Abstract
This paper gives an overview of the current methods of calculation and optimization of active power reserve capacity. Methods used in the interconnected power systems of European countries and interconnected power systems of Baltic and Russia are described. The paper also represents the possibilities to utilize higher share of transmission capacity avoiding violation of thermal transmission limits in network elements.

Keywords
Power reserve capacity, optimization, enlarged transmission capacity.

Introduction
A power system cannot operate without reserves. The generating power reserves are needed for compensation the load deviations from prognosticated (expected) values and to cover the generation deficit in case of unexpected power units outages. For every stage of control the adequate reserves are needed. The operating reserves are usually divided into [1]: 1) primary control reserve, 2) secondary control reserve, 3) tertiary control reserve (15-minute reserve), 4) slow scheduling reserve, 5) contingency reserve, including instant reserve, rapid reserve and slow reserve.

The reserves must be also in the electrical lines and electrical networks (transmission reserve, stability reserve, distribution reserve, reactive power reserve etc.). By the help of reserves the quality of energy, reliability of power supply and also reliability and security of power systems are warranted.

Generally the generation, transmission and distribution costs and also the losses of consumers bounded with interruption of electricity supply depend of the amount and location of reserves. The main costs bounded with reserves are:
- The investment costs for creation the reserves
- The operational costs bounded with keeping the reserves
- The operational costs bounded with utilization of reserves.

Main tasks for planning the reserves are to determine the optimal size and the geographical distribution of reserves over the power system [2]. Insufficient investments to new power sources or unsuitable allocation of reserves decrease the reliability and security of power system and may lead to system blackout.

One possibility to allow transmission over network with lesser security margins is to use market based retaliatory measures. Most common of those measures would be countertrade by which System Operator orders up-regulation of some power plants in the region of deficit when incidents in transmission network occur that limit the power transmission capability. The weakness of this method is that it assumes the availability of reserves in necessary regions. However under market influences only, there is no incentive for market players to keep such reserves.

This paper describes the common methods of calculating the necessary capacity of reserves and some principles of optimization for operating reserves. The paper is extension of work [2].

1 Traditional solutions of reserve problem
There are different principles of determining the needed capacity for operating reserve in different synchronous areas. In central European synchronous area (UCTE area) the requirements for reserve capacities are given separately for primary reserve and secondary reserve [1]. The requirement for primary reserve is given by so-called “reference incident” which needs to be fully covered by primary reserves around UCTE area. This reference incident is defined as the maximum instantaneous deviation between generation and demand in the synchronous zone by the sudden loss of generation capacity, load shedding or interruption of power exchanges. The reference incident depends on the size of the synchronous zone, the size of the largest generation unit or generation capacity connected to a single bus-bar in that zone.
The size of secondary reserve to be held by each
country is not precisely defined by UCTE. It can be
derived from the defined purpose of secondary
reserve, which is to restore the balance between
generation and demand within each Control Block.
Therefore the secondary reserve must cover both the
unexpected outages of generation and power
demand fluctuations. The part of secondary reserve
related to unexpected outages of generation is equal
to largest generating unit in the Block. It is
recommended by UCTE to calculate the reserve for
demand fluctuations as a function of system size:

\[ R_{\text{sec}} = \sqrt{aL_{\text{max}}^2 + b^2} - b \]  

where \( a \) and \( b \) – empirical parameters established for
power system;
\( L_{\text{max}} \) – maximum load of the Control Block.

Within Control Blocks the secondary reserves may
be divided according to agreements between
countries.

The size of tertiary reserve (manual reserve) in
UCTE is directly related to secondary reserve as the
purpose of this reserve is to free up secondary
reserve shortly after they are activated.

