged higher.

In Finland, the GSM-network is used extensively for all kinds of payment including electricity [Salo, 2000]. Similar data-collection, service functions and alarming services in combination with web-technology are considered to yield applications that might satisfy user needs and extend the profile of energy companies. A first application would be the introduction of real-time billing instead of estimate-based pricing as used so far in many countries. AMR, when used in conjunction with frequent meter readings, also gives the opportunity to influence the demand side and settle demand side response contracts.

The development of these (and other) energy services through automated meters requires AMR not only as remote metering tool, but as an intelligent gateway for access to the customer home network.

3. Functional requirements of grids with distributed generation

3.1 Functional requirements for future decentralized networks

The shape of the electricity supply in future will change, due to liberalization (i.e. Dutch situation) and a trend towards the use of renewable energy sources, owned by a large number of energy suppliers. Integration of these new sources asks for new and intelligent concepts and methods (e.g. for protection of the distribution network or electronic controlled transformers). Increasingly the need of new high-tech components arises which can be placed decentralized, to gain intelligence of the network, to gain the service of the network and to make better use of the network.

Research questions for these future networks are:

- design of an intelligent decentralized network; there is a great need of theoretical structured models of intelligent decentralized network with a large number of distributed energy resources. The main issue is: how can we achieve stability of such a network.
- methods for controlling of large infra-structural networks in combination with guarding and on-line diagnostics
- new distribution concepts for large buildings and installations
- reducing cost of electricity storage.

Functional requirements for this future networks are:

- General
  - overload of transport lines must be avoided
  - voltages level must remain within limits
  - short circuits must be eliminated in time.

- Structure
  - bi-directional transport flow structure with the possibility of energy storage
  - pro-active control of production units
  - active control of voltage levels.

- Controlling of components
  - new control mechanisms must be developed to handle the presence of variable and only partly predictable renewable primary energy sources
  - control possibilities of suppliers on the network
  - control possibilities of loads on the network.

3.2 Criteria for low voltage distribution networks

3.2.1 General design criteria, state of the art [15]

Low voltage networks are generally designed for a period of 40 years. The average load at the point of common connection (PCC) of a family house in the Netherlands is around 1kVA (1.2 kVA with electrical cooking facilities) if around 300 houses are connected to one transformer. Increasing of the load of about 0.75% per year has to be taken into account. If decentralized generators are connected, a standard generated power of 0.5 kW per house will be also taken into account per transformer.

According to the standard NEN 50160 the voltage level at the connection point should be between 230V ± 10%. In order to guarantee this voltage level the medium voltage level should be between 10 kV ± 3,3%. In a low voltage net a lot of asymmetry occurs. During switching of a one phase load of 3,5 kVA a voltage dip of max. 3% may be caused.

Low voltage networks are driven as star networks without any low voltage coupling with neighbour networks.

Since 10/2003 all networks should be designed concurring the TNA criteria. All grounding facilities should fulfil the criteria mentioned in the standard N5283. The network supplier ask for grounding facilities which is though and net protected:

a) everywhere in the network,
b) before the connection point,
c) after the connection point

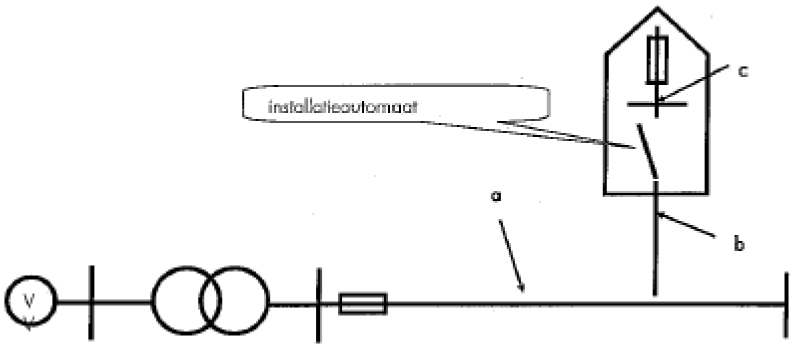

Figure 3.1 *Places for grounding facilities fulfilling the TNA norms*

In order to achieve a complete grounding protection the grounding of two neighbour cables can be connected. Figure 3.2 shows a network with a second (lighter) protection unit to solve grounding problems.

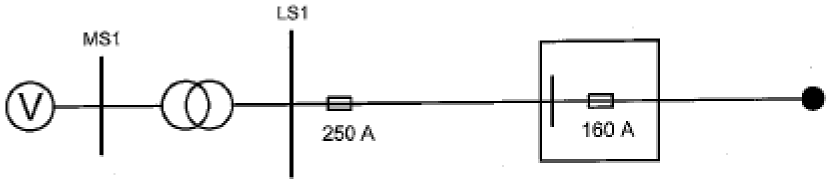

Figure 3.2 *Systems with two different protections units (MS=Medium Voltage; LS=Low Voltage)*

3.3 Impacts of Distributed Generation on power system protection

The major problems in power system protection associated with introduction of DG are as follows:

1. Increase or decrease of fault levels due to short-circuit contribution of DG.
2. Coordination of system protection and protection of DG.
3. Issues related to synchronization of DG and out-of-step protection.
4. Unintentional islanding and anti-islanding protection.
5. Integration with distribution network grounding.

1. Increase or decrease of fault levels due to short-circuit contribution of DG

During short-circuit DG generates fault current that depends strongly both on the generator type and the network configuration. Synchronous and induction generators are able to feed rather large fault current while inverter based systems may be controlled so that their output is limited to the rated current.

Introduction of directly-connected synchronous or induction generators may lead to false tripping as well as blinding of protection. For example, short-circuit on feeder 2 (see Figure 3.3) will cause false tripping of adjacent healthy feeder with DG due to large current contribution of DG to the fault and subsequent operation of over current relay at feeder 1.

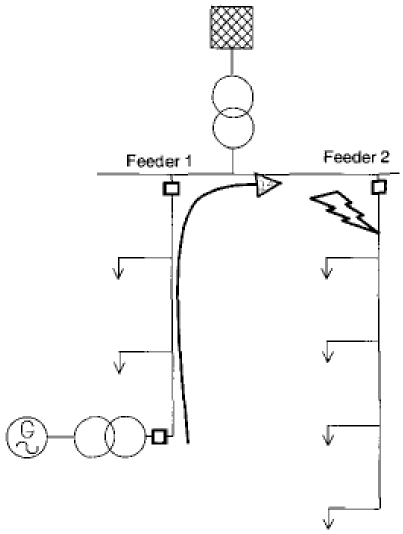

Figure 3.3 *Principle of false tripping*

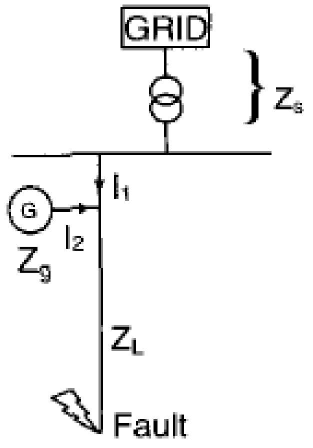

Figure 3.4 *Blinding of protection*

At the same time, if such generator is connected to the beginning of the feeder and a fault occurs at the feeder’s end (see Figure 3.4), the over-current relay of the feeder might not see the fault since the fault contribution of the grid is decreased in the presence of DG.

On the other hand, introduction of inverter based DG may lead to difficulties in a fault detection since such DG units do not feed any significant short-circuit current. Again, traditional way of protection, i.e. by means of over-current relays, will not help in this case [1].

2. Coordination of system protection and protection of DG

One of the great challenges is to coordinate actions of system protection and protection of DG in order to provide sufficient fastness and selectivity of operation of the whole system. The main aspect of the protection coordination is that the primary device, closer to the fault point, should act before the backup device. DG protection is quite complex and can include the following protection functions (depending on the type of DG): , over-current, field, over-excitation, loss of excitation, motoring, under-power, abnormal frequency, out of step, and commutation failure protection. If auto reclosure is an issue, system and DG protection must detect both phase and ground faults and be coordinated such that the DG trips and permits subsequent reclosing in the distribution system [2], [3].

3. Synchronization of DG and out-of-step protection

Directly connected synchronous generators have to be synchronized prior to their connection to the grid. After a short-circuit event these generators can loose synchronism. In that case they have to be disconnected from the grid since out-of-step operation will cause significant currents and damage of equipment.

4. Unintentional islanding and anti-islanding protection

Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by a distributed generator connected to the isolated subsystem. It can be desirable to permit such islanded operation to increase system reliability, and this is often done in the situations when a distributed generator provides backup power to the facility where it is installed (this is called ‘intentional islanding’). But unintentional islanding presents a number of problems related to power system protection:

A) Protection systems on the island are likely to be uncoordinated, due to drastic change in short-circuit current availability.
B) Utility breakers or circuit reclosers are likely to reconnect the island to the greater utility system when out of phase.

Due to the problems mentioned above current IEEE interconnection standards, for example [9], mandate control and protection measures to minimize the probability of an unintentional islanding, and to minimize the duration of island’s existence, if one should occur. A lot of papers are devoted to algorithms for fast islanding detection, for instance [10]-[13].

5. Integration with distribution network grounding

The interconnection of DG with distribution network must be compatible with the neutral grounding method used in distribution network.

For example, when DG is connected to the network by means of wye-delta transformer (see Figure 3.5), there are additional ground current paths. It is sometimes referred as a “ground source.” The current into a single-line-to-ground (SLG) fault is increased, and breakers or fuses attempting to interrupt this current may see excessive duty. The fault currents are no longer flowing in just one path from the substation to the fault, but are flowing in other parts – even those downline from the fault. Thus, relays can be fooled and line or transformer fuses can blow needlessly. Faulted circuit indicator devices will register fault current in many locations in the feeder not normally involved in the fault delaying the fault repair. One common side effect is that the feeder breaker will trip for any SLG fault on all feeders served off the same substation bus [14].

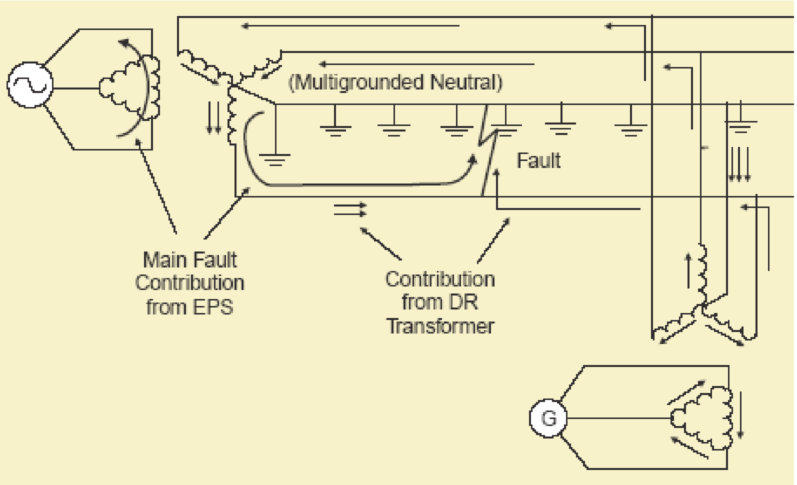

Figure 3.5 *A grounded-wye/delta transformer creates multiple ground paths and disrupts utility ground fault coordination*

4. ICT developments

4.1 Introduction

In general, ICT encompasses a number of different fields. Within an ICT context, the network connectivity and communication of computers, the computer hardware and the computer software are to be understood. In this chapter, each of these fields will be treated with specific reference to elements in the power system context. A combination of connectivity, communication, software and hardware constitutes a platform for an architecture for which a number of applications may be defined. ICT developments are relevant to power applications because this mainstream ICT-technology can be used for power applications. Furthermore, in equipment in the power net, e.g. switches and relays, dedicated intelligent components are used throughout. Furthermore, there have been a large number of efforts for standardization in the power sector resulting in IEC- and IEEE-standards. After a discussion of current developments a classification of developments and their impact on future, intelligent and flexible grids is given.

