Ancillary Services in Restructured Environment of Power System

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Abstract— In a restructured power market, apart from the firm transaction of the energy and power, independent system operator (ISO) make arrangement for certain additional services to maintain the reliability and quality of power supply. Such additional services are required for maintaining active and reactive power balance, variation in frequency and voltage within allowable limits in event of emergency handling of power system such as black start capability etc. In monopolistic market structure, these services have been integral part of the electricity company whereas in restructured electricity markets a separate mechanism exists for such services named as ancillary services. The present paper has investigated into various ancillary services and their necessity to ensure safe and secure operation of power system.

Index Terms— Active power, black start capability, operating reserve, power system, reactive power, restructured electricity markets.

I. INTRODUCTION

The electricity supply industry has been undergoing rapid and irreversible change reshaping an industry, which was for a long time remarkably stable and had served the public well. A significant feature of these changes is to allow for competition among generators and to create market conditions in the industry, which are seen necessary to reduce cost of energy production and distribution, eliminate certain inefficiencies, shed manpower and increase customer choice. This transition towards a competitive power market is commonly known as electricity supply industry restructuring or deregulation. A modified form of restructuring is occurring in the countries of Asia, driven by a need for rapid expansion of capacity in all the three branches, generation, transmission and distribution. Hence a variety of organizational structures are emerging [1].

Electricity supply is traditionally viewed as a natural monopoly. There is growing dissatisfaction with limited incentives for efficient operation of a cost-of-service regulated or government owned electric utility. As a consequence, regulators, worldwide, are now implementing new regulatory schemes and organizational reforms in an effort to improve the incentives for efficient operation of electricity utilities. All these reforms are consistent with the view that competition should be introduced into the electricity supply industry wherever it is technologically feasible. Only those portions which are most efficient and are being supplied by a single firm should remain regulated [2].

Electric utilities worldwide are undergoing a period of fundamental change with privatization, deregulation and the introduction of competition. Competition has resulted in renewed utilization of assets for generation, transmission and distribution with the aim of enhancing profitability and increase owners’ value. In an unbundled environment, important issues are also related to the type and level of services that should be included in system operation. In order to maintain the safe and reliable operation of the system, the system operator needs to its disposal various services from generation and larger consumers [3]. Therefore, it is important to quantify which system services should be provided by generators and which should be delivered by the transmission entity. Electrical power systems are designed and constructed to produce and deliver electricity at nominal voltage levels, waveform purity, phase balance and frequency. These are important attributes to the quality of supply of electricity delivered to the market participants at their respective connection points and to the integrity of the power system as a whole [4].
Deviations from defined standards may result in economic losses to market participants, and or may jeopardize the security of the whole power system. In most deregulated power markets, a common – and perhaps the only - good that is traded is amount of energy in specified time intervals/periods. For efficient trading in a deregulated power market, it is important that the energy spot market remains a valid model of the underlying physical power system during each market interval. This includes quality of supply and system security issues [5]. This provides a valuable perspective on the role of ancillary services in the deregulated power markets. Ancillary services can be defined as those services that provide for services not included in the energy spot market and that would not be provided on the basis of energy prices alone.

These services are:

- Power system security
- Quality of supply
- Enhanced energy market trading

Power system security can be regarded as a mandatory public good that is necessary to have confidence in the market. Quality of supply may have some public good characteristics but tends to discretionary, at least to a degree. Enhanced spot trading is either necessary for power system security or quality of supply. It refers to services that the system operator can use to improve the efficiency of the physical operation of the power system and increase capacity in the transmission network. The paper will present an overview of the most common ancillary services. Especially there will be focused on who have the advantages of use of ancillary services and how these services can be produced and distributed to the customers in an efficient way in a deregulated power system.

II. ANCILLARY SERVICES

Ancillary services can be defined as a set of activities undertaken by generators, consumers and network service providers and coordinated by the system operator that have the following objectives:

- Implement the outcomes of commercial transactions, to the extent that these lie within acceptable operating boundaries. That is, ensure that electrical energy production and consumption by participants match the quantities specified by the outcomes of spot markets.

- Maintain availability and quality of supply at levels sufficient to validate the assumption of commodity like behavior in the main commercial markets. This can be achieved by keeping the physical behavior of the electricity industry within acceptable operating boundaries defined by planning studies in conjunction with operator experience.

