Integral Resource Optimization Network - a new solution on power markets[1]

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Abstract - **Many of today's European power systems are influenced by the deregulated energy market. Although demand and supply result in free prices and customers are free to choose their supplier, the flow of information and motivation does not reach the end customer. Optimization is done on the energy spot market, and customers usually cannot benefit from the freedom and chances the free energy market offers. By means of information and automation technology, the IRON (integral resource optimization network) project tries to increase this flow of information. Every member of an energy distribution network – distributed generation, end customer, etc. – should be able to actively take part in the energy business. Currently, only big power plants are "networked" and coordinate their behavior, according to the demand and market situation. New trends and ideas in the energy business require a more detailed network, the IRON project started to investigate the technical feasibility of such networks.**

Index Terms – **Energy Systems, Automation, Load Management**

I. INTRODUCTION

Electric power is one of the most important resources of modern societies. Consistent provision of electrical power is an essential goal of national economy.

Since 2001 European electricity market structures are unbundled. Nevertheless the liberalization of electrical power markets encounter limitations. The structure and market situation has to cope with difficulties based on an antiquated structure, which has not been reformed yet. In the contemporary electricity supply, power is still dominated by a limited number of institutions providing electricity to a large number of consumers over the distribution network. Consumers themselves are not included in the flow of information within time-dependent processes of energy management. Based on years of experience with classical concepts of automatic control engineering the electricity providers are capable of predicting the daily demand curves precisely. But with the integration of large groups of small and distributed electricity providers new concepts and technologies for a global management have become necessary.

In classical supply-side management the increasing demand of the customers leads to building of new generation facilities. This development has stopped with the unbundling process. Due to the contemporary market situation submarginal supply capacities have been reduced without considering the increasing demand. Investments for additional generation facilities are necessary to cover the rising demand, but building up new generation facilities to supply users has become too cost-intensive and time consuming to be sufficient for this fast increase. Therefore the gap between the increasing demand and strategic decreases of electricity generation is already of a critical magnitude. A reliable supply for all consumers especially during peak load periods is at risk. Therefore concepts of load management are needed, which are capable of reshaping the electric utility load dependent on time. Load management techniques, as they are used in demand response programs, can help to reduce peak load by means of load shifting. To raise the utilization ratio of the generation facilities electrical "resources" can be used more efficiently. Additional economic benefits are the increase of sustainability and ensured efficiency. Generation companies and other stakeholders have conflictive interests based on their individual situation. Therefore public agencies like energy agencies or regulation agencies are trying to support more socio-economic ambitions.

The liberalization of energy markets was an important step in order to achieve more competition and efficiency in the energy business. It seems, however, that this should have been only the first step. The overall system can be optimized much more, and efficiency can be further increased. Unfortunately some members of the energy business would feel disadvantages, although the overall system would be optimized. The IRON project tries to identify ways to find a multiple-win-situation, where all involved players take a benefit. In this project, socio-economical ideas are supported and implemented by means of automation technology and information technology in order to harvest unused optimization potential.

To reach this significant increase of efficiency a new communication concept implicating all participants of the power grid is indispensable. The classical distribution structure is in flux becoming more flexible, but also more unpredictable in its behavior. On the consumer's end there is still less or even no infrastructure to optimize the demand side. Real costs of electricity cannot be accounted to the consumers. The use of communication technologies for direct load control and interruptible rates can support a reduction of demand during peak load hours. Therefore new groups of participants shall be integrated in global electrical

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power management:

- *Intelligent consumers:* There are already intelligent devices on the market that are capable of predicting their energy consumption. Using these functionalities optimization can be reached on a new level.
- *"Virtual storage" of electricity:* There are lots of slow and interruptible processes on the demand side, which can hold and store energy in another form like e. g. heating (heating system, air conditioning) or cooling energy (cooling units) over a certain period of time. This ability bestows new opportunities for interruption during peak periods.
- *Distributed supply facilities:* These new forms of supply using also smaller and more volatile units might cause a local lack of stability which might be balanced by appropriate load management techniques.

The basic idea for this communication system is to integrate high numbers of consumers even of medium and low size by using existing network and communication infrastructure to reach a maximum utilization of power resources. This means a high flexibility of the system providing "intelligent power" for a high diversity of different consumers combined with conventional management concepts of the generation side. Nevertheless these systems determine modern economical concepts like time-related prices to encourage efficient energy use on the demand side.

II. Requirements

The new system tries to "squeeze out" the last portions of non-optimized potential of energy systems that have been optimized for the last decades by means of technology and the market. Naturally, the system has to save more money than it costs. In detail, this means:

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:

- *Complexity of use:* The complexity of maintaining is the main barrier for such system. To reach high levels of scalability a user must be capable of maintaining his local part himself. But the complexity of the system has to transparent for the user. Therefore local front-end equipment has to be capable of automatic configuration processes.
- *Loss of quality of life:* The reduction of functionality can cause the social fear of a decrease of quality of services. Interferences in load processes have to be almost not discernible. Especially slow processes including virtual storages are preferred for this application area.
- *Additional costs:* Additional costs caused by the acquirement and 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.
- *Only marginal revenues:* Due to the fixed pricing of today there are no economic incentives to optimize the utilization of electrical power. Prices are very low and the consumer has no information about the real costs of generation of electrical power at a particular time.

