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Investment in transmission

by

Finn R. Førsund

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Finn R. Førsund

The Frisch Centre

Abstract: Transmission is an integral part of the electricity system. However, even within a centralised system of generation and transmission it has never been a trivial exercise to perform coordination of expanding loads, generation, and transmission capacities in a way that is socially optimal. There are features like lumpy investments, pervasive transmission system externalities, reliability as a public good, and the spatial distribution of both generation and transmission capacities. The unbundling of transmission and generation of newly deregulated electricity systems have substantially increased these coordination problems. To pursue proactive planning the investment decisions of independent generating investors have to be forecasted with sufficient accuracy in order to decide on socially optimal transmission investments. This calls for a systematic use of scenario simulations identifying locational generation investment and corresponding transmission investments. But since investors cannot be forced to invest, incentive schemes must be devised as part of the scenario simulations in order to entice both the right volume and the right location over time.

JEL classification: L14, L5, L52

Key words: Electricity; transmission investment; reliability; incentives; wind power

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1. Introduction

We will here mainly be concerned with the high-voltage central grid and not with regional grids of lower voltage and the distribution network involving consumers at low voltage, although the border lines between central grid, regional grids and local grids are not always clear-cut. The focus will be on economic issues involved, avoiding going into technical or engineering details more than necessary. The purpose of the paper is to illuminate fundamental questions faced when undertaking transmission investments.[1] There are several models as to organising the management of a transmission system and investments. We will concentrate on a transmission systems operator (TSO) owned by the public sector and responsible both for operating the network and undertaking investments. Merchant investments in transmission will not be considered.[2]

The fundamental role of a transmission network in a spatial setting is to secure that consumers at their locations are supplied with power produced by generators, typically located in a different geographical pattern. The main demand on a transmission system is that power should be delivered reliably. This means that the network should have the capacity to satisfy fluctuating demand. However, demand is in general a function of price, so this criterion is not purely technical.

Consumers and generators can be connected with an acceptable degree of reliability in many ways. A criterion for the design of the network has to be introduced. Already Lord Kelvin (Thomson, 1881) analysed the problem of optimal investment in a line. He focussed on the trade-off between loss on a line and the type of metal used for the line and the weight for a given length. Minimising cost of loss and line investment for a given power delivered at the consumer node he derived the rule that the value of the loss should be set equal to the annualised cost of the line investment (Smith, 1961). He assumed a given voltage level at the consumer node, thus he did not address the reliability question and system stability.

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[1] See Skjeret (2007) for a general review of both generation and transmission investment issues and extensive references to points raised in the paper.

[2] Merchant investment in transmission has been a popular issue, especially in American literature. But following the critique in Joskow (2006) we disregard this possibility. However, for direct current (DC) interconnector between areas or countries private investment may be fitted in together with a publicly owned TSO. The new DC sea cable between Norway and the Netherlands (NorNed) is a joint project between the publicly-owned Norwegian company and the Dutch central net company TenneT.

The reorganisation of the electricity sector seen in many countries the last two decades of unbundling generation and transmission of electricity, previously carried out by a vertically integrated utility, has separated investment decisions in generating capacity and in transmission capacity. Markets for power have been organised implying competition between generators, and decentralising investment decisions for generating capacity to the generators. There are signs that transmission networks in several countries are experiencing increasing levels of stress (Joskow, 2006), resulting in a higher frequency of service failure and even blackouts.

Changes in consumer demand is influenced by changing demographic patterns and residential and commercial building activity as regards general consumption, and change in demand from large energy-intensive industrial customers, like aluminium, ferro alloys, refineries, pulp and paper factories, off-shore oil and gas platforms, etc., following economic development of exit and entry of firms. Many of these changes are uncoordinated with investments both in generating and transmission capacity. At the present state of transmission technology there is no room for more than a single network, so the network as a cost-based natural monopoly is generally operated under one management. In many countries the public sector is the owner of the central grid. In European countries it is also common that the network operator is the system operator, i.e., we have the Transmission System Operator (TSO) construct.

The network operator is responsible for the investments in the network. However, due to the new organisation of the electricity sector there are fundamental coordination problems on the investment side, remembering also the spatial aspects involved. Changes in patterns of demand and patterns of generation must be coordinated in some way with changes in transmission capacities when we have generators and consumers making independent investment decisions.