In a competitive power market, there are energy market and different ancillary service markets.

To ensure the electricity energy to be delivered reliably and the system to be operated securely, various ancillary services are needed [5]. There are different types of ancillary services such as voltage support, regulation, etc. The real power generating capacity related ancillary services, including regulation down reserve (RDR), regulation up reserve (RUR), spinning reserve (SR), non-spinning reserve (NSR) and replacement reserve (RR), are particularly important. Regulation is the load following capability under automatic generation control (AGC). SR is a type of operating reserve, which is a resource capacity synchronized to the system that is unloaded, is able to respond immediately to serve load, and is fully available within ten minutes. NSR differs SR in that NSR is not synchronized to the system. RR is a resource capacity nonsynchronized to the system, which is able to serve load normally within thirty or sixty minutes. Reserves can be provided by generating units or interruptible load in some cases. When provided by generating units, the amount of reserve that can be supplied depends on the ramping rate, unit capacity and current dispatched output. Energy and ancillary services are unbundled in a competitive market, and can be provided separately by different market participants.

III CATEGORIES OF ANCILLARY SERVICES

Ancillary services can be divided into the following three categories that are described in more detail below:

- Related to spot market implementation, short-term energy-balance and power system frequency. These will be labeled Frequency Control Ancillary Services (FCAS).

- Related to aspects of quality of supply other than frequency (primarily voltage magnitude and system security). These will be labeled Network Control Ancillary Services (NCAS).
• Related to system restoration or re-start following major blackouts. These will be labeled System Restoration Ancillary Services (SRAS).

Spot-market implementation involves ensuring that participating generators and loads achieve their energy targets specified in the market solution for the current spot market interval. However market model imperfections or incompleteness (such as a lack of demand-side bidding or inadequate representation of network losses) mean that the spot market solution may not deliver an overall balance in electrical energy flows in actual operation. Also, unexpected phenomena (such as the failure of a generating unit) during a spot market interval may create a mismatch between the spot market solution and physical behavior. The overall balance in the electrical energy flows in a power system is not monitored directly because of its complexity. It depends on the operating states of all generators and loads as well as on network losses and can vary instantaneously.

However power system frequency is a useful surrogate for energy balance because it is a measure of the stored kinetic energy in the rotating masses of generating units and loads. Imbalances in electrical energy flows that persist for more than a few seconds will be reflected in a change in the stored kinetic energy and thus in power system frequency. Moreover, for time scales longer than a few seconds, frequency may be considered to be uniform across a power system. Thus ancillary services that control frequency may be used to manage short-term imbalances in overall electrical energy flows. Most generating units are fitted with active speed control devices (speed governors) and many motor-driven loads vary passively with frequency. Thus both generators and loads can contribute to managing energy-flow balance. At any particular time, the operating power level of each spot market participant will combine a power level designed to achieve its spot market energy target with that responding to frequency deviations. It is by no means straightforward to separate, monitor and account for these activities appropriately. Unlike frequency, voltage cannot be thought of as uniform across a power system under any circumstances.

Voltage drops occur across network elements due to current flows. Tap-changing transformers shunt capacitors and other control devices are used to control voltages at selected locations. Network losses and the power consumption of many loads vary with voltage. Thus there is interaction between voltage levels and spot market quantities and some coupling between frequency and voltage related ancillary services. The operating state of a power system that has suffered a major blackout may be very different from its normal range of operating states. Power system restoration or restart requires at least some generating units that are capable of self-starting and may require some special network equipment. Commercial contracts can ensure that such capability is made available.

IV FUNCTIONS OF ANCILLARY SERVICES

Ancillary services are functions performed by electrical generating, transmission, system control, and distribution system equipment and people alike - to support the basic services in power system operation, namely to keep the power balance from minute to minute and guaranty the security of the system [8]. Broadly ancillary services are:

A: Frequency control and Regulation
B: Load Following
C: Energy Imbalance
D: Spinning Reserve
E: Supplemental Operating Reserve
F: Backup Supply
G: System Control
H: Dynamic Scheduling
I: Reactive Power and Voltage Control from generators
J: Real Power Transmission Loses
K: Network Stability Services from generators
L: Black-Start Capability
M: Reactive Power and Voltage Control from Transmission and load.

