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Renewable Energy Sources vs Control of Slovak Electric Power System

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1. Introduction

The chapter presents issues of renewable energy sources connection into Slovak power system. It describes calculation techniques for estimating acceptable RES capacities, which can be connected into the system, without jeopardizing security and quality of supplied electricity. Calculations of additional expenses for regulation power purchase for various values of RES capacities connected are presented in the second part of the chapter.

The interest in construction of photovoltaic power plants in Slovak Republic soared in 2008. A new act concerning renewable energy sources and remarkably generous prices paid for electricity from these sources (associated with the act) stimulated investors' interest in building new plants. Based upon experience from other countries and following analysis of possibilities for procuring own sources of balancing electricity for auxiliary services, Slovak Electricity Transmission System, Plc. (SEPS) placed an order to Department of Power Electrical Systems to elaborate a study in which a maximum capacity of PV plants would be determined, which can be connected into the power system, taking into account availability of balancing power for secondary and tertiary regulation. Developed study determined 120 MWp as maximum power of PV plants, which can be connected in 2010.

Influence from EU side and from investors and construction of new thermal and nuclear power plants in Slovakia necessitated an elaboration of a new study, which would analyse the situation in transmission system with respect of balancing electricity for the case, when new PV plants with capacity up to 1 200 MWp are connected. This chapter presents solution of this matter and some results.

Determination of connectable capacity of PV plants into power system of Slovakia can be accomplished from different points of view. One of them can be based on the basic condition, which is used in all studies concerned PV plants connection into distribution network. This condition states, that voltage change in point of common coupling should be less than 2 %, compared with the situation before plant connection. If this condition is applied, resultant connectable capacity should be relatively high, as 22 kV lines can easily withstand considerably higher loads than those of current ones. Probably 80 to 90 % of demanded capacity could be accepted in this case. This consideration can be hardly accepted due to sources features, which show a vast variability of power, practically in whole power range. In addition, capacities of PV plants are usually lower than 4 MW, thus the responsibility for balance is brought to the distribution company. But the power balance can only be solved on the Slovak transmission system level.

The other possible approach is according to the act [1], where in § 1 sect. 2 the following is stated: „Operator of distribution system is obliged, after the price for connection to distribution system is reimbursed, to connect installation of electricity producer into distribution system with priority, if the installation fulfils technological conditions and sales conditions of connection into the system so that security, reliability and stability of system operation is unchanged“. Operator of regional distribution system uses electricity obtained according to sect. 6 for losses redemption. In case, when instantaneous power of obtained electricity exceeds the value necessary for losses redemption, operator of regional distribution system has the right to sell this electricity for the market price. This kind of electricity selling is not considered a business activity in energy sector and does not require a license for electricity supply.

The third possible approach for connectable capacity into distribution system determination is based on the assumption of PV sources variability and the responsibility for balance being bear by a distribution company. Purchase of auxiliary services is needed for balance compensation and this purchase can only be accomplished by Slovak transmission system operator. So the approach to PV plants connectivity with regard to the balance responsibility has to be solved on the Slovak transmission system level, cumulative for all PV plants connected into distribution systems in Slovakia. This approach is described in the following sections of the chapter. In this analysis wind power plants are also taken in consideration together with PV plants. Their connectable capacity was determined to maximum 200 MW. Generally, the term „renewable energy sources (RES)“ is used in the chapter.

2. Input data for PV plants influence analysis

Slovak Electricity Transmission System, Plc. was established on 1 April 1994. That day a former National Power System Dispatch Centre in Prague finished its activities and Slovak Power System Dispatch Centre in Zilina took over. Slovak power system was step by step transformed into several economically independent units.

Electricity production is concentrated in Slovenske Elektrarne, Plc, a part of ENEL Group (the company is partly owned by Slovak government).

Production sources are in the following structure:

nuclear sources	1820 MW
thermal sources	2584 MW
hydro sources	2478 MW
others	898 MW

Slovak Electricity Transmission System, Plc. with its National Power System Dispatch Centre in Zilina are performing transmission and controlling activities on transmission system.

This company operates:

- 1776 km of 400 kV lines
- 902 km of 220 kV lines
- 17 substations of 400 kV
- 8 substations of 220 kV

Total transformation capacity is 10 010 MVA.

Three distribution companies provide distribution services for end-consumers. These are:

- Zapadoslovenska energetika, Plc. (in Western Slovakia)
- Stredoslovenska energetika, Plc. (in Central Slovakia)
- Vychodoslovenska energetika, Plc. (in Eastern Slovakia)

owned by foreign companies.

The maximum load of the power system in 2010 measured on 17 December 2010, 17:00 h was 4 342 MW.

Minimum load in the same year measured on 8 August 2010, 5:00 h was 2 190 MW.

Today, there is about 470 MW of installed capacity in photovoltaic power plants in Slovak power system. Wind sources capacity is practically negligible. Hydro power capacity was already mentioned. Photovoltaic sources are characterized by rapid changes of powers, depending on weather conditions. Despite the fact that prediction of performance of RES is in progress these sources are causing unbalance between electricity production and consumption – mainly during periods of low loads in system. The main problem is the possibility to build PV plants with the capacity up to 1 MW. These plants (after connection into system) are not obliged to control deviation between agreed and actual electricity supply into network. These plants are connected to distribution 22 kV system (in 99 % of cases) and are not obliged to measure parameters and transfer data to dispatching centre. Mentioned deviations in electricity supply have to be handled by dispatching centre through purchasing auxiliary services. These additional purchases increase electricity price for customers. Also quality of supplied electricity can be affected. Different types of auxiliary services are described in the following sections together with analysis of their impact on the Slovak power system operation.

A basic property of power system operation is that equilibrium between production and consumption of electricity has to be maintained in every single moment. The consumption of electricity is given by consumers themselves by switching on and off a large number of different appliances and that is why can hardly be affected. Thus equilibrium has to be maintained on the electricity production side and the sources' power must be adapted to instantaneous consumption.

Power system load planning is based on, considering permanent time changes of electricity consumption, the behaviour of system load during 24 hours depicted in daily load diagram (DLD). Expected load during a year is determined from typical DLDs for power system of two days with the highest and lowest loads. DLD for Slovak power system is depicted in Fig. 1 for a summer day.

Calculations for auxiliary services were done only for summer season in the time of minimal value of weekly maximum - L_{MAX} for the values of 2261, 2394, 2660, 2926, 3192, 3458 MW. Evaluated scenarios of system electricity sources employment participating in coverage of DLD in regulation area of Slovakia during summer, in time of absolute minimum were considered according to available data and records from SEPS. In the calculation of the Slovak power system (SPS) operation substantial changes in electricity production installations can are considered. These are listed in Table 1 for individual years. For the purpose of simplified depiction of sources employment, the scenarios were marked A, B, C.

