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RELIABLE ELECTRICITY SUPPLY: STRATEGIC GOALS - SHORT TERM ACTIONS

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ABSTRACT

Upgrading the electricity grid to meet the growing needs of the society will be a vital step towards ensuring the viability and security in the coming years. The future electric system will build on the existing infrastructure. The emergence of new technologies, tools and techniques will proceed through several phases. The report address the topical issues elicited by the most important actual driving forces: grid reliability and security of fuel supply. Extracting maximum performance from transmission lines can be achieved by replacing the conventional conductor with advanced conductors. Given the complexity of the electric grid, better communications are keys to providing improvement in security and efficiency. Due to the multiplicity of criteria and uncertainty an urgent need of flexible grid planning methods permitting robust solutions has been manifested. New technologies must enable the full and cost effective integration of dispersed generation into the power system. The report highlights the ongoing efforts in these fields

KEY WORDS

Supply security, advanced conductor designs, dispersed generation, transmission planning, communication infrastructure

1. Introduction

It is evident that a smarter and more capable electric system is essential to the future economic growth and vitality of the information technologies based economy.

The technical sophistication of the electricity grid cannot satisfy the growing demand for high-quality, high-value services to end-users. Millions of generations and storage points, both remote and locally distributed, from many different primary energy sources will be needed to supply the amount of electricity needed for the well-being of the future generation.

The restructuring of the electricity industry and the recent catastrophic disturbances have fed concerns of the general public, legislators and governments regarding the reliability of their electricity supply. In the last decade competition has been introduced into electricity market with the goal of reducing costs to consumers. However, the transmission system was not designed to support today's electricity markets. Investment in the grid has not kept pace with the growth in generation and the increasing demand of the new power trading and the opening of the electricity markets. The transmission bottlenecks threaten the reliability of the electricity supply. As demand, sources of energy and distances between demand and supply increase, the grid becomes increasingly vulnerable not only to blackouts set off by equipment failures and weather but also to terrorist attacks. The aging electro-mechanical electric grid cannot keep pace with innovations in the digital information and telecommunication era.

There is little doubt that the gird will be transformed over the next 30 years from last century's electromechanical system to a fully modern system of digital era. For many reasons – a conservative industry, replacement cycles of 30-50 or more years, antiquated design philosophy – the future grid will be emerging during decades.

How we get there from here is a hard question. This report deals with the urgent needs for innovation. First we analyse the main driving forces and on this basis we select the most topical development issues. Two major driving forces were selected: grid reliability and security of supply (Table 1).

The development tasks investigated are: advanced conductors, next-generation communication, new transmission planning methods and integration of dispersed generation.

Table 1

Driving forces	Issues	Development tasks
	Extension of system capability	Advanced conductors
Grid reliability	Re-evaluation of planning criteria	New transmission planning methods
	Efficient operating tools	Next-generation communication
Security of fuel supply	Enhanced data needs	Integration of dispersed generation
	Robust fuel mix/technology options	

2. Reliability perspective

The recent blackouts highlighted the actual electricity grid is fragile and inefficient. The lack of critical infrastructure investment and the restructuring has pushed the operation of the electrical infrastructure to its limit. The system now runs under tight operating margins in order to sustain profitability without increasing rates. Credible forecast predict that underinvestment in transmission system may continue. This has led to unprecedented electricity reliability problems.

What were in the past occasional interruptions in electricity supply from extreme weather conditions, equipment failures, human error, may become more frequent and more extensive unless proactive measures are taken to ensure system adequacy and system security, the two conceptual pillars of the system reliability, in other words we must consider both long-term system expansion planning and short-term operational concerns.

From a technical perspective security and adequacy are closely related since a system with reserve capacity provides more flexibility in handling unforeseen disturbances. Similarly high-quality system operation can allow system operators to run the system closer to its limits.

The complementary nature of adequacy and security is clearly manifested in the case of recent cascading disturbances.

Cascading failure is the usual mechanism for large blackout of electric power transmission system. Spectacular examples are the August 2003 blackout in North-eastern America and September 2003 blackout in Italy. Blackouts due to cascading outages become more likely under heavy system loading.