4.2 Connectivity

In the ICT-industry, research efforts are geared to connect as many actors as possible. This holds to the large-scale level as well for the small-scale level. For large scale scientific computing 'grid computing' as a means to solve large distributed computing problems has attracted a lot of attention. On the small-scale level, many research projects are on personal area networks or looking a bit wider to ambient technology or even ambient intelligence and smart environments [Smart, 2005]. The theme of the latter projects comes from the realization of the increased value and functional potential of mobile equipment, that people carry today, when connected. Future scenarios take into account up to 50 devices involved in those small-scale personal area networks. Up to now, major drawbacks of these networks are the lack of standardization and the time it takes to start up communication between nodes (currently in the order of seconds). Another class of small-scale connectivity constitutes home automation networks. These networks are used to increase the comfort-level of inhabitants in homes by automating repetitive and tedious tasks. In the home automation world a special adapted version of IEEE-802 for small-scale wireless networks with a maximum reach of 30 meter, Zigbee [Zigbee], is attracting much attention. The next level of connectivity involves 'last-mile' networks. These include well-known telephone lines, connecting homes to a telephone exchange, serving a few thousand subscribers, glass fibre (connected to the TV-network), serving 20-60 households via a concentrator, and high-frequency RF-based connections (digital television like, WiFi). Power Line Communication has been extensively investigated as a means to transfer information via the power distribution network. For broadband purposes, this has not been a success so far. Narrow-band PLC applications, so far have been used in the power industry for some time. Recently, a number of intelligent metering projects have started, where PLC is used from the households to the transformer station. Most notable is an intelligent metering project in Italy by ENEL, where 27 millions of households have been equipped with an intelligent communicating meter, that is connected via a number of connections to administrative back-office applications. Main partner in this project was IBM.

4.3 Communication

Once a node is installed, it may communicate using a communication mechanism. In the last decade, there have been a lot of developments in communication and communications protocols using broadcast, client-server and peer-to-peer level primitives. The ISO/OSI layer model is the generally adapted standard to subdivide the whole process of information exchange between nodes. The TCP/IP protocol, as used extensively in the Internet, has been in use for some decades; the new version IPv6 presents an upward compatible update, allowing addressing every square cm of the earth. Communication protocols operating on a same abstraction level, include

RS-232, RS-485, X-10, Konnex and several more. Downscaling of TCP/IP-stacks and WEB-Server technology to ever-smaller footprints means that the proportion of Internet-connectivity for devices will increase in the near future. A large number of applications for these small, interconnected networks have been envisaged, but few have actually been realized at the moment.

4.4 Hardware

Currently, the performances for mainstream processors begin to deviate from Moore's law stating a doubling every 1,5 year. Word length range of processors in intelligent devices goes from 8 to 64 bit. 64-bit architectures start to increase their market share. Digital signal processors, designed to do fast computations with a number of analogous and digital I/O-ports follow this trend. Generally speaking computing capacity constraints do not affect power distribution applications.

4.5 Software

Given the popularity of TCP/IP, software components are increasingly equipped with functionality to operate in WEB-environments. XML, in this respect, forms an important development for transparent, portable exchange of information. XML provides opportunities for using Service Oriented Architectures for applications. These types of applications gradually lay the emphasis for providing physical computers and software to central nodes and makes software packages transparent as to where they are executed. Furthermore, XML forms a marshalling mechanism for portable exchange of information between different computing platforms. On a higher abstraction level, the Semantic Web has led to a large research effort. In this approach, the WEB not only is a number of directories containing pages, but is a number of objects, that are functionally related by an ontology and that each have a predefined meaning. In the semantic WEB-approach, every real-world item, when connected, knows what functionality it has in all applications and also has primitives, via the ontology definition, to discover what functionality other objects have. Another standard at the moment, yielding primitives for the development of service applications, is the OSG-i standard [OSGI, 2005].

4.6 The role of architecture in intelligent electricity networks

Parts of the development described previously are also in focus of the electricity world nowadays. In a number of research efforts, a number of architectural models have been defined or are in the process of being defined. In some industrial sectors a common framework for business operations has been developed. For instance, in the oil industry a comprehensive information architecture has been established and favours application integration and interoperability between applications and database models. In order for an architecture to be valid, essentially object models, application logic and events and responses for systems have to be described. In the US, in 1991 the UCA (Utility Communications Architecture) was established, as a first, generic descriptive framework for utility operations. An architecture, in ICT context, is the constellation of hardware and software satisfying the requirements of a number of applications. The architecture, then, was the incentive for the development of a number of standards in the utility field. As a successor to this architecture, recently a follow-up was developed as the results of the CEIDS-project, the IntelliGrid Architecture [Intelligrid, 2003]. The architecture was the result of an inventory of 400 utility applications in a number of electricity infrastructure application domains and from existing standards. From these, an extensive, abstract framework is derived to get a common view on how to structure these applications and to get ready-to-use design frameworks for applications and a common reference for the development of standards. The view is derived using methods, well known in information analysis and system architecture as used for developing application software. The applications are mapped to object models using use cases via UML (Unified Modelling Language). The distributed operation of the applications is modelled with RM-ODP [RM-ODP,2005]. Using a combination of these two techniques, for each work area in the electricity sector, an architecture environment is generated including all necessary object models, links between these models and inter-process communication behaviour. This enables a generic approach for applications and the possibility of reuse on the model level. The approach is suited to be implemented using WEB-based technology like XML and inter-process communication/context switching techniques like WSDL/UDDI and SOAP. A number of growth areas have been considered especially:

- Wide area measurement and control. Special emphasis has been on a pro-active, self-optimising grid and that has built-in reliability functions.
- Advanced Distribution Automation. Especially with regard to incorporating DG-RES resources w.r.t. fault detection and localization and pro-active response of distributed systems with a larger fraction of DG-RES.
- Customer portal. The portal facilitates real-time pricing, demand response, metering and mechanisms to implement market rules as well.

Within IEEE a commission recently has developed the P1547-standard [P1547, 2005], which is developed for interconnecting distributed, customer owned generation to the power grid with central control SCADA-systems. The IEC has developed a new standard for substation automation [IEC-61850, 2003].

4.7 Research-level architectures

In recent European projects, work on the information architectures has been done as well. The results of CRISP WP 2 and 3 [CRISP, D1.2] [AAMAS, 2005] [FPS, 2005a] [CRIS, 2004b] [IRED, 2004] [DE, 2005] show, that an agent-algorithm based approach, implemented on mainstream ICT, holds promise for coordinating of operation of a large number of distributed generators and consumers. Such an agent-based architecture viewed from a processing point of view is shown as a diagram in Figure 4.1. Clusters of appliances coordinate their operation in a hierarchical way. First, at the lowest (11n) level, supply and demand curves are matched using an auctioning mechanism executed at one step higher level in the hierarchy. A similar approach is followed in the Microgrids-project [MICROGRIDS 2005].

Ideally, in order to balance the total grid at a given time, then, first the lowest segments of the grid with their supply and demand curves are matched. To introduce power flow from adjoining or higher segments in the hierarchy, additional agents bidding with price limits for import or export based on initial value constraints are used. The latter account for distribution cost and may model line cost. The distance related component in the price then would avoid transport of power over too large distances to other subnets. Cycles of distribution refinement will be alternated with cycles of value refinement until convergence is achieved. Generic PowerMatcher Modules (PMMs) [PowerMatcher, 2005] are connected to one another using a CCI (Cluster Connection Interface), which establishes connectivity to higher level CCI's. PMMs may have an external interface to get access to specific external information (see figure 4.2).

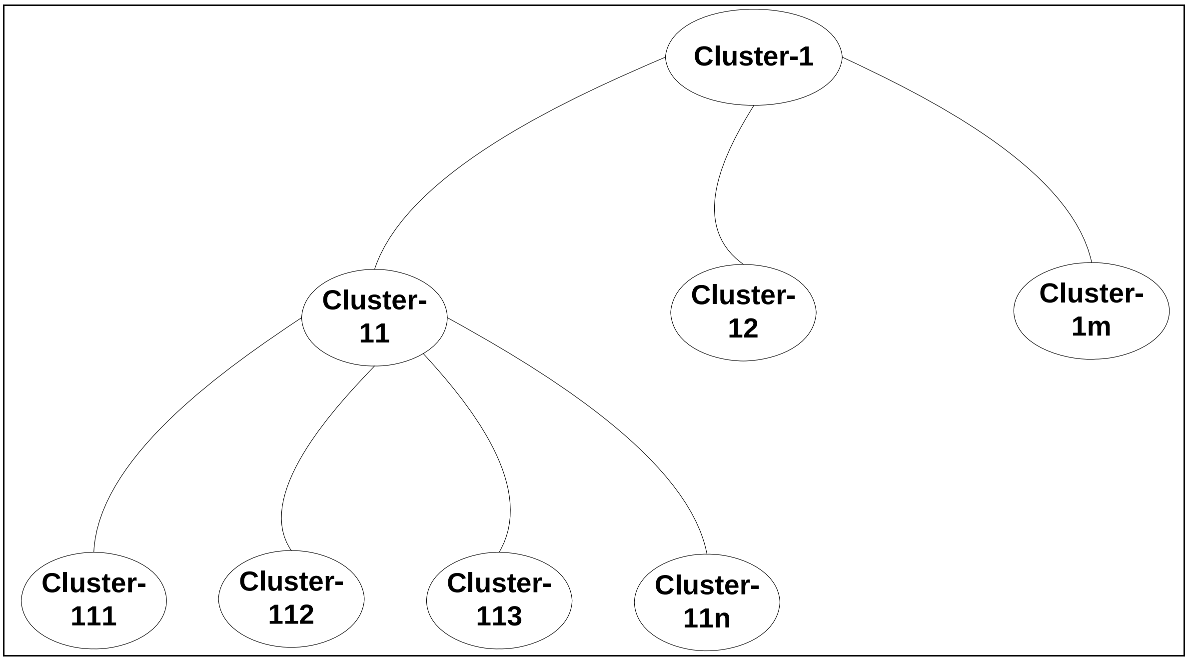

Figure 4.1 *Processing view of agent based operation*

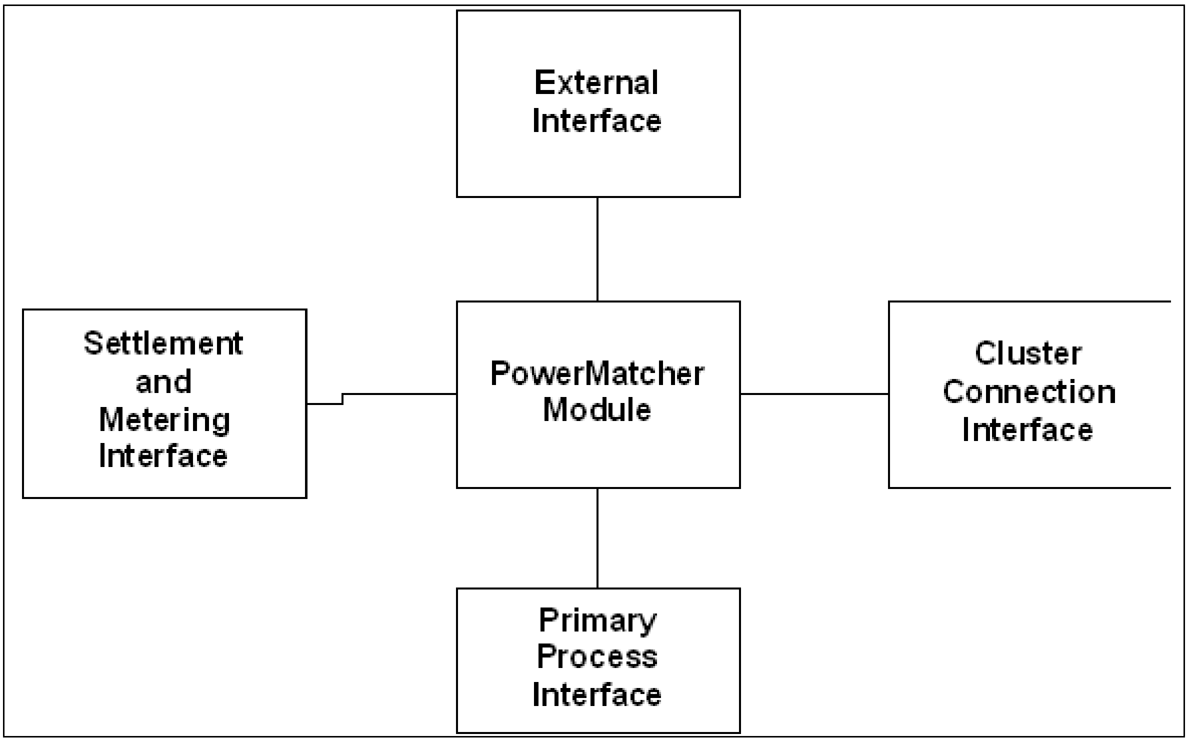

Figure 4.2 *Hardware/software partitioning*

For instance, this information may pertain to meteorological time series of future ambient temperature, used to assess effects of bids on the internal power market on the realized internal comfort of a building. Furthermore, the way the user applies settings to the appliance, specific to the bidding behaviour, is part of the external interface.