The planning of operating reserves in Interconnected
Power Systems of Baltic countries and Russia
(IPS/UPS) takes into account that most of the
frequency regulation is done centrally by the Central
Dispatching Unit situated in Moscow and the power
plants used for this regulation are hydro plants in
Volga river cascade. Therefore there is no need to
have predefined primary reserves for frequency
regulation in each separate power system of
IPS/UPS. The reserve, which needs to be held in
each separate power system, is slow reserve with an
activation time from 3 to 30 minutes. These
reserves are quite identical to the requirements of
tertiary reserves in UCTE system as the activation of
them is done mostly manually. Determination of
reserve capacity is done separately for load
deviations and power plant outages.

2 Principles of optimization
The value of reserves may be optimized mainly by
the 2 ways:

1) Minimize the sum of reserves costs and losses of
customers associated with interruptions of
supply [4]

2) Method of market for reserves [5].

The first method assumes that the functions of
reserves costs and losses of costumers are given. On
the occasion of second method compared the
incremental costs of reserves and the incremental
prices that the consumers willingness to pay for the
unserved energy.

The optimization of reserve distribution may be
happened by the economic dispatch models and by
unit commitment models with considering the
reserves requirements.

Power demand is a non-stationary complicated
continuous-time Markov process that can be
described by multidimensional density function. The
power demand process \( \bar{P}_D(t) \) can be written as follows:

\[ \bar{P}_D(t) = \bar{P}_D(t) + \Delta \bar{P}_D(t) \]  

where \( \bar{P}_D(t) \) – process of the expected values of
power demand;
\( \Delta \bar{P}_D(t) \) – random component of power
demand.

We assume that the intervals of power demand for
primary \((i=1)\), secondary \((i=2)\) and tertiary \((i=3)\)
control in the power system are given:

\[ \Delta P_{Di}^- \leq \Delta P_{Di} \leq \Delta P_{Di}^+ \]  

Now, solving the economic dispatch problem
between power units, we can find for every power
unit the maximum reserves to up and down for
primary, secondary and tertiary control. At last the
characteristics of regulators must be accommodated
with optimality conditions.

The optimization of reserves utilization, described
above, enables to decrease the fuel costs and
emissions of thermal power plants. At that it is
possible to consider also probabilistic, uncertain and
fuzzy information [2]. The optimization of reserves
and electricity markets must be coordinated in the
future.

3 Location of operating reserves in great
systems
As well as concerning the capacity of reserves, there
are also different philosophies of determining the
location of operating reserve in different
synchronous areas. In UCTE area the share of
primary operation reserve to be handled by the
Control Block \( i \) is determined by the coefficient of
contribution. This coefficient is calculated as follows:

\[ C_i = \frac{E_i}{\Sigma E} \]  

where \( E_i \) – annual electrical energy generated in
the \( i \)-th Block (including electricity generated
for export to outside of the Block);

\( \Sigma E \) – annual electrical energy generated in
the entire synchronous area.

The distribution of reserve within Control Block is a
subject to negotiations between Transmission
System Operators (TSO-s) of the Block.
In IPS/UPS the location of reserves is mostly influenced by two different contractual limits to each subsystem – one value for normal operation and second in case of disturbances (for instance when unexpected power generation outages occur). Therefore each subsystem may count on some system effect to cover its power deficit or surplus. The reserve for i-th subsystem can then be calculated:

\[ R_{i,j} = \frac{P_{\text{max}}^{k,j}}{P_{\text{max}}^i} (P_{\text{max}}^i - \sum_j R_{j,i}) \]  

where \( P_{\text{max}}^{k,j} \) – largest generating unit in the k-th country of i-th Block;
\( P_{\text{max}}^i \) – largest generating unit in the i-th Block;
\( R_{j,i} \) – reserve power granted by Block j to Block i.

