INTEGRAL RESOURCE OPTIMIZATION NETWORKS AND THEIR TECHNO-ECONOMIC CONSTRAINTS

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ABSTRACT

The currently observed lurking trends in possible shortages of primary energy (e.g. crude oil) as well as the high demand result to a steeply increase in electricity wholesale prices. Therefore, beside efficiency measures and the Kyoto target also Load-Management-Programs have to be of high interest for an economy. Such programs do not necessarily increase the energy efficiency, but they are able to stabilize electricity prices and reduce negative effects on the economy due to stable electricity prices. This paper describes the economic benefits derived from *Integral Resource Optimization Networks* (IRONs - an IT-infrastructure creating new opportunities for Load-Management and Distributed Generation). A simple economic model is presented which is able to describe the interactions between consumers and energy suppliers. Furthermore, policy conclusions for well working IRONs are derived. One of the major conclusion derived from investigations in this paper is: For a sustainable electricity system without unusual high price spikes a consideration of the (short term) demand curve is compulsory. It is necessary to introduce a technical infrastructure (e.g. IRONs) which gives consumers easily the possibility to react to price spikes in the short term without loss of comfort. Therefore, the second part of this paper describes the technical aspects of such *Integral Resource Optimization Networks* and possible concepts for their realisation.

1 INTRODUCTION

Worldwide liberalization (deregulation) processes of electricity markets have been significantly changing the supply structure of various countries enormous. A major goal of the market liberalization was to provide low electricity prices for the whole economy. However, currently there are signs that electricity prices will rise again, possibly reaching a very high level.

Empirical investigations of several spot markets show that prices increase and get more and more volatile. Especially, the on-peak price spikes are considerable. Average on-peak price spikes about 60€/MWh and more are common. As a result of lacks in supply during on-peak hours and decreasing demand the gap between on-peak prices and off-peak prices increase considerably.

One major reason for these price spikes is the missing possibility of consumers to react to high prices in the short term (≈ real time). No short term elastic demand curve exists in most of the electricity markets. This fact results in a very problematic situation: No information flow between suppliers and consumers is possible. In other words the electricity markets are in an instable diverging condition.

As a result of all observed market problems a consideration of the demand curve seems obvious to strike a balance between supply and demand. For a sustainable electricity system which contributes to the Kyoto target and without unusual high price spikes a consideration of the demand curve (and investigations of the corresponding energy efficiencies) is compulsory.

This work mainly deals with the short term demand curve which is responsible for a strike between supply and demand during a day. Efficiency programs generally result in long term elastic demand curves which are not discussed in this paper. Short term elastic demand curves can be created by so called *Integral Resource Optimization Networks (IRONs)*. These are distributed data and communication networks based on the latest advances in the field of information technology.

The presented work is highly interdisciplinary and therefore, apart from economic considerations, technical concepts concerning the realization of the communication infrastructure are presented in the second part of this paper. However, the major objective of this paper is to show current problems of the electricity markets and to indicate how they can be solved, at least partly, by the introduction of new, innovative, highly distributed automation systems.

1.1 Definition of the term IRON

An *Integral Resource Optimization Network* – 'IRON' indicates a robust and distributed automation network for the optimization of energy supply and usage. Networked consumers, producers, and storages (e.g. refrigerators) have the (technical) possibility and the right to manage their supply and consumption over time. This pattern will enable unused and inaccessible shiftable potentials and directly result in an elastic demand curve which contributes to energy market stabilization.

1.2 Decreasing supply capacities and increasing demand

Overcapacities built under regulated conditions in the past get more and more off-line. As a result of the volatile markets no secure money flows are predictable for the utilities. Therefore, since 1999 power plants have been closed dramatically in whole Europe.

With these plants being closed down in the near future 25 GW will go off-line in the EU-15 countries [13]. Of course, new power plants are under construction. A vast part of the decommissioned plants are and will be coal fired plants. However, most of the European countries do not have the possibility to compensate these decommissioned power plants with emission-free run-of-river or water storage plants. The only alternative are new nuclear stations, new renewables (e.g., wind) or Demand-Side-Management (DSM) programs. (The term DSM includes efficiency increasing measures and Load-Management measures). The construction of new nuclear power stations seems very difficult, at least in some European countries, due to an opposition against them because of the potential risks they present.

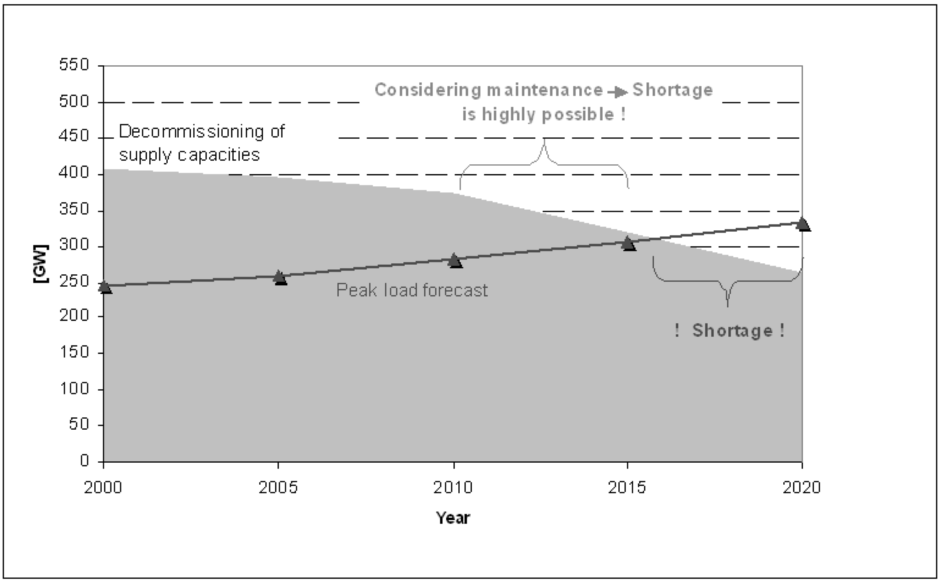

Figure 1.1: Decommissioning and peak load forecast for the central European Energy market (Austria, Germany, Switzerland, Italy, Slovenia, Hungary, Slovakia, Czech Republic, Poland, and France). Source: [2].

