The Challenge of Renewable Energies Integration in Energy Distribution Systems

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Introduction

Despite the global abundance of renewable energy resources, renewable energy generation capacity constitutes a small share in the global power capacity. The renewable energy capacity in 2000 was estimated to be around 102 GW (excluding large hydroelectric power) representing 3% of the world's installed power capacity. Since the past decade, however, there has been a renewed interest in many countries on renewable energy for power generation. Governments have intervened to promote renewable energy investments. In several developed countries, renewable energy policy interventions were driven by policy objectives such as greenhouse gas emission mitigation, internalisation of environmental externalities and energy security. The renewable energy capacity in EU member countries, for example, has grown 5 times from 1990 to 2001.

The integration of increased renewable energy capacity in electricity distribution systems could be held back by the limitations of the centralized power generation systems in accommodating distributed generation and by the full electricity market liberalization. The technical and regulatory frameworks of centralized power generation systems appear to be inadequate to provide support and incentives to distributed energy generation. While market liberalization increases opportunities for small and medium-sized renewable energy generators, it also exposes them to competitive market risks, thereby reducing the attractiveness of renewable energy generation.

The paper briefly reviews distributed energy generation, issues and options for power integration in electricity distribution systems and outlines research strategies for renewable energy.

Power generation integration in electricity distribution systems

Electricity generating plants utilizing either renewable energy or conventional fuels, integrated into distribution networks are broadly categorized as distributed generation. Renewable energy technologies suited for small to medium-sized distributed generation include photovoltaic cells, wind power and biomass-based technologies. Technologies fuelled by fossil energy are conventional steam turbines, combustion turbines, internal combustion engine generators, micro turbines, and fuel cells.

Key characteristics that differentiate distributed generation from the centralized power supply relates to location, capacity and grid connection. Distributed generators are located near the point at which the power is consumed. Distributed generation technologies are small in scale or can be produced economically in a range of sizes. Traditional electricity suppliers are connected to the grid at high voltage level while distributed generators are connected to the grid at distribution level.

Several developments have influenced the increased interest for distributed generation recently. These are

1) generation and distribution technology development;
2) liberalization in the electricity market;
3) energy supply security concerns; and
4) renewable energy policies driven by environmental concerns.

In Western Europe, particularly the European Union Member States, environmental policies, increased awareness on distributed generation technologies, and electricity market liberalization are the factors that generate increased deployment of distributed generators. In the

US, the growth of distributed generation is driven by issues related to poor power quality and supply security as well as increased recognition of environmental benefits of distributed generation.

The benefits of distributed generation include the following: greenhouse gas emissions reductions particularly for generation based on renewable energy and low carbon fuels; security and diversity of supply since various energy sources will be used in distributed generation; and cost reductions since electricity is generated by more efficient systems and close to the point of consumption. Additional benefits of distributed generation in general include deferral of upgrades from transmission and distribution systems, reduction of losses in the distribution system, and provision of network support or ancillary services.

In countries with liberalized electricity markets, distributed generation becomes attractive since it has short construction lead times, low capital costs, flexibility in operation, and its ability to expand output. It must be noted, however, that these attributes are mainly associated with fossil fuel-based technologies since most renewable energy technologies have intermittent electricity generation, high installation costs and limited flexibility in operation and expansion.

Issues and options

Grid interconnection

The existing electricity supply systems in most countries awre centralized systems where electricity is generated in large power stations and delivered to customers through transmission and distribution networks. Centralized systems support a unidirectional flow of electricity. The integration of small-scale generation at the distribution level can result in technical problems that may affect network stability and power quality. These problems include voltage control, reactive power control and islanding. For countries without grid interconnection standards, this may result in increased transaction costs since distribution network operators often require distributed generators to shoulder the grid impact assessment costs. The development of interconnection standards, guidelines for dealing with interconnection requests and procedures are often seen to reduce transaction costs for network operators and distributed generators.

In countries where distributed generation is growing rapidly, electricity networks are facing new challenges in terms of network stability and power quality. High penetration levels of distributed generation increase risks of serious network failures. In the case of Denmark where the penetration rate of distributed generation is high (around 35 % at present), it has been reported that the costs of network reinforcements have risen considerably. To allow further increase of distributed generation share, it requires new technological development. One possible development is for current passive distribution networks to evolve into actively managed networks. This means that the network must be treated not as a power supply system but as a transport system that provides connection between points of supply and consumption. In this case, bi-directional flows of electricity are possible, local control areas which enables local network areas to act as independent islands are used, and system services become specified attributes of a connection.