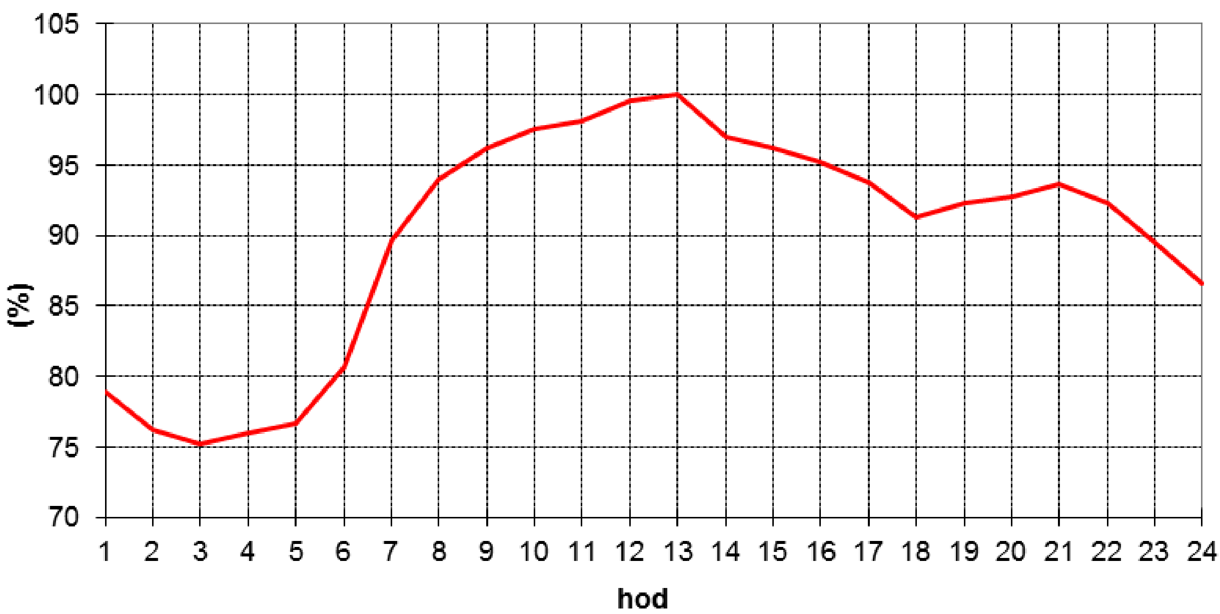

Fig. 1. DLD of summer day

Sources employment scenario		A	B	C
Source/Year		2010	2011	2013
Nuclear power plant	EMO 3,4			1000 MW
Combined cycle plant	Malženice		430 MW	430 MW
	New			850 MW
RES	wind+PV	variable	variable	variable

Table 1. Expected changes of installed capacity for years 2010 – 2013

For each of the sources employment scenarios A, B, C the following installed capacities of RES were used: 300, 400, 500, 600, 800, 1000 and 1200 MW. Each capacity of RES was then employed in the values of 10, 20, 40, 60, 70, 80 and 90 % of installed capacity.

Based on actual operational states of existing RES in SPS the installed capacity utilisation of RES in summer is 0 – 75 % P_{inst} . The variability depends mainly on actual time changes of global solar radiation and used photovoltaic panels.

The coverage of DLD depends on possibilities of each power plant, their failure rate and planned repairs cycles. Employment of individual sources for DLD coverage was performed according to the standards used in preparation of transmission system operation. Pumped storage plants were used to cover peaks of the DLD. Operation of industrial power plants in different regions was considered according to previous years' information. Cut-offs of production facilities and used electricity production technology have substantial impact on source employment in summer season. In case of cut-offs of production facilities, data from SEPS for the years 2010 and 2011 were used.

3. Methodology and calculations of auxiliary services necessary for RES regulation

The purpose of auxiliary services is provision of steady power balance. On one side there is electricity production starting from traditional sources to RES, on the other side are customers, i.e. final consumers. Production and consumption within the scope of interconnected power system must be in equilibrium at every moment.
A new approach to RES support, embodied in act No. 309/2009 about the support of RES and highly effective combined production [4], brings a quasi new group of producers to the electricity market. Those producers produce electricity not according to market demand but practically any time when climatic (wind, solar flux) conditions allow. Responsibility for sales of produced electricity and for the potential balance from the planned values are transferred primarily to operators of distribution systems who are obliged to buy electricity from RES, but eventually power balanced must be maintained by TSO. Supportive mechanisms for RES are currently only starting and massive capacities of these sources are not installed in SPS yet. The progress in installed capacity of RES in distribution system in 2010 is depicted in Fig. 2. Development trend of installed capacity is soaring confirming relevance of topic of availability and sufficiency of regulative capabilities and possibilities of SPS.

3.1 Methodology of setting necessary auxiliary services

The setting of necessary range of auxiliary services for securing reliable operation is closely linked to the degree of reliability of the system. The higher the rate of reliability is required, the higher the range of auxiliary services is needed, having a substantial influence on the final electricity price.
When setting the necessary range of auxiliary services important source information include not only expected loads in regulation area but also load diagram for considered interval of time, value of installed capacity of RES and other statistical data associated with system operation. Amount of auxiliary services was calculated according to the methodology published in [1].

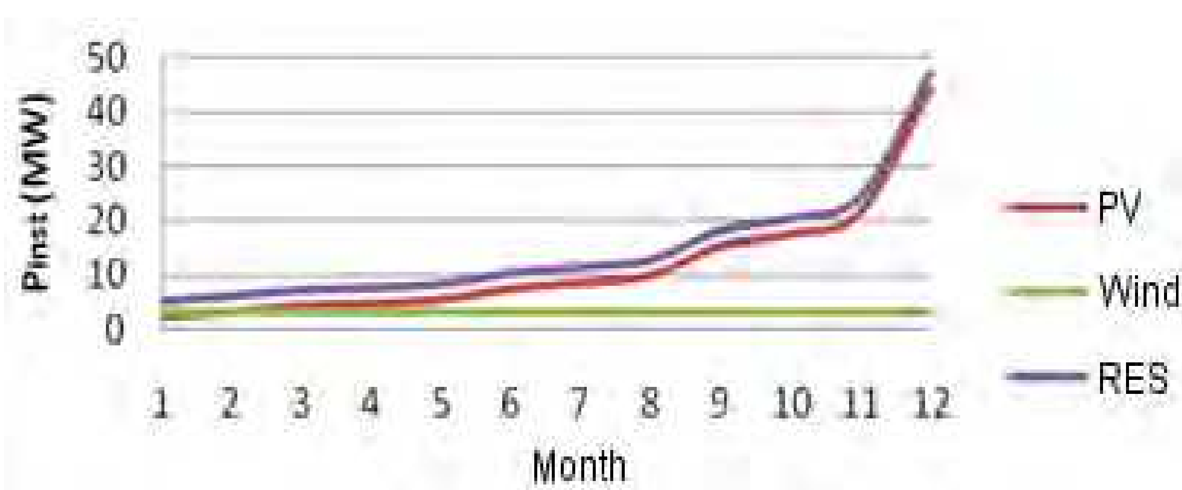

Fig. 2. Progress in installed capacity of RES in 2010

3.2 Setting necessary auxiliary services range for RES regulation

When setting the necessary amount of auxiliary services for SPS needs long term statistics of load and system balance are utilised. Because there is no centralised measurement of power on existing RES, it is not easy to define influence of RES to SPS especially to volumes of auxiliary services. SEPS can only expect that operator of distribution systems will be willing to provide high quality prediction of production from RES and placement of the electricity in the market thus minimising requirements for regulation reserves.