Due to the decreasing capacities and the yearly increasing demand (power) the lack of supply during on-peak hours will further increase. All these facts together result in a continues increase in wholesale market prices as shown in Figure 1.2. Furthermore, the arising primary energy prices for oil and gas will further boost the problems on energy markets.

1.3 Strategic Prices

In the past under regulated conditions electricity was sold at average costs. Now in the liberalized market with an economical point of view electricity should be sold at marginal costs and not at average costs or strategic prices. However, the missing possibility of consumers to react to price signals (= fully inelastic short term demand curve) provokes the threat of strategic prices. Therefore, a further reason for the observed increase in electricity prices seems the strategic behaviour of few utilities. Some sellers withhold power plants (e.g. because of faked maintenance) during periods with high demand and as a result of this all sellers gain higher profits (so called chicken game). The incentive to withhold capacities during off-peak[1] hours is minor (so called Prisoners' Dilemma). This strategic withdrawal of plants increases the on-peak price further. This threat of strategic prices is supported by the fact that consumers have only restricted possibilities to react to price spikes. Therefore, it seems necessary that consumers have the possibility to react to price spikes and contribute to the increase of market performance. In any case consumers need to see market prices otherwise there is no information flow and no demand response.

1.4 Wholesale price trends

All described market problems and boundaries result in increasing wholesale market prices as empirically indicated by Figure 1.3.

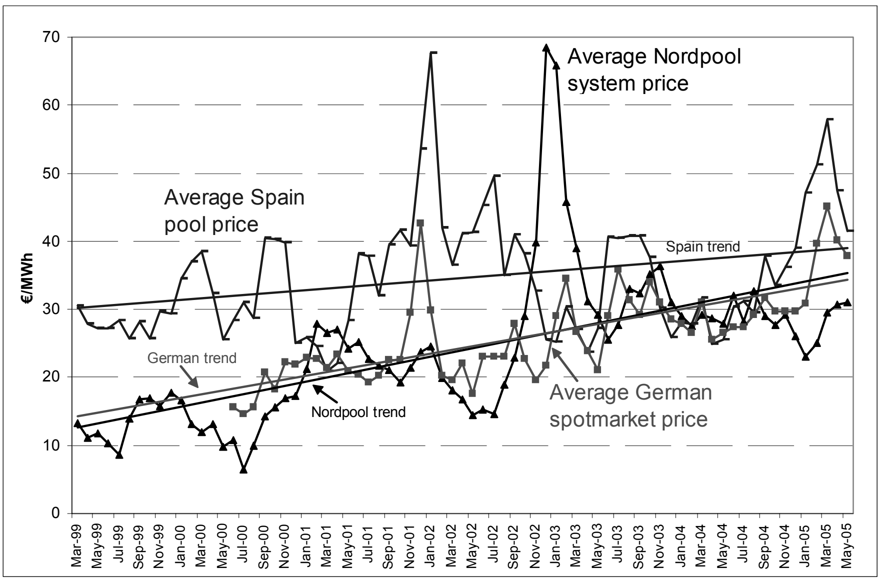

Figure 1.2: European wholesale market price trends. Source: Own database.

[1] In practice the definition of on-peak and off-peak depends on the country considered. On-Peak: 08.00 hours to 20.00 hours for Germany and Austria.

Since the liberalization process started in Europe the electricity prices have been increasing steadily. There is no evidence that wholesale electricity prices (and the according consumer tariffs) will go down as projected by the liberalization process.

1.5 Elastic short term demand curve

Historical investigations indicate that the potential for load shifting (meaning the creation of a short term elastic demand curve) without any automatic information system is very restricted [13]. The demand curve shows a logarithmic shape which saturates very early due to the restricted possibilities for load shifting or load reduction.

Without an information and automation system (like IRON), consumers only have very simple options for shifting their loads at their disposal (manually turning-off the lights, manually turning-down the heating system, and so on). They have to think about their options and they will probably lose comfort. This leads to the early saturation of the curve showing the willingness to reduce loads in times when (wholesale) prices are high. Figure 1.3 shows this circumstance for the residential sector in Germany and Austria.

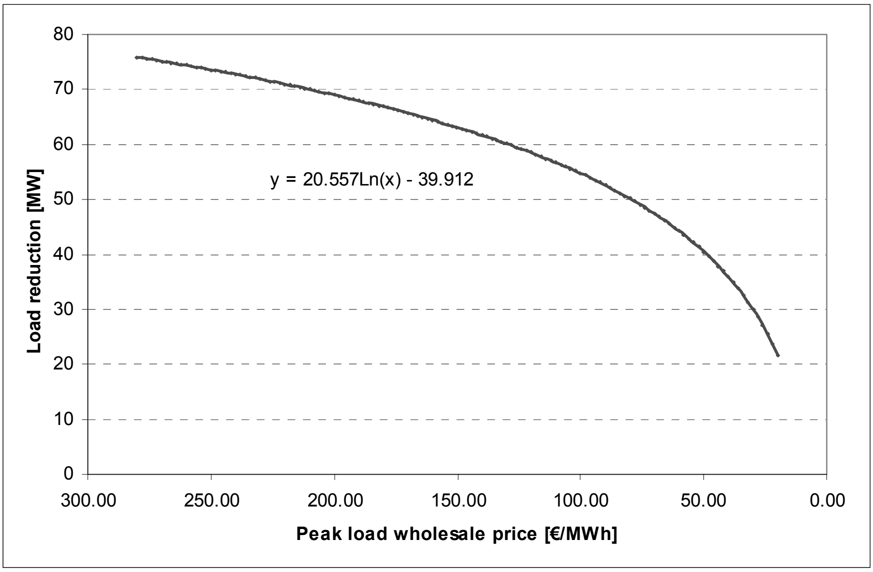

Figure 1.3: Empirical elastic residential demand curve for Germany and Austria. Source: [13].