The ancillary services issue is a complicated and multifaceted issue. It includes multiple markets, multiple purposes and also the issue of who benefits and who serves. This also leads to misunderstanding, which then in turn leads to disputes, and finally, too many disputes lead to a non-functional market. The ancillary services can be supplied from generation as well as transmission and the loads. However, most services are supplied from the generation level, but the supply strategy may change as the functionality of the ancillary service market is evolving. The individual players in the power system also have different objectives. Energy traders
want commodity; e.g. forward price where price is set at time of deal, anonymity, risk/reward trade-off and time granularity. Transmission system operators (TSO’s) want reliability; e.g. reliability and contingency preparedness, the system is always changing so they need continuous control, and there are interactions of complex problems such as real and reactive domains.

The ancillary services are an intersection of purpose as well as intersection of markets. The intersection of purpose can be illustrated by Table 1 where different ancillary services and their purposes are listed. The ancillary services also represent an intersection of markets as illustrated by Table 2.

![Table 1: Intersection of Purpose of Ancillary Services [4]](image1)

<table>
<thead>
<tr>
<th>Ancillary Service</th>
<th>Provide Reliability</th>
<th>Enable Market</th>
<th>Capacity Enhancement</th>
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**TABLE 1: Intersection of Purpose of Ancillary Services [4]**

As it can be clearly seen from these tables, the ancillary service issue is a complex task that includes intersection between different markets, they are supplied from both the generator side and the transmission and load level, and they could be looked at as a community versus local supply. Unit generation impacts the ancillary service market; e.g. AGC regulation availability and response and the reserve allocation, and the ancillary services limit generator MW output; e.g. requirements on spinning reserve, AGC regulation allocation and Var output/voltage support. Further, market bid clearing pattern impacts ancillaries service requirement, e.g. Var support and voltage schedule requirements and reserve requirement. The individual “players” in the power system also have different objectives. Energy traders want commodity; e.g. forward price where price is set at time of deal, anonymity, risk/reward trade-off and time granularity.

![Table 2: Intersections of Markets [4]](image2)

<table>
<thead>
<tr>
<th>Ancillary Service</th>
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**TABLE 2: Intersections of Markets [4]**

The ancillary service issue is a complex task and is now discussed in the Nordic countries as well as in other systems. Market solutions for pricing and support of ancillary services are discussed, and the goal is to maintain the right level of services at the ‘right price’. However, in such a market solution it is important to...
discuss the bid clearing scheme; e.g. look ahead - what will clear, resolve conflicts (overlaps such as lost opportunity costs or rules for market clearing prices, constraints (machines, network, intertemporal), adequacy of supply (all products) and to publish/ notify the market participants. Therefore, it is also a question of prescheduling and control/ dispatch. The prescheduling translates into unit ramp constraints, load generation imbalance/ forecast error, schedule changes/dynamic schedules, product changes /conflicts and it is a question of how much to automate, evolution of market rules and the level if fidelity to market clearing.

V ANCILLARY SERVICES REQUIREMENTS

The Indian power system should be operated in a safe, secure and reliable manner. In order to fulfill this obligation the state power pools should control technical characteristics of the system, such as frequency and voltage through ancillary services agreements [7]. The RISO/SISO should determine the ancillary services requirements on a regional grid basis and load zone basis using demand forecasts for the time frame for which the ancillary services are to be procured All users of the system should be provided the following ancillary services.

- **Automatic Generation Control**: The ability of a generating unit to respond to signals from the SISO/power pool in order to correct the system frequency within specified period and prevent overloading of network elements. The power pool should determine the total amount of AGC capacity required through studies that identify the amount of regulation required to meet control performance criteria and also by considering the likely variation in load over the period. This is the regulation response required to accommodate normal variations in demand and generation.

- **Governor Control**
  There should be inherent ability of a generating unit’s governor to correct the system frequency within a specified time frame. Provision of this service is a requirement of all generators connected to the system. All generating units are supposed to inform the power pool about the status of the unit’s governor control.

- **Contingency Reserve**
  The generating units should be able to increase the energy output from unloaded condition in response to transmission facility contingencies on the transmission system within specified time. The power pool should determine the total amount of contingency reserve capacity required to meet control performance criteria. This requirement is a function of the larger generation units and load blocks on the system as well as the combined demand. In most instances, the larger generation and load blocks on the system will be constant, and so the contingency reserve requirement becomes a simple function of demand.