3.3 Impact of powers of RES fluctuations on primary frequency regulation

The role of primary frequency regulation (PRV) is to avoid the occurrence of impermissible deviation in interconnected power system during few seconds. Resulting from the nature of primary frequency regulation the considerable deviations of balance between production and consumption caused by outages of large electricity sources are compensated within seconds. Overall power reserve of 3 000 MW is necessary to secure functionality of the primary regulation in the interconnected international system RG CE [8].

Primary regulation is of proportional nature and maintains equilibrium of production and consumption in synchronous interconnected area based upon frequency deviation. Aliquot part of the primary regulation reserve of Slovakia for 2010 is PRV = ±30 MW. Value of active power is symmetrical, which means ±30 MW.

3.4 Impact of powers of RES fluctuations on secondary power regulation

Secondary power regulation (SRV) maintains equilibrium of production and consumption as well as system frequency in each regulation area taking into account regulation programme without violation of primary regulation, that works concurrently in synchronous interconnected area.

Secondary regulation uses centralised automatic production regulation which maintains setting of active power of production units during seconds up to 15 minutes (typically) after the event. Secondary regulation is based on the secondary regulation reserves controlled automatically. Adequate secondary regulation depends on production sources offered by production companies for disposal for auxiliary services.

Minimal recommended value for secondary regulation reserve within interconnected system RG CE is derived from the expected value of maximum system load in give time period according to the empirical formula [8]:

$$SRV_{\mathrm{RGCE}} = \pm\sqrt{a \cdot L_{\max} + b^2} - b\,, \tag{1}$$

where $a=10$ (empirical constant), $b=150$ (empirical constant),
$L_{\max}$ - expected maximum load, SRV - secondary power regulation.

The other part of the secondary regulation reserve within the regulation area Slovakia is a component resulting from load changes dynamics of regulation area ($SRV_{DYN,L}$). The value of this component can be derived from the statistics monitoring system load during a longer period of time and is within the range of 20 to 40 MW, which means circa 1 % recalculated to average yearly load of SPS.

$$SRV_{\mathrm{DYN,L}} = \frac{R_{\varphi}}{2} + \sigma\,, \tag{2}$$

where R_ϕ – arithmetic average of 10 minute differences of maximal and minimal load values for whole hours,
σ – standard deviation.
Resultant value of secondary regulation of regulation area Slovakia then equals to sum of minimal recommended value RG CE and a dynamic component. The value of power is symmetrical.

$$SRV_{FIN} = \pm (SRV_{RGCE} + SRV_{DYN,L}) \tag{3}$$

With the help of secondary regulation the central controller of regulation area maintains compensation of frequency deviations and compensation of active power balance on the planned level. The value of active power is symmetrical. Minimal offered power for SRV is ±2 MW per unit. The whole regulation range must be realised within 15 minutes from the request and has to be symmetrical according to the basic power. Basic power is unit power for DLD coverage determined by provider within the preparation of operation.
Unit has to allow continuous repeated power changes in any direction within offered regulation range for SRV. Offered regulation power has to be available during whole negotiated time period (hour, day, etc.).
When calculating required range of secondary power regulation it is necessary to consider the influence of RES mainly wind and PV plants. RES are causing additional power fluctuations is regulation area. This undesirable phenomenon has a direct impact on secondary regulation reserve increase. Various foreign system analyses proved the fact that after implementing RES dynamic variations and increase/decrease gradient of non-covered load (difference between overall load and RES production) have risen. In view of the secondary frequency regulation mission (whose role is to maintain dynamic unbalance between planned production and expected load, and thus to keep the balance of regulation area) a new component of secondary regulation reserve $SRV_{DYN,RES}$ has to be introduced.
Additional components of secondary regulation reserve take into account fluctuation of load and production of RES. As there is neither mutual relation nor dependency between mentioned components, these components cannot be directly arithmetically added. If the arithmetical addition is used the value of overall secondary regulation reserve would rise inadequately. One way how to consider both non-correlating components is the use of the function which calculates geometric sum of the values. Resultant value of secondary regulation reserve is then symmetrical and can be calculated according to the following formula:

$$SRV_{\mathrm{VYS}} = \pm (SRV_{\mathrm{RGCE}} + \sqrt{SRV_{\mathrm{DYN,L}}^2 + SRV_{\mathrm{DYN,RES}}^2}) . \tag{4}$$

Component $SRV_{DYN,RES}$ constitutes of two partial components, which consider the influence of wind and PV plants and final value can be calculated according to the following formula:

$$SRV_{\mathrm{DYN,RES}} = \pm (SRV_{\mathrm{DYN,WIND}} + SRV_{\mathrm{DYN,PV}}) . \tag{5}$$

Amounts of secondary regulation reserve for wind plants $SRV_{\mathrm{DYN,WIND}}$ were specified according to the findings in study [9]. Amounts of secondary regulation reserve for PV plants $SRV_{DYN,PV}$ were specified according to the statistical values from PV plants in operation in Czech Republic and Slovakia [23, 24]. However it has to be remarked that considered were only roof applications with low installed capacity and mentioned statistical data did not include long term information.

P_{inst} (kW)	10	20,1	62,4	68,3	84
$\Delta P_{hour}(\%P_{inst})$	2,8	2,4	1,8	1,7	1,4

Table 2. Hourly changes of PV plants power

The basis for the necessary range of the secondary regulation reserve $SRV_{DYN,PV}$ determination is hourly sample of expected time changes of overall PV plants' power taking into account hourly power shown given in Table 2. Additional values for secondary regulation reserve were calculated according to the method of $SRV_{DYN,PV}$ calculation.
Based on statistics, performed calculations and after adaptation of the values for the conditions in Slovakia the expected volumes of secondary regulation reserve for RES $SRV_{DYN,RES}$ were determined and are shown in Table 3.

$P_{inst\ RES}$ (MW)	300	400	500	600	800	1000	1200
$SRV_{DYN,RES}$	43	50	58	65	80	95	109
$SRV_{DYN,RES}$ (% of $P_{inst\ RES}$)	14,29	12,57	11,53	10,84	9,98	9,46	9,11

Table 3. Expected volumes of secondary regulation reserve for RES

3.5 Impact of powers of RES fluctuations on tertiary power regulation

Tertiary regulation (TRV) uses tertiary reserve, which is usually activated manually by TSO in the case of actual or expected secondary regulation activation.
Tertiary regulation is principally used for secondary reserve's release in the balanced state of the system, but it is also activated as a supplement of the secondary reserve after larger outages for system frequency restoration and following release of primary reserve within the whole system. Tertiary regulation is typically performed within the responsibility of TSO.
The nature of tertiary regulation differs from that of secondary regulation. While secondary regulation maintains dynamic unbalance between planned production and expected consumption, tertiary regulation corrects errors in production programme introduced by larger imperfections in consumption prediction and sources outages – Fig. 3.
This regulation affects the change of active power of generators in the whole range up to their withdrawal or connection into operation. It reacts to overall state of given power system and acts after the secondary power regulation or cannot be activated at all. The sources covering tertiary regulation of active power can use their whole regulation range or its parts for it. When starting from the zero power they have to supply power to the electric system equivalent to the basic regulation range of tertiary regulation (technical

minimum of source). Reserve of tertiary regulation of active power can be secured with different activation times.

