Quality assessment of primary frequency regulation reserve on EWIS power system

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***Abstract*—This paper deals with the quality assessment of primary frequency regulation in Pan-European EWIS power system modification. Impact of renewable energy sources (photovoltaic power plants (PPP) with a total installed capacity of 18.7 GW and wind power plants (VPP) with a total installed capacity of 15.9 GW.) on network dynamics is investigated. Comparison of dynamics of cloudy and sunny days with activated support services and renewable energy sources are investigated.**

Keywords*—*wind power plant, photovoltaic power plant, dynamic, support services

I. Introduction

With the changing structure and scope of possibilities, building new sources and using new sources of energy coming from matrices, even though they have changed in the transmission system itself. The construction of new lines at a voltage level of 400 kV can be transmitted, operated reliably and not informed of the reliability and security of energy supply, whether on a large scale, or supplied separately distributed on the end-user.

The second factor entering the development of PS SR is the construction of new RES, in particular PPP and the obligatory purchase of all production from these sources in real time. This places increased demands on support services and regulatory energy.

A. Impact of RES on the pan-European network dynamics

The Pan-European EWIS model was developed according to [3]. For the purpose of this work, the model of a part of the transmission system of continental Europe was modified and supplemented with nodes, lines and blocks of PS SR. Precise adjustments are described in the next chapter [1].

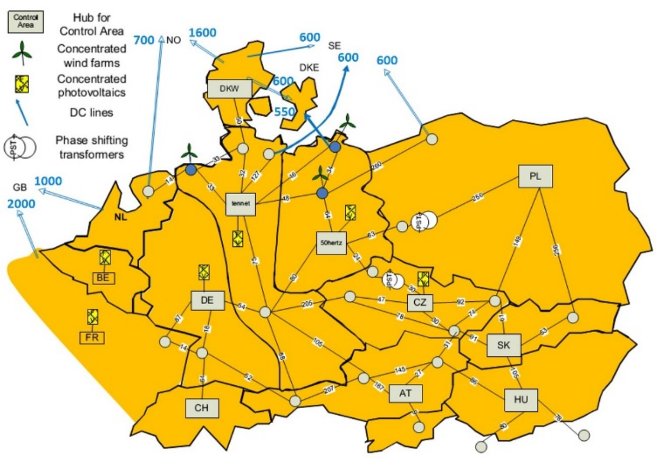
II. Pan-European EWIS model

For the purposes of dynamic simulation of the impact of RES on the interconnected system of continental Europe, a Pan-European model of the electricity system was created, see Fig. 1. The model was expanded to include national lines and resources of the Slovak WG and significant lines of surrounding MAs. Modification of the model also affected the dynamic parameters of individual elements of block models, especially sources in the Slovak PS. The blue lines represent one-way lines with NORDEL systems [2].

The network model was created for the EWIS study and then imported into MODES to model the dynamic transition events in [3].

The network topology has been reduced from the original 8521 nodes to 156, which has a major impact on the simulation rate, ensuring the accuracy of the dynamic simulation outputs is within the required offset.

Fig. 1. EWIS network topology of pan-European model [3]



III. EWIS modifications of the EWIS model model

The Pan-European model was developed to model the impact of RES on the long-term interconnected system dynamics in part of continental Europe [3] based on the EWIS model. For modelling long-term dynamics, a simplified model of the continental Europe transmission system was sufficient. Part of this work is modelling of medium-term, respectively. short-term dynamics. The system was therefore extended.

The PS SR model was thus imported into the EWIS model. The resulting pan-European system thus presents a detailed and complete PS SR model with all sources and their dynamic parameters, which are described in detail in the electronic Appendix D.

The modified pan-European model thus consists of 202 nodes. Thanks to this fact, the long-term dynamics of the whole pan-European interconnected system can be modelled much faster. long-term dynamics with respect to the model imported model PS SR more accurately than in the original model. Output data from long-term dynamics modelling and PPP impact on PpS are compared and analysed at the end of this work. The single-pole scheme of the modified modelled pan-European model is shown in Fig. 2. The imported PS SR, which also forms a separate RO, is highlighted in a darker colour relative to the surrounding RO.