After the unbundling process the rate of consumers changing their power supply company was about 5%. 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. 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.

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 technically 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 several important technical issues which are discussed in detail:

- *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.
- *Quality of service, real-time behavior:* 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, and must not exceed a defined propagation time. Besides data has to be delivered to all customers at the same time (atomic multicast problem) [1].

- *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 also 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".
- *Reliability:* Every malfunction of the system means 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 and hardware quality are assumed. Furthermore the system has to be capable of detecting and handling failures, but also of initiating recovery and automatic re-integration of broken and repaired parts.
- *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.

III. State of the Art

According to [2] demand side management (DSM) specifies a set of planning and implementation activities designed to influence demand patterns insomuch to achieve an optimal production of electrical power. DSM programs have to face a grave optimization and scheduling problem to fulfill all requirements necessary for widespread management of electrical power consumption.

Contemporary demand response programs are mainly conducted in the USA. Especially in the metropolitan area of New York various concepts have been established (Tab. 1). There are three main forms of demand-side management used, which differ in reaction time, duration of shutdown, minimum load and pricing [3, 4].

Tab. 1: Demand side programs in New York/ U.S.A.

Program	Emergency Demand Response Program (EDRP)	Installed Capacity Special Case Response Program (ICAP SCR)	Day Ahead Demand Response Program (DADRP)
Minimum load	100kW	100kW	1MW
Duration	≥ 4hours	≥2hours	
Notice	2hours	Offer: 24hours Conf.: 2 hours	Prior afternoon

Beside payment of performance and reservation, there are penalties to punish subscribers who do not provide the claimed load reduction in real-time.

One of the few concepts found in Europe is settled in Ireland since the early 90ties of 20th century. Beside initiatives of general reduction of power consumption within the DSM strategy, a "Short Duration Interruptible tariff" was introduced already in the 1980s. Since 2000 activities concentrating on load management during peak periods have been intensified.

In general all current concepts used for DSM are on a low level of automation. Subscribers are metered passively. The actual real-time curtailment is calculated from the subscriber's baseline load minus his actual real-time consumption [4]. But there is still no direct influence on the interruptible load itself. The consumer himself is responsible for the interruption of consumption processes, no matter how to execute the load reduction. Penalties are the only method of monitoring. Without a universal communication system the contemporary DSM strategies lack an essential level of automation. Because of simple metering the granularity and flexibility is very low. Therefore the connection of consumers at the level of a house is still infeasible with current programs. Concepts for real-time pricing systems designed for residential customers (e. g. [5]) have already been presented, but not put into practice so far.

The majority of existing load management systems are found in industrial application areas, usually installed by the customers themselves or on behalf of them. Having an energy contract that respects peak loads on the basis of "measurement periods" (15 minutes in Europe), the tool to limit the consumption within such periods is a so called "maximum demand monitor" (MDM). *Fig. 1* shows three of such periods, the current time being in the third period.

Period 1 was ended by having consumed exactly the allowed maximum of energy per period, while the consumers were not so "hungry" in period 2. The MDM permanently calculates the "trend" (the expected value of the energy consumption at the end of the current measurement period) by simply extrapolating the current consumption. Based on this trend, priorities are changed, devices are scheduled, etc.

"Intelligent" consumers would greatly support MDMs, since they might "know" and not guess the future. The way from our current "non-intelligent" devices to networked, informative and collaborative "intelligent" devices is not that easy, but possible as explained in [6]. Combined with real-time pricing (RTP) information of the utility, environmental and other sensor data this increase of data and data quality would allow for a new level of service quality strategies for load management [7].

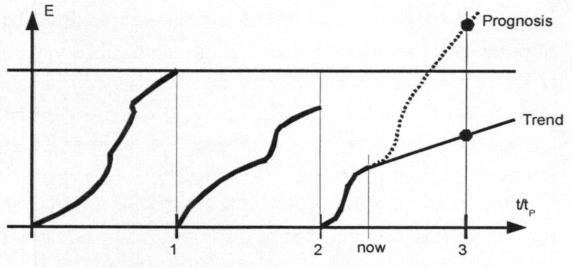

Fig. 1: The difference of trend and prognosis

At the Institute of Computer Technology practical DSM research has been conducted within several industrial and academic projects. One of the main projects supervised by the institute deals with the design of the REMPLI system (Real-time Energy Management over Power Lines and Internet). Its main focus is communication based on power lines. It provides an infrastructure to access remote control for metering and controlling processes [8]. The main application of this project is global energy management, where whole buildings can be interconnected and do DSM to reduce energy costs.

Another important project called smart kitchen is focused on the interconnection of different parts of a kitchen, e. g. light, oven, sunblinds, etc. via a similar network [9].

IV. Concept

The IRON system is supposed to focus on the following four targets (*Fig. 2*):

- Small industries and small businesses
- Buildings
- Homes
- Single sites (wind power stations, etc.)