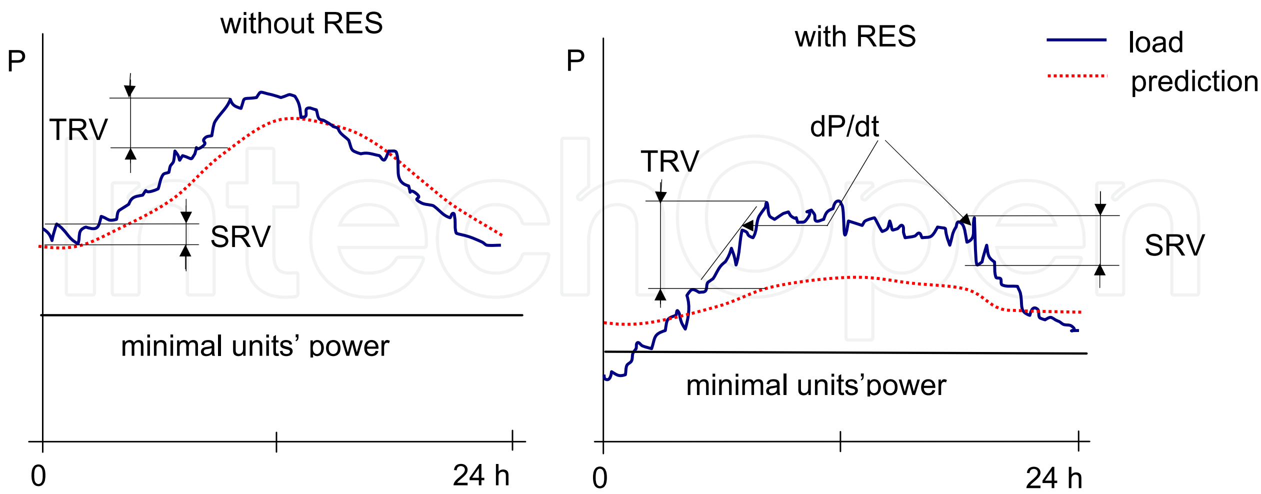

Fig. 3. Impact of RES operation on tertiary regulation reserve

Tertiary regulation *TRV30MIN* provides coverage of load changes caused by temperature, uncertainty in load estimates, outages of sources and electricity demand.
Necessary power reserve for tertiary power regulation coverage *TRV30MIN* can vary for both regulation directions and thus is split to positive and negative reserve.
Positive tertiary power regulation *TRV30MIN+* is calculated according to [1] and consists of several components:
Inaccuracy of load estimation and influence of temperature

$$TRV_{no} = NP_{\phi} \cdot MAX / 100 \tag{6}$$

(NP_{ϕ} – inaccuracy of load estimation, MAX – maximum load).
Stochastic load change:

$$TRV_{nz} = NP_{\phi+} \cdot MAX / 100 \, , \tag{7}$$

($NP_{\phi+}$ – positive inaccuracy of load estimation).
Substitution of tertiary power regulation in case of power production facility outage:

$$TRV_{vypbl} = SRV_{RGCE} \, . \tag{8}$$

Adjustment of the electricity market influence (this component can append value *TRV30MIN+* based on the historical data or expected changes depending on the electricity market).
The final value of *TRV30MIN+* is then calculated:

$$TRV30MIN+ = \sqrt{(TRV_{vypbl})^2 + (TRV_{nz})^2 + (TRV_{no})^2} \tag{9}$$

Negative tertiary power regulation *TRV30MIN-* is calculated according to [1] and consists of several components:
Inaccuracy of load estimation and influence of temperature

$$TRV_{\text{no}} = NP_{\phi} \cdot MAX / 100 \tag{10}$$

(NP_{ϕ} – inaccuracy of load estimation, *MAX* – maximum load).
Stochastic load change:

$$TRV_{\text{nz}-} = NP_{\phi-} \cdot MAX / 100 \tag{11}$$

($NP_{\phi-}$ – negative inaccuracy of load estimation).
The final value of *TRV30MIN-* is then calculated:

$$TRV30MIN\text{-} = \sqrt{(TRV_{\text{nz-}})^2 + (TRV_{\text{no}})^2} \tag{12}$$

In view of some unpredictable fluctuations of RES power that can occur practically in the whole range of installed capacity, it is necessary to have sufficient regulation power of tertiary power regulation available at any time. Currently there are no statistical data for SPS which could be used to set starting values of increased tertiary regulation reserve caused by RES operation. That is why it would be suitable to use meteorological data as one of the supporting inputs for RES electricity production prediction.
Value of 30 minutes tertiary regulation reserve for RES considering a given degree of accuracy of RES production prediction is as follows:

$$TRV_{\text{RES}}^{30\min\pm} = k_{\text{NP}} \cdot P_{\text{inst RES}}, \tag{13}$$

where $TRV_{RES}^{30\min\pm}$ — increased 30 minutes tertiary regulation reserve caused by RES operation.
When calculating final values of *TRV30MIN* it is necessary to distinguish winter and summer and also *TRV30MIN*+ or *TRV30MIN*- services.

$$TRV_{\text{Fin}}^{30\min+} = TRV_{\text{RES}}^{30\min\pm} + TRV30MIN+ \tag{14}$$

$$TRV_{\text{Fin}}^{30\min-} = TRV_{\text{RES}}^{30\min\pm} + TRV30MIN- \tag{15}$$

Final values of tertiary regulation reserve TRV_{Fin} for different installed RES capacities and loads are in Table 4.

L_{max} (given) (MW)	**1700**						
L_{max} (calculated) (MW)	**2261**						
$P_{\text{inst RES}}$ (MW)	300	400	500	600	800	1000	1200
TRV_{no} (MW)	85	85	85	85	85	85	85
$TRV_{\text{nz+}}$ (MW)	82	82	82	82	82	82	82
TRV_{vypbl} (MW)	62	62	62	62	62	62	62
TRV30MIN+ (MW)	133	133	133	133	133	133	133
$TRV_{\text{RES}}^{30\min\pm}$ (MW)	84	112	140	168	224	280	336
$TRV_{\text{Fin}}^{30\min+}$ (MW)	217	245	273	301	357	413	469

L_{max} (given) (MW)	**1800**						
L_{max} (calculated) (MW)	**2394**						
$P_{inst\ RES}$ (MW)	300	400	500	600	800	1000	1200
TRV_{no} (MW)	90	90	90	90	90	90	90
TRV_{nz+} (MW)	86	86	86	86	86	86	86
TRV_{vypbl} (MW)	66	66	66	66	66	66	66
TRV30MIN+ (MW)	141	141	141	141	141	141	141
$TRV_{RES}^{30\min\pm}$ (MW)	84	112	140	168	224	280	336
$TRV_{Fin}^{30\min+}$ (MW)	225	253	281	309	365	421	477

L_{max} (given) (MW)		**2400**						
L_{max} (calculated) (MW)		**3192**						
$P_{inst\ RES}$	*SRV* +/-	*TRV30MIN-* for different values of installed RES capacity						
(MW)	(MW)	10 %	20 %	40 %	60 %	70 %	80 %	90 %
300	140	148	157	173	190	199	207	215
400	145	151	162	185	207	218	229	241
500	152	154	168	196	224	238	252	266
600	158	157	173	207	241	257	274	291
800	171	162	185	229	274	297	319	341
1000	185	168	196	252	308	336	364	392
1200	198	173	207	274	341	375	409	442

