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Future Developments in Power Industry

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Introduction

Long term developments in power industry depend on expectations for future political, financial and technical conditions. Taking into account these factors and based on past experiences since the beginning of electrification, it is possible to predict further developments for certain limited period of time. Of course, such judgements are valid only if no catastrophic events would happen during this time.

We therefore present expectations for the developments in power industry for the time up to the year 2030. The horizon of about 30 years is based on following important characteristics:

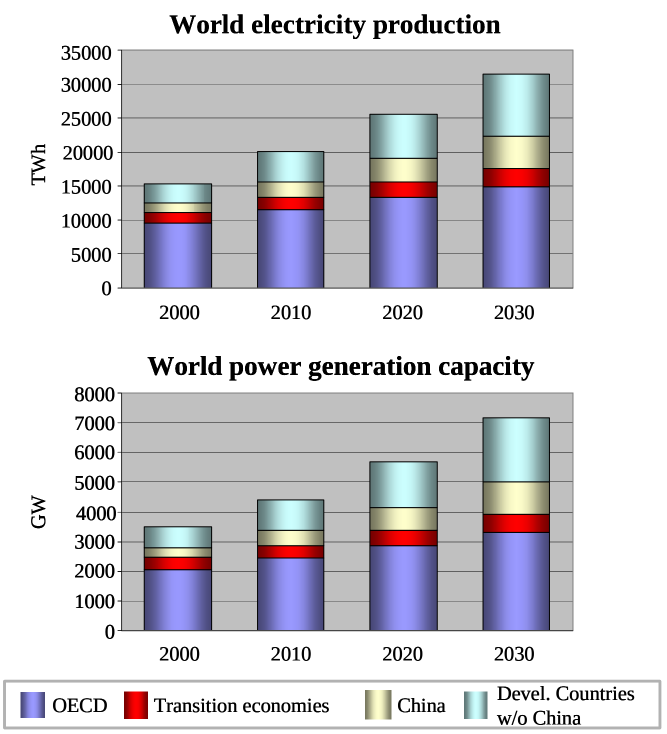
- Lifetime of the equipment for power systems is in the range of 20 to 50 years. It means that the possible changes in the systems through the exchange of equipment and introduction of new technologies can progress only slowly. For the time period of 30 years the error in the analysis is therefore in acceptable limits.
- Introduction of new technologies takes at least 10 to 20 years from the start of the development: building prototype, analyzing first operating experiences, and than increased use of the technology in the systems. The expected changes are therefore only evolutionary and not revolutionary.
- It is time of one generation of engineers. It means that the way of thinking will probably not change considerably during this time.

Power Demand

The driving force for the future development is the further increase of electrical power demand, based on expectations for increasing world population, development of economy and the fact that electric energy is the most suitable form of the energy with respect to commodity for people and environment. IEA Investment Outlook judges for the development up to 2030:

- 1 % increase of population per year,
- 2.4 % average increase of economy (GDP) per year,
- 2.4 % increase of power demand per year in average with increasing electrification rate in the areas where electricity is not available yet.

Of course, the 2.4 % increase of power demand is an average value which differs strongly between different world regions. It is rather at the lower limit, at least for the period of the next decade, for which detailed plans already exist in most countries. In industrialized countries (OECD countries) the expected increase is predicted to be about 1.6 % per year, leading to the additional demand of power of 60 % in the next 30 years. On the other hand, in developing and emerging countries the average increase will be more than 4.0 % per year leading to the total increase of power demand for more than 300 % in the same time. In some countries, for the coming decade, the yearly power demand increase is expected even in the range of 8 % or more, leading to the doubling of the total demand in less than 10 years. Fig. 1 shows the expected development of world electricity production and generation capacity up to the year 2030.



Source: IEA

Fig. 1: Development of world electricity production and power generation capacity

The estimation of needed investments in the power industry for the next 30 years is 10 trillions U$ or roughly 350 billion U$ per year. In Fig. 2, the sharing of the investments among power generation, transmission, and distribution is given. Generation amounts about 46%, transmission 16%, and distribution 38% of total expected investments.

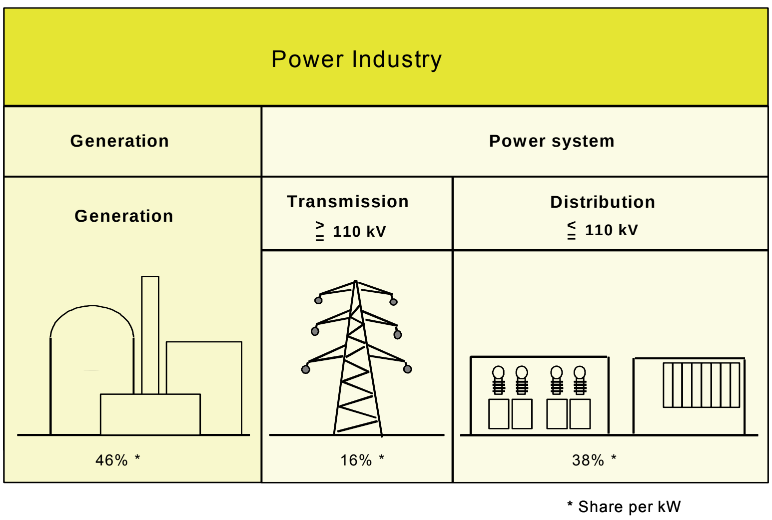


Fig. 2: Structure in power industry

The trend in the power industry developments will be influenced by

- Liberalization and globalization with the goal to open markets, not only for delivery of equipment but also to include new market players in the generation and transmission of the energy.
- Increasing environmental constraints (e.g. CO2 reduction, regenerative power generation, and difficulties to get right of way for overhead lines) will influence the type and location of new generation and changes in the structure of power systems.
- Continuous increase of price for oil and gas can speed up the use of new generation technologies if they would be technically available.
- High demand on financing for new investments can slow down the fast development in emerging countries. In industrial countries measures will be used to prolong the lifetime of equipment to save costs.