- **Reactive Power**
  The ability of a generator to control system voltage by the generation or absorption of reactive power should be known. Provision of this service is a requirement for all generators connected to the system. The power pool should conduct technical studies based on the quantities, characteristics and locations of forecasted demand to determine the quantities and locations of reactive support required to maintain voltage levels and reactive power margins within limit.

- **System Restart**
  The good response of a generator to self-start and supply the transmission system after a complete system failure is desirable. The power pool should prepare an emergency restoration plan. The power pool should determine the quantities and locations of self-start generating units that are required in order to provide system restart service. This determination should be based on contingency studies performed in the preparation of the emergency restoration plan. Such studies should, at a minimum, take into account the range of reasonable initiating disturbances, the magnitude, extent and likelihood of the outage. It should monitor the status of generation after the initializing disturbance and the system demand level at the time of the disturbance [11].

To assist the RISO/SISO in the preparation of emergency restoration plans, each generator should inform the power pool regarding startup capabilities, ramp rate and connection times for its self-start
VI STANDARDS FOR ANCILLARY SERVICES

The RISO/SISO should establish the standards for ancillary services. The ancillary services standards should, at a minimum, comply with the system appropriately [12]. The RISO/SISO may change its ancillary services standards as needed to account for variations in system conditions, real time dispatch constraints, contingencies, voltage stability transient stability and dynamic stability requirements, and other conditions. The periodic review of the operation of the transmission system should be done to determine whether the ancillary services standards should be revised. Such periodic review may include, but may not be limited to analysis of:

- Deviations between actual forecasted demands.
- Patterns of generating unit outages.
- Grid operations during system disturbances.
- Patterns of transmission facility outages.

VII PROVISION OF ANCILLARY SERVICES BY PARTICIPANTS

Payments to service providers for ancillary services can be categorized as following.

- Availability Payments: Due for every trading period in which the contracted generating unit is available to provide the service.
- Usage Payments: Due, on a per event basis, for each time the particular service is used.
- Payment for Reactive Power: Every generating unit should be able to provide a minimum amount of reactive power to the power pool which allows for dispatch instructions directing the generating unit to operate at any point within a band of specified power factor.

In the event when the power pool requires reactive power from a generating unit outside this band, such that it limits the real power output of that unit, the power pool should compensate the generating unit for its lost opportunity cost [14].

VIII PERFORMANCE TESTING

The performance of service providers in meeting their dispatch requests for ancillary services should be monitored by the RISO/SISO as follows:

- Monitoring should be a combination of ongoing monitoring, unannounced tests and detailed analysis of response to actual contingency events.
- Any information that is brought to the attention of the power pool, either by way of direct communication with a service provider, or through other data which can to be retrieved, must be logged.
- Any apparent deficiencies in terms of ancillary service performance should in the first instance be discussed with the participant concerned.
- If there is continuing variation from dispatch expectations the occurrence should then be logged and the participant advised to that effect.
- Logged details should include specific information offered by the participant and all other evidence that is available.
- Due to repeated violations SISO/power pool may demand fresh proposals and subsequently cancel the original annual contract with the deficient service provider.

IX TRADING OF ANCILLARY SERVICES

System requirements

The main goal when allocating the reserves is to locate the reserves in such a way that the costs are minimized while the security of the system is maintained. Trading of reserves are therefore an important tool for achieving this goal. However, the trading of reserves must be done within the technical limitations of the power system. In the new market situation with deregulation and competition the focus is on the markets needs, efficiency and costs. [3] Due to the dynamic nature and changing operational conditions in the power system (e.g. continuously imbalance between generation and load) a small transmission reliability margin is always reserved on the transmission interconnections. Therefore, exchange of instantaneous reserves is possible without influencing the pricing and traded volume in other energy markets. If additional transmission capacity is needed for exchanging reserves, the capacity that is available for the energy exchange is reduced and hence the markets may be influenced. A permanent reduction in transmission capacity for exchanging reserves does not seem to be a case. Constructing new transmission corridors for exchanging reserves is neither a practical nor an economical or environmental solution Trading of reserves can be organised in different ways. Examples are:

- Trading between the TSO’s
- Trading between a TSO in one system and a market
Player (producer or load) in an other system

- Trading between market players in different systems.