L_{max} (given) (MW)		**2600**						
L_{max} (calculated) (MW)		**3458**						
$P_{inst\ RES}$	*SRV* +/-	*TRV30MIN-* for different values of installed RES capacity						
(MW)	(MW)	10 %	20 %	40 %	60 %	70 %	80 %	90 %
300	145	160	168	185	202	210	219	227
400	151	163	174	196	219	230	241	252
500	157	165	179	207	235	249	263	277
600	163	168	185	219	252	269	286	303
800	177	174	196	241	286	308	331	353
1000	191	179	207	263	319	347	375	403
1200	204	185	219	286	353	387	420	454

Table 4. Final values of positive 30 minutes tertiary regulation reserve for different installed RES capacities and maximum loads L_{max}

4. Provision of auxiliary services and balancing electricity purchasing

Slovakia, as one of the members of interconnected European power system ENTSO-E, has to meet basic requirements for parallel operation of power systems. One of these basic requirements is also range and quality of auxiliary services, taking to account on one side global view of secure and reliable operation and on the other side, local nature of consumption of individual country. While the range of some service is strictly ordered from ENTSO-E (i.e. range of the primary regulation, which principally performs locally, reacts according to instantaneous frequency deviation, in tens of seconds, but impulse, i.e. origin of imbalance between electricity production and consumption can occur anywhere in interconnected system), ranges of other services can vary based on local behaviour of system and thus it has to meet only certain frame requirements.

Basically every power system must have power reserve secured for coverage of an outage of the largest source in order to be balanced in power in relation to other countries. This condition is secured by so-called stacking of various kinds of auxiliary services, or bi- or multi-lateral contracts with international partners, usually neighbouring countries.

In Slovak environment TSO SEPS acts as a partner for ENTSO-E. SEPS after consideration of before mentioned criteria elaborates i.a. a proposal of range of individual auxiliary services and in sense of valid legislation (as a regulated subject) submits to the national Regulatory Office for Network Industries, who in the form of decision defines range and price for a instantaneous availability of auxiliary services and balancing electricity

Fluctuation of electricity production from RES primarily imposes higher demands on regulation sources of SPS either on amount available reserves or on the quality of regulation. In the frame of interconnected system ENTSO-E the SPS is regulated for an agreed balance. SEPS has to keep the agreed value and quality of this regulation is monitored at the coordination centre level. Potential deterioration or violation of accepted standards in area of agreed balance would result in investigation of SPS by ENTSO-E.

4.1 Determination of necessary financial volume

In determination of necessary financial volume actual volumes for provision of individual kinds of auxiliary services are taken in account. These are in Table 5.

These values can be considered as maximums. In real operation they are not always achieved caused by various forces such as equipment failure, regular maintenance, financially underrated services (from the providers' point of view), unavailability on the market and other. Wider offer and competition on the auxiliary services market can be expected when new energy sources are being put into operation, e.g. combined cycle power plant Malženice, nuclear plant EMO 3 and 4 with expected favourable regulatory features and range.

Decision No. 0013/2010/E of the Regulatory Office for Network Industries determined prices and tariffs for auxiliary services provision for the time period of January 1, 2010 to December 31, 2010. Maximum prices for provision of auxiliary services are in Table 6.

Month	*PRV±*	*SRV±*	*TRV30MIN+*	*TRV30MIN–*	*TRV3MIN+*	*TRV3MIN–*	*TRV120MIN*
January	30	129	280	155	220	130	80
February	30	129	280	155	220	130	80
March	30	129	270	155	220	130	80
April	30	124	260	135	220	130	80
May	30	118	250	130	220	130	80
June	30	118	240	125	220	130	80
July	30	118	240	125	220	130	80
August	30	116	250	125	220	130	80
September	30	119	260	135	220	130	80
October	30	124	260	145	220	130	80
November	30	128	270	155	220	130	80
December	30	128	280	160	220	130	80

Table 5. Informative ranges of auxiliary services values (MW) for 2010

Auxiliary service	Price in € per MWh	Average range of auxiliary service (MW)
PRV	73,02	30
SRV	63,06	120
TRV3MIN+	17,59	220
TRV3MIN–	5,31	130
TRV30MIN+	16,92	250
TRV30MIN–	8,29	130
TRV120MIN	10,95	80

Table 6. Maximum prices for provision of individual auxiliary services

Deriving from actual range (Table 5.) and prices (Table 6.) of individual auxiliary services financial volume necessary for provision of reserved power in 2010 can be determined – so called payment for instantaneous availability according to the following formulae:

$$DE = O_{\mathrm{PpS}} \cdot t_r \qquad [\mathrm{MWh,MW,h}] \tag{16}$$

$$RN = DE \cdot C \qquad [\text{€},\mathrm{MWh},\text{€}/\mathrm{MWh}] \tag{17}$$

where *DE* is instantaneously available electric energy
O_{PpS} average range of auxiliary service
t_r number of hours per year
RN yearly costs
C price for auxiliary services provision
Calculated financial volume for *PRV*, *SRV* and *TRV* as well as costs to secure voltage regulation and auxiliary service "Black start" are in Table 7. Summing up yearly costs for instantaneous availability of individual auxiliary services shown in Table 7 overall yearly cost can be obtained for 2010, which is 183 594 016 €.

Auxiliary service	Yearly costs (€)
PRV	19 189 656
SRV	66 288 672
TRV3MIN+	33 899 448
TRV3MIN-	6 047 028
TRV30MIN+	37 054 800
TRV30MIN-	9 440 652
TRV120MIN	7 673 760
Voltage regulation	3 000 000
Black start	1 000 000
Sum	183 594 016

Table 7. Yearly cost of individual auxiliary services

Different scenarios of installed RES capacities rise (300, 400, 500, 600, 800, 1000 and 1200 MW) include also pressure on auxiliary services primarily to *SRV* and *TRV*±. The determination of accurate values with direct financial quantification is not simple as a number of unknown quantities are in play. To avoid placing a grave financial burden on consumers and excessively jeopardising power system operation appropriate effort will have to be given to harmonisation of these influences with the volume of *SRV* and *TRV*± with regard to actual increase of RES energy production and continuously with verified impact on power system.