Power Generation

In the deregulated environment, responsibilities for generation, transmission and distribution are separated. However, from technical point of view there are strong interdependencies among all the parts of power systems. Generation locations depend on the available primary energy sources (water, wind, etc.), mostly not close to the centers of power demand. The transmission system then has to transmit power over long distances. In case primary energy as gas or coal is available close to the load centers or it can be transported by other means (e.g. pipelines, shipping), generation can be placed close to the load, even in sub transmission or distribution systems. The attractiveness of power plants regarding technology, financial, environmental and social acceptance is shown in Fig. 3. This attractiveness results in the to-day market volume.

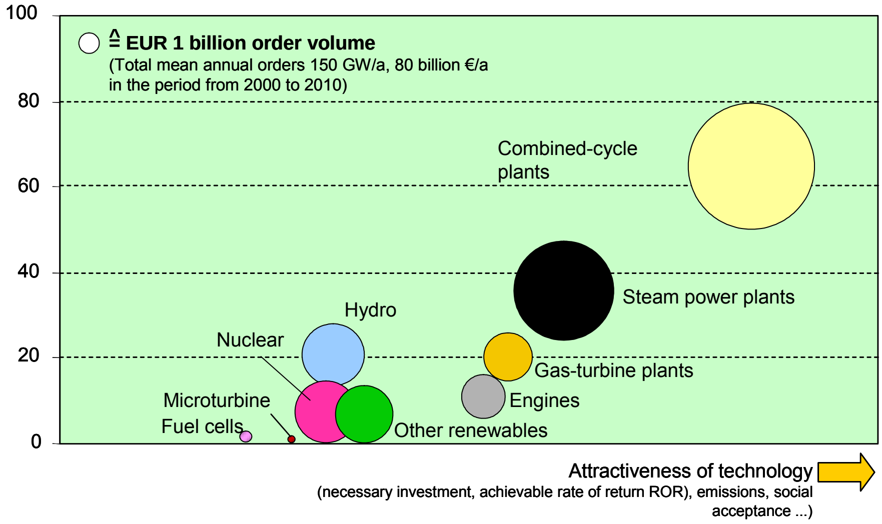


Fig. 3: Attractiveness of power plants

Financing of power plants plays an important role in the deregulated environment. Therefore payback times are an important factor in the decision for new power stations. Fig. 4 shows payback times for different types of power plants. Technologies with the shorter playback have economic advantages.

In the decades to come it can be expected that the main primary energy will still be gas, with declining use of coal. Studies show that the gas exploitation will increase for more than 4 times in the next 30 years. The large economically feasible water power sources will be further utilized. Nuclear power plants will be built in the countries where the technology will be politically acceptable, especially if prices for gas and oil will further increase. The renewable power generation (wind, solar and biomass) will increase considerably in some countries; however, because of still high costs and the need for additional generation as running reserve, it will not exceed a major share in the total generation.

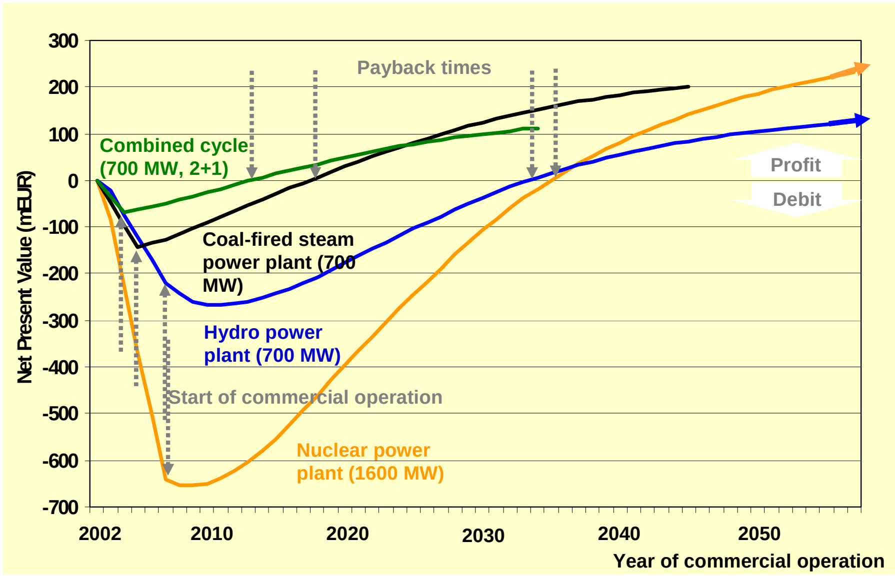


Fig. 4: Payback times for power stations

New technologies as fuel cells are still in the early phase of the development. Fig. 5 shows an optimistic scenario for the future development. To be economical, the production costs have to be reduced considerably. This depends, however, on the progress in the development of new materials. The expectations for the economic break-through are therefore uncertain. In the next 30 years fuel cells will be used only for small ratings in distribution networks and will not play a major role in power industry.