The PPI (Primary Process Interface) provides the link to appliance control. For a number of examples of a PPI, reference can be made to the design of the CRISP field test, where a number of OPCServer-based interfaces have been defined.

The fourth interface is concerned with metering and settlement. Metering in this respect means collecting consumed and produced energy with sufficient accuracy in time and power. Settlement for an SMI refers to the process of final accounting of the proposed bids and settling charges based on the actual productions/consumptions. Metering infrastructures for C/I customers currently are based on public telephone networks based on one-way communication. The metering company phoning in to the customer exchanges metered data periodically. Metered data serve the purpose of billing according to contracts and for settlement by the TSO. For smaller customers metering infrastructures are based on Power Line Communication (PLC) to the transformer station with access to a public glass fibre or mobile network like GSM. From metering access there essentially is a need for only one-way communication with a simple protocol; the central metering server issues a request and verification of a customer station-id and an upload of metering data for a certain time-period is done. For more advanced applications, there is a need for real-time information exchange on a two-way communication basis. In this architecture, an always-on connection exists, which can be used by both SMIs for real-time information exchange. Thus, for metering and for more advanced control related applications different requirements are to be met. Metering requires secure one way-up communication on a possibly irregular basis. Thus, it is based on a loosely coupled client-server connection. Responsibility is at the central level. An SMI, in this architecture, is a peer-to-peer communicating entity.

For more advanced applications, there is a need for real-time information exchange on a two-way communication basis. In this architecture, an always-on connection exists, which can be used by both machines for real-time information exchange. Thus, for metering and for more advanced control related applications different requirements are to be met. Metering requires secure one way-up communication on a possibly irregular basis. Thus, it is based on a loosely coupled client-server connection. Responsibility is at the central level.

The requirements for Demand Response related applications [IEA-DDR, 2004], which involve influencing local control on the basis of central coordination, are different. Here responsibility is shared between the local and the central level with an emphasis on the local responsibility for the primary user process.

Looking from an architectural point of view, metering processes and behaviour/nature of events is not similar to control processes as are intended for demand response applications. Therefore, a metering infrastructure preferably has to have a small, transparent interface to the local control system of suppliers and demanders of energy. Another advantage of having responsibilities for control applications at the lowest level is, that managing and coordinating a high DG-RES infrastructure in a hierarchical way can hardly be imagined using SCADA-based approaches using existing energy management (EMS) and distribution management systems (DMS). Virtual entities at a number of aggregation levels are necessary. Within the aggregation levels, coordination takes place using bottom-up mechanisms.

Agents as a metaphor for small, responsive software entities to be actors within this new context and micro-economic algorithms for coordination, that directly give a mapping of utility and cost for coordination of these multi-actor systems, play a key role in future architectures for virtual aggregation levels. In order to further elaborate on this context further first some points in the context have to be clarified.

Virtual entities aggregating supply and demand have to do with various kinds of 'markets' for coordination. These may closely resemble those currently defined to operate in a liberalised power market and generate value for PV-parties but have to be distinguished clearly. A key value-generating factor is the 'flex'; the flexibility in time and in capacity for supplying and demanding energy. Translating the 'flex' locally into strategies that expose the demand and supply most profitably on the market is the key issue for the end-customer.

4.8 Applications to be executed using the architecture

ICT enables the definition of a number of applications. The applications to be envisaged in the future cover a number of aspects:

- Metering and settlement. Trends to be envisaged are more frequent read-out of electricity data and more frequent information exchange with the back-office applications in the field. Settlement may take place according to new financial schemes including exposure of customers to more real-time prices and allowing capacity payments for curtailing of loads or extra generation in certain periods.
- Energy management. Control of load flows in grids by actively searching favourable operation modes to satisfy common optimisation goals.
- Distribution management. Operating the flows in a scheduled, pro-active way in the lower grid areas in order to mitigate bottlenecks and to postpone investment in grid enforcement, once a larger proportion of local small-scale DG-RES generators are introduced in the grid.
- Home portal. This may be the successor of the traditional yearly energy-bill on paper. Internet portals are becoming a commonplace on the Internet for getting feedback and performing transactions (e.g. for banking, online reservations). Similar roles may be envisioned once electricity usage and grid operational data are connected to the Internet-databases. In the Scandinavian countries and Italy these applications with customer feedback already have been introduced following the implementation of intelligent metering.
- Formation of virtual communities with a common aim. ICT has the ability for transparently coupling power related entities in separate geographical areas in so-called virtual power plants (VPPs). These may be operated in much the same way as an ordinary power plant; however, if the configuration is chosen in such a way, that a considerable flexibility in reaction to real-time pricing incentives is possible, considerable financial gains may be achieved on the day-ahead electricity market and power imbalance market [CRISP D3.2A].
- Power quality and installation monitoring applications. Introduction of DG-RES leads to a lower level in the grid, which power quality parameters as Voltage and frequency as well as the occurrence of harmonics have to be monitored and corrected for.
- Remote maintenance and servicing. Currently, utility buildings and installations are constantly monitored on-line and monitoring data lead to a more structured and pro-active role of maintenance. Installation maintenance takes place only when necessary and as indicated by the monitoring system. With the introduction of narrow-band control gateways in households for other purposes (e.g. monitoring elderly people, domotics functions), maintenance applications may be a welcome addition.

4.9 From top-down coordination mechanisms in traditional settings to fine-grained control in dispersed, novel grid architectures with a high percentage of DG-RES

The role of retail and small business consumers in future 'toppled' electricity grids will shift to a more reactive and pro-active one. Supply and demand tariffs will be more differentiated towards time of consumption/production and type of energy carrier involved. Innovative business models and contracts will be developed, as they are now already available for larger industrial and large business customers. An intelligent ICT-infrastructure will support these models.

In current nationwide operations of TSO's, a market design has been made to ensure a secure and continuous balance between supply and demand for electricity on all levels of the network.

The market design is based on the actual subdivision of demand and supply in the electricity network on all voltage levels and the characteristics of the primary processes, present in the context of the power system as a whole viewed in a top-down fashion. In a network based on a considerable percentage of small DG-RES resources, the primary process characteristics of systems involved in energy supply and demand differ considerably. This means, that a different layering of the markets and different market types and auctioning mechanisms may yield a better expression and articulation of the flexibility of demand and supply. Opposite to the current situation, in this respect, one could consider, various time span, intra-day markets and many-to-many auctioneering mechanisms.

From an power quality point of view, an active network, with customers both generating and consuming electricity, may require new instruments and mechanisms for distribution network ancillary services to maintain quality of supply. Ancillary services address the short term balancing of supply and demand and the quality of the power delivered.

As an example of today's operation, current system balancing markets are based on the auction model. Reserve capacity is offered to TenneT at a supplier offered energy price in blocks of a quarter of an hour. A bidding ladder constitutes the price setting at each imbalance period. In an active distribution network (part of) the spinning reserve (currently 160 MW on a nationwide basis) might be taken over by making use of degrees of freedom in the dynamics within the network. The PowerMatcher concept, featuring distributed decision making on the basis of local information exchanged between peers, is able to deal with these dynamics at a local power market level. Although the PowerMatcher is applied in earlier projects as a planning instrument on a time period scale of hours and quarters of hours, the concept itself can be scaled to time periods of seconds if infrastructure (communication, speed of processing) allows it. Thus the PowerMatcher needs to be transformed from a planning instrument to a control strategy and eventually a control instrument.

It is possible to control the stability of the local power system by reading stability information from network locations. The technical parameters in the electricity network that can provide input to local stability control have to be identified, such as: capacity constraints; dips and surges; voltage level and frequency; ancillary services etc. The time scale from operation to control is essential here. Some control aspects will have to be solved locally at the node, others may provide input for valuation in the optimisation process of the PowerMatcher. Note that this is a new research area, which we cannot cover completely within the Flexible project.
Thus, a detailed, further characterisation of demand and supply nodes in high DG-RES distribution networks at low voltage levels is necessary. In the current grid, from electrical appliances and generators, only a limited number of parameters are known within a limited scope. In a future distribution grid, appliances are more exposed to the outside world and to each other. Table 4.1 gives an example of a comparison of typical information per device currently necessary for operating the electricity grid in a top-down way and possible extra information necessary for concerted operation using agent algorithms when operated in a fine-grained, bottom-up way.

Table 4.1 *Example attributes of appliances for operating the grid*

Top-down	***Toppled***
Power (t;W); consumed or generated Energy (Δt,Ws)	Minimal/Maximal Power (t,W) Power (t,W); consumed or generated Energy (Δt;Ws) ICT_Connectivity EPS_Topology Primary Process Linked Secondary Process Linked External Context Physical aggregation Virtual aggregation

In the top-down manner, the power of an appliance determines the consumption at a certain moment. For small consumers, the prediction of Power(t) is a certain period ahead is obtained by statistical methods with a large population of appliances. The delivered energy is determined for one or a number of appliances at a transfer point for a metering period ranging from 5 minutes for large consumers/producers and 1 year for small retail customers. The ICT_Connectivity address represents the physical connectivity information. As for metering, the connectivity may be physically aggregated for a number of electricity network nodes. The EPS_Topology represents the information about the physical location in the power network. The topology enables introduction of distribution components and cost for grid optimisation applications. The primary process is the process the power is used for (e.g. lighting, washing, drying etc.). The primary process represents an opportunity for clustering based on common interests. For instance, precise prediction of the amount of electricity for lighting a day ahead is risky, while predicting the lighting load for 1000 households can be done with error margins below 2 %. The linked secondary process allows introduction of co-generation and/or storage. The linked external context can represent the dependency upon the meteorological circumstances of the primary or secondary process. Physical aggregation can be seen as a static clustering of nodes in the physical grid topology for metering, control and settlement purposes. Virtual aggregation can be seen as a dynamic way of incorporating a set of installations to a market portfolio.
A few examples may make things clearer.
Co-generation: Typically, these types of installations have to be operated with a certain minimum duration of operation. The rationale between physical clustering here is the spread in operating conditions, which enables each participant to operate during a minimal time-block length yielding a constant supply of the cluster avoiding transmission bottlenecks to higher grid levels. At the same time the installation may also be part of a virtual aggregation level to maximize yield on power markets optimally using the operational flexibility limits.

Photovoltaic: Physical clustering here will reduce risk due to unexpected local clouds and increase the value of the portfolio. A Photovoltaic system can be associated on the local level with an electricity storage unit or on a higher level with a storage cluster.

Bottom-up supply-demand matching involves an interplay between strategic clustering of portfolios and operation of appliances on the local markets.

In making an architectural model, local intelligence of nodes has to modelled and functions have to be designed for:

- Local context discovery
- Cluster evaluation functions; what advantage will be obtained by matching profiles
- Getting best market results

In order to achieve pro-active and reactive power network support of clustering in order to serve local ancillary services and market portfolio optimisation goals a number of topics have to be investigated:

- The data model with relevant power related attributes of local nodes in the grid.
- Agent design model and local market design variants for coordination.
- Multi-optimisation target coordination mechanisms supporting above designs.
- The underlying ICT enabling mentioned services, the related message exchanges and the semantics of the messages.
- Possible new or adapted market architectures for concerted and coordinated operation of large numbers of small DG-RES nodes in an aggregated and clustered setting
- Possible new business cases emerging from these designs: stakeholders, profits, suppliers and consumers of services.
- Comparison of advantages and disadvantages of centralized versus decentralized control.
- Calculation of stability indicators & time scales: are these techniques also suited for compensating dips and surges: in the milliseconds range; for voltage control: in the seconds range.
- Scenarios and simulations in the Flexible standard grid configuration.

5. Commercial supply and demand matching concepts for load control and energy storage optimisation

5.1 Load control measures

Demand side management

Demand side management has been a topic of attention during the last 20-30 years. Main goal is to utilise both production capacity and transport capacity in an optimal way and especially to solve peak load problems. This is not only a concern for the utilities, but requires cooperation from the consumer side as well. Since electricity is not the core business of a consumer, the supplier has to take a lead in this process and make it economically profitable for both sides. Additional advantage may be a strengthened relationship between supplier and consumer.