Due to the great number and the rarity of possible events, interactions and dependencies the analysis of large blackouts has been made mostly case-by-case post-mortem analysis. As the number of investigations of different types of blackouts is increasing, understanding is growing and mitigation tools are being developed.

A typical large blackout has an initial disturbance or trigger event followed by a sequence of cascading events. Each event further weakens and stresses the system and makes subsequent events more likely. The initial events recently observed were short circuits of transmission lines through untrimmed trees, protection device misoperation and bad weather. Number of the efforts in avoiding cascading failures has been focused on reducing the chances of the start of the cascading failures.

However, some modelling studies reminded that the mitigation can have controversial effects. In certain cases, efforts to mitigate small disruptions can even increase the frequency of large disruption. This occurs because the large and small disruptions are not independent but are strongly coupled by dynamics [1]. When we instead increase some types of redundancy of the system there is an overall decrease in the large blackouts with a concomitant increase of the smallest blackouts. In this respect advanced conductors can reduce the transmission system loads in an inexpensive way, the revision of the deterministic design criteria permit to address cost effective mitigation actions. Besides, the fundamental transformation of the capabilities of the communication infrastructure provides improvement in security and efficiency of power grid operation.

3. Security of fuel supply perspective

Security of supply can be enhanced either by the diversity of fuels or by diversity of sources. The electricity sector's dependency on natural gas leaves the economy with diversity neither of type nor source of fuel. To limit environmental pollution and to slow the rate of increase of CO_2 concentration, long term fuel mix strategies exploiting the maximum potential of non-greenhouse gas emitting energy sources [2]. However, the future energy mix that evolves will depend not only on environmental considerations, but also on economic, societal and political factors. On the global level, difficult policy decisions to foster reduced reliance on fossil fuel lie ahead [3].

All varieties of local distributed resources offer positive benefits to security of supply in that they do not rely on imported primary fuel. In addition, in the case of a combined heat and power (CHP) generation, there are significant benefits in terms of efficiency. CHP has the potential to make the use of less efficient fuels more attractive, such as biomass and municipal solid waste. In order for CHP schemes to be viable, they must be situated close to a costumer for their low-grade heat output. This can be even an advantage in terms of distributed generation (DG) of electricity, reducing strain on the transmission networks.

The capacity to generate electricity and the energy produced are the chief contribution of DG, but the ability of the system to produce and deliver that energy in the power form depends on ancillary services. Not all of these services can be provided by all forms of distributed resources.
To pave the way to a sustainable energy future, there is a clear need for the large-scale integration of renewable and other distributed energy sources [4].

4. Advanced conductors

The actual grid was not designed to satisfy the current level of electricity transport. The construction of new high voltage transmission lines is limited while the system loads are increasing spectacularly. The transmission bottlenecks boost electricity costs to consumers and increases the risk of blackouts. Extracting maximum performance from existing overhead lines requires advanced monitoring and diagnostic tools, new insulation and conductive technologies. Marginal increases in power flow of an existing transmission line may be achieved by low-cost methods, such as applying the dynamic rating to the circuit or monitoring the conductor sag. Beyond the real-time monitoring is the possibility that existing structures have sufficient safety factor in their design. This means that there is an untapped mechanical capacity available to allow for restringing with larger, heavier single or bundled conductors. The upgrading of the voltage level by replacing an existing line with a higher voltage line or by putting more circuits on the same right-of-way have become standard procedures. Substantial increases can be achieved by replacing the existing conductor with advanced high temperature, low sag conductors. For about the past 100 years we have been using aluminium conductor, steel-reinforced cables. Due to the low operating limits, it is timely to find advanced conductor designs.

The objectives of the advanced conductor designs are to

- achieve more electrical conductivity,
- achieve more capacity,
- less mechanical elongation at operating temperatures,
- achieve strength increase,
- reduce weight.

The relatively cheep gap type conductor reduce the sag by using only the steel core to hold the conductor. These conductors are constructed of aluminium layers and a steel core separated by a highly stable compound filled gap. The current-carrying capacity of gap-type conductors is 1.6 times that of the conventional ACSR conductors
The current rating of the conventional (ACSR) conductor can be doubled by the use of a standard conductor composed ultra thermal resistant aluminium alloy and aluminium clad invar wire in central core. The thermal expansion of invar wire is as little as 1/3 of the steel wire. The maximum temperature is 200 C^o. The use of a heat resistant metal matrix composite core instead of steel core as the strength component can effectively eliminate most of the cable sag that results from heating when transmitting more power during hot weather conditions. The light weight, high-strength composite core allows more conductive aluminium to be wound around it, thereby enabling to transmit 2-3 times more power than conventional cables of the same diameter and weight and creating energy savings.