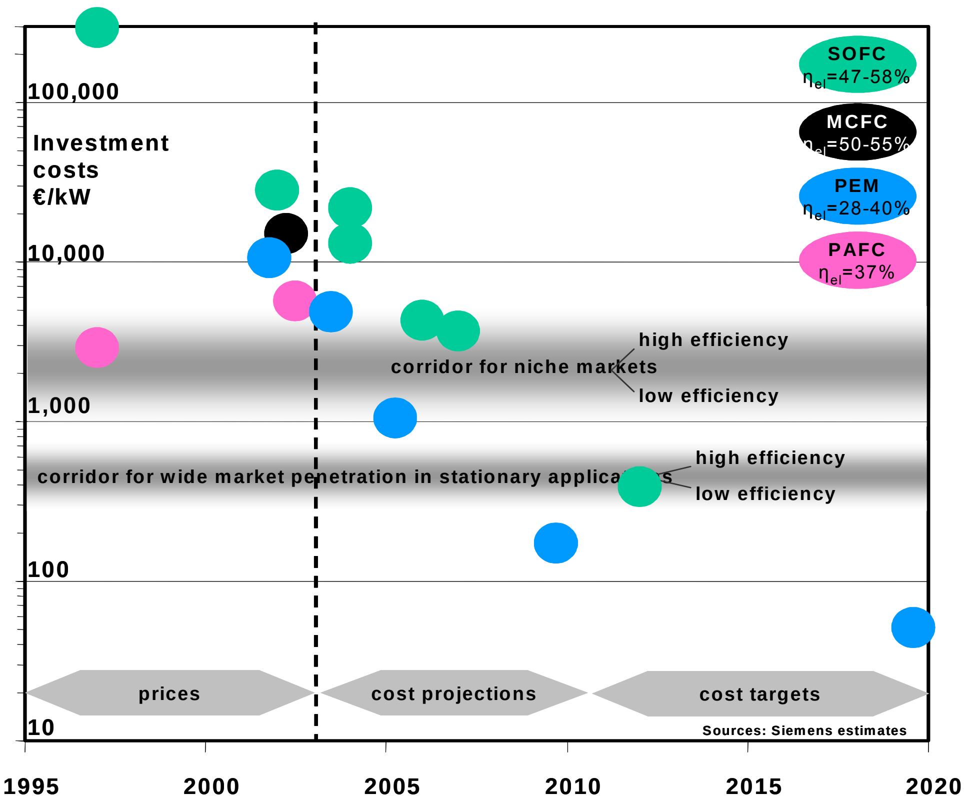


Fig. 5: Development of fuel cells

Development in the field of fusion to produce electric energy is just at the beginning with problems in the field of materials which have to resist very high temperatures. The realization in the next future can not be expected. It can, however, be possible that fusion generation will be built in 50 years or even later.

Transmission and Distribution Systems

The development of power systems follows the requirements to transmit power from generation to the consumers. With an increased demand on energy and the construction of new generation plants built first close and then at remote locations from the load centers, the complexity of power systems has grown. This development is schematically shown in Fig. 6.

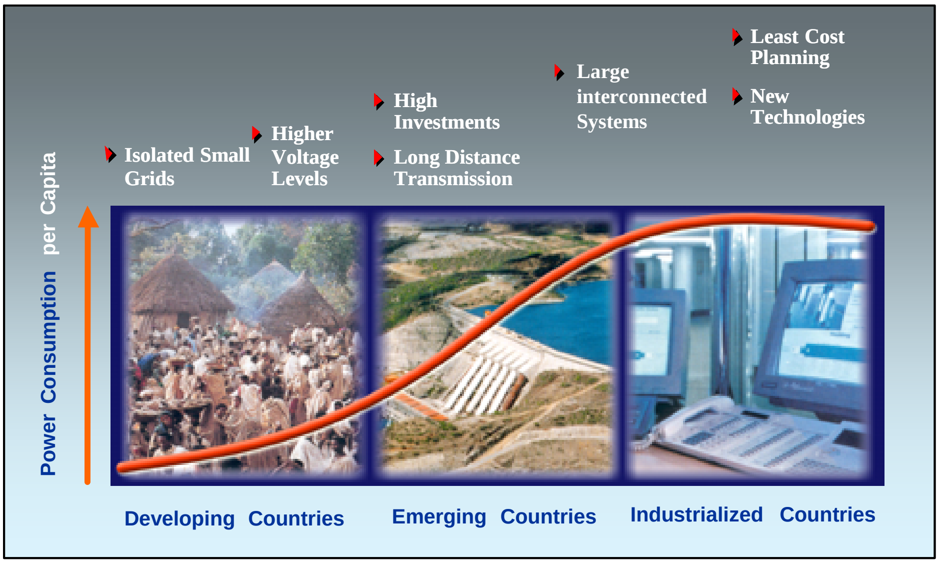


Fig.6: Development of power systems following the energy demand

The operating voltage of power systems depends mainly on the geographic conditions and the average transmission distance. In Europe, 400 kV became the highest voltage level, in Far East countries mostly 550 kV, and in America 550 kV and 765 kV (Fig. 7). The 1150 kV voltage level has been anticipated in the past in some countries and also some test lines have already been built. However, it is not expected in the future that this voltage level will commercially be utilized. Reasons for this are very high development costs for the equipment of the new voltage level, restrictions for right of way for such lines and too big power outage in case such a line is disconnected.

In industrialized countries power systems have grown first to regional, then to national and finally to the large internationally interconnected networks using high voltage levels. The goal for power industry to establish electricity supply arrangements with neighboring partners is a major stimulation towards the extension to interconnected systems. The high complexity of such large systems can be demonstrated by the UCTE, NORDEL and UPS systems in Europe, shown in Fig. 7.