However, it is expected that fully automatic IRONs - without any restrictions in consumer comfort - will increase the amount of actually accessible flexible loads considerably and therefore IRONs seem to be a very feasible solution for the discussed market problems.

2 SIMPLE ECONOMIC DEMAND RESPONSE MODEL

This chapter analyses, in a basic way, some (macro-) economic effects of short term elastic demand curves provided by the consumer located IRON part.

In case of strategic withdrawal or legitimate outage of plants, a (short term) elastic demand curve improves the performance of an energy market as indicated by Figure 2.1.

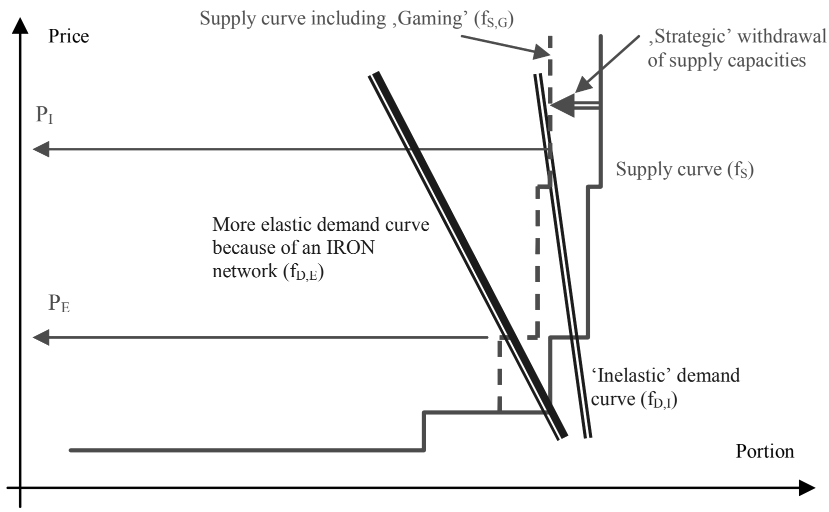

Figure 2.1: The influence of demand curves on market prices.

The original market price considering an 'unaffected' supply curve f_S and an inelastic demand curve f_{DI} result in the market price P_E. Now, considering a strategic withdrawal or legitimate outage of capacities, a shifted supply curve $f_{S,G}$ comes into being. Because of this shift and the 'inelastic' demand curve the market price jumps to P_I. However, if it is possible for consumers to react to price signals by short term elastic demand curves $f_{D,E}$, the price would be more stable in case of strategic withdrawals of capacities. Elastic demand curves decrease the negative effects of outages induced by the revision of plants or 'Gaming' and contribute directly to a stabilization of market prices.

2.1 Benefits derived from elastic demand curves

Starting with the original 'inelastic' demand curve $f_{D,I,n}$ for the year n, a demand M_n and the supply curve f_S, the market price $P_{I,,n}$ can be observed. Assuming that there is a yearly average increase in energy demand and no DSM program, there will be a shift of the fully inelastic demand curve by $\Delta M(n,n+1)$ from $f_{D,I,n}$ to $f_{D,I,n+1}$ (Figure 2.2). In the year $n+1$ supply and increased demand M_{n+1} will meet at the (higher) price $P_{I,n+1}$.

By introducing real time price signals instead of flat tariffs in the year $n+1$, consumers have the possibility to react to price signals. This would result in the lower market price $P_{E,n+1}$ and the lower demand M due to the elastic demand curve $f_{D,E}$[2]. The new price is between the 'old' price $P_{I,n}$ an the price without elastic demand curve $P_{I,n+1}$.

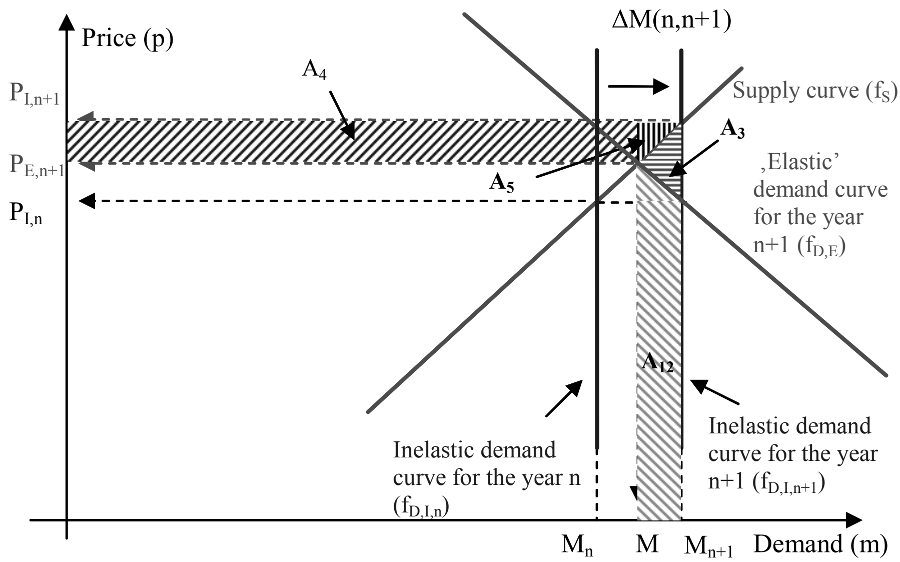

Figure 2.2: Identification of gains due to possibility of elastic demand curves.

