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INTERNATIONAL ENERGY AGENCY

Workshop

Transmission Network Reliability in Competitive Electricity Markets

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Scoping Paper

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INTRODUCTION

Several supply disruptions in Europe and North America during 2003 have created considerable concern among policymakers, practitioners and the general public about transmission network performance and its implications for the efficient and reliable operation of electricity markets.

In response, the IEA has initiated a project to:

- identify and analyse the key issues affecting the development and performance of transmission networks serving competitive electricity markets;
- promote understanding of these issues among policy makers and regulators; and
- facilitate debate and exchange of views between stakeholders about these issues and how best to address them.

The project will include two workshops in 2004, culminating in an IEA publication in early 2005. The first of these workshops focuses on transmission network reliability in competitive electricity markets, and will provide an opportunity for stakeholders to consider the key policy issues arising from recent experiences and their implications for maintaining reliability and effective system operation. Topical sessions will consider:

- lessons from the recent supply disruptions in North America and Europe;
- potential technological responses to improve system operation and reliability;
- regulatory arrangements to strengthen transmission reliability in competitive markets;
- regulatory and organisational options to improve transmission system operation; and
- the broader policy issues relating to transmission performance including regulation and investment.

This paper provides a brief context for each topical session and introduces some of the policy issues associated with reliability and system operation in competitive electricity markets.

SESSION 1: NORTH AMERICAN AND EUROPEAN CASE STUDIES

Several substantial supply disruptions involving a failure of network services struck North America and Europe during 2003 including:

- North-Eastern United States and South-Western Canada: The largest supply disruption in North American history struck at around 4.10 pm on 14 August 2003, affecting the states of Ohio, Michigan, Pennsylvania, New York, New Jersey, Connecticut, Vermont, Massachusetts and Ontario. Over 60,000 MW of electricity load was lost over a 9,300 square mile area. Around 50 million people were disconnected, with services to most customers affected in the United States restored within 48 hours.

- Sweden-Denmark: Transmission disruptions were experienced at around 12.35 pm on 23 September 2003, cutting off around 3,000 MW of generating capacity in Sweden and 1,850 MW in Denmark. Over 2 million people in southern Sweden were disconnected and services to Copenhagen were also disrupted. Most services were restored by around 7.00 pm.

- Italy: The worst supply disruption in over 50 years struck Italy at around 3.30 am on 28 September 2003. Around 19,600 MW of electricity load was lost over a 277,000 square kilometre area. Nearly 56 million people were disconnected, with services restored within 24 hours.

These recent supply disruptions clearly demonstrate the fundamental importance of networks to the efficient and secure operation of electricity markets and highlight the vulnerability of electricity markets to network failures.

Some, particularly in the popular press, have sought to blame electricity market reform for these disruptions, raising public concern and damaging the credibility of electricity market reform. Growing public sensitivity to supply disruptions reflects the increasing dependence of modern economies on reliable and efficient electricity supplies, and adds to the pressure on governments to effectively address these issues.

Although the individual circumstances surrounding these disruptions were unique, investigations of these events are beginning to suggest some common causes including:

- the inherent vulnerability of AC transmission networks to multiple breaches of operational reliability contingencies where they occur within the period normally allowed for the system to recover from a single breach;

- poor communication and coordination of real-time system operation where markets span more than one system operator's responsibility;

- inadequate training and loss of experience among system operators;

- a more fragile network operating environment, reflecting the erosion of excess capacity under economic regulation, and greater volatility and increased inter-regional trade resulting from electricity market reform;

- continuation of pre-reform operating procedures which were not designed to accommodate the new demands placed on the network as a result of electricity market reform;

- inadequate maintenance of diagnostic equipment and network infrastructure; and

- inability to enforce voluntary reliability standards.

- What common causes and issues are emerging from the recent supply disruptions?

- To what extent has the introduction of electricity market reform affected transmission network reliability?

- What are the key lessons for policy makers and practitioners from these recent events?

- in relation to the nature and application of reliability standards?
- in relation to system operation?
- in relation to incentives for efficient network performance in competitive electricity markets?