Most demand side techniques that have been developed in practice or in theory rely on estimations of the effect of a demand side action. Good estimates of the effect relies either on (i) a good personal knowledge and experience among involved personnel, or (ii) other knowledge based on consumption patterns of the involved consumer categories, etc.

The extent to which a user demand may be controlled, depends upon the quality attributes and the demand articulation. The first aspect covers the interruptibility of the power delivered to the device. Power used for feeding computer hardware has to be exactly at the right voltage level and should be uninterrupted. On the other hands, power for heating water in washing processes has very limited quality demands and is interruptible.

Examples:

- Batch processes

  Batch processes in industry can be scheduled to avoid peak demand or take advantage of peak supply. Washing and drying processes at the household level also fall in this category.

- Rotating equipment

  The demand elasticity for industrial pumps and ventilators often is high. On the small customer scale, the pump of a private swimming pool can be part of demand response. In the US, investment in this kind of apparatus is shown to be the most easily paid back application for cost saving.

- Industrial freezing and heating loads

  Long-term food storage industries (cold stores) and industries using industrial ovens to reach a constant high temperature level form another category of switchable loads. Currently control of these freezers and heaters is on an on/off basis with immediate delivery of power expected when a certain temperature bandwidth has been exceeded. New types of freezers have a continuous instead of an on/off control mechanism. These are the first that would benefit from appliance connectivity by induced control from price signals.

- Thermal comfort control

  Thermal comfort control can be expressed by articulation functions, allowing a shift in demand at certain times more reluctantly than at other times. Recent developments such as the SMART Building [ISPLC, 2002] for large offices and the Comfort-Box for residential houses show the ability of thermal controllers to react to price signals and control user comfort.

- Lighting loads
  In office environments, experiments conducted by the Lighting Institute [**LI, 2003**] show, that a reduction of the lighting level by 30 % in case of power supply scarcity, did hardly impede the visual comfort for office workers. Lighting loads are switcheable in horticultural environments, when used for assimilation lighting. Traffic lighting, especially during quiet hours, can also be diminished.

- Hot tap-water generation and heat buffers
  Hot water generation by an electric heater is one of the switchable loads, which have been used extensively for demand side management programs. Heat buffering also plays an important role in the horticultural sector, coupled to power production of (micro)CHP.

- Electricity buffers
  Direct storage of electricity in buffers would be a direct way to act directly to market signals. Redox flow cells are attracting a lot of attention in this respect. These are also in the picture as a source of reserve capacity in power outage situations.
  There is a large research interest in all forms of power storage with different duration ranging from the millisecond range in the form of super-capacitors to hours and days in water pumping installations between the two levels. On the consumer level, charging units for all-electric or hybrid vehicles is a future prospect.

- Power consuming PC's, audio/video and home automation equipment
  This demand is hardly shiftable, except for standby devices.

Demand response resources
[IEA-DDR, 2004] defines demand response as *the ability of electricity demand to respond to variations in electricity prices in 'market' or 'real' time*. Demand response resource (DRR) programs are the successors of Demand Side Management programs. A fundamental difference between DRR and DSM is the interaction with the consumer. In DRR-programs the emphasis is on consumer-action as opposed to utility control room action. An important aspect in the role of DRR is the associated information technology to settle contracts in liberalised markets.

Part of problems of liberalised markets, especially in the US, currently is the low credit rating of the energy generation sector. This means investments in the infrastructures are decreasing and must have a short payback period. This trend has led to a larger proportion of DG in the US. DRR is a comparable option to DG in this changing scene. DRR can be considered to be a means of selling (back) an already contracted amount of something you do not want to consume, in the light of new information. A main driver for this action is the current market price.
A special application of DRR can be found in DRR programs as currently set-up in the USA that are positioned on the wholesale market. DRR-markets are examples of forward markets in which risks on traditional power wholesale markets may be mitigated in the same way as in other financial derivative markets futures are used to hedge risks.

Electricity traditionally has low price elasticity. By increasing consumer responsiveness to price incentives, the elasticity of demand will be increased. DRR involves "elastic" demand, with a certain flexibility. Apart from elasticity, articulation also plays an important role: the demand articulation indicates the necessity a demand has to be fulfilled within a certain time.

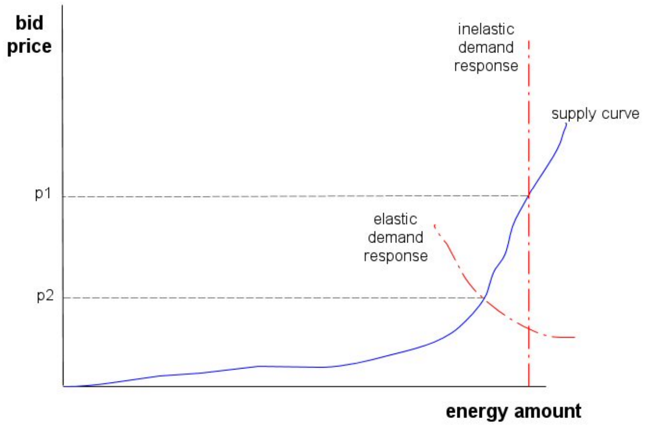

Figure 5.1 *Impact of elastic demand on market clearing price*

The impact of demand elasticity on the market-clearing price can be seen in Figure 5.1. The figure shows, next to a supply curve, two demand curves: the vertical red line denotes a static demand curve, showing inelastic demand and leading to price p1; the curved red line indicates the elastic demand response curve, which leads to a price p2. The ultimate price can be seen to decrease.

DRR-capacity may serve several roles in the power grid:

- Power curtailment in emergency situations (low-probability/high-consequence events). Typical customer response times are in the order of a few hours. DRR-contracts may not lead to any curtailment of power during years, but then sometimes may be effectuated more than one time during a year.

- Capacity driven: with the aim of avoiding congestion in the network. Using DRR, investments in transmission lines or in new large power plants can be deferred. Apart from the cost prevented, more time for planning procedures is available. Although the current 8/14 2003 power outage in the US was not a result of congestion or emergency situations, but due to an operator misjudgement, power contracted in DRR-programs in NY facilitated start-up of essential power functions after the black-out.

- Price peak reduction: contracted amounts of power are switched-off in case short-term market prices reach certain levels. One of the problems here is, that DRR itself has an influence on price formation and that financial profits not necessarily go to parties involved in DRR-contracts. Market simulations suggest, that a 5 % share of DRR may result in a 50 % decrease of prices in peak periods.

DRR can be seen as an extension on Demand Side Management, in which the customer gets an active role based on market mechanisms. However, DRR, depending on its role, can also be seen a form of intelligent load shedding or peak shaving. In both views it fits well in the liberalised electricity market field.

Experiences with DRR are being built-up at the moment worldwide; the largest programs being in the USA (NYISO: 1531 MW with 1419 customers) and South Korea. Furthermore, due to imminent power shortages, initiatives are being undertaken or investigated in Norway, Australia, Spain, Italy and New Zealand. A trial in Australia [CSIRO] shows significant results in which DRR could be worth up to $1 billion per year to the National Electricity Market for a relatively small investment in coordination.

DRR, making large customers aware of their time-dependent energy use, can be shown to increase the energy efficiency. In California, with the threat of power distribution grid capacity problems during summer, the amount of power that can be withdrawn from the grid is limited by a utility switcheable customer maximum load capacity. An IEA-subtask in the "Demand Side Management: Technology & Programmes"-task to further investigate the potential of demand response resources has found worldwide support.

Supply and demand matching

The introduction of large scale distributed generation based on small units and RES will change the operation of the power distribution infrastructure. Power systems typically are operated in a top-down matter, reflecting the fact that power production and planning take place on a central level. When incorporating a more considerable fraction of small-scale producers at a low level in the power network on the basis of, for instance, renewable energy, operation of the distribution grid requires large amounts of distributed data to be collected, resulting in a more extensive information and data communication network.

In this distributed power network the essential difference between supply and demand is no longer prevalent. Supply can just be considered as negative demand. Traditional demand side management (DSM) will need inclusion of supply side management. DRR can be extended to not only increased demand elasticity, but also supply elasticity at every level in the power network. As we have seen from DDR, market mechanisms can be used to control this process. New developments in ICT such as distributed and intelligent information networks, supported by the Internet paradigm, can be the carrier for this control. A framework of novel concepts and possible technology directions, called Supply and Demand Matching (SDM) have recently been developed in the CRISP project [CRISP D1.2].

5.2 Energy Storage Optimisation

In order to be able to introduce large-scale renewable energy resources in the electricity infrastructure, the intermittent character of RES requires to find low-cost, high-efficient energy storage systems to overcome the gap between times of generation and time of consumption and for stabilisation of the electricity network. A range of existing and emerging technologies are applicable:

- Lithium-based
- Redox-flow - combined storage of heat and electricity; independent sizing of power and capacity.
- Super capacitors - energy storage devices with high power but small energy storage capacity
- Flywheels (high power, low energy)
- Hydrogen storage / Fuel cells
- Hydro-storage

The choice of energy storage depends on the type of application. A number of parameters characterise each solution:
- operational temperature
- power / capacity
- number of cycles
- charge/discharge efficiency
- technical lifetime
- production cost
- environmental and health safety

Types of application:

- Load levelling: shifting of peak load by storage at times of overproduction / low cost and discharge at periods of high consumption / high cost.
- Momentary voltage dip suppression: requires short response characteristics.
- Emergency power supply: requires low storage losses.
- Compensation for intermittent supply (PV, wind).
- Demand and supply control: as part of a PowerMatcher cluster.

Reference: http://www.islandsonline.org/island2010/PDF/RES and Technologies.pdf

Several basic scenarios for direct marketing of electricity storage systems can be applied:

- Day and night tariff differences for households.
- Keeping the locally produced electricity in-house.
- Direct profit from the APX market: selling at (expected) high prices, buying at (expected) low prices.
- Reduction of imbalance for programme responsible parties.
- Improving the value of centrally produced electricity from renewable sources.

Algorithms have been developed by ECN [ESTORE] in order to evaluate the economical value of electricity storage on these markets. At the moment it is very hard to define a profitable scenario. The algorithms may give insight in technological constraints and directions of improvement.

5.3 The PowerMatcher

Combining multi-agent systems with microeconomic principles, creates? a coordination system for supply and demand of electricity in networks with a high share of distributed generation.

The PowerMatcher is an intelligent software concept for distributed control of power production and consumption and storage systems. It is developed by ECN, in cooperation with industrial and academic partners. The PowerMatcher enables control of a cluster of devices, such that the cluster behaves as one single system. This is achieved by tuning of demand and supply within the cluster in an optimal way.

The PowerMatcher makes use of advanced ICT technology such as multi-agent systems and electronic markets.

Reference: [AAMAS, 2005].

PowerMatcher - the value of local energy

Large scale distributed generation confronts us with the question how to make use of the distributed infrastructure to deliver better value to the customers. By increasing the demand when ample supply is around, and by decreasing the demand at peak consumption periods we can make a cost-effective use of generated power. Adding the fact that, in general, use of electricity as close as possible to the site of its production will be part of a cost-effective solution, and lowering distribution cost, a local power market concept analogous to the APX power exchange market comes into mind.

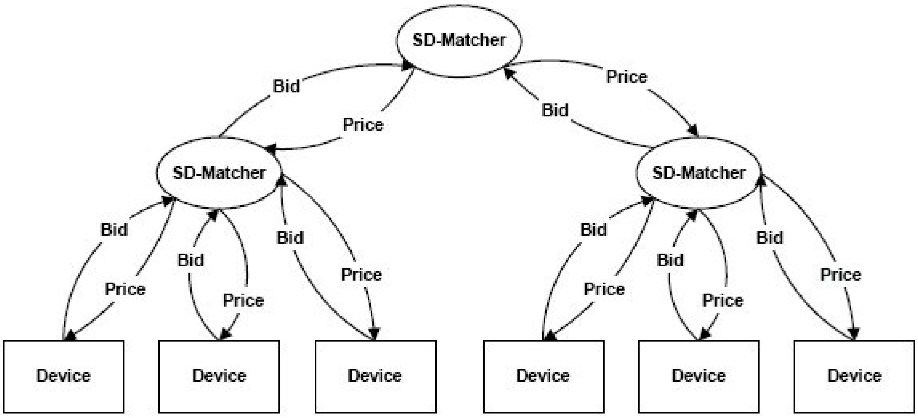

Figure 5.2 *Hierarchical tree-structure of electronic markets for supply and demand matching*

PowerMatcher - distributed control and microeconomics

Large-scale industrial control in network settings is an example of real-world applications involving large numbers of interacting agents. A first start in developing a fundamental theory of distributed intelligence underlying such applications can be found in [CRIS, 2004b].