f_S	Supply curve
$f_{D,I,n}$	Inelastic demand curve for the year *n*
$f_{D,I,n+1}$	Inelastic demand curve for the year *n+1*
$f_{D,E}$	Short term elastic demand curve for the year *n+1*
$\Delta M(n,n+1)$	'Natural increase of demand' from year *n* to *n+1* without DSM-programs
M_n	Demand in year n with inelastic demand curve
M_{n+1}	Demand in year *n+1* with inelastic demand curve
M	Demand in year *n* with short term elastic demand curve
$P_{i,n}$	Price with inelastic demand curve in the year *n*
$P_{I,n+1}$	Price with inelastic demand curve in the year *n+1*
$P_{E,n+1}$	Price with short term elastic demand curve in the year *n+1*
A_{12}	Consumer expenditures for demand response programs
A_3	Net gain due to elastic demand curve
A_4	Consumer gain because of price reduction due to elastic demand curve
A_5	Additional losses for producers
ΔCS	Change in consumer surplus
ΔPS	Change in producer surplus

[2] The elastic demand curve is introduced in a way that prices higher than the price in the year *n* result in demand reductions. This means that consumers realize the 'old' price level from the year *n* and reduce or shift load when the price in the year *n+1* is higher than the old well-known price $P_{I,n}$. Note that in this model consumers realize tariffs instead of the above mentioned market prices. However, in practice market prices do serve as a basis for tariffs.

Due to the elastic demand curve all consumers gain by lower prices (A_4 and A_5 in Figure 2.2) and a lower demand (A_3 and A_{12} in Figure 2.2). On the other hand, the consumers have to invest in demand response programs and these expenditures are represented by A_{12}.

Summing up all expenditures and benefits the change in the consumer surplus results in a positive value. Consumers gain because of an elastic demand curve (equation 3).

$$Benefits_{Consumers} = A_{12} + A_3 + A_4 + A_5 \tag{1}$$

$$Expenditure_{Consumers} = A_{12} \tag{2}$$

$$\Delta CS_{Total} = Benefits_{Consumers} - Expenditure_{Consumers} = A_{12} + A_3 + A_4 + A_5 - A_{12} = A_3 + A_4 + A_5 > 0 \tag{3}$$

In contrast to the consumers the suppliers lose money due to lower prices and less sold energy ($\Delta PS<0$).

$$\Delta PS_{Total} = -A_4 - A_5 < 0 \tag{4}$$

However, one important fact which can be shown by summing up the change in consumer and producer surplus is that the entire balance is positive (equation 5).

$$\Delta CS + \Delta PS = A_3 > 0! \tag{5}$$

The shift of money (from producers to consumers) due to the elastic demand curve results in an economic surplus. Elastic demand curves are more efficient for an economy than flat tariffs (and the according inelastic demand curves).

Even more important than showing the surplus is the possibility to show with the model roughly the reasons why suppliers are often very restrictive when it comes to elastic demand curves.

2.2 Barriers and incentives for elastic demand curves

The model described in chapter 2.1 is also able to indicate barriers and incentives for demand response programs. According to this model the producers of energy do not have incentives to introduce elastic demand curves[3]. The reason is very simple. Because of the negative change in the producer surplus they are the monetary losers of DSM programs. However, the barrier is basically described by the change in the market price (ΔP) and therefore decreasing market prices correspond with higher barriers against demand response programs.

$$Barrier = -A_4 - A_5 < 0 \qquad \textbf{(6)}$$

$$Barrier \approx -A_4;\ A_4 \sim -\Delta P^{4} \qquad \textbf{(7)}$$

In case that producers or distributors of energy are forced to join demand response programs they may recognize the possibility to regain some of the 'deficit' during off-peak hours as it will be described in chapter 2.4.

Basically, all consumers benefit from the decreasing market price, and therefore, the incentives are almost proportional to increasing market prices[5]. Consumers feel the natural drive to participate in demand response programs – provided there are short term price signals available.

$$Incentives = A_3 + A_4 + A_5 > 0 \qquad \textbf{(8)}$$

$$Incentives \approx A_4;\ A_4 \sim \Delta P \qquad \textbf{(9)}$$

with

$$A_4 = M \times (P_{I,n+1} - P_{E,n+1}) = M \times \Delta P \qquad \textbf{(10)}$$

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[3] Please note that the portfolio of interest for companies contains more than one item. 'Money' is only one import part of this portfolio. This means that suppliers might be interested in DSM-programs if they have other benefits besides money (e.g. public relation). The considerations shown above assume that monetary losses are a very important issue for a company.

[4] Note: For $\Delta M(n,n+1) << M \rightarrow A_5 << A_4$

[5] Please note that the proportionality of the barriers and incentives to ΔP does not mean that there is a linear dependency. The supply and demand curve is a non linear function and therefore also the change in price is a non linear function.

2.3 The influence of international transaction costs

The model represented above shows that elastic demand curves reduce inefficiencies of an economy. However, the model does not answer the question: *"What happens if only a part of an economy participates in such DSM-programs?"* For example, DSM-programs only in Switzerland and no programs in the rest of Europe or DSM programs only in Vienna and no programs in the rest of Austria.

Low transaction costs because of network overcapacities and no barriers for the electricity transport between two regions or countries result in disappearing differences in the electricity wholesale prices. Different wholesale prices would encourage electricity traders to sell and buy electricity till the price difference between the regions/countries is too little for profitable transactions.