SESSION 2: TECHNOLOGICAL DIMENSIONS OF TRANSMISSION SYSTEM OPERATION AND RELIABILITY

Transmission networks have typically been designed to transmit electricity in one direction, and over relatively short distances, to local load centres or distribution points. They must be constantly monitored and maintained within acceptable operating limits to avoid overheating, loss of voltage, and loss of system synchronisation.

Electricity market reform has fundamentally changed utilisation of transmission networks. Reliance on the transmission system to facilitate electricity markets is a purpose for which these networks were not originally designed. Increasing electricity trading involving substantial volumes of electricity transfer over long distances, increasing network congestion and increasing use of distributed and intermittent generation sources are making management and operation of transmission networks more complex. Operational limitations are made even more acute in the more dynamic operational environment created by electricity markets.

Refinement of regulatory approaches or investment and expansion of the transmission network to maintain existing operating standards may not be sufficient to ensure reliable transmission services in the new market environment. Adjusting to both the new market regime and to the change in technical practice will require new and enhanced technological solutions.

Several technological options could be considered to help improve transmission network reliability and performance including:

- advanced super/conductors, advanced composite materials and other advances;
- improvements in transmission lines (improved tower design to meet appropriate standards);
- alternative transmission systems (higher voltage levels and 8- and 12- phase transmission line configuration);
- transmission system devices (conversion to high voltage DC, flexible AC, phase-shifting transformers and dynamic brakes);
- real time load and limit monitoring/control, of individual devises and the overall system (especially in relation to managing intermittent, non-synchronous, and distributed energy resources); and
- energy storage devices (batteries, superconductor magnetic energy, pumped hydro and compressed air storage, flywheels and hydrogen).

The technologies and tools required to successfully manage the new operating conditions must in some cases be developed or further developed.

- What are the key technological issues affecting transmission network system operation and reliability?
- What technological options exist to improve transmission system operation and transmission network reliability?
  - quality of protection information
  - communication security
  - voltage collapse prevention
  - online security monitoring
- Are there any barriers to efficient deployment of these technologies?
  - If so, how can they be overcome?

SESSION 3: REGULATING TRANSMISSION RELIABILITY

Operational standards to regulate transmission network reliability apply in all electricity systems to ensure that sufficient contingency exists to accommodate extreme operating conditions or events. Such standards are not designed to achieve absolute operational reliability, as this would require a level of investment that is neither practical nor cost-effective. Rather, they are typically designed to achieve reliability up to specified limits.

At present, operating standards for transmission networks typically employ a deterministic approach, such as the N-1 standard[1]. These standards are mandatory in some jurisdictions, while in other they are implemented through voluntary agreements.

Until recently, many transmission networks had sufficient redundant capacity to comfortably meet these operating standards. However more effective regulatory arrangements implemented with electricity market reform have seen a steady erosion of redundant transmission capacity.

At the same time, competition reform of the electricity sector has fundamentally changed the nature and volume of transmission network usage. Previously stable and relatively predictable patterns of network use have in many cases been replaced with:

- less predictable usage;
- greater volatility of flows; and

[1] N-1 refers to the level of network contingency a system operator must maintain to ensure that the network can continue to deliver electricity of a given frequency and voltage when an element of the network (eg a transmission line or a transformer) ceases to function within its control area.

- significantly greater volumes of electricity transported, reflecting growing inter-regional trade and increasing consumption in some regions.

Together these factors are likely to have significantly changed the nature, frequency and probability of transmission system failure, calling into question the appropriateness and effectiveness of reliability standards that were typically established to address operating conditions that existed prior to electricity market reform.

Attention has focused on reliability standards in the wake of the major supply disruptions during 2003. There have been several suggestions to make reliability standards more effective including:

- making voluntary reliability standards mandatory
  - this would improve the likelihood of existing standards being met but does not address the fundamental effectiveness of existing standards in reformed electricity markets;
- strengthening the existing deterministic standards; in essence moving from an N-1 standard to something like N-2
  - such an approach may be seen as a means of sending a clear and strong signal for new transmission network investment, however, it may also be a very expensive and not necessarily well targeted response; and
- revising the underlying assumptions and methodology for calculating reliability standards, to more effectively reflect the new dynamic operating conditions resulting from electricity market reform
  - this could involve employing more sophisticated analytical approaches including, more refined system and scenario analysis, and probabilistic risk assessment[2], to simulate and evaluate system behaviour under various conditions, and to develop effective response strategies
  - application of these techniques may yield more effective reliability regulation that encourages transmission system operators to develop more pro-active and effective risk management strategies to strengthen transmission network reliability in competitive electricity markets.