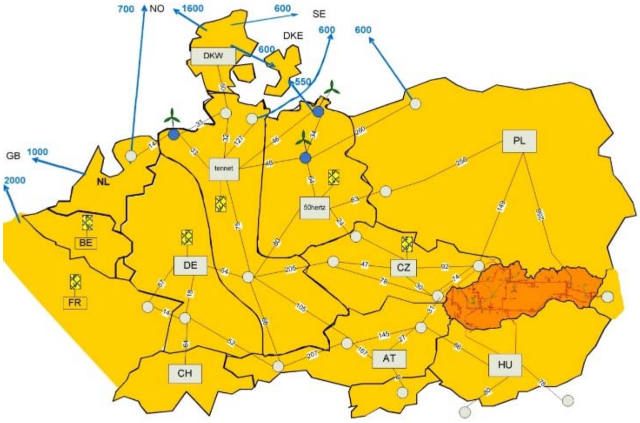


Fig. 2. Single-pole diagram of the supplemented pan-European EWIS

IV. Primary frequency regulation reserve (PRR) quality assessment

The offered RV power at a frequency deviation equal to or greater than +/- 0.2 Hz must be fully activated

A. Criterion for changing the PRR performance

In the primary frequency regulation, the slope of the linear regression line, which expresses the variation in the power output of the PRR-providing device to the frequency change (MW / Hz), is evaluated. If the RV-providing equipment responds correctly, the linear regression line slope is negative and should be at least five times the available power availability. Linear regression line is calculated according to (1):

$$b = \left(n\sum xy - \left(\sum x\right)\left(\sum y\right)\right) \Big/ \left(n\sum x^2 - \left(\sum x\right)^2\right) \qquad (1)$$

Where:

b - slope of the linear regression line,

x - frequency values, which are an independent variable,

y - the power value given by the independent variable on the frequency.

The evaluation is performed only in quarter-hours, when the frequency has changed by at least ± 0.07 Hz, which corresponds to the balance change in the whole interconnected system by about ± 1000 MW. If the PRR is provided concurrently with the SRR, the evaluation shall be performed only in quarter hours when the frequency has changed by at least ± 0.1 Hz.

The source of the frequency and power values of the PRV facilities are the measurements from the RIS dispatching centre of the TSO recorded in the second archive of the MES. In order to eliminate the effect of secondary regulation on the equipment providing TSOs also included in secondary power regulation, the difference between the actual and desired output in SRR is used as the power value.

The quality criterion in a given trading hour is met if the values of the calculated directives in the four-hour period when the quality assessment was carried out are negative and their absolute value average is greater than or equal to 60% five times the offered PRR availability. If the PRR is provided concurrently with the SRR, the quality criterion in a given trading hour is met if the values of the calculated directives in a quarter-hour when the quality assessment was performed are negative and their absolute value average is greater than or equal to 50% PRV. If, at any given hour, no evaluation is carried out in any quarter-hour due to a frequency difference less than ± 0,07 Hz, the quality criterion is met in that business hour.

B. Required power criterion

In the primary power control, the actual behaviour of the PPS providing devices in the primary control is evaluated by determining whether the actual power value is within the determined tolerance power range of the calculated PRV value.

This criterion is evaluated every quarter-hour using the actual power and frequency values from the RIS dispatching PPS, which are stored in the second MES archive.

The activated value of the RV equipment providing power shall be calculated according to (2).

$$\Delta P_{Gvyp} = -5 * P_{PRV} * \left(f_{skut} - f_{nom}\right) \qquad (2)$$

Where:

ΔP_{Gvyp} - calculated activated power value of the PRR providing device (P_{PRVvyp}),

P_{PRV} - PRR power value from ADSR terminal,

f_{skut} - actual frequency,

f_{nom} - nominal frequency 50 Hz.

The actual value of the performance of the PSO providing that is only in PRR shall be determined according to (3)

$$\Delta P_{PRVskut} = P_{skut} - P_{50Hz} \qquad (3)$$

Where:

ΔP_{skut} - e actual performance of the facility providing PRR,

P_{50Hz} - actual average power in a given quarter converted to 50 Hz according to (4)

The actual average power in a given quarter-hour is recalculated according to the relationship (4)

$$P_{50Hz} = P_{15MIN} - \left(f_{nom} - f_{15MIN}\right) * 5 * PRV_{ponuka} \qquad (4)$$

The actual value of the power output of the PPS providing equipment which is also in the SRR shall be determined according to (5).

$$P_{PRVskut} = P_{skut} - P_{ziadloopback} \qquad (5)$$

Where:

P_{skut} - the actual performance of the PRR providing equipment,

$P_{ziadloopback}$ - requested power Secondary regulation reserve (SRR) sent from ADSR terminal.