There are other candidate core materials as high-strength carbon and glass fibre composite or carbon fibre. However, despite the important benefits of these improvements, there is a great amount of tests needed to achieve the same level of knowledge as the long-time behaviour of the innovative conductors in different conditions accumulated during long decades for the conventional types.

Carbon nanotubes are a specific category of advanced carbon materials. They are stronger and lighter than steel and highly conductive and can be strung together into strong, light, conductive ropes. In theory at least, nanotubes would be substitutes for steels and aluminium in transmission lines. Within the next decades it is possible that the companies manufacturing overhead conductors may be able to incorporate nanotubes into their products.

However, taking into account the near term reinforcement needs of the transmission system, it can be stated that technologies allowing 3-5 times gain of ampacity on the existing lines are required in the near future.

5. Next generation communication

The large electric power infrastructures are among the most complex system ever constructed. This extreme complexity is being coordinated with rudimentary communication technology and an infrastructure that is many decade old. Better communications are keys to providing improvements in security and efficiency [5].

The inadequacy of the existing communication infrastructure manifested in several ways. The slow response of operators to contingencies during the recent blackouts was party due to inadequate situational awareness across utility and national boundaries to protect against catastrophic blackouts [6, 7].

The existing communication infrastructure does not allow control the system for improved stability, reliability and efficiency, the data are not usable for controlling the distributed generation. New and more efficient approaches for grid control that allow faster adaptation and protection are not feasible without better communication.

Step by step improvement of the grid communication infrastructure could be very expensive and could jeopardize the evolution of the grid control and protection schemes. Therefore open evolvable, adaptable and distributed communication architecture is required for the smarter control to better utilize the transmission and generation assets, improved system protection and control for distributed generation.

An improved communication infrastructure is important for the system operators too as they are responsible for monitoring all network components under their jurisdiction. The topical goals of the ongoing development efforts are:

- A complete set of system requirements to support the self-healing grid and integrate actors communication development,
- Open key standards to develop a robust industry infrastructure,
- Analysis of requirements and development of the convenient architectural designs,
- Identifying the potential for infrastructure sharing and synergy between power engineering operations and other application domains.

The emerging requirements for trust management are unprecedented. A communication architecture that supports the needs of the evolving power grid has to face serious security challenges given the multitude of participants in a power grid.

Evolution of disturbances shows that protection system has been involved in a great majority of the blackout events. As system conditions change, it is necessary to perform studies and review protection designs to prevent protection misoperation. In addition, the designers can increase the security of protection designs in the areas vulnerable to blackouts by making the protection more dependable (making sure that protection acts when it should) or more secure (protection does not misoperate). System protection schemes have proliferated during the past 10-15 years because they offer an attractive alternative for maintaining operational security levels without major capital investment. They are used to preserve the integrity of the power grid and prevent cascading outages. As the failure of system protection can be catastrophic, comprehensive and industry-wide standards have to be developed for the many complexities associated with their design and operation.

6. New transmission planning methods

Historically, transmission planning was much simpler than it is today and than it is likely to be in the future. In today’s electricity industry, generation and transmission are increasingly separated. The disintegration combined with the competitive nature of electricity generation, makes it much harder for transmission planers to coordinate their activities with those of generation owner. The owners of generation are reluctant to reveal their plans for new construction or retirement of units sooner than they have to. Further more, the disintegration of generation and transmission means that congestion management is no longer an internal matter. Congestion management involves system operator, transmission owners (if different from system operator), power producers and load-serving entities. The amount and complexity of wholesale electricity commerce is much greater than it was few years ago.

This complexity makes it difficult for the system operators to know the details of transmission flows and even more difficult to project what these flow might be like in the future [8].