- How could regulation of transmission reliability be improved in competitive electricity markets?
  - How can deterministic standards such as N-1 be improved?
  - What other methods could be explored to improve the effectiveness of transmission reliability regulation in reformed electricity markets?
- What are the merits, drawbacks and practical issues associated with the various options?

[2] Probabilistic risk assessment (PRA) involves identifying initial events and possible sequences of related events that can lead to system failures, and estimating the total probability of these events occurring. PRA has been successfully applied in several industries with complex engineering systems that are exposed to low probability, high consequence failures, such as the nuclear power sector.

SESSION 4: TRANSMISSION SYSTEM OPERATION IN COMPETITIVE ELECTRICITY MARKETS

Effective system operation is fundamental to the successful performance of competitive electricity markets. The unique role of system operation in electricity systems is a direct consequence of the physical characteristics of electricity. In particular, electricity can not be efficiently stored and electrical imbalances at any point within an interconnected transmission network can have immediate and severe repercussions for the quality and deliverability of electricity throughout the whole interconnected network. As a result, supply and demand must be balanced in real time across the whole interconnected network to ensure reliable supply that meets defined voltage and frequency requirements. The most efficient way to achieve this outcome is through central, or centrally coordinated, system operation.

System operation is generally undertaken by local transmission system owners, with a degree of coordination between them where integrated regional networks incorporate two or more transmission systems. Coordination has principally focused on the management of flows across the interconnects immediately linking adjacent transmission networks.

System operators are also generally responsible for executing emergency procedures, such as load shedding, to manage extreme events in a manner that minimises the impact on supply while protecting critical electricity infrastructure.

Local transmission system operation was effective in the past, in an operational environment characterised by relative stability, predictability, more than sufficient transmission capacity and limited inter-regional electricity flows. However, the combination of electricity market reform and more effective regulation has fundamentally changed the transmission network operating environment, creating new challenges for transmission system operators.

Electricity market reform has brought unbundling and independent, decentralised decision-making. As a result, decisions relating to network use and investments affecting network operation and performance that were once made in a centrally coordinated way within vertically integrated utilities are now made by independent market participants. Transmission system operators' capacity to manage system balancing through coordinated actions across the value chain has thus been greatly reduced.

Decentralised decision-making may also magnify exposure to systemic risk[3] adding to the challenge for system operators to maintain reliable supplies in the event of failures outside their direct sphere of operational responsibility. Increased exposure to systemic risk may have implications for the frequency and nature of extreme or emergency events, and how best to manage them.

Electricity market reform and effective transmission network regulation have combined to further magnify these complexities and challenges for system operators. Market reform has generally led to increased network usage and greater volatility of usage, reflecting independent and decentralised decision-making, and the growth of inter-regional trade and development of regional electricity markets that span multiple system operators' spheres of responsibility. As noted above, no existing

[3] Systemic risk in this context refers to the impact of a failure in one part of the value chain on the operational performance of other parts of the value chain.

transmission networks have been designed for such use. At the same time, tighter regulation has led to a reduction in excess transmissions capacity. As a result transmission systems are becoming more fragile from an operational perspective, increasing the real-time balancing challenge for system operators.

A closely related issue is the degree to which the roles, responsibilities and accountabilities of system operators have been adequately defined and aligned, to ensure that transmission system operators have clearly defined and appropriate authority and incentives to effectively manage system operation in a manner that is consistent with efficient electricity market operation and development. It is important that system operators are not expected to accept responsibility for aspects of maintaining reliable system operation which are outside their direct control. Regulatory arrangements affecting investment and incentives for efficient management of transmission networks can greatly influence the effectiveness of system operation and capacity to effectively manage extreme or emergency events.

There may also be opportunities for market-based approaches to help improve and strengthen incentives for efficient system use that may help to improve the environment for system operation, and in so doing help to strengthen reliability. An example is the Frequency Control Ancillary Services market operating in the Australian National Electricity Market.