The regulation of networks usually demands that the cost of the activities of a network including investments should be covered by charges levied on the users. But some charges have the role of making the current use of the network efficient. If charges, e.g., reflect losses on lines and congestion, then increasing transmission capacity will decrease such efficiency-based charges. In order to finance investments pure connection charges independent of energy flows must also be used.

There is a new role for the transmission system in countries running competitive short-term wholesale markets. Transmission should also facilitate competition[3] by reducing the potential for use of market power. Within a constrained transmission system import-restricted sub regions may be created where market power can be exercised. Increasing the capacity of the transmission system will reduce the physical potential for using market power. This may imply that if a well-functioning competitive market is judged to be desirable on its own, then a certain amount of excess investment from a technical point of view in transmission may be called for.

In Section 2 reliability criterions are discussed and the connection with congestion is explored. The planning of transmission investments is addressed in Section 3, encompassing investment criterions and types of planning. Practical planning procedures are discussed in Section 4, and Section 5 concludes.

2. Reliability and congestion

Reliability criterions

As pointed out in the Introduction reliability is a fundamental demand on the transmission system. The transmission system serves as a hedge against unplanned generator outages. The system should be redundant enough to avoid service interruptions in the face of various system contingencies. However, reliability can involve several aspects. In Blumsack et al. (2007) the following criterions are suggested as common reliability metrics:

1. The N - k criterion; if k out of N pieces of equipment is lost, damaged or disconnected from the network, then the system should continue to provide uninterrupted service (k may commonly be set to 1).
2. The Loss of Load Probability (LOLP); the probability that the network will fail to provide uninterrupted service.
3. The Loss of Energy Expectation (or Probability); the expected amount or proportion of demand not served (Unserved Energy Expectation or Probability).

To improve reliability according to the metrics above is obviously costly. Therefore there is a trade-off between investment costs and operating costs on one hand and degree of reliability

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[3] This is actually explicitly stated as an objective of the Norwegian TSO, Statnett.

on the other hand. In the final decision about level of probabilities the social cost of interruptions have to enter the picture.

Introducing wind mills on a large scale in a region may affect the short-run use of the transmission system, since wind production is intermittent. In Holttinen (2005, p. 4) it is argued that the N -1 criterion provide a too conservative estimate of transmission capacity in these instances. The strain on the network at maximal wind-power production has to be taken into consideration.

In addition to reliability there is also the related question of quality of service, i.e., the quality of electricity itself. Reduction in quality may be measured by deviations from target voltage and frequency levels.

Transmission investments relieving congestion

Studies by economists of transmission in the short run have often focussed on congestion of lines. Congestion on a line is usually defined with reference to the thermal capacity of the line. The line is congested when the capacity is exhausted. For systems with alternating current (AC), that is the rule, the line resistance to electricity flows is more general than Ohm's resistance, adding inductance, and the total resistance is termed impedance. The meshed nature of many grids results in loop flows complicating the definition of congestion, due to Kirchhoff's laws distributing flows over possible loops in proportion to the impedance of each loop. Thus if one link in the loop is congested, this set an upper limit on electricity flows also on the other lines.

Congestion of lines happens in real time and necessitates actions by the TSO in order to keep the system in physical equilibrium with supply equal to demand at every node. Economists have proposed using congestion charges to improve efficiency of utilising the network in the short run. Investments in transmission capacity may be motivated by relieving congestion. What is, then, the connection between investments focussing on congestion relief, termed economic investments by Joskow (2006), and investments to maintain reliability? According to Joskow it is meaningless to distinguish between congestion-relief and reliability investments since most investments are driven by reliability concerns. However, Blumsack et al. (2007) take this critique one step further by arguing that in many cases it will be not only meaningless to draw a line between these types of transmission investments, but actually wrong. A type of network termed a "Wheatstone Network" is used as an illustration where introducing a new line, the *Wheatstone bridge*, between production nodes increases the reliability of the system, but decreases the capacity. This phenomenon is parallel to *Braess Paradox* for adding a link to a road network. The paradox is that adding a link may increase traffic congestion. The paradox appears in meshed electricity networks due to loop-flows governed by Kirchhoff's laws. The system must have embedded Wheatstone sub-networks for the paradox to appear. Such subsystems allowing lines to be introduced between generator buses are commonly found in meshed networks.