It can be shown that the maximum national (regional) wholesale price reduction (at on-peak periods) is limited to the doubled transaction costs (C_T).

$$\Delta P_{\max} = 2 \times C_T \qquad \textbf{(11)}$$

The transaction costs have a high impact on the achievable national (regional) price reduction due to national (regional) demand response programs as shown in the next chapter.

2.4 Necessary criterion for load shifting

The economic model shown in chapter 2.1 indicates – among other things – the benefits for consumers due to on-peak load reduction. In practice, consumers will shift avoided consumption during on-peak periods, at least to some extent, to off-peak periods in order to limit comfort losses. Because of this load shifting during off-peak periods additional costs for consumers will occur which reduce the monetary benefits for them.

The supply and demand curve for off-peak periods is shown in Figure 2.3. During off-peak periods the supply curve is flat compared to the on-peak supply curve. This circumstance results in a light increase in off-peak price due to the higher consumption. However, for this model it is assumed that the increase in off-peak prices can be neglected ($P_1 \approx P_2 = P_{off\text{-}peak}$) and the only important additional costs for consumers result from $A_{1235,off\text{-}peak}$[6]. The comparison of on-peak benefits and additional off-peak expenditures (for 100% load shifting) results in a necessary criterion for load shifting:

$$\Delta P > \frac{\Delta M}{M} P_{off-peak} \qquad \textbf{(12)}$$

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[6] More precisely, the entire benefits due to load shifting are $(A_4+A_3+A_5)_{(at\ on\ peak\ periods)}$ - $(A_4 + A_{1235})_{(off\text{-}peak)}$. Assuming that $A_{4,off\text{-}peak} \approx A_3+A_5$ results in $A_4 - A_{1235,off\text{-}peak}$.

The on-peak price reduction (ΔP) has to be greater than the relative load reduction during on-peak multiplied with the off-peak price.

ΔM	Reduced load during on-peak periods due to elastic on peak demand curve; $\Delta M = (M_1 - M_2)$ for the case that all during the on peak reduced load is shifted to the off-peak period
M	On-peak demand due to elastic on-peak demand curve
ΔP	On-peak price reduction due to on peak elastic demand curve

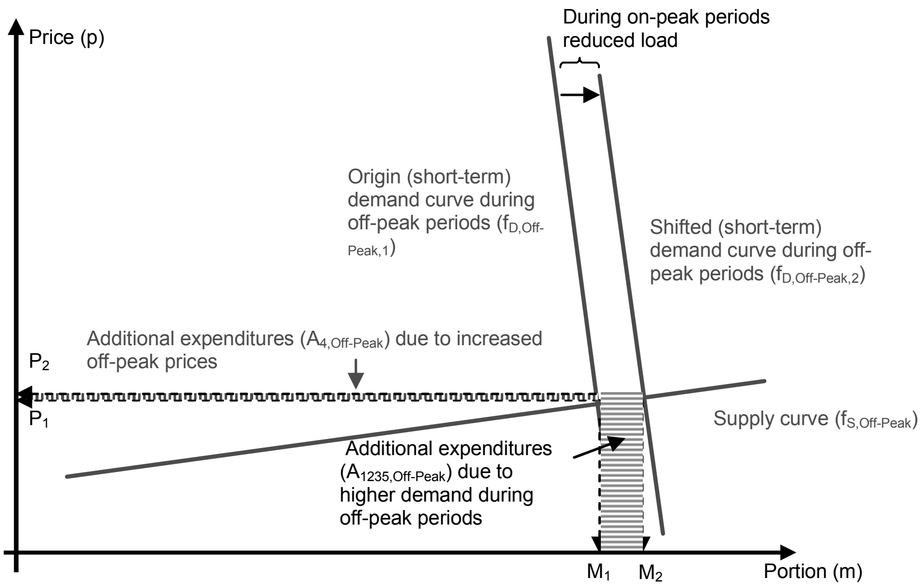

Figure 2.3: Identification of additional costs due to load shifting.

Now it is clear why the transaction costs are of high relevance for national demand response programs. In case that the on-peak national (regional) price reduction *(ΔP)* is bounded by transaction costs the relative load reduction is limited by following equation.

$$\frac{\Delta M}{M} < \frac{\Delta P}{P_{off-peak}} \tag{13}$$

Furthermore, the off-peak price is also of relevance for the achievable on-peak load reduction (in case of load shifting to off-peak periods) and therefore special focus is necessary to the off-peak tariff design. If energy providers recognize the possibility to regain parts of the on-peak losses during off-peak periods they might be tempted to increase their off-peak tariffs.

2.5 Economic conclusions for IRONs

We have seen in chapter 2.1 that

- Elastic demand curves due to IRONs stabilize the electricity market and
- Elastic demand curves due to IRONs create an economic benefit (A3).

 →Elastic demand curves reduce economic inefficiencies: The effect of sluggish or fixed flat tariffs can be shown by the California Energy Crisis happened in the year 2001. The California deregulation process contained the circumstance of frozen end user tariffs on basis of the year 1997 minus 10%. The responsible designers of the market conditions believed that deregulation will necessarily result to lower electricity prices which is obviously wrong. This mistake leaded to an information flow cut between consumers and producers and therefore the consumers had no information about the energy problems (besides the information they got from newspapers, but this is no real information flow due to no monetary effects for them). The missing possibility of a short term elastic demand curve resulted to such high economic inefficiencies that no stabilisation of the problem (increased primary energy prices, strategic withdrawals of capacities, shortages in water for run-of river plants in Washington and Oregon, etc) was possible. The market crashed in January 2001.