Consider an interactive society of a large number of agents, each of which has an individual control task. What kind of control strategies will interactively emerge from this agent society, and how good are these with respect to both local and global control performance criteria? There are two, very different but both well-formalized, theories that can be brought to bear to this problem: control theory and microeconomic theory. The conceptual picture, then, is that agents are negotiating and trading with each other on a marketplace in order to acquire the resources that they need to achieve their individual control action goals.

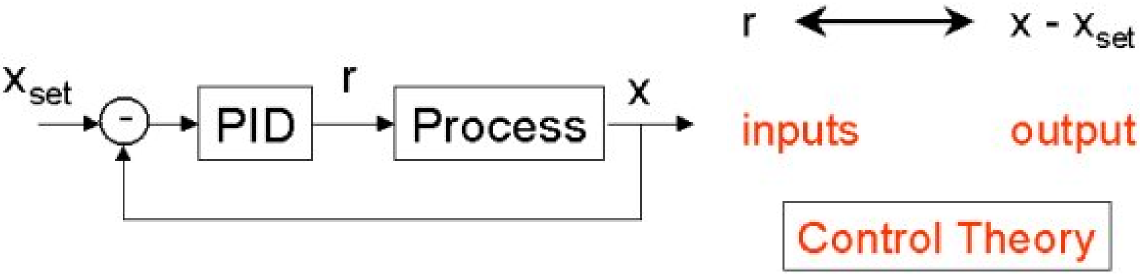

Figure 5.3 *Control theory: (a) feedback control loop; (b) input - output matching*

Control theory deals with the behaviour of dynamical systems over time. The desired output of a system is called the reference variable. When one or more output variables of a system need to show a certain behaviour over time, a controller tries to manipulate the inputs of the system (in Figure 5.3 denoted by "r") to realize this behaviour at the output of the system (denoted by "x - xset").

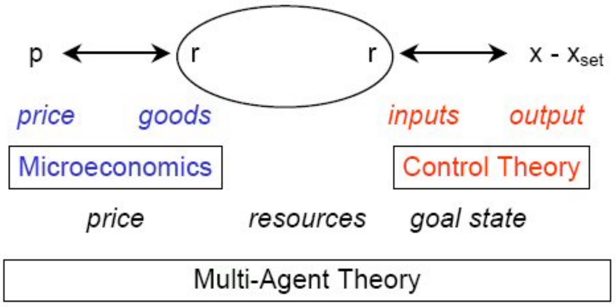

Figure 5.4 *Microeconomics and control theory unified*

In microeconomics a commodity is traded at a certain price. The price formation process is based on the value of the commodity in a market. If we associate the commodity (or goods) with the inputs of a control system, as sketched in Figure 5.4, we can develop a control, where price formation is directly coupled to the system under control.

In the PowerMatcher, agents represent the dynamical systems. On the price formation market the buying and selling agents evaluate the value of the electricity to be traded, based on their internal process state. Thus microeconomics and control theory are combined into a market-based control.

PowerMatcher - technical constraints

Although it seems that the first version of the PowerMatcher looks only at costs and benefits to consumers and generators, this is not the complete truth. Commodity prices are not just market prices, but can also be used in a cluster of power systems to value production and consumption based on other measures than cost. The price-forming process is then just a means to control or coordinate the cluster.

This aspect of the PowerMatcher concept is not yet fully worked out, but within the Flexibel project we plan to look at technical parameters in the electricity network that can provide input to the valuation process of the PowerMatcher cluster, such as: capacity constraints, voltage level and frequency, ancillary services etc. These technical parameters have to be considered in the optimisation process of the PowerMatcher.

6. Mechanisms to improve grid stability

6.1 Introduction

Achieving stability in future electricity networks can be far more difficult than in today's situation, because future electricity networks will be far more complicated. Low voltage (LV) areas will have large numbers of distributed energy resources and therefore cannot only be seen as a load. However, in future there are more possibilities to control this complex situation, for example all kinds of decentralized generators with modern electronic converters can provide inductive or capacitive reactive power, just like today some types of rotating generators can. One of the questions to be answered in this project is: what can be the role of distributed generation with respect to frequency and voltage control in future LV areas? With ICT we can achieve the control of large groups of decentralized generators, however to avoid the kind of instability that bring oscillations in the frequency and voltage, a very fast and reliable ICT system would be needed, therefore in this project we will investigate the possibilities of building a inherent stable system, with the focus on low voltage areas. This system should avoid oscillations and contribute to frequency control, without the need of ICT.

To acquire more knowledge of the mechanisms that brings stability in the network, good insight is needed in possible future grid structures and a number of components in the network, especially on the low voltage side.

In this chapter future grid structures are discussed, hereafter the role of reactive power handling in low voltage areas and special attention is given to the relevant character of domestic appliances and standards in force. Further a decision support model is given.

6.2 Future Grid Structures

6.2.1 Definition of the studied grid

In the near future, when distributed generation is embedded into the low voltage infrastructure, the medium voltage grid still exists. The function of this grid changes from a distribution function towards a more transport function. The medium voltage grid connects the mainly self-supporting low voltage grids (see figure 6.1). These grids are known as sub grids.

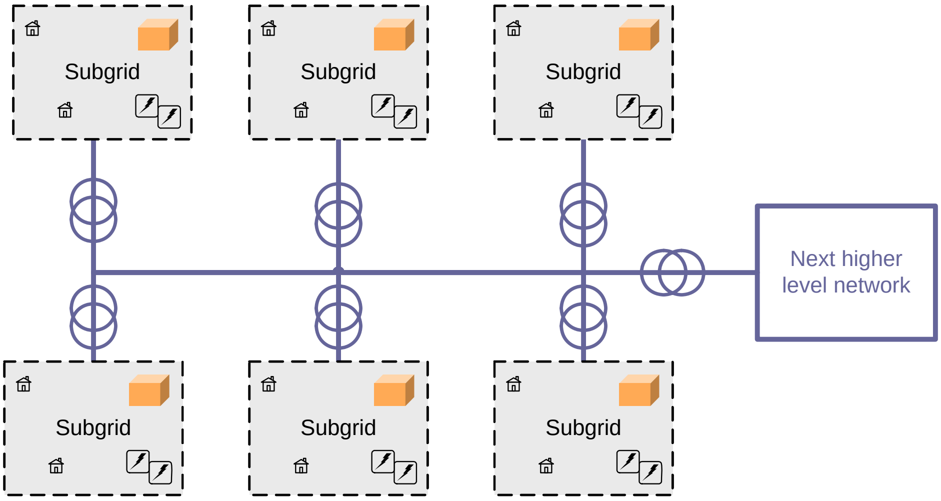

Figure 6.1 *Grid layout*

The size of every sub grid can be compared with a town or with a (small) part of a city.
The sub grid consists of numerous households, some retail, and decentralized generation and storage possibilities. When the amount of decentralized generation increases in the sub grid, the function of the connection with the next higher voltage level will change from distribution to transmission.

Within the EOS FLEXIBEL project, not the whole electrical infrastructure is considered. Figure 6.2 shows the elements that are taken into account:
distributed generation (close to the consumer)
local storage,
consumers (households and retail)
the connection with the next higher level network.

The transformer that connects the low voltage network with the above-lying network is taken into account. The other existing sub grids are out of scope, but are considered as an equivalent to the selected sub grid and can be used to exchange power to neighbouring networks.

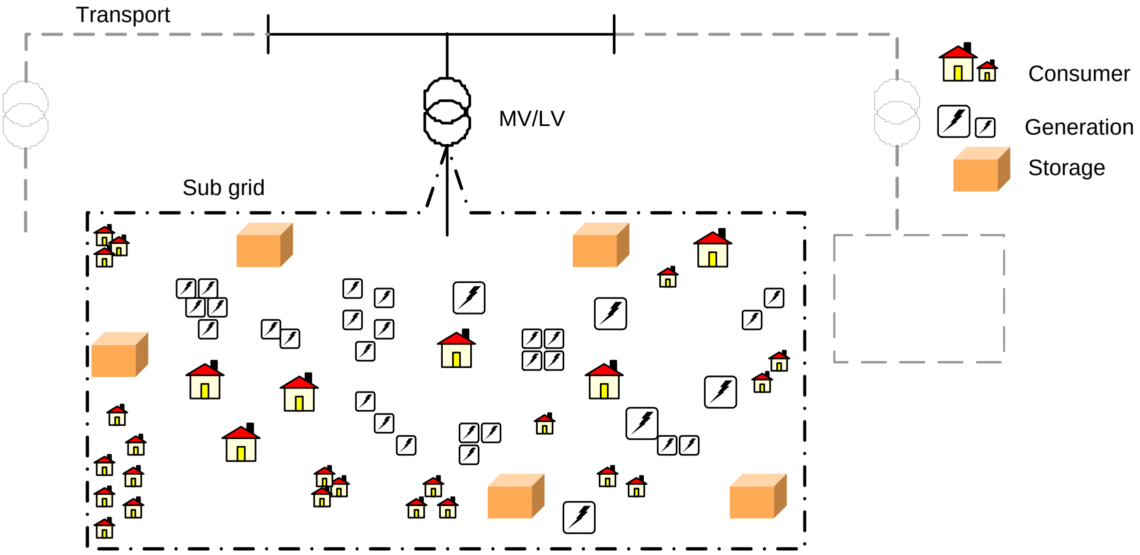

Figure 6.2 *Definition of the grid and the scope of the FLEXIBEL project*

6.2.2 Assumptions

Before starting the study, a number of assumptions has to be taken into account. These assumptions are described below:

1. The described sub grid will be fully operational at 2030. All existing decentralized generation will be connected to the grid or to the households and offices.
2. Compared to 2005, the electricity demand in 2030 still increases year-by-year and maybe doubled.
3. The electricity demand does not only increase in absolute numbers. The relative share of electricity, compared to the total energy consumption, increases.
4. Due to the increasing use of wind generation and photovoltaics the simultaneity of generation and load grows.
5. Both generation and load have more uncertainty and causes a growing intermittency of generation.
6. The consumption and the generation within the sub grid are not perfectly balanced at every moment. In some cases assistance from a neighbouring grid is necessary to balance the power. Therefore the connection with the next higher level network is kept.
7. The consumption needs will be characterized as pulsed. The consumption will become short and fast and tend to behave more peaked.
8. The studied grid will bean new grid with components that are suitable for expected requirements in 2030

6.2.3 Changes in exchanging power

A key question to consider for the future is how will the power exchange layer develop between the still existing large-scale generation, including large-scale offshore wind power, and the numerous distributed resources. Two models that can be examined are the camel and the dromedary model, which are illustrated in Figure 6.3. The Camel model envisages large power plants connected to one another via a high-voltage network, while a low-voltage network interconnects the micro and mini grids that are more-or-less self-supported. Power is exchanged between the high (HV) and low voltage (LV) layer over a relatively lightweight medium-voltage (MV) network. Alternatively, the dromedary model assumes that both the large-scale plants and the micro networks are connected to each other via a well-developed and strong medium-voltage network.

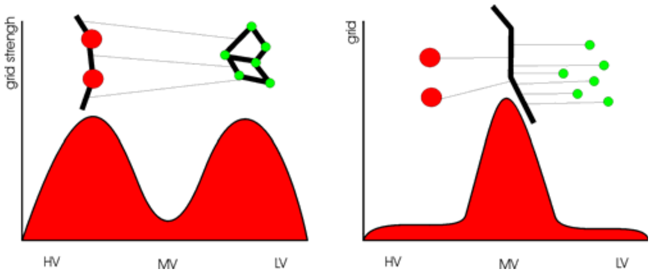

Figure 6.3 *Camel and dromedary model for the exchange of power between HV and LV layer*

If the camel model becomes reality, with a relatively weak MV interconnection layer, the investments are done mainly in the HV and LV network (MV network investments are avoided when possible). When looking at the LV network substantial investments are done locally (probably at the customers site) to balance between local demand and supply as much as possible, maintain voltage levels within tolerances and control the Power Quality (PQ) at the connection points. Because maintaining the voltage levels and control the PQ is a difficult task in the LV network with a weak MV coupling there will probably be a large emphasis on information technology and control systems.