In meshed networks with pervasive loop flows it is no so easy to pinpoint the congested line which capacity should be increased. A change in one place of the system may give system-wide repercussions leading to quite another line being congested. Therefore a system-based approach of simulating the new flow patterns, following an investment in transmission capacity, must be performed to create enough information to make the best social choice. It is not enough just to monitor the system and report where congestion appears in the existing system.

3. Planning transmission investments

Types of transmission investment

Transmission investments can either represent incremental reinforcements and upgrades of existing facilities, or be investments in new lines. Investments in new lines may be a consequence of new generation capacity coming on stream, or substantial demand growth, e.g., new energy-intensive plants. The generator has to be connected to the net, and new demand has to be served, and then there is a question whether the existing net has to be reinforced due to the generating investment or increased demand. In Joskow (2006) the following list of upgrading investments is found:

a) new relays and switches
b) new remote monitoring and control equipment
c) transformer upgrades
d) substation facilities
e) capacitator additions

f) reconductoring of existing links
g) increasing the voltage of specific sets of transmission links

There may be significant technical progress taking place concerning the different technologies represented in the list above. During the last decades the bulk of transmission investment in Norway has been of these types, excluding interconnector capacity investments to Sweden, Finland, Denmark and recently the Netherlands. Investing in new lines may use existing corridors, or set a new "geographical footprint." The problem with new corridors in Norway is mainly environmental concerns since hydro power development is usually taking (or has usually taken) place in remote areas of natural beauty. But reactions against new corridors are widespread, as expressed by the term NIMBY (not in my back yard).

Criterions for investment

The classical investment criterion, mentioned in the Introduction, is to follow a procedure of minimising social costs of transmission investments and loss in the network, given a number of physical constraints expressing present and planned levels of demand and generation, and given reliability standards. The question of how far one must look ahead is related to lead times from identifying relevant projects and to when capacities are installed, and related to the degree of lumpiness of transmission investments. These factors vary according to the type of transmission investment, as described above. For small enough improvements of transmission system improvements the cost minimising mode with system characteristics as exogenous variables will do. The usual criterion of non-negative net present value applies. New lines, especially along new corridors, would be at the other end of the scale as being significantly lumpy or indivisible. For such investments the question of which variables to regard as exogenous and which ones to regard as endogenous will be crucial for the investments proposed. Stoft (2006) illustrates a case where – when taking several periods into account – privately profitable investments should not be undertaken. The value of postponing investments may have a positive value.

The planning benchmark

However, the investment criterion set out above is too limited. The dimensioning of the electricity system should be seen in a social welfare perspective. The most common approach is to formulate a partial model and maximise the sum of consumer and producer surpluses, without modelling the links of the electricity system to the rest of the economy. The ultimate benchmark for transmission investment will be integrated resource management planning, coordinating both generation and transmission investment within a spatial setting. In addition to assuming that the network is centrally planned it is also required that the TSO accurately works out the optimal sequence of generation and network investments into the future. Even in a setting with integrated planning, in order to realise perfect coordination, short-run utilisation of existing generating- and transmission capacities incorporating the spatial structure, must also be in place. Such pricing schemes are necessary for giving the right incentives for efficient utilisation of existing capacities. This means extensive use of nodal pricing and correspondingly differentiated locational energy charges as the benchmark. Without such schemes realising short-term efficient utilisation in place, the investment signals will be distorted. As commented in Sauma and Oren (2006) such a benchmark planning procedure may never have been in place in any country, even before unbundling of generation and transmission. In order to be realistic one then has to look at second-best approaches as benchmarks. Turvey (2006) discusses the long-run and short-run incentives for optimal location of generation capacity. He does so with a particular focus on the British system, and its use of geographically differentiated system charges.

Proactive planning

The restructuring of the electricity sector, as in Norway, means that investment decisions in new generation are taken by independent companies, publicly or privately owned. It is reasonable to assume that investment decisions are based on standard profitability considerations, i.e., based on maximising net present value. Investors will make their location and plant choices based on the present value of selling at future prices and future charges related to the use of the network. The expectation about prices, and in a transmission context the expectations about transmission charges in terms of connection charges and production-related charges, will directly influence investment decisions. It is therefore important for transmission investments that the reactions of generation investments to transmission investments are considered when planning transmission investments. Kirby and Hirst (1999) and Wu et al. (2006) point out that transmission line investments take longer to complete than what most generation investment does. It is reasonable to believe that generating investments and location of such investments will react to expectations about changes in charges due to new transmission investments. Sauma and Oren (2006) call transmission investment planning, taking the reaction of generating investments into consideration, for *proactive planning*.