In all cases, the trade must be limited by the actual system status and technical limitations in the systems and between the systems. This implies a trading scheme on short-term basis. Information about the system status and power flows on the interconnections establishes the basic guidelines for the exchange. Such information is only available at the TSO control centers. Trading of reserves between the TSO’s is already practiced in a limited way and an extension of the trade into a more sophisticated trading scheme can be established quickly and easily. Trading between the TSO in one system and a market player in an other system, can be possible if e.g. the TSO must have to compensate for the reserves and finds it cheaper to buy it from outside his own system. Trading between market players in different systems, may also be motivated by when e.g. a market player in one system is forced to keep a reserve level and finds it cheaper to buy the it from a market player in an other system.

However, due to the discussion above it’s not a practical nor an economical solution to reserve additional transmission capacity for exchanging reserves other than the capacity already used for the transmission reliability margin. The same holds for the question of building new transmission corridors for reserve purposes. The TSO’s must be directly involved to ensure that the exchange is within the operational and technical limitations of the system. Theoretically, all information related to the system operation could be made available to the market players, but this requires a complicated information exchange system. Such information could contain information that may be traced back to individual market players. Therefore, the most straightforward way to create a simple and efficient trading scheme is to trade between the TSO’s.

The trade should be based on the pricing and willingness to pay within each system, and the traded volumes and prices should be available to the market players. In the beginning the trade should be formed as a simple and easy administrative system, By starting simple, the participants in the market will gain experience that can be valuable in making the trade system more effective and sophisticated in the future.

Instantaneous reserves may be traded without any further transmission capacity reservations. Due to changing system conditions, the reserves should be traded between the TSO’s and on short-term basis only. The fast and slow reserve can in principle be traded on both short and long-term basis. A long-term trade requires that sufficient transmission capacity is available beyond the capacity used for exchange of instantaneous reserves and regulating power. This implies that additional transmission capacity must be withdrawn from the transmission capacity used for exchange in other organized markets [6].

**Ensuring the reserve**

The TSO’s must have a certain level of reserves available in order to keep the security of the system, and keeping the power balance from minute to minute. Different ways of ensuring the reserve are possible.

**Requirements**

One way is to put requirements on the market players (e.g. in accordance to annual production or consumption or according to installed capacity). In practice the requirements are placed on the producers, even if the consumers also may contribute in some cases. In this case the reserve requirement is viewed as a support to the society and the system as a whole. No compensation is needed or the suppliers may have modest compensation and the costs to the TSO are then included in the transmission tariff. In this way the reserves are usually not placed in the most economical manner.

**TSO owns generation capacity**

In this case the TSO owns generation capacity. If this is a practical solution depends on legislation and other governmental and legal documents in each country - e.g. the Norwegian TSO is not allowed to own generation. The solution requires that the TSO has strict limitations regarding operation of the generation so that regulating power/ balance markets are not influenced.

**Market solution**
In this case market signals and incentives are transformed into capacity investment decisions made by the market players. This requires that price signals and market incentives are given early enough to make the investments in time so that the capacity is available when needed. This brings an uncertainty into the reserve management.

Contract/agreements

In this case the TSO has negotiated a contract or agreement with one or several market players. The contract may be negotiated for a given time period and reserve level, and may vary depending on the system characteristics. The contract may also be based on a bidding process where multiple players are invited. The TSO then know where the reserves are located and which players are holding it. In the present situation - and with the present national legislation in the Nordic countries - there are no single methodology that is satisfactory for ensuring the reserves. In practice different combinations of methods is applied in all systems. Therefore, these differences may cause distortions between the different systems. However, the trading scheme that be implemented must be in harmony with the legislation and governmental rules in each country. These differences need to be further analyzed, and in the long term it is necessary to evaluate the need for harmonization.

X CONCLUSION

Restructuring of power industry is being fast adopted by many countries. The introduction of competition in the electricity industry is a complex process and is only solution for survival of same. The main commercial activities in a restructured electricity industry assume that electrical energy behaves as a commodity. Ancillary services play a crucial role in underwriting that assumption. Therefore, it is even more complex to achieve economically efficient outcomes in ancillary services than in the main commercial activities. Ancillary services play a vital role in maintaining the reliability and stability of the power system. The ancillary services like voltage control, operating reserves, frequency control are very necessary for successful operation of the power system.

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