When the dromedary model becomes reality, the MV network will be reinforced and serves as a primary means for keeping the voltage levels of the feeders within limits and maintain a certain PQ. As a consequence limited special measures need to be taken at the local LV generators. The network companies install advanced measuring and control tools at the feeders and the MV substation transformers, cables and switchgear is upgraded and expanded to make a “strong network”.

Even in a strong MV network maintaining the voltage profiles within the tolerance and assure PQ with a lot of small scale embedded generators will become increasingly difficult. With only direct control functionality at the entrance point of the feeders, it is therefore likely that there will again be a demand for intelligence (power electronics) being introduced at the individual connected generators.

As illustrated, the power exchange layer has an impact on how the main issues in future networks will be handled and in both cases, for different reasons, calls for more intelligence in the power system. Recent studies suggest that ultimately the camel model will prevail.

6.3 Future electricity networks and reactive power

In future electricity networks reactive power handling can be different than today's situation. Low voltage (LV) areas will have large numbers of distributed energy resources and therefore cannot only be seen as a load. LV-areas can be partly self-supporting. Future electricity networks will be far more complicated then today's networks. However, in the future there are more possibilities to control this complex situation, for example all kinds of decentralized generators with modern electronic converters can provide inductive or capacitive reactive power, just like today some types of rotating generators can. One of the questions to be answered in this project is: what can be the role of distributed generation with respect to reactive power in future LV areas? With ICT we can achieve the control of large groups of decentralized generators.

Today reactive power is used for the following aims:

- voltage control by steering reactive power through transmission lines
- compensation of reactive power to achieve an acceptable Power Factor.

Assuming that decentralized generators in LV-areas in future can contribute to reactive power compensation by steering the power factor of (small) decentralized generators, the control of reactive power in transmission and distribution systems will always remain a necessity because of the character of overhead lines and underground cables.

Compensation of reactive power is normally done near a load, to avoid reactive current coming from far away central generators. Compensation of reactive power will bring the power factor closer to the maximum figure of one. A load with a power factor of one means that no reactive power is flowing to the load and a power factor of zero means that only reactive power is flowing to the load. Reactive power does not contribute to energy transfer in a load, this kind of power oscillates between the generator or compensator and the load. Therefore a compensator is often called a reactive power generator and an inductive load is called a reactive power consumer.

6.3.1 Bringing reactive power provision and supply into account

For a study on a control system for provision and supply of reactive power in LV-areas, with the purpose of controlling reactive power in (a part) the electricity network, insight of the energy flow of the surrounding network is needed. Management of the small-distributed generators in the area is necessary; simply reducing the amount of reactive power generation of one LV-area can be not sufficient. The action can be far more complicated, because a number of LV-areas can be involved.

One of the main questions to be answered is: Is a control of reactive power in LV-areas sufficient to control usefully (a part of) the reactive power in transmission and distribution systems? If yes, studies can be made in this field, also the necessity of such a control can be studied. If no, solutions must be found in the MV-area and distribution system. To find an answer on this main question, simulations within this project are foreseen.

6.3.2 Voltage control and stability

In an electricity network both P (active power) and Q (reactive power) must be in balance for a stable operation. Both P and Q can be controlled approximately independent of each other if the reactive part of the transport line impedance is much larger then the resistive part. Today's use of this phenomena is that the reactive power flow through transport lines is used to regulate voltage at the end of the line; because of the high inductive character of transmission lines this can be done with acceptable energy losses. For cables the resistive part is larger then the reactive part, so voltage control by reactive power in practice brings little effect and too much energy losses. The reactive power in the transmission line can be adjusted by the amount of compensation at the end of the line. Even a voltage rise at the end of a lightly loaded line is possible in combination with consuming compensation or lagging power factor loads.

The amount of reactive power of small-distributed generators with electronic converters can be continuously adjustable on a short time base, so in future there might be a possibility to use this feature for compensation and controlling voltage. However in an electricity network it is not self-evident that controlling the reactive power in a LV-area will affect the voltage in the transmission part of the network. For configurations of future networks, studies on this effect must be done.

To achieve voltage control by reactive power in future networks a total view of the load flow in the network is needed and beside this a control of the decentralized generators. Further the uncertainty of some types of renewable energy sources makes that this kind of voltage control must take place on a short time base, depending on the predictability of the situation; therefore it might be necessary to estimate the load flow situation on short time base too. Once load flow information is more or less continuously available, it can also be used for other opportunities like fault location estimation.

Other methods of controlling the voltage in a network are the use of tap changing transformers. Tap changing transformers can be used to compensate voltage drop in a line.

6.3.3 Character of components

- Fully loaded overhead lines absorbs Q (inductive character), in light loaded overhead lines the shunt capacitance predominant and the lines generate Q (capacitive character).
- Underground cables are generators of Q owing to their high capacitance.
- Transformers always absorb Q.
- Synchronous generators can be used as generators of Q or as absorbers of Q, by steering the field current.
- Coils can be used as absorbing reactors.
- Capacitors can be used as generating reactors.

Compensation of reactive power

Methods of injecting Compensation of reactive power are:

- Static shunt capacitors & reactors
- Static series capacitors
- Synchronous compensators

Static Shunt capacitors & reactors

Shunt capacitors are used for compensation of lagging power factor circuits. Shunt capacitors are disposed along routes to minimize losses and voltage drops. On light loads, when the voltage is high, the capacitor output is large and the voltage tends to rise to excessive levels.

Shunt reactors are used for leading power factor circuits, as in lightly loaded cables.

Static Series capacitors

On a long high voltage transmission line under heavy load conditions, reactive power compensation can be provided by installing series capacitors The major drawback of series capacitors is the risk of high over voltages, therefore special devices have to be incorporated like spark gaps. If the reactive power load requirement is small, series capacitors are of little use. Voltage fluctuations due to some types of loads are evened out. If the total line reactance is high, series capacitors are very effective and stability is improved.

Synchronous compensators

Synchronous motors running without mechanical load can absorb or generate Q depending on the excitation. As the synchronous motor losses are considerable compared to static capacitors, the power factor is not zero. When used with a voltage regulator, the compensator can automatically run overexcited at times of high load and under excited at light loads. The advantage of the synchronous compensator is its flexibility of operation for all load conditions.

6.4 Survey of voltage characteristics for low voltage distribution systems

6.4.1 Distribution systems

Voltage characteristics of distribution systems are laid down in European and national standards. Dwellings are connected to the local distribution system of a district. This distribution system consists mainly of a low voltage network. The local distribution system is part of a complex national network on a higher voltage. This national distribution system is connected to a European network that allows importing and exporting of electrical energy. Because distribution systems are more than local matters, power quality must be guarded on national and international level in order to have an acceptable power quality level for the consumers.
This chapter describes the relevant standards for power quality in low voltage distribution systems in the Netherlands.

6.4.2 Power Quality

In the Netherlands the power quality of the electricity distribution system is guaranteed in different ways. First there are requirements regarding generating and distributing of electrical energy. Secondly there are emission levels, generated by the connected equipment to prevent pollution.

The European standard NEN-EN 50160 gives the main characteristics of the voltage at the customer's supply terminals in public low voltage and medium voltage electricity distribution systems under normal operating conditions. The standard gives the limits or values within which any customer can expect the voltage characteristics to remain. The NEN-EN 50160 (Voltage characteristics of electricity supplied by the public distribution system) gives requirements for low voltage and medium voltage distribution systems regarding:

- Power frequency (nominal and range)
- Magnitude of the supply voltage
- Supply voltage variations
- Magnitude of rapid voltage changes
- Flicker severity

- Supply voltage dips
- Short interruptions of the supply voltage
- Long interruptions of the supply voltage
- Temporary power frequency over-voltages between live conductors and earth
- Transient over-voltages between live conductors and earth
- Supply voltage unbalance
- Harmonic voltage
- Inter-harmonic voltage
- Mains signalling voltage on the supply voltage.

The European standard EN 50160 is accepted by the Netherlands and is known as NEN-EN 50160. Standards are not obligatory, they do not have a legal status. If a law is directly or indirectly pointing out a standard than there is an obligation to comply with the standard. The NEN-EN 50160 is pointed out by the grid code with some exceptions. Because the grid code is obligatory by law, the NEN-EN 50160 also is.

6.4.3 Grid code

The Grid code (article 31, paragraph 1,sub a of the Electricity law 1998) describes the conditions specified in the electricity law of 1998 of the Netherlands. By complying the Grid code also the electricity law of 1998 is satisfied. The grid code points out standard NEN-EN 50160 for power quality and gives also the deviations.

The Grid code gives conditions for the behaviour of DNO's and consumers regarding the operation of public distribution systems.

The Grid code gives requirements as well as for low voltage distribution systems and high voltage distribution systems. The Grid code states that NEN-EN 50160 is applicable with the exception for

- Frequency
- Slow voltage variations
- Fast voltage variations
- Asymmetry
- Harmonics

These matters are individually described in the Grid code.

IEC 61000

IEC 61000 lays down the conditions regarding electromagnetic compatibility (EMC).

These series of standards specify emission levels and susceptibility levels of equipment connected to the distribution system. It is published in separate parts, according to the following structure:

Part 1:	General General considerations (introduction, fundamental principles) Definitions, terminology
Part 2:	Environment Description of the environment Classification of the environment Compatibility levels
Part 3:	Limits Emission limits Immunity limits (in so far as they do not fall under the responsibility of the product committees)
Part 4:	Testing and measurement techniques

Measurement techniques
Testing techniques

Part 5: Installation and mitigation guidelines
Installation guidelines
Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Part three gives requirements for harmonic current emissions etc. and has the following subdivision:

Part 3-2: Limits for harmonic current emissions (equipment input current <= 16 A per phase)
Part 3-4: Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
Part 3-12: Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and <=75 A per phase
Part 3-3: Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current <= 16 A per phase and not subject to conditional connection
Part 3-5: Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A
Part 3-11: Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current <= 75 A and subject to conditional connection
Part 3-6: Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication
Part 3-7: Assessment of emission limits for fluctuating loads in MV and HV power systems - Basic EMC publication
Part 3-8: Signalling on low-voltage electrical installations - Emission levels, frequency bands and electromagnetic disturbance levels.

6.5 Methodical load categorisation

This chapter describes a methodical categorisation of domestic appliances and building energy equipment and their problematic electrical characteristics.

The power systems considered in general consist of:

- Centralized synchronous generators
- Grid (transport and distribution)
- Distributed loads
- Distributed asynchronous generators

Grid stability or instability is a result of the interaction between these elements.

(An *asynchronous generator* is defined here as a generator that does not operate at the grid frequency when it is not connected to the power system.)

Problematic electrical characteristics could be the cause of instabilities in the power system. These mainly originate in the distributed loads and distributed asynchronous generators, as the centralized synchronous generators and the grid are highly predictable (controllable) and behave linearly at the fundamental grid frequency.

Therefore, in order to find mechanisms to improve grid stability in future grids, it is necessary to describe the electrical characteristics of the distributed loads and asynchronous generators connected to power grids of the future.

In this chapter, we confine ourselves to residential areas. For this reason only domestic appliances and building energy equipment (including asynchronous generators) for domestic purposes are considered

A complete description of problematic electrical characteristics in residential areas can be established by:

1. Categorising problematic electrical characteristics
2. Categorising the principal needs of an occupant in a residential dwelling
3. Forming a set of electrical functions that could fulfil these needs
4. Forming a set of domestic appliances and building energy devices that can perform these electrical functions
5. Describing the problematic electrical characteristics of the domestic appliances and building energy devices in the two sets.

This is done in the following paragraphs.

6.5.1 Categorisation of problematic electrical characteristics

In order to operate a stable power system a number of tasks have to be performed. The principal ones are maintaining the:

- Power balance at the fundamental grid frequency
- Power flow at harmonic frequencies below maximum values
- Grid voltages within limits
- Grid currents below maximum values

Problematic electrical characteristics are defined here as characteristics that could influence the principal tasks in the power grid.

As a single disturbance will not be noted in the power system, only disturbances that occur at the same time on a large scale will be able to cause instabilities. In general these characteristics can be divided into:

a) Unpredictable variations in many synchronised loads
b) Unpredictable variations in many synchronised power generators
c) Unpredictable generation of many synchronised harmonic currents

Some examples of these types synchronized electrical disturbances are given in

Table 6.1, together with the specific unpredictable factor and the synchronisation mechanism.