Similar large systems are present also in both Americas, Japan, and in the future also in China and India. The further development will move in the direction of further interconnections (HVAC or HVDC, High Voltage DC Transmission), transport of large power blocks from the remote locations by HVDC, and the use of decentralized power generation in-feeding distribution networks (Fig. 8) However, with the size of interconnected systems, the technical and economical advantages diminish. On the other hand, the additional investments for enlarging the systems increase with the size of the interconnection. This could be one of the reasons that the continental and especially inter-continental network can hardly be built in an economic way. A further reason is that the transmission costs increase with the transmission distance. Taking into account to-day transmission costs of about 0.8-1.0 Cent per kWh and 1000 km, the advantages of the energy taken from the interconnected systems over very long distances would not be economical any more. The reasonable maximum distance to transmit energy still economically could be therefore in the range up to 3000 km. These conditions, however, could possibly change if strong political efforts will prevail the use of renewable energy in remote areas, in large scale, independently on production and transmission costs.

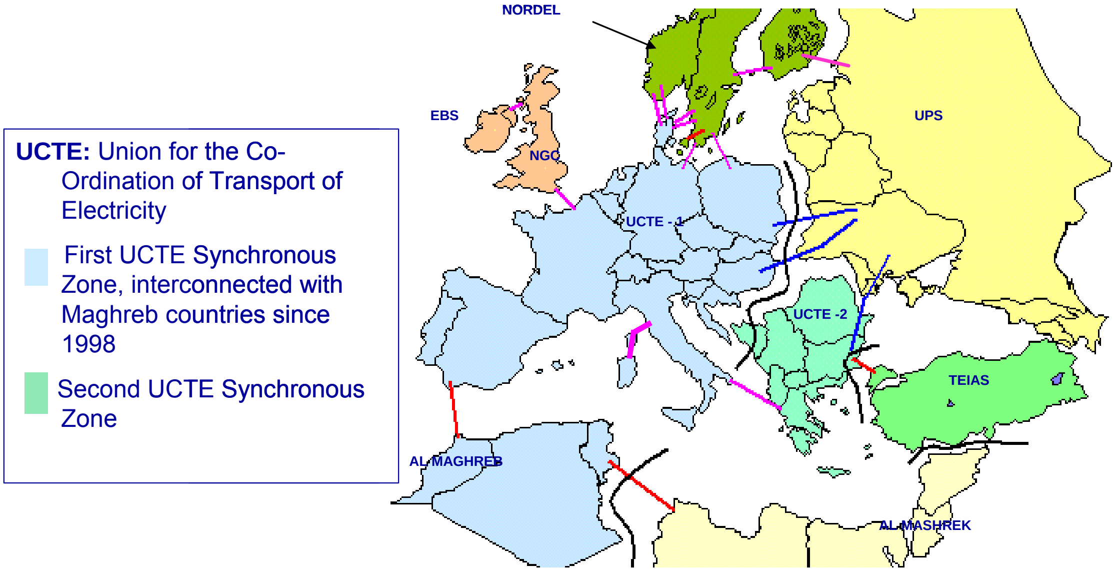


Fig. 7: Large interconnected systems in Europe

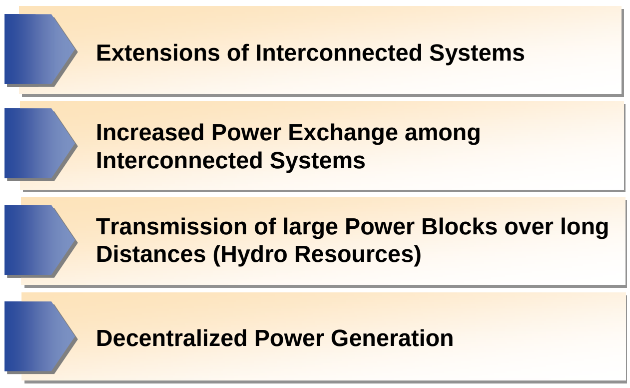


Fig. 8: Development of power systems

According to the expectation for increasing power demand in the next decades the existing systems in industrialized countries will be loaded by additional power of at least 60%, without the possibility to build a larger number of new overhead lines. The existing lines will be therefore loaded up to their thermal limits. The solution in density populated areas will be to introduce more underground cables and preferably to use GIL (Gas insulated Lines) for bulk power transmission corridors, as GIL technology can transmit large amounts of power at reasonable costs through narrow rights of way. FACTS (Flexible AC Transmission Systems) technology could also help to improve the loading of power corridors. With the increasing load the short circuit current will also further increase. Short-circuit current limiter based on FACTS technology could avoid this problem.

However, with the increasing complexity of power systems, the reliability of power supply will diminish as already shown by a number of large blackouts in Europe and America. Studies show that the probability for large blackouts is much higher than theoretically expected. Reason is that the fault sequences leading to blackout don’t result only from statistical failures. An essential role plays human errors, insufficient maintenance and systematic errors in planning and operation, leading to cascading of the faults. These systematic errors can not be completely avoided, because of too high complexity of the systems.

Improvements will be made by the use of HVDC. Back-to-back HVDC could separate parts of the interconnected systems to avoid the widening of big disturbances through the system. HVDC will further be increasingly used to transmit large power blocks from the remote locations to the load centers. Fig. 9 shows the complexity of transmission solutions in such systems.