Installed RES capacity (MW)	**Rise of *TRV30MIN*± at per-cent supply from installed capacity to power system**						
	10 %	**20 %**	**40 %**	**60 %**	**70 %**	**80 %**	**90 %**
300	8,4	16,8	33,6	50,4	58,8	67,2	75,6
400	11,2	22,4	44,8	67,2	78,4	89,6	100,8
500	14	28	56	84	98	112	126
600	16,8	33,6	67,2	100,8	117,6	134,4	151,2
800	22,4	44,8	89,6	134,4	156,8	179,2	201,6
1000	28	56	112	168	196	224	252
1200	33,6	67,2	134,4	201,6	235,2	268,8	302,4

Table 8. Increase of demand rise of *TRV30MIN*± for different scenarios of installed RES capacities increase

L_{max} (given) (MW)	**2200**						
L_{max} (calculated) (MW)	**2926**						
$P_{inst\,RES}$ (MW)	300	400	500	600	800	1000	1200
SRV_{UCTE} (MW)	77,5	77,5	77,5	77,5	77,5	77,5	77,5
$SRV_{DYN,L}$ (MW)	36,4	36,4	36,4	36,4	36,4	36,4	36,4
$SRV_{DYN,RES}$ (MW)	43	50	58	65	80	95	109
SRV_{FIN} (MW)±	133,8	139,3	146,0	152,0	165,4	179,2	192,4

Table 9. Final values of *SRV* at various scenarios of installed RES capacity increase and for L_{max} (given) 2200 MW

Increase of demand rise of *TRV30MIN*± for different scenarios of installed RES capacities increase for different per-cent supplies from installed capacity is in Table 8. The amount of per-cent power supply to power system is influenced mainly by weather factor, which is due to global climate change becoming more and more unpredictable, for example May and June 2010 with having the most rainy days in the whole recorded period of weather observation in Slovakia (approximately 130 years). Cloudy weather without solar flux does not allow electricity supply from PV plants to power systems with any available installed capacity. Wind power plants have the advantage of not being directly dependent on solar flux and can produce electric energy during the whole day depending on wind conditions.

During summer season electricity produced by PV plants can be ideally supplied from 6:00 to 18:00, while in winter season from 9:00 to 15:00 with characteristic curve, where again these assumptions are subject to almost full solar flux. Without long term observations or long term acquired data from the operation these values can hardly be estimated.

For the necessary volume of auxiliary services it is also important whether sunny conditions last for a longer period of time or are unpredictably alternating with cloudy conditions.

In a longer period of sunny weather electricity supply from PV plants settles in daily cycles allowing distribution system operator to credibly implement this supply into DLD. Thus demand for range or activation of auxiliary services decreases. The opposite situation occurs in unstable weather with sunny spells. In this case the demand for range or activation of auxiliary services depending on installed or available power from RES will be enormous. From this point of view for the higher values of installed capacity in these sources bigger emphasis must be put on the possibility of operative increase of range of required auxiliary service, or make provision of non-guaranteed balancing electricity in exposed periods of time more flexible.

Installation of RES will require apart from increased volume of necessary regulation reserves also changes in actual system of procurement of auxiliary services by SEPS. Currently the substantial part of auxiliary service is procured in the frame of yearly selection procedure what appears as very ineffective for these kinds of sources. SEPS will be forced to procure large amounts of auxiliary services only at a frame of daily procurement or during the day as an auction of non-guaranteed balancing electricity. In this way contracted volumes of auxiliary services can be optimised while preserving or even enhancing operational security of power systems.

For determination of necessary financial volume for provision of auxiliary services at various scenarios of installed RES capacity increasing of *TRV±* is considered from Table 8 and final values of *SRV* at various scenarios of installed RES capacity increase and for L_{max} (given) 2200 MW from Table 9. A modelling situation is considered, where for TRV± increase (Table 8) an average supply of 40 % from installed RES capacity during whole day is estimated. Furthermore, actually prices for auxiliary service provision stated by Regulatory Office for Network Industries and values ranges are used from Table 6.
After summing-up these considerations, sum of financial costs necessary for auxiliary services provision, considering RES putting in operation for various scenarios of installed capacities at the day of L_{max} (given) = 2 200 MW can be calculated.
Graphical comparison of the costs for auxiliary services provision at the day of L_{max} (given) = 2 200 MW for various scenarios of installed RES capacities against the costs for auxiliary services without RES are in Fig. 4.

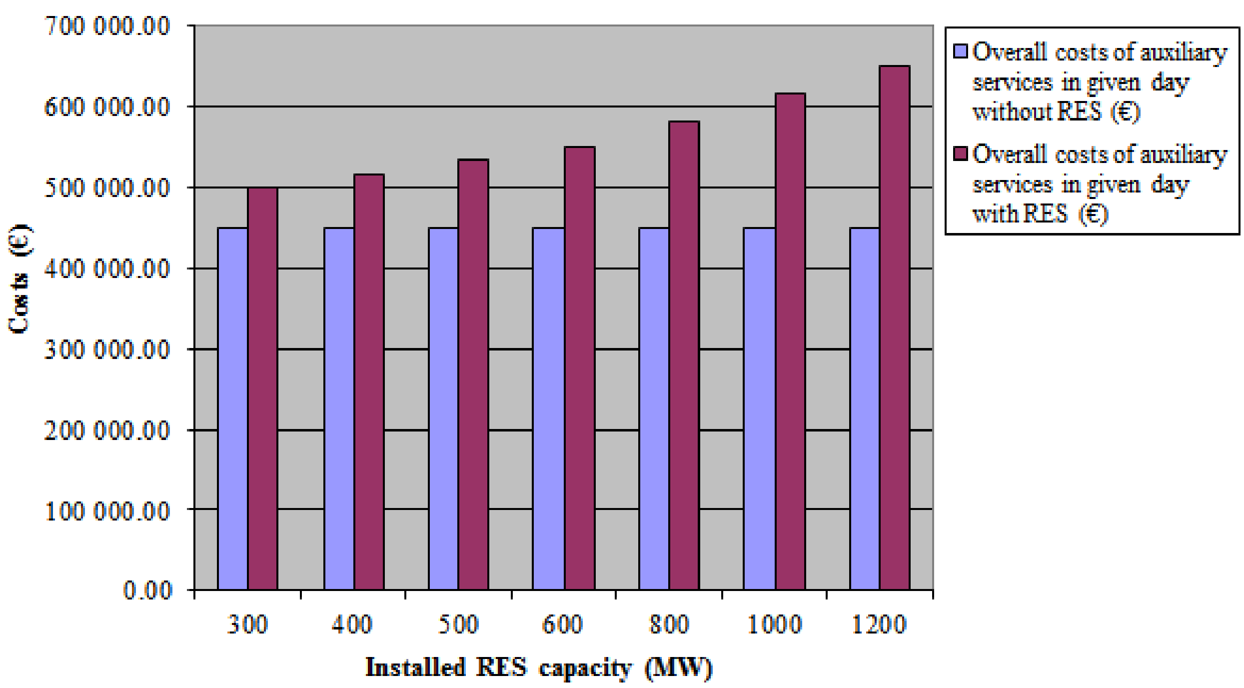

Fig. 4. Comparison of costs for instantaneous availability of auxiliary services at the day of L_{max} (given) = 2 200 MW for various scenarios of installed RES capacities and 40 % of supply

These values should be considered as the first estimation, without having possibility for results precising according to history. A simplification was used in calculations – use of averaged power supply from installed RES capacity during given day – in the amount of 40 % of average power supply. From this value a necessary range of *TRV30MIN±* is derived. Based on at least one year data (better on couple of years data) acquired from RES in operation, this parameter can be precised, what will lead to more reliable estimations. Costs for auxiliary services are determined for the day of summer maximum for 24 hours. The reason is, that individual volumes of auxiliary services without RES are changing during the year and are depending on the load (expected maximum load was not mentioned in study entry values). Supplementary costs for auxiliary services for RES regulation are calculated only from estimated installed capacity and estimated production of RES.