Table 6.1 *Examples of synchronized electrical disturbances*

Type of synchronised electrical disturbances	Example	Unpredictable factor	Synchronisation mechanism
Unpredictable load variations	Switching on of heat pumps in the morning of a cold day	Weather forecast	Start of business hours
Unpredictable power generation	Large wind park	Wind speed	Extended air flow field
Harmonics generation	Electronic inverters for Photovoltaic arrays.	Clouds absorbing solar radiation	Electronic phase and frequency coupling.

In Table 6.2 an assessment of the influence of synchronised electrical disturbances on the principal tasks in the power system is shown.

Table 6.2 *Assessment of synchronized electrical disturbances influencing the power system*

Type of synchronised electrical disturbances	Affected task in the power system			
	Power balance at grid frequency	Power flow at harmonic frequencies below maxima	Grid voltages within limits	Grid currents below maxima
Unpredictable load variations	👎			
Unpredictable power generation	👎		👎	👎
Harmonics generation		👎		👎

6.5.2 Principal needs and corresponding electrical functions

As occupants living in a dwelling acquire all electrical devices out of personal motives, it seems a good approach to make a categorisation of electrical functions that can fulfil the principal needs of these occupants. Next, types of electrical appliances can be listed that can perform the electrical functions needed. In this methodical way a set of electrical appliances that is consistent with the needs of the occupants of the residential dwelling considered is found.

A list of principal needs of occupants of a residential dwelling and their corresponding electrical functions, though it might not be complete, is given in

Table 6.3.

Table 6.3 *Principal needs of occupants and corresponding electrical functions*

Principal need of occupant	Electrical functions
1. Air	• Ventilation • Cleaning • De-humidification
2. Beverages	• Heating • Cooling
3. Constant body temperature	• Space heating • Space cooling • Direct body heating
4. Food	• Heating (cooking) • Cooling
5. Hygiene	• Showering and bathing • Clothes cleansing • Clothes drying • Space cleansing • Dish cleansing
6. Light	• Space lighting • Skin tanning
7. Medical care	• Measuring and monitoring • x ??
8. Entertainment	• Interactive games • Television • Video
9. Remote communications	• Video and sound • Text and graphical information
10. Physical exercise	• X ?? •
11. Spatial movement	• Electrical vehicles • Electric elevators
12. Environmentally friendly appearance	• Renewable electricity generator • Backup heaters for solar water heaters

6.5.3 Appliances and building energy devices

Now types of appliances and building energy devices that performing electrical functions can be enumerated that can perform the electrical functions listed in

Table 6.3. In this methodical way a set of electrical device types is found that is consistent with the needs of the occupants of the residential dwelling considered.

In Figure 6.4 an example is given of the electrical device types resulting from the methodical categorisation of domestic appliances and building energy equipment in this chapter.

However, one has to keep in mind that the final choice of specific devices depends on the occupants of the residential building considered.

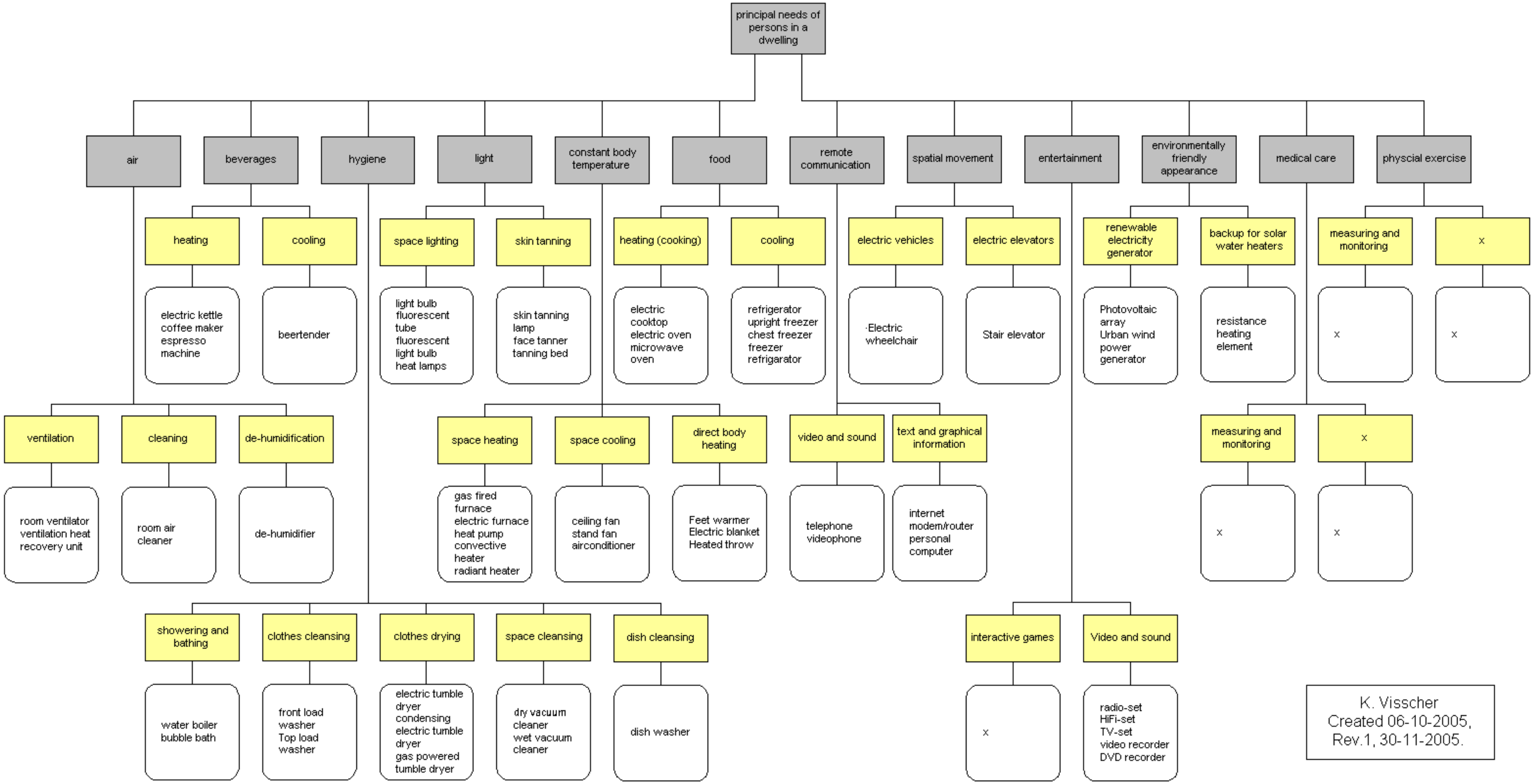

Figure 6.4 *Example of methodical categorisation of electrical device types*

6.5.4 Problematic electrical characteristics

In Table 6.4, a complete list of domestic appliances and building energy devices is given as in Figure 6.4, together with an assessment of synchronised electrical disturbances as in Table 6.2.

The problem areas seem to be mainly in the electrical functions associated with the principal needs:

- Constant body temperature
- Light
- Medical care
- Entertainment
- Remote communications
- Spatial movement
- Environmentally friendly appearance

Table 6.4 *Assessment of problematic synchronised electrical characteristics of the domestic appliances and building energy devices*

Principal need of occupant	Electrical functions	Electrical device types	Problematic synchronised electrical characteristics		
			Unpredictable load variations	Unpredictable power generation	Harmonics generation
1. Air	Ventilation	Room ventilator			
		Ventilation heat recovery unit			
	Cleaning	Room air cleaner			
	De-humidification	De-humidifier			
2. Beverages	Heating	Electric kettle			
		Coffee maker			
		Espresso machine			
	Cooling	Beer tender			
3. Constant body temperature	Space heating	Gas fired furnace			
		Gas fired micro CHP		👎	
		Electric furnace	👎		
		Heat pump	👎		
		Convective heater			
		Radiant heater			
	Space cooling	Ceiling fan			
		Stand fan			
		Air conditioner	👎		
	Direct body heating	Feet warmer			
		Electric blanket			
		Heated throw			
4. Food	Heating (cooking)	Electric cook top			
		Electric oven			
		Microwave oven			👎
	Cooling	Refrigerator			
		Upright freezer			

Principal need of occupant	Electrical functions	Electrical device types	Problematic synchronised electrical characteristics		
			Unpredictable load variations	Unpredictable power generation	Harmonics generation
		Chest freezer			
		Freezer refrigerator			
5. Hygiene	Showering and bathing	Water boiler			
		Bubble bath			
	Clothes cleansing	Front load washer			
		Top load washer			
	Clothes drying	Electric tumble dryer			
		Condensing electric tumble dryer			
		Gas powered tumble dryer			
	Space cleansing	Dry vacuum cleaner			
		Wet vacuum cleaner			
	Dish cleansing	Dish washer			
6. Light	Space lighting	Light bulb			
		Fluorescent tube			
		Fluorescent light bulb			
		Heat lamps			
	Skin tanning	Skin tanning lamp			👎
		Face tanner			👎
		Tanning bed			👎
7. Medical care	Measuring and monitoring	X			👎
		X			
8. Entertainment	Interactive games	X			👎
	Video and sound	Radio-set			👎
		HiFi-set			👎
		TV-set			👎
		Video recorder			👎

Principal need of occupant	Electrical functions	Electrical device types	Problematic synchronised electrical characteristics		
			Unpredictable load variations	Unpredictable power generation	Harmonics generation
		DVD recorder			👎
Remote communications	Video and sound	Telephone			👎
		Videophone			👎
	Text and graphical information	Internet modem/router			👎
		Personal computer			👎
Physical exercise		X			
		X			
Spatial movement	Electrical vehicles	Electric wheelchair			
	Electric elevators	Stair elevator			
Environmentally friendly appearance	Renewable electricity generator	Photovoltaic array		👎	👎
		Urban wind power generator		👎	
	Backup for solar water heaters	Resistance heating element	👎		

6.6 Susceptibility of domestic appliances

In this chapter susceptibility of domestic appliances against voltage and frequency fluctuations will be illustrated.

6.6.1 Dips and Harmonics

Future electricity networks will be significantly different than today's networks. Nowadays networks consist mainly of large energy plants strategically distributed in the network. In future many small and medium DER units exist like PV, Wind and micro WKK. These DER are randomly distributed over the country. It is expected that PV will be concentrated in areas with high population densities whereas concentrations of wind-turbines can be found in rural areas. Concentration of DER does not automatically mean coordination. If the voltage in the network becomes too high, a number of DER switches off. The moment the DER switches off depends on the settings of the DER and the local voltage in the network. After switching off the voltage drops in the network and the DER will switch on again. This results into more and larger sudden voltage variations.
Harmonics are repetitive voltage variations within a sinus. The shape of the generated voltage or current of electronic power generators is seldom a perfect sinus. By increasing the number of DER units in the network the harmonic distortion in the network can also increase.

In future we will be more and more dependant on electric and electronic equipment for our daily life. Therefore energy supply must be guaranteed and of sufficient quality. The availability of energy supply is a prerequisite. Without the energy supply no electric or electronic equipment can operate. Secondly comes the quality. Quality means an accepted level of quality. The quality of the voltage of electricity networks is described in national standard NEN-EN 50160 and by law in the Grid code.

Dips and harmonics determine the quality and are deviations of a perfect continuous sinusoidal signal. These deviations can last for microseconds to hours. Dips are amplitude related deviations and harmonics are frequency related deviations. Generally these signals are distortions and equipment powered by a distorted voltage can become malfunctioning.
In order to prevent malfunctioning there are three ways:

1 don't generate distortions
2 don't transport distortions
3 immunize equipment

6.6.2 Generation of distortions

Much electric and electronic equipment generate distortions. International standard IEC 61000 describes the acceptable limits of distortion. Each product shall comply with the IEC 61000. Due to interaction, large-scale application of equipment like PV-inverters can result in a higher level of distortion than the sum of all individual distortion levels. Legislation exists but shall be adjusted to future situations and new developments.

6.6.3 Transportation of distortions

Distortion is energy or a lack of energy. It is an energy flow at the same time with the normal energy. They share the same network. Harmonic distortions can be filtered out. Filters made of capacitors and inductors have the advantage that they can work bi-directional. Local generated distortions are reduced or stopped entering the network. Also distortions in the network are reduced or filtered when passing through the filter to the next segment of the network. This can be effective for harmonic distortions.