An alternative model is *reactive planning*, where planning is based on given generation capacities and the purpose is to minimise transmission costs observing reliability constraints (see also Hirst and Kirby, 2002). The reaction of generating companies to proposed transmission investments is then not considered. Reactive planning means reacting to generation investments when in place without influencing the scale or timing of the investment.

In order to formulate an efficient proactive planning procedure it is important to be clear about which variables are exogenous and which variables are endogenous. The change in demand and its spatial distribution are often treated as exogenous. This may be in order for consumer nodes with slow and organic change in demand for electricity due to demographic changes and expansion in residential and office buildings, and development of light industry and services. But a political decision on space heating technology, e.g., going from electricity to natural gas, may be important enough to warrant coordination with transmission investment. There is a question mark about how to treat large demand changes due to exit and entry of energy-intensive industries. Examples from Norway are supply of electricity to oil platforms from the mainland, restructuring of aluminium production between two different locations in Western Norway, and closing down of a pulp and paper mill. It is a question whether such consumption changes should be taken as given when planning transmission investments, or whether transmission considerations should also influence such large changes in demand. Different spatial configurations of energy intensive industries may have large differences in transmission costs.

Coordination of generation and transmission investments is also needed because there may be a substitution between generation and transmission. Investing in transmission will always substitute for increased generation if losses are reduced because of transmission investment. Generation can substitute for transmission by relieving congestion by counterflows, e.g., investing in generation in an import region is a substitute for increasing the transmission capacity on a congested line from an export region to an import region (Wilson, 2002).

When following a proactive planning approach it is important to recognise the fundamental externality of system reliability, making reliability a public good. One cannot therefore look at efficient short-run prices and charges only in order to deduce when new investments in transmission should be done. A wholesale market for electricity, mimicking a competitive solution due to efficient prices being applied, will still not be a relevant guide for investment in a public good. The prices and charges reflect short-run efficiency and will not necessarily serve as socially correct incentives for transmission investments. Considering energy charges reflecting marginal short-run losses in the system before investments, the physics of loss generation will change when investments are carried out, and then also the new efficient levels of loss charges will be different from old levels. In general many energy-related charges will decrease. The power transfer distribution factors used in studies of flow and losses in a network will change due to investments. Given the lumpiness of transmission investment large deviations of current nodal prices from their values after transmission investments have been carried out can be expected.

The key feature of the proactive planning approach of Sauma and Oren (2006) is the ability of the TSO to predict the reactions of generator investors and load demand when transmission investment is carried out. In order for prediction to be of high quality, the TSO needs, in principle, as much information about the investment procedures of the investors as in the central planning benchmark case. If such information is not available, it will be difficult to design investment incentives in such a way that the optimal response to transmission investments is forthcoming.

4. Towards a practical planning procedure

We assume that the net operator (TO) of the high-voltage central grid is also responsible for carrying out transmission investments, according the Norwegian model. The TSO in Norway, Statnett, is responsible for carrying out transmission investments based a general social-economic criterion. More specifically, Statnett is responsible for reliable delivery of electricity and to promote a well-functioning market for electricity. California ISO (2004) gives an example of one method to plan transmission investments ahead and also provides an example. Other examples of planning approached can be found in Wu et al. (2006) and Hirst and Kirby (2002). The state is the owner of the net in Norway, but this is not so important. The importance lies with the instructions about how to carry out transmission investments. The general objective is to achieve the best social solution, but the question of endogenous and exogenous variables is not so clearly specified. As to financing of operations and investments the net operator is in principle to be self-financed. The net operator has the power to introduce connection charges, independent of energy flows, and energy charges that may be related to marginal losses. The regulatory setting for the electricity sector is dominated by unbundling. Markets for energy and reserves are unbundled, while there is open access to transmission within Nord Pool for agents connected to the net. There is no independent market as such for transmission services, and the TSO deals with congestion through arranging counterflows and splitting Norway up in different price areas. New investment in generation is proposed by generating companies (private or mostly publicly owned; municipal and state ownership) and subjected to concessions given by the electricity regulator (NVE) that may consult the transmission operator.