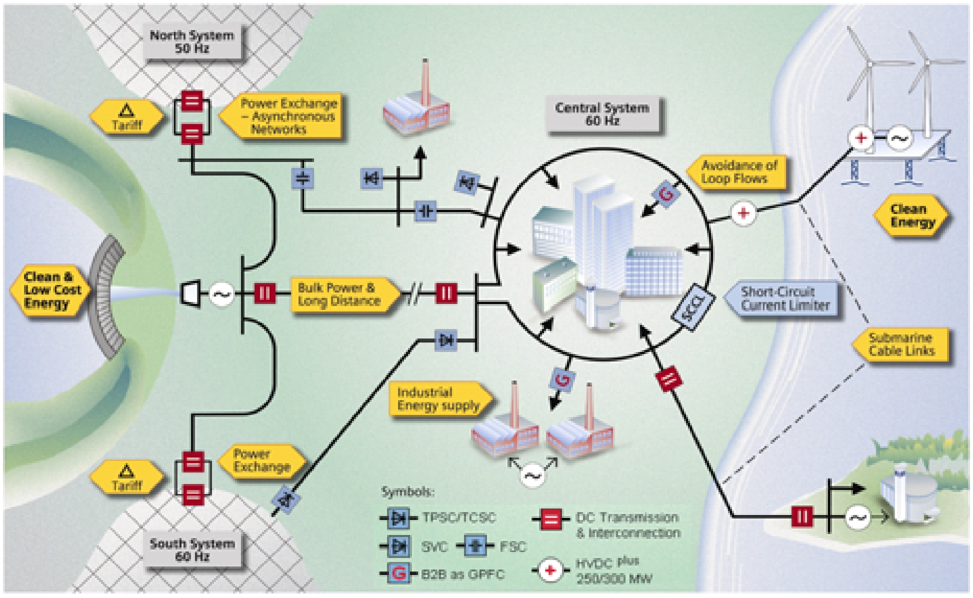


Fig. 9: Transmission solutions

In emerging and fast developing countries the increase of power demand will be more than 3 times higher compared to the today conditions. This extremely fast development, especially in the next decade means need for large extension of transmission systems. Power has to be transmitted over long distances. Therefore, extra high AC transmission or HVDC will be introduced or extended. The highest AC transmission voltage will, however, stay with 765 kV because of technical, cost and reliability reasons. Transmission problems at AC will be improved by the use of series compensation and other shunt and series FACTS equipment. For power transmitted over distances more than 800 km in general HVDC transmission will be applied. The maximum operating voltage will be +/-600 kV with bipole ratings of maximum 4000 MW. The role of HVDC technology in the transmission will further increase.

The long term strategies for the development of large power systems goes, however, clearly in the direction of hybrid transmissions, consisting of HVDC and AC interconnections among regional subsystems. Such interconnected systems have technical and reliability advantages. Examples for such strategies are China, India and also Japan. Fig. 10 shows schematically such a hybrid system.

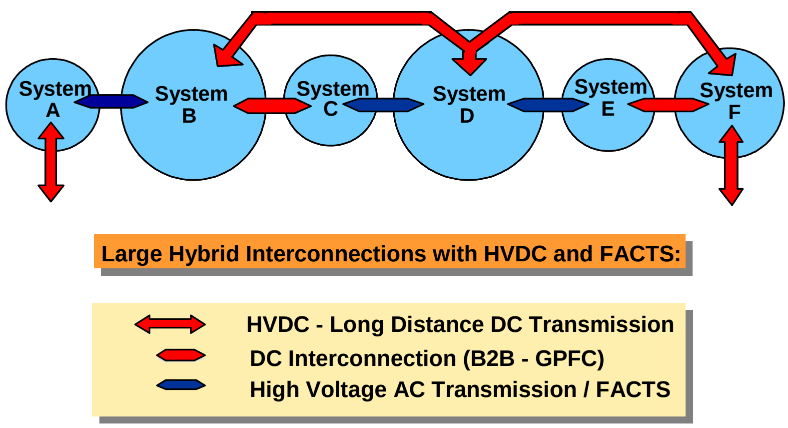


Fig.10: Hybrid system interconnection

Power exchange in the neighboring areas of interconnected systems offering most advantages can be realized by AC. Transmission of larger power blocks over longer distances should, however, be utilized by the HVDC transmissions directly to the locations of power demand. The HVDC transmission at the same time can strengthen the AC interconnections to avoid possible dynamic problems, which exist in such huge interconnections.

The effective operation of large and complex power systems both in industrialized and emerging countries will ask for new modern control systems combined with new protection strategies. The goal of new control and protection will be to assure economic and reliable operation even under emerging conditions.

The loading in distribution system will also increase leading to high current networks. In addition, decentralized power generation will be in larger extent connected to the distribution networks. The structure of distribution networks will therefore change from vertical oriented power in-feed to the mixed structure with part of power in-feed from the superposed power system and part delivered by own generation, as shown in Fig.11.

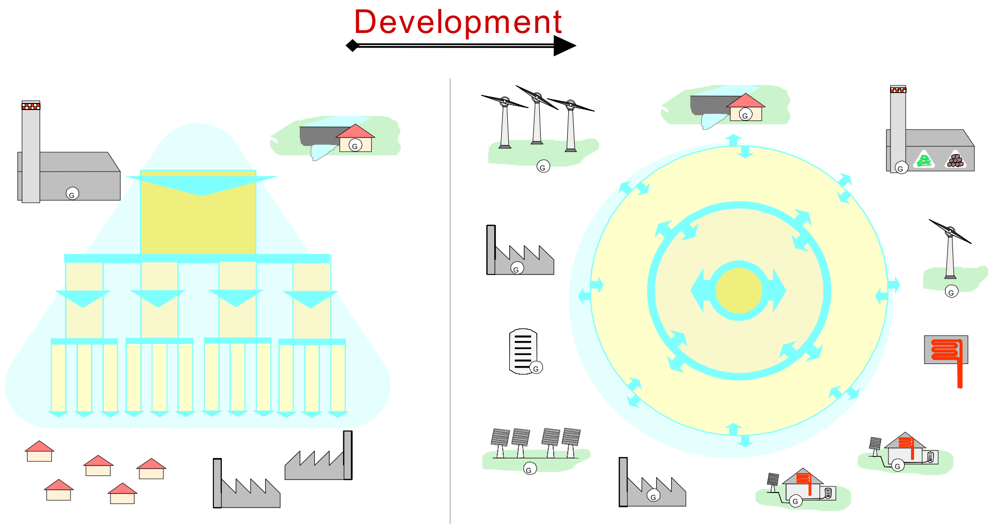


Fig. 11: Structures of distribution networks

Distribution systems will operate in similar way as high voltage systems. Because of high short-circuit currents and reliability reasons they will be separated to smaller systems interconnected by current limiters or DC back-to-back stations.