The importance of effective coordination and management of system operation across regional electricity markets has been recognised and several different approaches have emerged including:

- In the United States, a system of regional transmission organisations is being implemented to help coordinate the activities of individual transmission system operators within larger regional markets.

- In the Nordic region, independent system operation is undertaken by transmission system owners in each country with coordination achieved through cooperative agreements that address operational standards and emergency procedures. Market operation is managed through subsidiaries owned by the transmission operators.

- In Australia, an integrated market and system operator has been established to enable effective whole-of-market system operation of the interconnected transmission network. The market and system operator is independent of the transmission network owners.

- In the United Kingdom, system operation is undertaken by a single independent transmission owner, and market operation is independent of the transmission owner.

- What are the new risks and challenges to maintaining reliable system operation in competitive electricity markets?

- What implications does this have for efficient system operation in competitive electricity markets?

- What can be done to improve system operation effectiveness in competitive electricity markets?

- How can coordination be improved in regional markets that span more than one system operators control area?
- To what extent could responsibilities be clarified, and incentives and authority to act be strengthened, to facilitate efficient and reliable system operation?
- What are the implications for the design and execution of emergency procedures?
- What role might market-based approaches have to help support effective system operation?

SESSION 5: ISSUES AFFECTING TRANSMISSION NETWORK PERFORMANCE

This session introduces some of the inter-related policy issues affecting the performance and development of transmission networks in competitive electricity markets. These issues will be the focus of the IEA's second workshop scheduled for October 2004.

Policymakers recognise the critical influence transmission networks have on the efficient operation and development of competitive electricity markets. To date, transmission networks have typically been treated as natural monopolies, to be physically separated from the other components of the value chain and separately regulated.

Regulation has sought to create incentives for efficient operation and development of transmission networks, to deliver outcomes consistent with those that might be achieved in a competitive market. It has a pervasive influence on transmission network operation and development, affecting all aspects of performance, from planning and investment approvals through to network access and pricing.

Concerns are beginning to emerge about the operational and investment incentives regulation has created. Underinvestment in transmission networks and interconnectors has been raised as a critical issue in the United States and appears to be an emerging issue in Europe.

A particular challenge for regulators is to achieve an appropriate balance between incentives to minimise costs and network charges on the one hand, and augmentation of transmission networks on the other. Some concerns have been raised that regulators have been too focused on reducing costs, at the expense of incentives for effective operational performance and efficient maintenance and investment, leading to operational decisions with substantial efficiency losses and financial costs for consumers and market participants. Potential examples include taking major transmission lines from service for maintenance during peak periods, and inadequate maintenance and investment in transmission networks.

Efficient transmission investment is also affected by the efficacy of network planning and investment approvals processes. In a regulated environment, investment proposals are typically developed by network owners and subject to regulatory approval. However, the regulator can be at a considerable disadvantage in assessing such proposals, particularly where it is reliant on information provided by the network service provider proposing the investment. Benefit-cost assessment in these circumstances can be problematic and open to dispute, possibly leading to

delays and uncertainty. Access to accurate and reliable information about the operational condition of the network is crucial to helping improve the effectiveness, timing and credibility of such planning and investment approval processes.

Locational marginal pricing has the potential to improve operational information about the performance of transmission networks, enabling regulators and market participants to more clearly identify and assess cost-effective options for transmission network augmentation and investment. It may also help regulators to develop more effective performance incentives, possibly providing greater scope for competitive network services.

New transmission network investment is also affected by other approval processes including construction, siting and environmental approvals. Inefficient and inconsistent processes have the potential to create uncertainty and regulatory risk, which can undermine timely and appropriately sized investment responses.

Transparent, consistent and balanced regulatory decision-making and outcomes are required to help address these challenges. Some regulators are exploring ways to strengthen incentives for more efficient network performance and to encourage efficiently timed and sized transmission investment. Issues associated with improving the cost-reflectivity of network prices could be considered in this context.

- What are the key policy issues affecting transmission performance in competitive electricity markets?
  - What scope is there for greater reliance on competition to strengthen incentives for efficient transmission performance?
  - What are the key regulatory issues?
  - What are the key issues relating to efficient and timely transmission investment?
  - What are the key issues relating to transmission network pricing?
- How should these issues be addressed to improve transmission network performance?