Mentioned calculations shown that influence of RES upon the SEPS economics will be circa 10 mil. € per year, even at the lowest scenario.
Costs for auxiliary services are not the only costs that can be expected from RES installations caused by electricity production fluctuations. The highest costs will definitely be imposed to distribution systems operators. They will be charged for caused balance. Increasing of value of costs for balance in the whole SPS is hardly forecasted in advance, any calculations would be distorted. SEPS can expect also increase of additional costs for system operation in case of overloading of some parts of system due to energy production from RES, i. e. circular power flows, necessary network topology changes, re-dispatching of energy production (within the SPS or in adjacent regions) and other corrective measures. Their price can only be determined ex-post.
Graphical presentations of increase of costs for auxiliary services provision at various scenarios of installed RES capacities and for different per-cent supplies from RES capacities are depicted in Figs. 5 and 6. Values of auxiliary services, *TRV30MIN* and *SRV* are in Tables 8 and 9. For costs calculation an actual prices of auxiliary services are used from Table 6. Yearly costs for instantaneous availability of auxiliary services forced by RES are on Figs. 7 and 8.

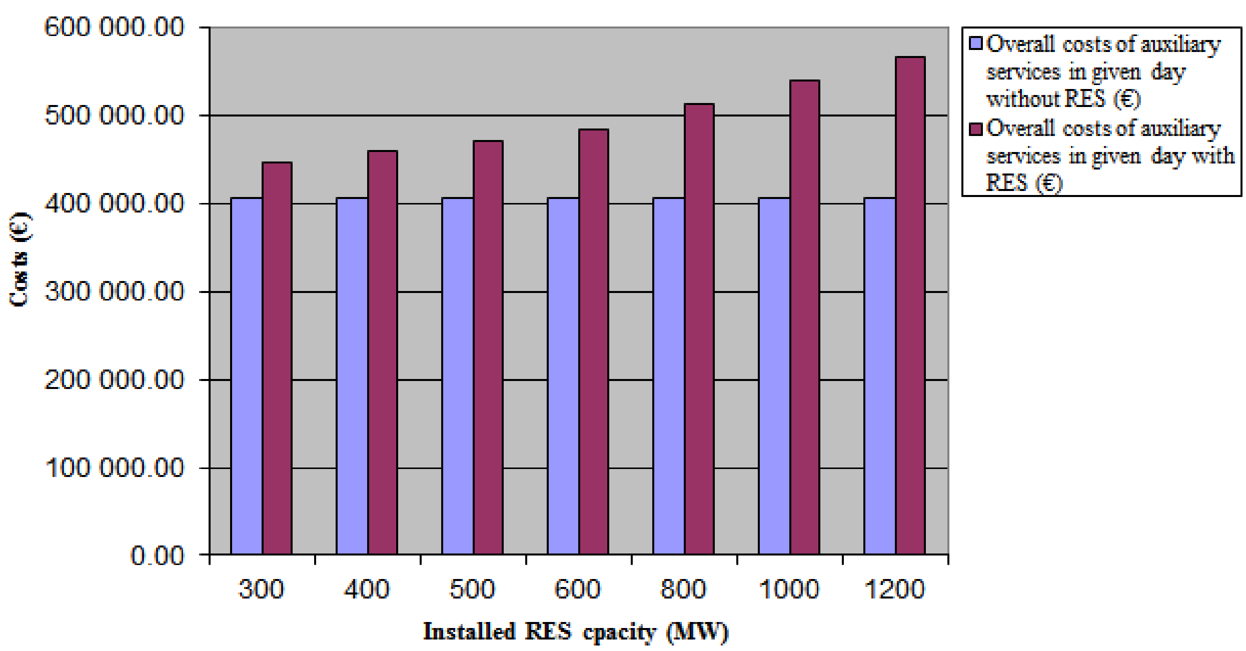

Fig. 5. Comparison of costs for auxiliary services at the day of L_{max} = 1 700 MW for various scenarios of installed RES capacities and 20 % of supply

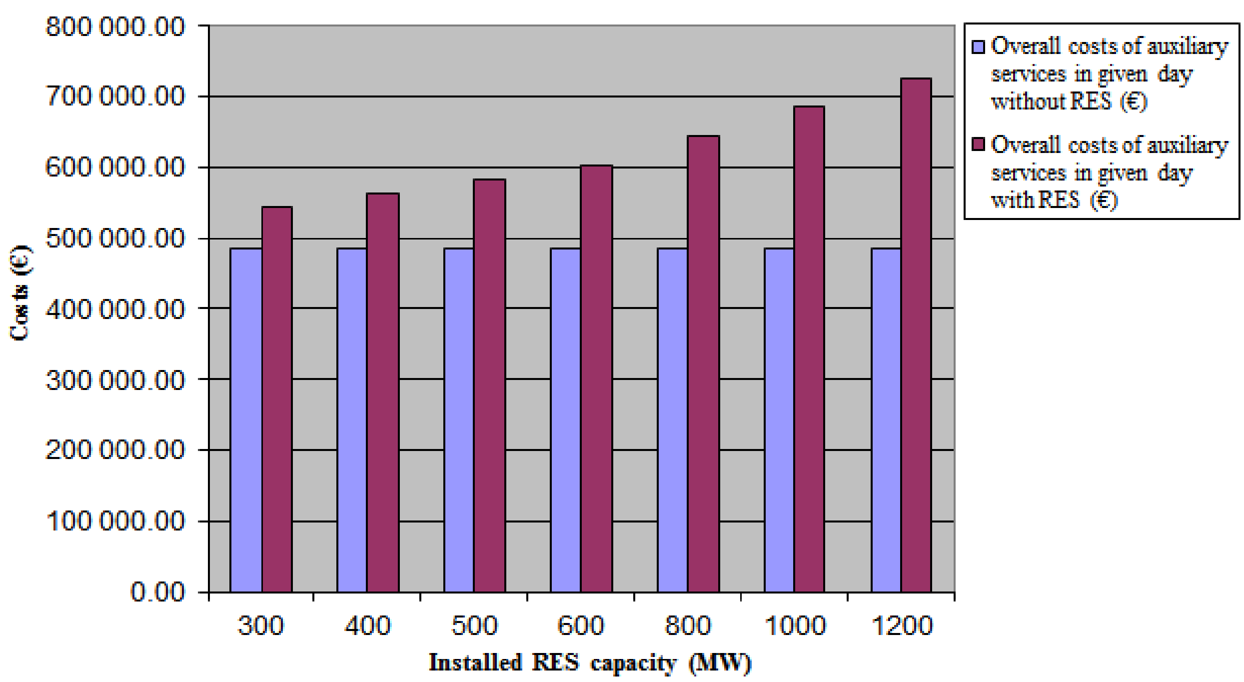

Fig. 6. Comparison of costs for instantaneous availability of auxiliary services at the day of L_{max} = 2 600 MW for various scenarios of installed RES capacities and 60 % of supply