System Elements

Existing Technologies

Most of existing and already since years used technologies for equipment in power systems will stay in use also in the next 30 years. These basic technologies are mature; however, the further development will seek for lower cost, higher reliability and less maintenance.

The developments of new equipment mostly use the existing technologies to design new products. They should cover niches of special applications. During time, however, these new products can further be developed and can later substitute the existing basic technologies.

Breakers and substations. For high voltages, SF6 circuit breakers and SF6 gas insulated switchgears, for medium and sub transmission voltages vacuum circuit breakers are basic technologies. These technologies will remain, as alternatives do not exist.

As shown in Fig. 12, emerging technology for special applications e.g. Short-Circuit Current Limiter using FACTS elements exists already as prototype. The Very fast Circuit Breaker will be used in the next decade, and finally some years later the Semiconductor Circuit Breakers. In the field of substations the trend will be further towards gas insulated substations (GIS) or hybrid solutions between gas insulated and open air substations, because of savings in space and higher reliability.

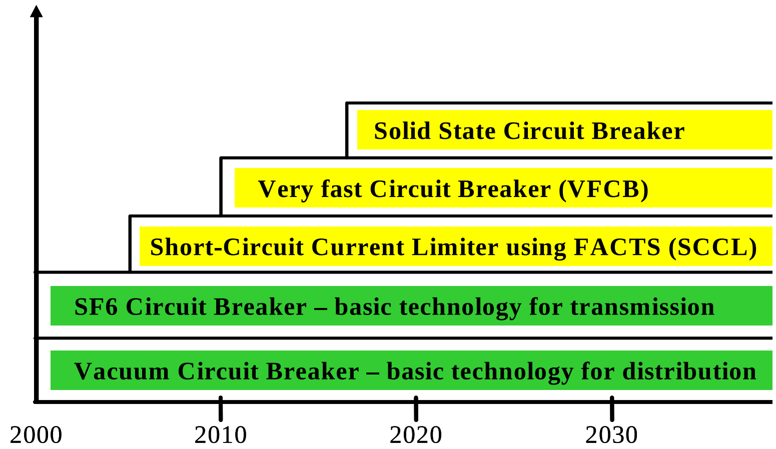


Fig.12: Switching technology development

Overhead Lines and cables. The trend in the field of overhead lines will be towards multisystem lines to increase the transmitted power through the given corridor. To save the right of way compact lines will be used. The conventional underground power cables are close to the limit of their transmission capacity and only small evolutionary steps can be expected in the future. However, with the increased transmission power through the corridors, GIL (Gas insulated Lines) will be used (Fig. 13).

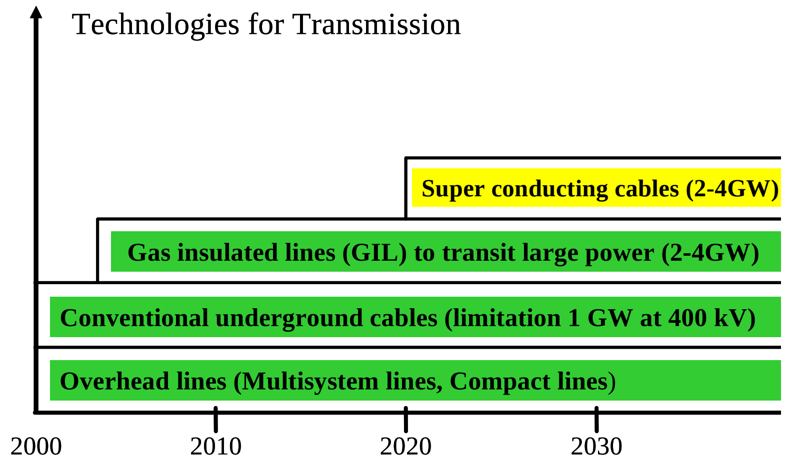


Fig.13: Developments in the field of overhead lines and cables

The advantages of this technology, proven in commercial projects for voltages of 400 kV and higher, are high transmission power and less environmental impact. GIL can substitute not only underground cables, but also overhead lines in high density populated areas. The superconducting cables are in the development since long time; however, still major progress is needed in the development of materials. The economy of superconducting cables is questioned. Technology will be therefore used only in niche applications.

Transformers and reactors. For these system elements built in traditional technology there are no alternatives. The development goes towards better materials, further reduction of losses, and achieving higher reliability through on-line monitoring.

Automation, protection and communication. Grid automation systems have evolved gradually in parallel with digital technology and, since the mid-1980s, also with communications technology. Meeting the requirements of the past and the present, existing automation systems enhance the reliability of power networks so that grid operation can be optimized under given conditions. Nevertheless, different systems and protocols are today being used between the EMS system itself, the EMS and substation automation systems, substation automation systems and protection/monitoring devices, etc..

The recent blackouts on one hand and emerging new requirements such as for "temporary operation under overload conditions" are posing new challenges for grid automation and monitoring systems to provide solutions for grid operation under future conditions and philosophies.