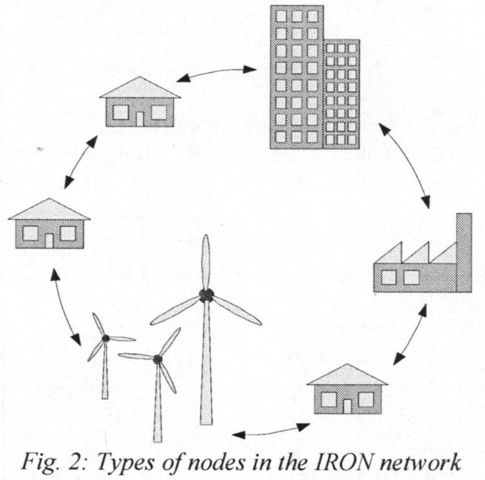

Fig. 2: Types of nodes in the IRON network

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

Inside such nodes, in-house communication spans additional networks in order to reach individual parts (subnodes) of the nodes like multiple relevant consumers within one node (*Fig. 3*). So the IRON network consists of

- Global communication infrastructure
- Local communication infrastructure

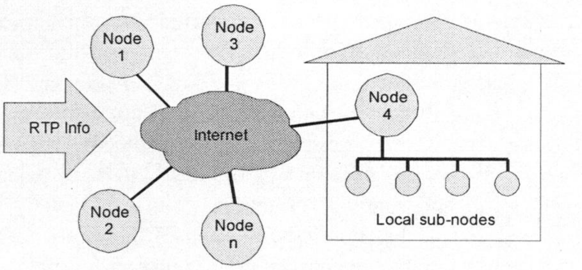

Fig. 3: Nodes and subnodes receive real time prices

The global communication infrastructure is without doubt the Internet, as it is widely available and a de-facto 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 network.

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

Small industries are typically bakeries, small production sites for wood, textile or metal products, and similar customers. 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 energy stock market. The requirements for such small businesses are rugged, industrial design, which leads to rail mounted embedded design. The in-house communication of the system must be EMC proofed, robust and reliable. The usage of energy, especially peak load energy, 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 network.

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 relatively costly — device like the ones used for large buildings cannot be justified. The way the IRON system will take 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 network in the Internet and the in-house consumers, networked via some (possibly wireless) protocol [10]. 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 customer's 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 for 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 proxy outside thee customer's network is necessary, because the nodes only initiate connections, but are not contacted directly from the network. This 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 USB 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 (sub-)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 (of course there are situations in which both fail). 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 a protocol like ZigBee or (especially due to cost reasons) some primitive proprietary protocol can be used.

V. TECHNICAL CHALLENGES

Making the relevant parties accessible by the IRON network is dominated by the question "how much does it cost and how much does it bring?". As the IRON project showed (soon to be published), the cake is very thin, and unfortunately cut into pieces by deregulation. Therefore, IRON infrastructure must be very low cost, in order to make money.

Beside this obvious financial limit, there are also technological obstacles. Some of the potential nodes of the system might already be equipped with some IT-equipment, probably even with a remote channel, it would be unwise not to integrate such systems. Unfortunately such a heterogeneous system causes high costs in maintenance and has a permanent source of data loss: gateways between two technologies are usually lossy.

Additionally, the IRON infrastructure must come in different qualities. Some of the devices have to survive a winter with temperatures below −40°C, while others are installed in a living room. The same applies to electromagnetic compatibility and immunity in distorted industrial environments. The requirements of IRON to the design of embedded systems are therefore not trivial and there is no space for not-necessary functionality. IRON must be based on specialized and minimized infrastructure.

VI. Discussion

All demand side management programs are cost driven. Maximum cost saving can only be achieved by the cooperation of load control and unit commitment based on processes to ensure an optimum [11]. This form of profit oriented load management must be integrated into a business model. Actually the "intelligent (i. e. flexible) customers" can behave in a way, that the grid provider, the utility and the energy trader have financial benefits. Unfortunately in the unbundled energy system, these three entities 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. We have, however, identified two main scenarios, that look feasible for making business by means of the IRON system:

Establishing an independent energy provider: A private company selling "intelligent energy" to its customers. This trader has advantage over the other players on the energy stock 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 customers and the provider. A main barrier of this model is the 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.

A public service provider: The only party in this system that sees all the benefits is the government: reduction of emissions, higher productivity, lower national energy costs, etc. Additionally, a provider with public ownership can plan in longer terms than a private one could ever do. Unfortunately the liberalized energy market wants anything, but a step back towards regulated, publicly owned parties.

As proposed above the technical aspects have to be verified under economic aspects: The IRON network offers a new solution to integrate participants, who have been considered unreachable in conventional structures of contemporary power 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 a drawback which has caused a great socio-economic loss within the liberalized contemporary power markets.

VII. Outlook

The current stage of the project is a finished concept and a technological/economical analysis of the system environment. Phase 2 will start in Q4 2005 and will include important stakeholders and other parties involved in the energy business. It will cover the design and development of the system. Finally, phase 3 is a field trial in Austria, where the technological and economical benefits, problems and prospects of the IRON system will be tested and analyzed.

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