We have also seen in chapter 2.2 that

- Energy suppliers might have concerns (barriers) against elastic on-peak demand curves.

 Due to this circumstance the EC launched some programs in which these barriers are directly addressed.

- Consumers are in principle interested in IRONs.

 To inspire consumers to reduce/shift load it is absolutely necessary to introduce price signals (~real time) in the electricity system. Another important conclusion which can be derived from the model shown in this work is that IRONs should be operated by consumer groups. Consumers have the natural drive to react to price signals and this reduces economic inefficiencies. An operation by a supplier or a supplier group includes the risk that the suppliers optimize the system to their own needs because of the identified negative effects for them and this increases the risk of economic inefficiencies.

 Unfortunately, this economic constraint is in strong contrast to the technical constraints of electricity systems. The energy suppliers have the necessary equipment (network) and know-how to introduce such an IRON. However, the question of the possible operator of an IRON seems the most crucial question appearing in this work. In case that the energy suppliers will operate such systems, it is absolutely necessary to introduce a control system to avoid inefficiencies as described above. To find a clear answer for this question future further investigations are planned in this field.

In chapter 2.4 a necessary criterion for load shifting was presented which shows that:

- Load shifting is limited by the elasticity of the on-peak demand curve and the off-peak price.
- To avoid economic inefficiencies, an accurate off-peak price design has to be guaranteed to avoid economic inefficiencies during off-peak periods
- Efforts to eliminated international transaction costs are counterproductive for national (regional) DSM-programs

All this considerations result in the main conclusion that elastic demand curves are absolutely necessary to introduce a stable, sustainable energy system and it cannot be only a national (regional) issue. All European countries have to enforce such programs to stabilize the energy system otherwise there will occur free rider effects.

3 PRACTICAL ASPECTS OF IRONS

After these economic comments and conclusions, possible technical concepts for *Integral Resource Optimization Networks* are described in a more detailed manner in the following sections. All important technical and social requirements for IRONs are listed and discussed. Furthermore, possible technical solutions for an implementation of such systems are represented.

3.1 Economic and social requirements

The interest of a global communication system can be determined in all parties of the electrical power market. Although the technical potentials can be taken for granted, there is almost no initiative to implement or put into practice additional communication systems. This tendency is partially caused by economic and social effects. The main drawbacks of additional communication systems have been named by consumers of the power market as follows:

3.1.1 Complexity of use

There is a fear that the maintenance of the new communication systems will be (too) complex. To reach high levels of scalability users must be capable of maintaining their local parts of the system themselves. But the complexity of the system has to be transparent for the user. Therefore, local front-end equipment has to be capable of automatic configuration processes.

3.1.2 Loss of comfort
The reduction of functionality (due to load shifting) can cause the social fear of a decrease of service quality. Interferences in load processes have to be almost invisible to ensure a well working system.

3.1.3 Additional costs
Additional costs caused by the installation and the use of an additional communication system have to be as low as possible. At least the costs have to be below the refunds caused by the use of the system.

3.1.4 Marginal revenues
Due to the fixed pricing of today there are no economic incentives to optimize the utilization of electrical power. Consumers have no information about the real costs of generation of electrical power at a particular time. As a result of this households and other consumers on a low consumption level have little or no interest in changing the system, even though they might cut down costs and get a more reliable supply. Therefore, the system has to be extremely cheap and easy to participate. High refunds can be achieved in small and medium size businesses having distinctive load shape curves.

3.2 Technical requirements

Beside economic restriction there are also various technical requirements on a communication system for global load management. All demand side management programs rely on data quality and timely information. There is already a wide range of technical feasible methods to implement communication. The main issue is to determinate which of the various contemporary technologies are suitable for these applications. Generally, there are requirements for security and safety, robustness, scalability and flexibility, self-adjusting, reliability (fault tolerance), and network management. In this context there are three important technical issues which are discussed in detail.

3.2.1. Scalability
With the increase of subscribers the flexibility and degree of freedom will rise within the system. So the technology used shall not create limits for the number of associated nodes, which might range from some hundreds up to even millions of nodes. However, this means a great challenge in technical terms, as the complexity of the system must not increase with its size. To meet this requirement open and flexible concepts are essential. With the accession of a rising number of subscribers, the diversity of used communication protocols might increase as well. This scalability requirement applies to the communication infrastructure as well as to network management and the used algorithms.

3.2.2 Real-time
To meet the essential sensitivity the dynamics of load management programs, both commercial and physical have to be ensured. Depending on the application the need for real-time services is evident. As time depending processes have to be

managed through this communication system, the transport time has to be very short – real-time, and must not exceed a defined propagation time. Besides these data has to be delivered to all customers at the same time (Atomic Multicast Problem [11]).

3.2.3 Maintainability

The complexity of the system has to be transparent for its subscribers. All local devices have to be capable of configuring and maintaining themselves. This feature might be referred to as "Plug & Work". These mechanisms also allow a reduction of costs. A remote control mechanism should also be integrated to upgrade services and repair software failures. Remote control might be implemented on different levels of protocols. The ideal level of maintainability is "zero-maintenance". All components (hardware and software) must be designed for remote or self-diagnosis and should not demand any manual configuration but rather work "out-of-the-box".

3.2.4 Reliability

Every malfunction of the systems means an economic loss for one or more parties. Therefore, the system has to face high demands on reliability, but also on data integrity and security. To accomplish demands on reliability, a high level of service quality, software quality and hardware quality are assumed. Furthermore, the system has to be capable of detecting and handling failures, but also of initiating recovery and re-integration of broken and repaired parts automatically.

3.2.5 Security and Safety

The information delivered over the communication system is the basis of accounting. The system has to guarantee the integrity and security of data.