Operating under new conditions and philosophies means, for example, that, based on process optimization, the trend is to operate larger regional areas with less manpower. Likewise, "temporary operation under overload conditions" means, for example, that overload/temperature-protection systems must be integrated into the grid automation system in such a way that the parameters for operation and protection must be adapted dynamically according to the actual situation. These requirements call for a fully integrated grid automation, protection and monitoring system, and therefore data exchange and communication protocols have become important elements in these systems. IEC 61850 is the forthcoming global standard for communications in substations. Fig. 14 shows the complexity of communication, interconnecting all the relevant software elements supporting the operation of the system.

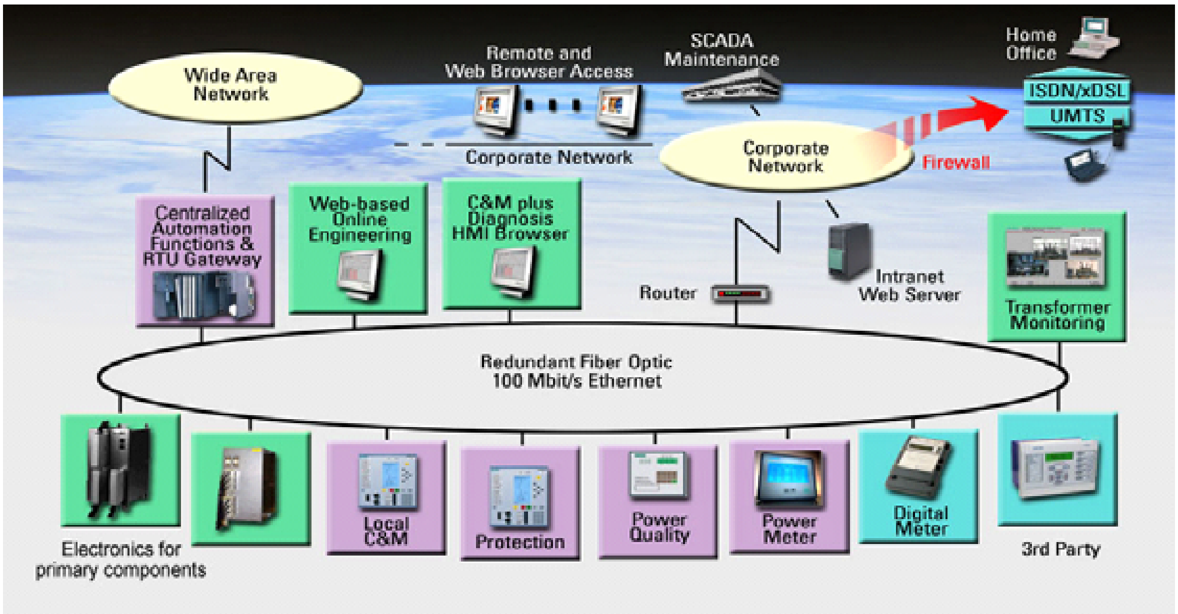


Fig. 14: Communication in future power systems

Simulation. Network simulation is an important tool to support planning and operation of power systems. It will play an essential role also in the future. Fig. 15 gives the expected development of simulation for testing of power electronics, system controls and protection, including thyristor and VSC models and medium to large power system set-up. On the other hand it will be extensively used to control and monitor the system operation, first off-line and later also in real-time.

HVDC and FACTS. The HVDC became a mature technology which complements AC transmission. In total over 50 GW transmission projects have been put into operation and a large number of big projects are planned in the coming decades. The conventional HVDC is based on thyristor technology as it offers excellent performance and low costs. The expectations for the future are listed in Fig. 16. For small ratings in special applications voltage source converter technology has been introduced. However, it will take still long time until this technology will be used for larger projects as it is more costly and has higher losses.

A variety of different FACTS devices has been developed. They are widely used in the systems to improve voltage conditions and to control load flow. They are still mostly based on thyristor technology, but the development goes into the direction of the voltage source converter based technology. Power electronics, HVDC and FACTS can be expected to play an extremely important role in the future power systems.

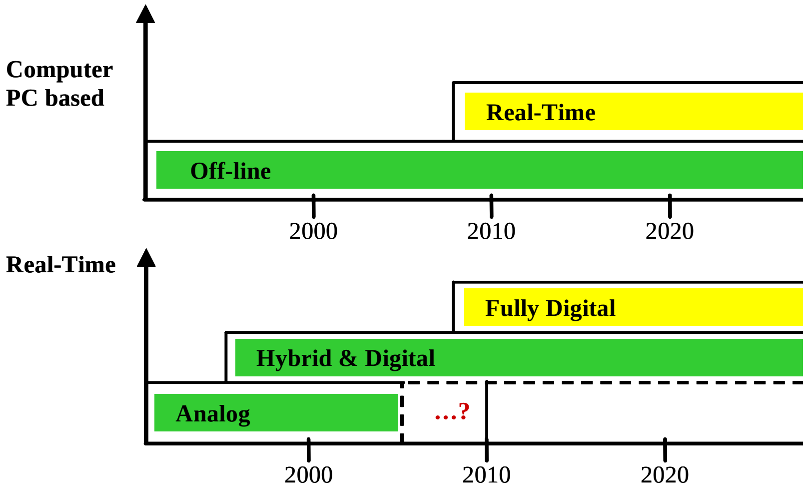


Fig.15: Developments in the field of simulation – including detailed HVDC and FACTS models