### 4 Generation reserve for enlarged transmission power

When large amounts of power are being transmitted via relatively weak interconnections between different parts of power system, high enough security margins must be maintained to keep transmission system’s state stable during and after disturbances. The classical approach for guaranteeing stable transmission is to set security margin factors for active power and voltage:

\[ k_p = \frac{P_{\text{max}} - P - \Delta P}{P} \times 100\% \]  
\[ k_U = \frac{U - U_{cr}}{U} \times 100\% \]

where \( P_{\text{max}} \) – maximum power corresponding to the steady state stability limit of an interconnection;
\( P \) – actual power transmitted through the interconnection;
\( \Delta P \) – peak value of irregular power oscillations in the interconnection;
\( U \) – actual voltage in the node;
\( U_{cr} \) – critical voltage corresponding to the steady state stability limit of given load in the node.

According to current Estonian Grid Code, \( k_p \) must be at least 20% in normal operation and 8% in restorative operation while \( k_U \) must be at least 15% in normal operation and 10% in restorative operation. Those values are equal to those, used all over IPS/UPS.

The stability limits may not be violated during operation of a system even for a short term. But frequently instead of stability the thermal capacity of the network becomes the limiting factor in power transmission. In other words, the desired power flow in the interconnection is greater than the thermal limit. Power of overload is usually calculated for the initial operating state:

\[ P_{\text{overload}}^i = P_{\text{desired}}^i - P_{\text{safe}}^i \]  

where \( P_{\text{desired}}^i \) – power flow through the interconnection resulting from marked needs;
\( P_{\text{safe}}^i \) – maximal power flow through the interconnection which guarantees resulting power flow after an outage in the network below thermal limit of remaining network elements.

As thermal overload of power lines or transformers is not hazardous during short intervals of time, there is a possibility to use non-instantaneous generating reserves as a remedial action against it. As a most logical solution, the reserve should be activated in the power system region, which the deficit is causing the overload. However it is often unlikely to find excess reserves in regions that are already importing power or the cost of holding the reserves in those regions turn out to be uneconomical. There is a possibility to use the help of neighbouring systems in a meshed network so that the reserve itself does not necessarily need to be located in the importing power system.

Let us assume that power system \( i \) is importing power and power system \( j \) is exporting it. The interconnection between those power systems may become thermally overloaded if there should occur an outage of an element of the interconnection. To relieve overload on the interconnection, activation of generation reserves is needed. In a meshed network, activation of reserves in power system \( i \) has an effect on the interconnection less than equal to the power of reserve activated. This can be described by effectiveness factor:

\[ k_{\text{eff},i} = \frac{P_{\text{wo,res},i} - P_{\text{w,res},i}}{R_i} \]  

where \( P_{\text{wo,res},i} \) – power flow through the interconnection without the activation of power reserve in power system \( i \);
\( P_{\text{w,res},i} \) – power flow through the interconnection with the activation of power reserve in power system \( i \);
\( R_i \) – power reserve activated in power system \( i \).
Therefore the responsibilities for overloading an interconnection have to be shared between all importing power systems having the effectiveness factor greater than 0 on that particular interconnection. An additional reserve to be kept in power system $k$ in order to use excess power transmission in interconnection $ij$ for importing purposes can be calculated:

$$R^{k}_{ij} = P^{\text{overload}}_{ij} \cdot k_{ij}^{\text{eff}(k)}$$

(10)

When there is any incentive to locate the reserve to other power system $m$, then the amount of reserve to be held in this other system must be calculated:

$$R^{m}_{ij} = R^{k}_{ij} \cdot \frac{k_{ij}^{\text{eff}(k)}}{k_{ij}^{\text{eff}(m)}}$$

(11)

Conclusions

1) Currently reserve capacity and location calculations are done as a function of load variations and possible loss of biggest generating unit.

2) Current methods of reserve capacity and location calculations do not consider possible relieving of network overloads.

3) There is a possibility to enable higher utilization of transmission capacities when the limitations are caused by possible thermal overloading of power network elements.

4) There is also a possibility to use reserve reallocation in a meshed network that takes into account reserve effectiveness in different locations.

5) The direction of optimizing the reserves distribution in power systems looks very promising.

References