Identifying needs for transmission investment

The first stage in planning transmission investments is to identify investment needs. Monitoring continuously the network, the TSO may observe increased stress within the net in the form of increasing marginal losses, increasing frequency of periods with congestion problems and increasing episodes with struggling to maintain the reliability standards set for the system. However, in a social efficiency perspective, investment plans should not be made unless current charges are adapted and used to obtain short-run efficiency in using the system. Peak load episodes may be alleviated by increasing the energy-related charge during such episodes, etc.

Uncertainty about occurrence and severity of stresses on the transmission network may make it optimal to over-invest in transmission capacity, considering the magnitude of the cost of net failures like blackouts compared with additional investment costs. There is an asymmetry in social costs between under- and over-investment.

There is a system externality effect when considering reliability, making calculating for one piece of equipment at a time a faulty procedure. Various options for relieving system constraints concerning reliability and congestion must in general be considered in order to develop a suitable package of micro investments that it is socially profitable to carry out.

If a zonal pricing scheme is used to deal with congestion it may not lead to optimal investment in transmission, following a policy of equalising prices as advocated in Brunekreeft et al. (2005). Optimal nodal prices differ both before and after transmission investments, so equalisation of zonal prices is a too limited objective to pursue. The general objective is maximisation of consumer plus producers surplus subject to reliability constraints.

The TSO must be aware of any “inc – dec” game going on, i.e., generators playing on the need for the TSO to increase or decrease the use of one or more generators in order to balance demand and supply by manipulating their bids into a day-ahead spot market. Assuming that price zones are used, if the inc – dec game is taken at face value the TSO may be misinformed about the need for investing in transmission capacity between price zones.

As mentioned earlier a new objective introduced by using market–based systems is to mitigate market power. In electricity networks the creation of importing and exporting zones may give opportunities for exercising market power even for firms without a large market share within the total grid area. Over-investing in transmission will reduce the possibility of taking advantage of zones created temporarily.

There is also the question about the incentives for the TSO itself to undertake efficient network expansion and operation, including losses, congestion and balancing. When considering how the TSO’s budget is financed it has to be avoided that a TSO benefits from congestion.

The role of network charges

As pointed out above a transmission net may function within given reliability criterions at different levels of total costs. A natural purpose of investments is to seek to minimise these costs. However, the problem is that it is not straightforward under what conditions such a minimisation should be carried out. At a micro level an investment opportunity, of the type of system improvements described above, may be found by comparing cost savings with investments costs as a regular activity with a certain frequency over time, and the investment activity carried out when the net present value is non-negative, using the relevant rate of discount (usually set by the owner). However, such an identification procedure is not as straightforward as it appears if the overall objective with transmission investments is to maximise the social value of the investments within a standard objective of maximising the sum of consumer and producer surplus.

First, the existing transmission system must be utilised in an efficient way in the short run. Without any element of charging for current transmission services provided by the network the calculation of the profitability of the investment project may easily be biased. If there is a charge for transmission services, then this charge must be set correctly. The general reference is nodal prices. These prices change in principle over continuous time, and may be complicated to calculate in meshed networks with loop-flows. As pointed out in Brunekreeft et al. (2005) there is a question whether nodal pricing sets efficient long-term investment signals to generator and load, or whether additional locational differentiation of grid charges is necessary. The structure of network charges will have a potentially significant impact on network use, and influence location of new generation and load as well as influencing bids in wholesale spot markets.

According to Brunekreeft et al. (2005, p. 75) the structure of network charges should encourage:

- the efficient short-run use of the network (dispatch order and congestion management)
- efficient investment in expanding the network
- efficient signals to guide investment decisions by generation and load
- fairness and political feasibility
- cost recovery.

The theoretical notion of nodal pricing as continuously changing prices in real time is not implemented in any system. In US the PJM has established a scheme with important nodal pricing features. In Norway there is zonal pricing with a small number of price zones formed endogenously by the TSO for shorter or longer periods. In view of transaction costs, cost of information gathering, etc. the more interesting question in practice seems to be what kind of most efficient second-best system to aim for. Transaction costs of running perfect pricing schemes may easily become excessive, so a more realistic second-best approach of pricing policies may be followed with corresponding effects on optimal transmission investments.