Beside technical requirements, the cost factor has to be kept in mind as all modules of a load management system are cost driven. To achieve the necessary properties, the system can only be implemented based on a highly distributed structure based on open protocols.

3.3 Technical concept for IRONS

The IRON system is supposed to focus on the following four targets (Figure 3.1):

- Small industries and small businesses
- Buildings
- Homes
- Single sites

These are the top level "node" types of the IRON network.

Inside such nodes in-house communication spans additional networks in order to reach possible individual parts (subnodes) of the nodes like multiple relevant consumers within one node (Figure 3.2).

So the IRON network consists of a

- global communication infrastructure, and a
- local communication infrastructure.

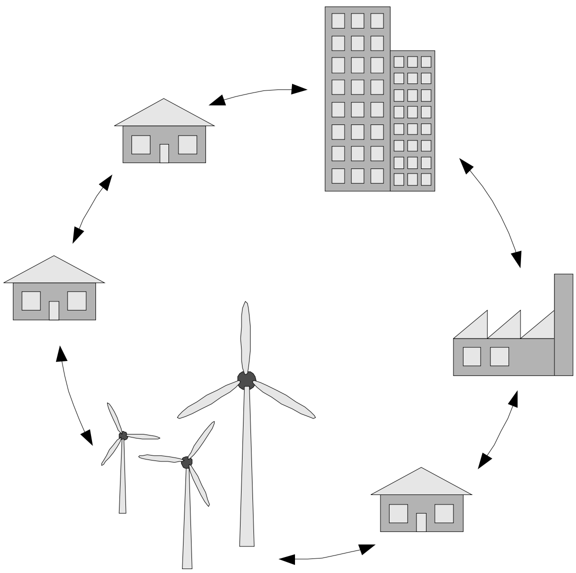

Figure 3.1: Types of nodes in the IRO-network

The global communication infrastructure must be, without any doubt, the Internet as it is widely available and a basic standard for networking large numbers of spatially distributed nodes. There are plenty of IP-able platforms, products and systems available on the market that can be integrated into the IRON.

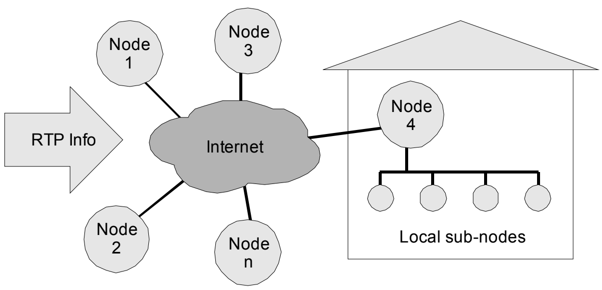

Figure 3.2: Nodes and subnodes receive real time prices

The local networks – or in-house networks – depend on the individual node type.

Small industries, like bakeries, small production sites for wood, textile or metal products, and similar, usually do not have very sophisticated energy management systems. In contrast, large industries are usually already equipped with their own energy management systems, linked to on-site production or even do corporate portfolio management for their purchases on the wholesale market. The requirements for small businesses are a rugged, industrial design which leads to a rail mounted embedded design. The in-house communication of the system must be EMC proofed, robust and reliable. The usage of demand, especially peak load demand, sometimes causes significant costs, since such businesses tend to have certain energy contracts that 'punish' peak loads. This is why such businesses often already have a maximum demand monitor, although these devices are not connected to a global optimization system like the IRON system. The IRON devices must interface with any existing maximum demand monitor system. Other relevant consumers must be networked with the in-house part of the IRON.

The second customer scenario - office, public and other large buildings - is similar to small industries. Rugged, embedded, rail mounted devices are the standard in building automation. Modern buildings are equipped with a building automation and control system (BACS), that controls heating, ventilation, air conditioning, sunblinds, and other equipment inside the building. It is essential to integrate such BACS into the IRON system, since many important consumers and virtual energy storages are accessible via the BACS. It makes sense to extend the BACS to parts and devices that are relevant for the IRON system but not initially networked by the BACS.

Private homes are the most difficult scenario. The expected savings per node are relatively low, although the high number of nodes results in an important overall impact. It is therefore extremely important to minimize costs wherever possible. A dedicated embedded - and relative costly - device like the ones used for large buildings cannot be justified. The way how the IRON system will work here is to use existing communication infrastructure. An existing personal computer (PC), connected to the Internet, equipped with BlueTooth (BT) or Universal Serial Bus (USB) communication can be the link between the IRON and the in-house consumers, networked via some (possibly wireless) protocol [6]. Naturally, this node is only part of the IRON system when the PC is up and running: 'intelligent' energy is only consumed during these periods; the rest of the day, energy is consumed in the conventional ('unintelligent') way.

Single sites in the energy distribution network are consumers like pump stations or producers like wind power stations. They typically do not need a local indoor network, such nodes have no sub-nodes. The technical requirements are similar to small industries.

The system is supposed to work as distributed as possible and there are several requirements for the protocols used for communication between the customers' premises and the global management. It has to cope with the fact that it has to work over firewalls and routers with network address translation (NAT). This makes it necessary, that communication is always initiated from the in-house system, not from the global management system. An alternative to overcome this limitation would be the use of separate modem or GSM/GPRS connections between the in-house and the global management system. However, this solution has the drawback that it would introduce additional costs. To get information from the global management system, like price signals, or target demand curves, and to provide information to the global management system, like expected future demand curves or possible interruptions, HTTP can be used as protocol. It has the advantage that it is simple to implement and works well with proxies and firewalls. In order to provide network security, HTTP over SSL (HTTPS) might be used. But for various optimization tasks the customer nodes might not only have to communicate with the operator of the resource optimization network, but communication between these nodes might be necessary (for example several branches of a supermarket chain have to coordinate their consumptions in order to achieve a certain overall demand curve). For this communication some kind of outbound proxy is necessary because the nodes only initiate connections, but are not contacted directly from the network. This outbound proxy can be the abovementioned server of the operator that provides information received from one client to other clients via HTTP services. Another possibility is to utilize protocols used by various peer-to-peer instant messaging systems like ICQ, KaZaA etc. Either the IRON nodes take advantage of the infrastructure provided by such services or a similar infrastructure is set up.