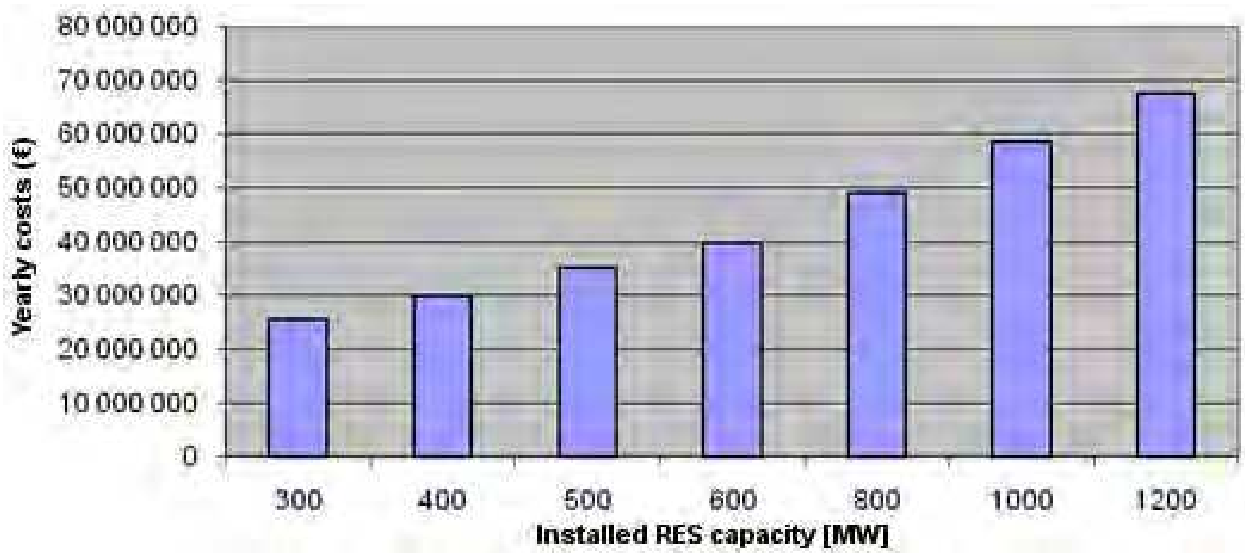

Fig. 7. Yearly costs for instantaneous availability of auxiliary services forced by RES at 10 % of supply from installed capacity

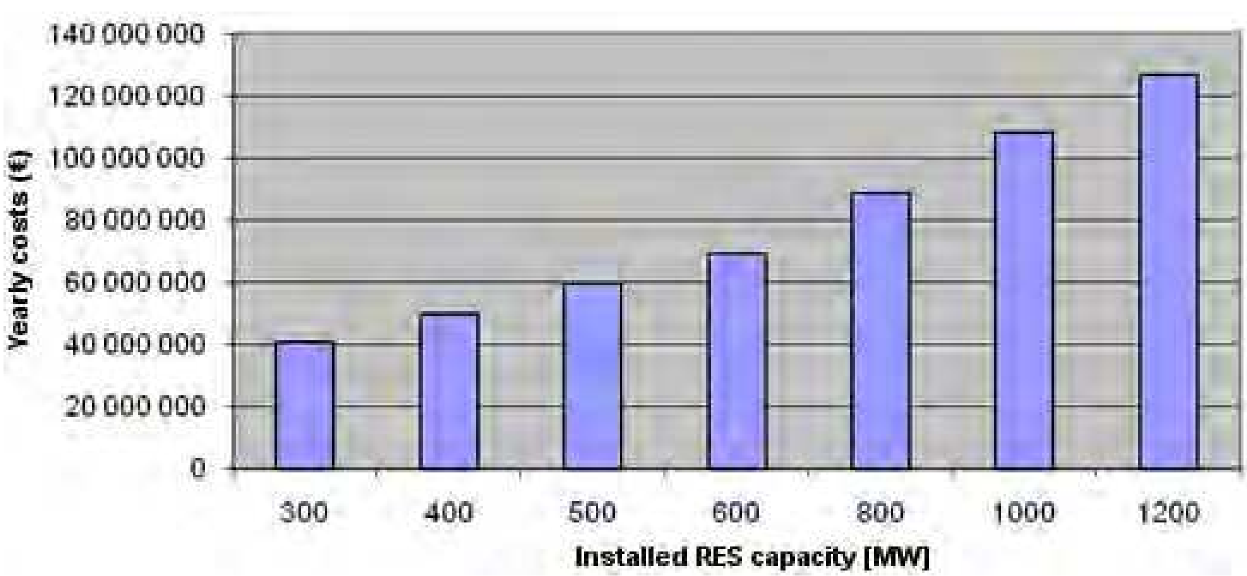

Fig. 8. Yearly costs for instantaneous availability of auxiliary services forced by RES at 90 % of supply from installed capacity

5. Results of analyses

Taking into account before mentioned analysis, the calculations were performed to demonstrate the influence of 300 – 1 200 MW RES connection on transmission system. These calculations were accomplished for three scenarios with different spectrum of sources. Results can be briefly summarized as follows:

Scenario A – year 2010. From the point of view of DLD covering by own sources some power shortages occurs, mainly for combinations at higher absolute minimums, i. e. 2 400 MW and 2 600 MW and for lower power supply from RES. DLD is fully covered for higher values of power supply from RES. The situation is different from the point of view of auxiliary services covering. Possible operation of RES is restricted to 60 – 120 MW at higher system loads, when auxiliary services are reserved mainly for the outages of traditional sources (non RES).

Scenario B – year 2011. In this scenario a new source has been put in operation – combined cycle Malzenice, which provides power for DLD coverage and also a good deal of auxiliary services. The situation from the point of view of auxiliary services covering is partially improved. Theoretically, secure operation of RES is possible with powers of 250 – 300 MW.

Scenario C – year 2013. In this scenario, due to large additional installed capacity in the new sources, SPS will be fully self-sustaining in DLD covering and installed RES capacity can theoretically reach values up to 1 000 MW for any system load. Accomplished calculations have shown that any DLD can be covered and there are no problems with auxiliary services, but substantial problems will rise in electricity export. Specified technological limits for electricity export across border profiles can be found in SEPS web pages www.sepsas.sk. Maximum possible electricity export from Slovak transmission system is 2 000 MW. If this number is taking in account, i. e. considering maximum export of 2 000 MW, electricity production will be higher then allowed export in 90 % of calculated cases.

From the figures showing yearly costs for instantaneous availability of auxiliary services follows, that electricity price for end-consumers will depend on installed RES capacity, if actual electricity purchase prices and auxiliary services prices are valid.

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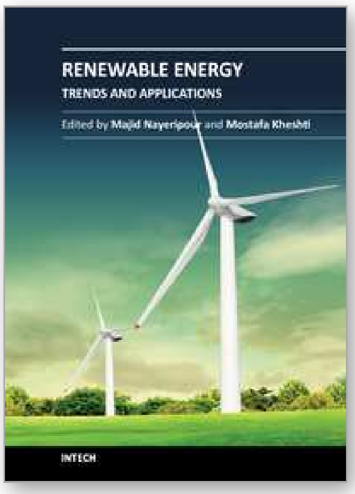

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Increase in electricity demand and environmental issues resulted in fast development of energy production from renewable resources. In the long term, application of RES can guarantee the ecologically sustainable energy supply. This book indicates recent trends and developments of renewable energy resources that organized in 11 chapters. It can be a source of information and basis for discussion for readers with different backgrounds.