Incentives for investment in generation

The general incentive for investing in generation is the standard profit opportunity looking at the net expected price of electricity and the investment costs. Since the spatial aspect is crucial for the coordination of generating and transmission investments, the net price received by the generator has to be spatially differentiated. This can be done by applying an energy charge based on location-specific marginal loss. The requirement of self-financing of the TSO will typically lead to connection charges (of a postage-stamp nature independent of transacted energy volume), collected per period over time, also having to be used to generate enough income. Such a charge has no locational signal. The most powerful locational signal can be given by using a connection charge varying according to location to reflect the cost of extending and upgrading the network, in addition to generator-specific shallow connections, caused by the generator investment. This charge is by nature a lump sum capital charge, but may be annuitised (Turvey, 2006).

As stated in Brunekreeft et al. (2005), wind power in particular creates new flow patterns across grids. In Norway many wind-mill investments have been planned along the coast. The location of many of these planned projects is such that there is some distance to the existing network, but there may also be a need for large upgrading investments of existing lines if wind power is to be phased in. As reported in Brunekreeft et al. (2005) grid reinforcement costs to handle modest amounts of extra wind power in Scotland might be 75 - 80% of the total cost of all wind power. Excessive costs of net upgrading in order to phase in wind power in Finnmark are also documented in Statnett (2003). The question of wind power has therefore accentuated the discussion of what part of the grid investment to regard as a part of the generating investment to be covered by that investor, and what part should be socialised and covered by the general use of the net. This corresponds to the terminology of shallow connection charges and deep connection charges found in the literature (Joskow, 2006). Using shallow connection charges only may promote new entry, which may be attractive to those wishing to promote renewables.

The general problem is how to charge new generators where their entry requires expanding and/or upgrading the grid, both in the sense of a shallow connection and in the sense of a deep connection. When line investment and other network investments are indivisible it may be optimal to increase capacities by more than what is needed just to phase in a single generator investment (Turvey, 2006). If upgrades take account of such indivisibilities to over-build ahead of future demand, what fraction of the costs is attributable to the present connection? Is it reasonable to charge the security benefit to a new entrant?

In principle the additional net investments that have to be done due to the new generation, should be regarded as a part of the generating investment project if the transmission investment is of no additional benefit to any other existing or potential future generator. This should also hold for wind power projects. There may be willingness to subsidise wind power, e.g., due to environmental consideration of zero emission of CO_2, but the extent of the subsidy needed to make the project economically viable (without payment for emission reductions) should be made explicit. Charges applied to wind generators must properly reflect the load patterns of wind compared to conventional generation, reflecting the greater and stochastic variability of generation.

Grid reinforcement may, however, contribute to reliability, which is a public good, implying that a part, even all, of this investment should be socialised. In addition there is the question of lumpiness of grid investment. It may be that the minimum scale of the grid reinforcement is considerably larger than what is strictly necessary to accommodate the single wind power project in question. It may also be the case that there is significant economies of scale in investing even more. This means that there is room for future growth in generation without additional grid reinforcement investments. The optimal strategy for the net operator may be to give incentives to more projects than just one in order to utilise these scale effects and investment in a public good. The first project to be accepted cannot then be charged with the total cost of reinforcing the net. The investment cost is to be shared with future growth in generation and the general system. See for instance Turvey (2006) for a discussion in relation to the British charging regime.

In order to dimension the development of transmission capacity in a socially optimal way the net operator must also predict the growth in generating investment. Potential hydro power projects, new development or upgrading of existing power plants, have given locations. Wind power will be located along the coast, so although a specific wind mill has a fixed location, ex ante, before commitment to investment, the wind mills can be regarded as footloose along the coast. The planning task of the net operator is to give incentives to the location creating the highest net social value. In view of the lumpiness of the transmission upgrades and externalities, one way to proceed can be to consider larger areas for development and not single wind mills. Based on information about wind conditions and availability of sites, taking environmental cost considerations duly into account, model simulations should point to areas to start with that have the highest social value. Providing transmission capacity first to one or more of such areas will then offer firm commitment as investment incentive.

The expectation of future gross prices and level of user charges plays a crucial role in the generation investment calculations. In order to facilitate coordination of generation and transmission investment the net operator should see to it that the potential investors have as much information as possible to form expectations about future prices and charges. The net operator may be in a better position to run model analyses yielding price predictions. It is certainly best placed to give predictions about the development of connection charges and energy charges. It has been suggested in the literature that the net operator should give investors contracts for charge levels for a considerable number of future periods in order to reduce risk for investors. At least the net operator should provide predictions based on model simulations for future periods incorporating new generation and transmission investment and the time path for charges based on the present rules for setting these charges.