The IRON box (our synonym for the hardware of the IRON nodes) itself — at least for home environments — has to be some cheap device that on the one hand is connected to a PC using its Internet connection in order to integrate itself into the global optimization network, and on the other hand communicates with (sub-) nodes at various power consuming devices within the house. One possibility is to implement it as a USB device, perhaps similar to the popular memory sticks. Another possibility would be to design it as a BlueTooth device. But anyway it has to be a small embedded system in order to keep the price low. Complex calculation tasks have to be performed on the connected PC, not on the IRON box. For industrial/business or building environments the functionality of the IRON box can be integrated with a PC like device into a rugged chassis that is somehow connected to the Internet. The exact design mainly depends on the communication system used within the house.

If some fieldbus system is available like the BACS in large buildings, it can be used for in-house communication. However, in home environments it is not possible to install a dedicated infrastructure for communication between the IRON box and the nodes at the energy consuming devices. Therefore, the system has either to use existing infrastructure or to not require infrastructure at all. So, one solution is power line communication, taking into advantage that obviously each node is located at an access point to the power net. But due the various reasons (depending on the network topology and distortions) power line communication does not work in every situation. Therefore, the system should be designed in a way that at least one alternative communication media can be used. One obvious solution are wireless technologies which are complementary to power line communication, as both do not work in all situation, but often one works, if the other one fails. BlueTooth as proposed for the communication between the IRON box and a PC (acting as gateway to the Internet) is not suitable for this purpose, since its range is very short and it was definitely designed for other purposes. Therefore protocols like ZigBee or (especially due to cost reasons) some primitive proprietary protocol can be used.

4 CONCLUSIONS

The development of the short term demand curve (e.g. by introducing an *Integral Resource Optimization Network*) is of core relevance for the achievement of a functioning competitive electricity market, its corresponding market performance and market price. Furthermore, the implementation of a market, taking the short term demand curve into account would contribute to the Kyoto target.

The investigations presented in this paper show that such short term demand curves will increase the efficiency of an economy due to reduced possibility of strategic power plant withdrawals and lower on-peak wholesale prices. However, the higher economic efficiency will reduce the producer surplus of electricity suppliers which results to barriers against such flexible IRON systems from this side. This naturally complicates the implementation of IRON systems. In principle grid operators and suppliers have the necessary equipment to set up a flexible *Integral Resource Optimization Network,* but they might also lose money or strategic power due to such systems. Therefore, if an IRON is run by a grid operator or supplier, the risk of strategic behaviour might be given and result in economic inefficiencies. This leads to the conclusion that an IRON should be operated primarily by an independent company to avoid strategically induced economic inefficiencies and conflicts. However, this has also disadvantages which will be discussed below.

From the consumers' point of view, all load management activities are supposed to be cost driven. Actually, the IRON can be run in a way giving the customer, the grid operator, and the supplier a financial benefit. 'Unfortunately', in the unbundled energy system, the supplier and grid operator are independent companies. Therefore, the overall benefit of the system is not visible, the 'cake is cut' into three pieces, that might be too small to cover the costs of running the IRON system

From an economic point of view following concepts can be considered:

Establishing an independent energy provider

A private company who is selling 'intelligent energy' to its customers. This trader has an advantage over the other players on the wholesale market: influence on its customers' demand. Being able to consume or not consume at the right time, it is possible to save a certain percentage of the energy bill. These saving must be shared between the customer and the provider. A main barrier of this model is building up the business. Below a critical number of participants the system cannot be run profitable. Large initial investments are necessary in order to survive the startup phase.

Establishing an IRON managed by the grid operator

This scenario would include the advantage that the grid operator owns the needed technical equipment and infrastructure necessary for the IRON system. However, in this case a monitoring by an independent authority is necessary to avoid optimizations by the grid operator which results to non-optimal points for the entire economy.

One further important conclusion which was gained within this paper is that also the off-peak price is of relevance for the consumers' incentive to shift load to off-peak periods. High off-peak prices compared to the possible on-peak price reduction reduce the incentives for load shifting. Therefore, besides the need to ensure 'right' on-peak prices, the 'right' design of off-peak tariffs is necessary. If suppliers recognize the possibility to regain parts of the on-peak 'losses' due to IRONs the incentives for load shifting will decrease.

However, the IRON network offers a new solution to integrate participants which have been considered unreachable in conventional structures of contemporary electricity markets. The fact that all participants are equally capable of exerting influence on the consumption and use of the electrical 'resources' means a great economic and socio-economic benefit. This reduces the disadvantages which has caused to socio-economic losses within the insufficient liberalized contemporary electricity markets without (short term) elastic demand curves. Unlike traditional means of demand side control, the described IRONs exploit unused optimization potential without influencing the customers' processes or comfort. The system acts in the background, in a distributed and flexible manner.

All investigations performed in this paper show impressively the possibility of the customers to decrease the whole electricity system price. Because of this found advantage the total electricity market performance increases a lot. The 'old' opinion that only (central) additional power plants can manage the problem of imbalances between supply and demand is outdated. Nevertheless, load management alone will not solve the future energy problems, but it is important that the electricity industry recognizes that there is also another side to balance the system – the customer.

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