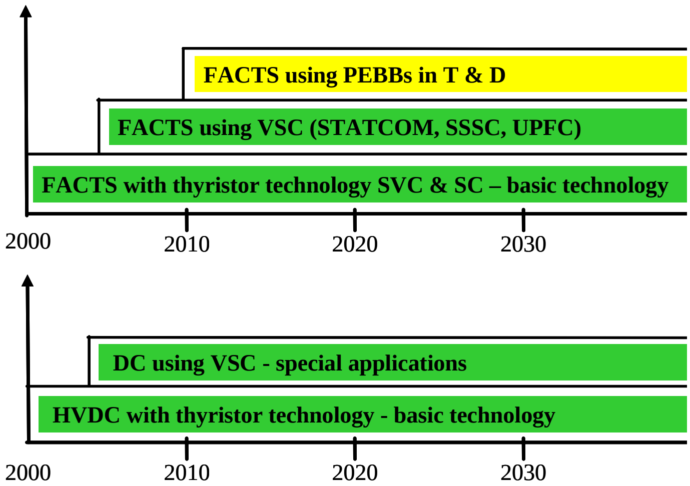


Fig.16: Development of power electronics for transmission systems

Future Technologies

There are a number of new technologies which have been developed since considerable time. Because they use new materials and new processes the progress is bound to the basic research. The time prospective for these developments is therefore difficult. It takes decades until new developments are technically accepted and commercially applied in the system.

Superconductivity. Since the discovery of superconductivity and especially since the discovery of high-temperature superconductivity engineers are developing possible applications using this technology for power systems. The applications look for optimization of conventional elements as cables, transformers, generators and motors with the advantage to reduce losses and increase power density in the equipment. The second part of possible applications are new equipment (magnetic storage, superconducting bearing for rotating storage, and current limiter) which could improve the operation of complex systems (Fig. 17).

Some superconductive equipment has been already applied as prototypes in niche applications. However, the real break through of the technology can not be expected in the next future. Further developments are needed to produce more effective materials to reduce the costs.

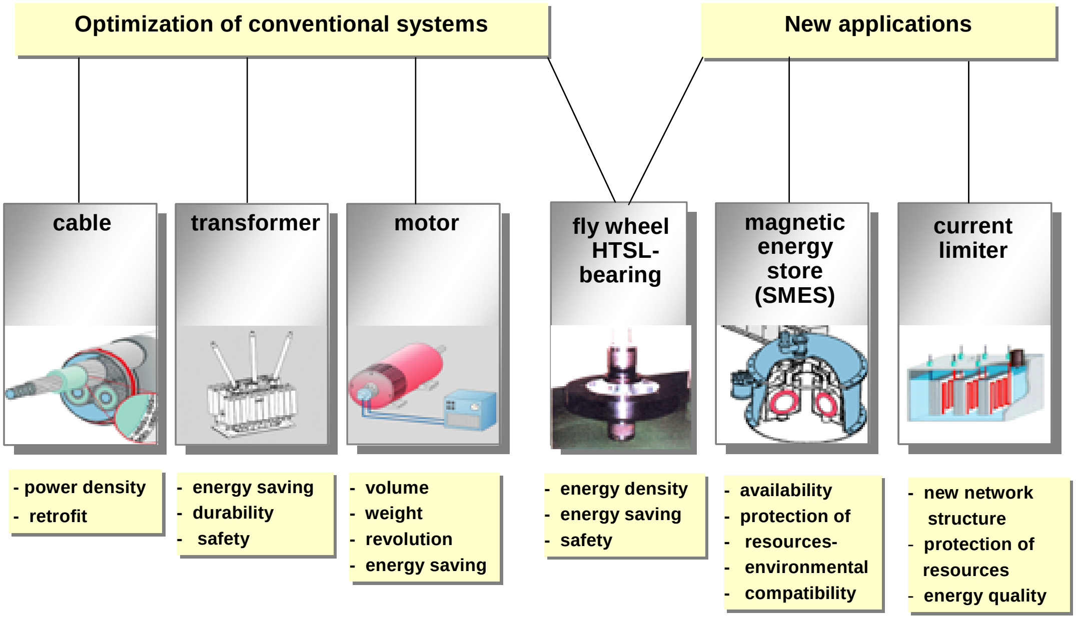


Fig.17: Applications of superconductivity

H2 Technology. One of the visions for the future power supply is the use of hydrogen. It can be produced from coal, gas, or oil through different steps of refinery. However, the only alternative to reduce CO2 production is to place photovoltaic in areas with strong solar emission and enough space (e.g. North Africa) and produce hydrogen by electrolyze. The advantage of this technology is the possibility to store the solar energy. Hydrogen can then be transported to the power stations close to the loads by pipelines or combined by shipping and pipelines. Problems would, however, arise with the security problems for such pipelines and because of high costs. To-day cost analysis shows that the transmission of electrical power by HVDC over long distances would be even on long term much cheaper than to transport hydrogen.

Summary

30 years is a reasonable time period for the analysis of the future developments in power industry. The progress of the world economy and the development of power demand can well be judged for this period. Changes in power generation and power systems progress slowly and have time constants in the range of 15 to 20 years. In industrialized countries the power demand will increase in this time period for 60% and in emerging countries for more than 300%.

Power generation will be focused to gas and combined cycle power stations. Coal fired power stations will remain one of the essential energy sources. In some countries nuclear power plants will be further built. The regenerative generation (wind, solar, biomass) will remain only one of the additional factors in the power generation. New technologies as hydrogen and fusion will not play any role in this time period.

The configuration of power systems in industrialized countries will not change considerably, however, the lines will be further loaded close to the thermal limits. Because of reliability, power systems should be restructured in a way to prevent big outages. This can economically be done by additional HVDC interconnections. Equipment using the existing technologies will be further used. To increase power transmission in populated areas GIL will be applied. New technologies as HTSC, because of long development time between first prototypes and commercial application, will be used only in niche applications.

In emerging countries power systems, however, will grow fast. Because of reliability and economic reasons, HVDC and FACTS will play a significant role. The future power systems will be hybrid systems, consisting of AC and HVDC transmission.