Simulation scenarios

It is difficult to think that a unique modelling approach will be feasible, yielding only a single unique solution. The more tentative nature of the proactive planning approach envisaged here calls for a number of alternative investment plans in transmission to be investigated. These alternatives should reflect the lumpiness of especially investments in new lines and in lines in new corridors. As to wind power investments and small-scale hydro sufficient cost and production efficiency data must be collected, and both the need for shallow connection investments and deep investments in line upgrades and reinforcements explored. It is important for the economic analysis of deep connection transmission investments that the wind power investment does not only consist of a single wind power project, but covers a number of wind park sites over a larger area or region. It should then be possible to work out a list of a limited number of prioritised locations for wind power according to values of the social objective function used for the model simulations. The simulations will also give information about the optimal sequence of phasing in capacity from the prioritised location of wind power.

The next step is to tailor-make investment incentives to match the prioritised investment areas. The simulations will also give information about the level of charges to apply to satisfy the requirement of cost recovery, setting the postage stamp charge residually. It then has to be checked whether these price signals will lead generators to locate efficiently. The investors must be given a sufficient degree of certainty both about energy independent charges and energy-dependent charges for a number of future years. But such incentives may not be enough to actually realise investments. It should then be observed that is not the role of the TSO to subsidise wind power investments, unless explicitly instructed to do so. A better approach seems to be that political organs determine the degree of subsidisation. Direct investment support then seems most attractive. The role of the model simulations of the TSO should serve the need of identifying both location and corresponding volume of wind power (or other renewables) that minimise the level of investment subsidies necessary to realise a total volume of investment in renewables formulated as a policy goal by politicians.

As part of the simulations the reliability of the system also has to be tested by applying the most relevant version of the $N - k$ criterion, and to investigate, e.g., the consequences of choosing different probability levels for outages.

5. Concluding remarks

Transmission is an integral part of the electricity system. However, even within a centralised system of generation and transmission the optimal coordination of expanding loads, with a spatial distribution, with optimal volume and location of generation and transmission capacities has never been a trivial exercise. Lumpy investments, involvement of a public good like reliability, and pervasive transmission externalities in loop-flow systems contribute to the difficulties. The unbundling of transmission and generation of newly deregulated electricity systems have substantially increased the coordination problems. The investment decisions of independent generating investors have to be forecasted with sufficient accuracy in order to decide on socially optimal transmission investments, given that these investments are decided by a single entity; a transmission operator that is also the system operator, as is the case in Norway. Under a financial requirement of self-financing, charges for using the network has to be set in such a way that both short-run efficiency in utilising the transmission system and long-run signals for optimal investment in generation are forthcoming. A second-best planning procedure would probably be the most realistic to aim for. It is most important to take account of the lumpiness of major investments in transmission having as a consequence that the pressure on the transmission system will be cyclical; higher pressure than apparently optimal if investments could be implemented incrementally in front of transmission investments, and lower pressure than apparently optimal after carrying out significant investments.

In a system with independent investor decisions about generation, an issue is whether decisions on transmission investments should be based on expectations only about generation investments, in view of the longer lead time for at least lines in new corridors, or whether a more firm commitment to use the investment option is required. The TSO may be stuck with a too large transmission investment. Various options for strengthening the control of generation investment, including the location, may be developed, keeping the independence of the generation investors. One option is to use the concession system screening investment proposals to conform to the locational aspect, and, may be, give incentives for using an investment option within a certain time. These are further research issues, as well as how scenario simulations may be used to inform potential generating investors about transmission implications of investment options in order to form better expectations and improve the dynamic efficiency of the system.

A key question as to giving the right investment incentives is the extent of transmission investments that should be an integral part of the generating investment projects. Renewable energy projects like wind power seem to require significantly larger deep investments in transmission than more footloose generating technologies. A political wish to subsidise renewable energy should not interfere with the correct application of connection charges. The calculation of the necessary investment subsidies for such a project to be commercially viable should be done after the calibration of all charges. Maintaining the socially correct locational investment incentive will bring out the true cost of pursuing a quantitative goal for renewable capacity, assuming that emission reduction is not integrated into the modelling framework. It may be the case that, taking the quantitative goal into consideration, the optimal location of renewables actually changes. The reason will then be the limited capacity of renewables within each location.

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