Intermittent distributed generation (renewable energy technologies) pose a different technical challenge. High penetration rates of intermittent distributed generation pose a serious technical constraint, which requires some form of back-up power or energy storage. The high share of wind power in Denmark is being backed-up with a large capacity from the Nordic electricity pool. To some extent, combined heat and power (CHP) plants have also provided back-up capacity. There is a revival of interest of energy storage as a technical option for intermittent energy generation. The current particular interest is on the production and storage of hydrogen from electricity at off-peak period and during the times where there is surplus of renewable energy.

Market liberalization

Under a vertically-integrated monopolistic electricity industry structure, electricity produced by distributed generators is purchased by utilities under various contractual arrangements. Under liberalized markets, opportunities for distributed generators are increased since they can sell their outputs directly to customers with the opening of access to networks. Limited reforms, however, may be unfavourable to distributed generators. If reforms are limited to wholesale competition, the conditions will be similar to monopolistic industry structure. In partial retail competition, utilities may practice anti-competitive behaviour by offering price discounts to contestable markets creating entry barrier to distributed generators. Full retail competition therefore is vital for the development of distributed generation. If cross-ownership is allowed under full retail competition, electricity distribution companies owning generators to supply electricity to their customers still have the incentive to discriminate against distributed generators. This incentive to discriminate is removed with the separation of distribution from generation.

The complexity in market structure, operation and pricing is increased with liberalization making it more costly for small-scale distributed generators, particularly small and intermittent producers, in dealing with market competition, in undertaking bilateral contracts with consumers, in meeting electricity dispatch requirements (balancing requirement), and in procuring back-up power. This could be mitigated by developing trading arrangements and market rules that provide correct signals and right incentives to facilitate the growth of distributed generation.

Regulatory frameworks

The integration of distributed generation in distribution networks presents costs and benefits to the network, which needs to be properly valued in order to facilitate the growth of distributed generation. The current regulatory frameworks often fail to recognize, allocate and evaluate most of these costs and benefits. The values (costs and benefits) of distributed generation can be categorized into capital and operational values. Capital values relate to generation and distribution facilities and these include the following: distribution capacity cost deferral, connection costs, metering costs, reserve capacity costs and avoidance of over capacity. Operational values include reduction losses, voltage support, reactive power support and balancing power. It must be recognized that economic values for reliable distributed generation are higher than those for intermittent generation.

A sustainable network regulatory system must provide correct signals to generators. This means that all distributed generation costs and benefits must be properly valued. Distribution network operators must be given regulatory incentives to consider costs and benefits of all network users related to network services. A sustainable regulatory framework uses a charging system that combines shallow connection charges, use of system charges with entry and exit charges, and performance based incentives.

Research Strategies for Renewable Energy Integration

The issues and options discussed above can be broadly categorized into issues related to distributed generation in general and those related more specifically to renewable energy generation. The generic issues affect both renewable energy and fossil fuel-based distributed generation. Research strategies must address both the generic distributed generation issues and renewable energy-specific integration issues. As discussed earlier, flexibility, reliability and low generation costs - attributes that are weak in renewable energy generation – are valued highly in competitive and complex electricity markets. Research strategies to facilitate higher integration of renewable energy generation in distribution networks must focus on these weak attributes.

Flexibility in generation maximizes economic benefits by increasing output at times of high pool prices. Intermittent generation from renewable energy can be mitigated and flexibility can be achieved through energy storage. With energy storage, scheduling of energy dispatch would also become possible for intermittent renewable energy generation.

Scheduled generation provide higher economic returns than unscheduled generation. There are several options for storage, but current industry interest is on hydrogen production and storage. There is a current need for research, development and demonstration of energy storage systems.

Predictability of output is very important in balancing actual and forecasts generation. Penalties are high and producers are required to pay higher prices for imbalances in competitive electricity markets. This penalizes the highly variable renewable energy generators. Energy storage could mitigate variability problems. Another area where there is a need for research, development and demonstration is on the improvement of predictive capabilities, such as the development of better weather forecasting techniques and software. With these technologies the variability of forecasts and actual outputs could be significantly reduced.

In competitive markets, renewable energy generation need to compete with central power generation. At present, small-scale renewable energy generation remain uncompetitive unless subsidized for grid applications. Despite the decline of generation costs of several renewable energy technologies since the past decades, technology costs need to further decline in order to become competitive in displacing grid-power. Continued research on renewable energy technology cost reductions and efficiency improvements remain important.

The above strategies can be reinforced by research strategies on generic distributed energy generation. Technical research strategies can be divided into those dealing with the issues associated with the existing centralized power systems and those related to future system design and operation. The former includes research and development of new control technologies (current fault and voltage) as well as distribution management systems while the latter includes interconnection and active network management. Research strategies for electricity system regulation can be focused on the valuation of distributed generation costs and benefits as well as on various regulatory incentives to distribution network operators to connect distributed generation.