6.6.4 Immunity of equipment

Equipment must have certain immunity for distortions. Distortions can be generated far away in the network and also in the same room. By increasing the immunity the allowed distortion level may be higher. In equipment two ways of immunization can be achieved. First by filtering the outgoing harmonics also the incoming harmonics are rejected. Secondly much equipment includes an AC to DC converter. By increasing the input voltage range and the control speed of the converter, the equipment can cope with dips. High power equipment directly connected to the local energy network, like motors or heaters, can still loose their function.

Many articles are available on the Internet about the generation of dips and harmonics. They can be generated in the low voltage network as well as in the high voltage network. They are caused by switching on and off of equipment, continuous operation of equipment or accidental destruction of the network. Information about the correct functioning of equipment in relation to dips and harmonics is scarce.

The change of network type from centralized to decentralized energy generation makes it necessary to study the immunization level of electric and electronic equipment as these equipment must retain their functionality. Also in order to develop new quality levels for future networks equipment must be studied to what extent the immunization levels can be used without loss of functionality.

6.7 Decision support model

The decision support model is developed by KEMA and is often used by utilities to support them with long-term investment decisions. Since the level of uncertainty within this project is high, the model will be used to create insight into decision possibilities, per scenario. After several scenarios are identified, alternative solutions are generated and evaluated. Finally the decision has to be taken and the decision will be the first step towards the physical implementation.

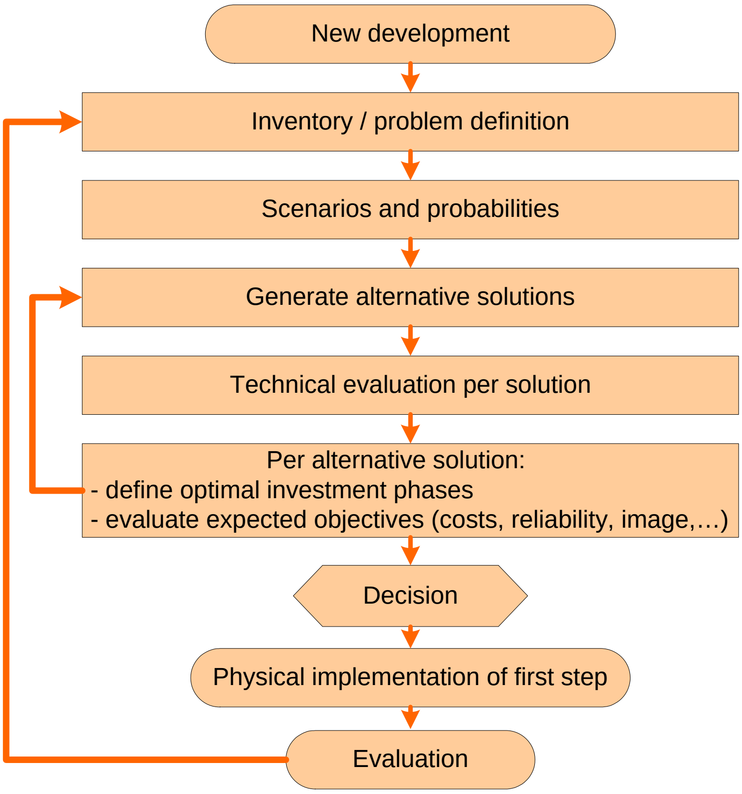

Figure 6.5 *New development. Change in demand and supply*

6.7.1 Scenarios and probabilities

1. Demand and supply do not increase. Increasing peaked demand.
2. Demand and supply increase both, but demand increases faster than supply. The number of kWh rises with an unknown percentage.
3. Demand and supply increase both, but supply increases faster than demand, due to the increasing number of photovoltaic systems on roofs and the increasing number of combined heat and power systems (CHP). The supply will be intermittent, due to the coincidence of the photovoltaic systems.

6.7.2 Generate alternative solutions

To generate solutions, a morphological table can be used. The morphological brainstorm technique is an interactive, structured method to solve complex or vague problems. A set of possibilities (a morphological table) is set up in which the solutions have to be sought. This method is very applicable, because it solved one of the biggest problems: how to be sure the solutions cover all the stated problems. By creating a list of characteristics per solution and attributing a limited number of values per characteristics, it is possible to create a matrix in which a number of choices have to be made. When the proper characteristics and accompanying values are chosen, the whole range of solutions is covered.

The morphological table is shown below.

Quality	**Storage**	**Tariff structure**	**Ownership DG**	**Location DG**
1. No quality regulation	1. No storage located within the sub grid	1. Only energy (kW)	1. Customer	1. Scattered throughout the sub grid
2. Quality regulation, based on power quality	2. Local storage at every consumer	2. Energy and capacity (kW and kWh)	2. Customer group (e.g. association of proprietors)	2. Close to the demand
3. Quality regulation, based on reliability	3. Storage located within the sub grid	3. Energy, capacity and power quality	3. Third parties (DNO, supplier, producer)	3. Few larger generation units within the sub grid

After the morphological table is defined, the solutions have to be evaluated against preconditions. The evaluation is divided into two elements: a technical and a financial evaluation.

6.7.3 Technical evaluation per solution

1. Power quality
2. Safety
3. Reliability

Per alternative solution:
After the technical evaluation, the expected objectives will be evaluated on a financial indicator: EUR.

A combination of solutions can lead to the desired situation. In the figure below an example is given. A combination of solution 1 en 2 (red line) leads towards the desired situation faster then a combination of solution 2 and 3 together (blue line). A combination of solution 1 and 3 does not lead to the desired situation.

The main goal is to create insight into the desired situation and the accompanying path. The path described the transition route: how does one get to the desired situation? T1 up to and including T4 stands for different unities of time. (e.g. T1 is 2010 and T2 is 2020)

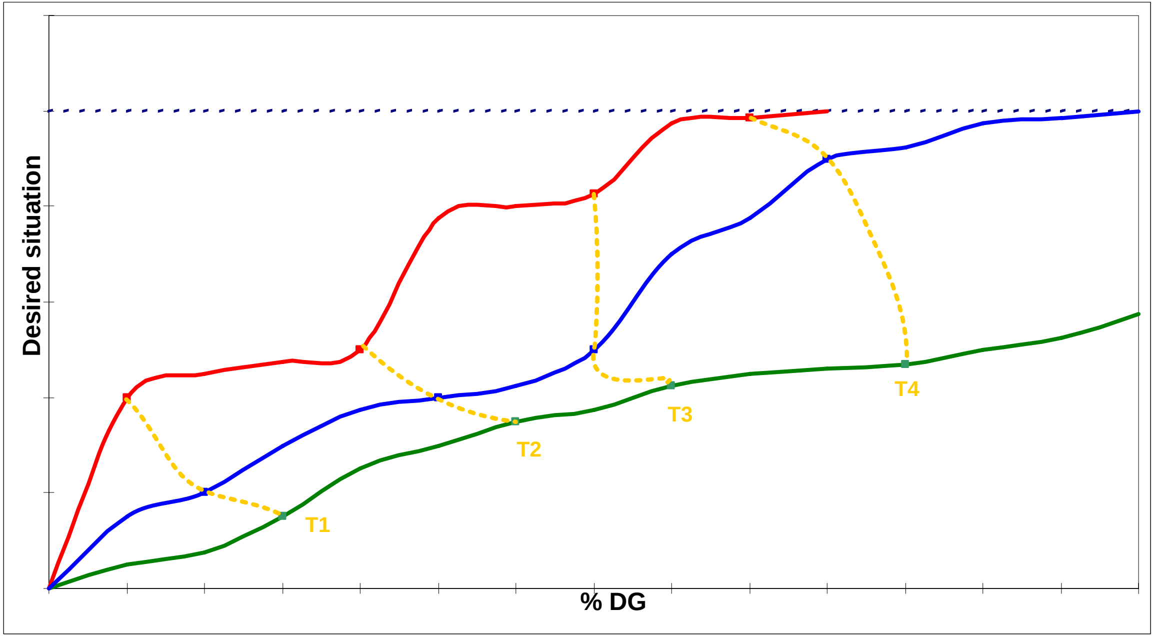

Figure 6.6 *Path towards desired situation*

A possible solution to reach the desired situated is e.g. tariff structures. A customer can choose several packages, based on his needs. An example:
Package A: reliability is 0,9999, power quality is low
Package B: reliability is 0,99999999, power quality is high, there are storage possibilities at the consumer.
A number of packages can be described to fulfil the (growing) needs of the consumers. An example of possible packages is given in Figure 6.6.

	Basic	Basic + PQ	Basic + tariff	Basic & environment	Basic +++
PQ, low level	🟨		🟧	🟧	
PQ, high level		🟨			🟥
Reliability 0,9999	🟨		🟧		
Reliability 0,99999999		🟨		🟧	🟥
Fixed tariffs	🟨	🟨			
Variable tariffs			🟧	🟧	🟥
Directed demand			🟧		🟥
Generation				🟧	🟥
Storage					🟥

7. Role of safety, security, reliability and dependability from an ICT point of view

ACRONYMS AND ABBREVIATIONS

DG-RES	Distributed Generation with Renewable Energy Sources
DNO	Distribution Network Operator
DRR	Demand Response Resources
GSM	Global System for Mobile communications
ICT	Information and Communication Technology
ISO	Independent System Operator (~ TSO, USA context); International Standards organisation
IEA	International Energy Agency
LV	Low Voltage
MV	Medium Voltage
PRP	Programme Responsible Party
PV	Photo-Voltaic
SDM	Supply and Demand Matching
TSO	Transmission System Operator

7.1 Introduction

The water, gas and telephone delivery networks only surpass the current level of reliability of the power network expressed in MTBF. Average outage-time in the Netherlands is in the order of 25 minutes. Threats when introducing ICT and connectivity to power networks may occur at a number of levels. The same may holds, when larger proportions of small, intermittent producers are part of the electricity network. On one hand, distributed generation spreads the risk and size of outages when compared to the risk of outages in current interconnected electricity networks with very large producing facilities. On the other hand, small, intermittent and user process connected DG-RES resources do not have as predictable power profiles as large installations.

Safety in this chapter context is defined in terms of power system related safety as a thread to humans during installation of components in the grid or in the cables connecting them. Small co-generation systems are known to present problems during installation, because heating system and electrical system knowledge is required. Furthermore, introduction of novel software technology may add to increased safety, but also to unpredictable behaviour due to increased complexity. In this chapter only the last point will be discussed.

Security is considered from an operational system context with an emphasis on safeguarding the data-streams for unwanted leakage of information to other parties. An example could be, that, with the advent of ICT in power systems, data about the life-style and presence patterns might be induced from energy consumption data in real-time. Also effects not specifically targeted at persons/institutions (non-intrusiveness) like protection against viruses/worms and spy ware belong to this category.

Reliability requirements are very tight in power applications. Adding ICT to these applications increases the state space, thus, increasing the size of the testing program and requirements. Making available ICT to small customers (SME's and retail) further tightens the constraints.

Dependability describes the flexibility in response of new ICT-enabled power systems in case of events. This also holds for their response on one another.

7.2 Security

Due to design flaws in a number of software artefacts, intrusion of software programs and access to non-privileged databases is not difficult. Notorious examples are the handling of memory allocation in C and C++, leaving space for intrusion and the usage of macro's in Microsoft-tools in Visual Basic for Applications like the mail handling tool and other products. Further security leaks come from the initial design of the Internet as an open, transparent platform for the research community and as a means for inherently complex distributed applications using standards like COM and CORBA. Finally the port mechanism for communication allows intended subversive use of the infrastructure The transparent, distributed character allowing peer-to-peer communication now is used to get customer information in commercial applications, but also in spy-ware applications. A hardware or software firewall inhibit data transfer in certain directions if configured in the right way.

Security is considered a high-risk item in distributed software applications at the moment and it surely is for the infrastructure at which all other infrastructures depend.

7.3 Reliability

Reliability has to do with 'graceful' stopping of certain tasks and starting up others in applications, once erroneous situations are encountered. In the power sector three operational states are currently defined for the state of the network: normal, critical and emergency and out-of-operation. The degree of reliability of an application then determines the smoothness and the lack of human intervention of the software to go from one state in the other.

7.4 Dependability

Dependability determines how the software environment is able to execute 'principally' unreliable software in a reliable way. In certain approaches, a additional software layer underneath the software execution environment constantly guards dependable execution of modules, taking into account requirements from an independent model [Mellstrom, 2005].

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