The following key issues can be identified for a successful transmission planning process:

- Involvement of the wide range of actors throughout planning process
- Broad range of alternatives considered, including generation projects and demand-management programs, new technologies
- Effects of transmission on generation market power
- Effects of transmission on compliance with reliability standards, both planning and operating
- Effects of transmission on congestion costs
- Comprehensive risk assessment of transmission plans
- Proactive, rather than reactive, transmission plan (consideration of needs for increased throughput and for new local resources, not just responses to generator-interconnection requests)
- Development of a practical and robust, rather than a theoretically optimized, transmission plan
- Support for projects built through competitive-market mechanism

Due the multiplicity of criteria and uncertainty to be taken into account an urgent need of flexible, new generation and transmission planning methods has been manifested.
Today system security is generally based on deterministic rather than probabilistic analysis that is commonly referred to as N-1 contingency criterion.

Consideration of multiple events is a combinatorial process that is not generally possible even with powerful computers. It is well known that some multiple contingency events are more probable than some single contingency events and the impact of many single contingencies is negligible.

An approach could be considered in which both the probability and impact of events can be addressed to evaluate system reliability. In this way low probability, very high-impact events may require as much or more attention than many high-probability but lower impact events. The probabilistic approach should quantify the economic impact of reliability. Unfortunately there are no known technologies that automatically identify important events based on probability and impact.

7. Integration of dispersed generation

Recent technology improvements have provided the opportunity for dispersed generation (DG) at the distribution level. It has received considerable attention as an alternative to grid-based power for its environmental, reliability and efficiency benefits.

Distributed generation is specially expected to play a role in the following cases:

- Supporting available capacity to meet peak power demands,
- Provide critical customer loads with emergency standby power,
- Grid support (in areas such as voltage and frequency),
- Reduction of line losses and reactive power control,
- Improved user power quality,
- Low-cost electricity and heat.

The electric power system was not designed to accommodate DG and two-way power flow needed to support high penetrations of DG. New technologies must enable the full integration of DG into the power system.

As with traditional generation the reliability of supply is a very critical requirement. Any addition of generating capacity to the grid has to be closely monitored and controlled, so that it does not result in a decrease in the power quality, decrease in reliability, nor an increase in system instability. A highly integrated, real-time monitoring and control system is required to maintain this stability [4]. The concept for operating DG under local control in micro grids is emerging. The actual research is organized around a flexible, controllable interface between micro grid composed of a number of small DG and the wider power system. The interface shall isolate the surrounding distribution networks while maintaining the economic connections between them. These solutions can meet the twin goals of delivering more reliable service to specific customers and enhancing the performance of interconnected grid.

The integration costs are very high. The expense of interconnecting distributed generation can be as a high as that of the generating equipment. Interface in most cases involves power electronics except traditional synchronous generations.

The current state of power converter design and manufacturing is seen to impede ability to mass customized products for a variety of applications while most converters are based on a few common topologies; they are designed on a custom basis. Perpetual reengineering produces converters with uncertain reliability indices; they are unserviceable and economical only in high volume. The standardization of computer architecture interfaces and the connection of elements via buses provided a framework for rapid development of the computer industry. Similarly, the power electronics industry has begun searching for standardized approaches to unify converter packaging and interconnection. One of the most important issues to be investigated is the degree to which the practicality of the bus-centred approach to power converter connection scales with increasing power rating.

A new framework to realization of power converters needs three elements: modular components, from which any converter topology can be constituted, buses for interconnection of modules, and a software environment.

This kind of framework has the potential to significantly improve the power electronics design and manufacturing process. The expected benefits include reduced cost, increased serviceability and performance improvements.

8. Conclusion

The conventional types of equipment used for electricity delivery today will continue to compose even the future grid. The continuous development of the existing devices, software and analytical tools will secure the adoption of the new generation of technologies promised by ongoing basic research efforts that will dramatically upgrade the system and protect the quality of power generated as well as the reliability.

To improve the reliability of the grid there is urgent need for the cost effective upgrading of the overloaded transmission lines using advanced conductor designs. The blackout mitigation strategies have to build on a new generation communication system and more robust planning criteria. The increasing use of local and renewable energy sources shall be integrated in the system with the help of modern power electronics, communication and control technologies. A number of research projects are under way. However, the major driving forces require timely and reliable answer to these challenges.

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