The tolerance band of the calculated activation value shall be determined according to (6):

$$TP_{PRV} = 0{,}25 * P_{PRV} \qquad (6)$$

Where:

P_{PRV} - PRR power value from ADSR terminal,
T_{PPRV} - tolerance band around calculated activation.

The criterion in a given quarter-hour is not met if more than 25% of the actual power values are outside the calculated activation tolerance range.
The availability of the PRR is not granted in the trading hour unless the criterion has been foamed in more than two quarter hours of the trading hour.

V. Renewable Energy Sources Connected to a Modeled System

According to [4], RES in the system is represented by photovoltaic power plants (PPP) with a total installed capacity of 18.7 GW and wind power plants (VPP) with a total installed capacity of 15.9 GW. The blue arrows in the unipolar diagram of the system (Fig. 1) represent the transmission via DC couplers to RO UK, SE and NO.

PV plants operating in individual ROs are represented by one unit with equivalent installed power in each RO. The list of PPP is in Tab. 4. The type parameters of the individual PPPs are the same as the PPP parameters modelled in the previous chapters [5].

The units representing wind-power plants are situated in the network in places where the production of electricity from wind generation is concentrated. These are mainly areas of northern Germany. The models and parameters of the units representing wind power generation in the system have been adjusted according to [6] to be able to represent the specific dynamic properties of wind power plants (variability of production during the day depending on wind speed, regulatory characteristics, etc.). The blocks are in the table in the VPP section (Table I).

TABLE I. Blocks and Their Installed Performance Representing Resources in a Modeled System

Blok	Uzol	S_N [MVA]	Nt_{MIN} [MW]	Nt_{MAX} [MW]	Typ OZE
FV_CZ	FV_CZ	1200	0	950	PPPP
FV_DE	FV_DE	4000	0	4000	
FV_50H	FV_VET	2000	0	2000	
FV_BE	FV_BE	1000	0	600	
FV_FR	FV_FR	2000	0	1600	
FV_TNT	FV_EON	8000	0	8000	
FV_SVK	FV_SVK	512	0	620	
VPPOFF	DE_DKE	750	0	10	VPP
VPPON	D8WOL_11	1125	0	10	
Suma		**27462**	**0**	**33670**	

VPP are modeled as 750 resp. 1125 generators with a power range of 0 to 10 MW per unit. It replaces wind farms situated in Germany. The course of wind intensity for the wind power plant units is 400 m a. s. l for August Day. The power flow of all PVP and VPP units during 24 h is shown in Fig. 3. The power curve is similar to the PPP curve.

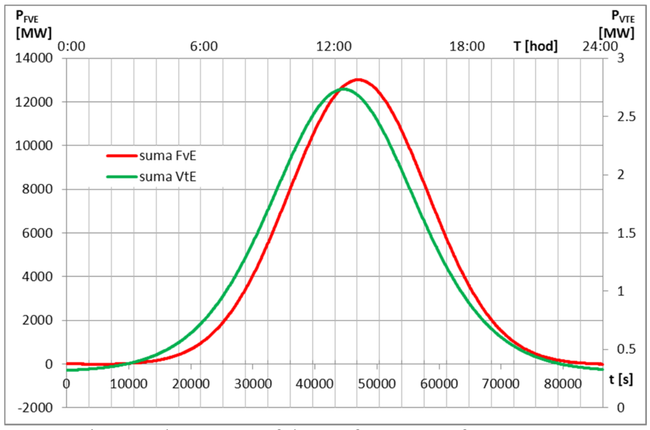


Fig. 3. The course of the performance of PPP a VPP

The system is modelled the impact of RES on long-term resp. medium-term dynamics and system stability. Similarly to the previous chapters, the activities of PRR and SRR are evaluated.

A. *PRR quality assesment.*

The course of frequency deviation for the individual cases monitored is shown in Fig. 4. In the dynamic simulation, TRR was also activated in this case, changing the turbine power input of an equivalent DE block representing the installed power in the western part of the German transmission system (see Fig. 3 and Table II) to compensate for the increase in power supply from PPP and VPP [7].

The change of the turbine power input simulates in the system the change of the control band of the units connected to the TRR in the interconnected system (respectively connecting or disconnecting [8] the units providing TRR) and thus ensuring the SRR for the SRR. Parameters of TRR automatics setting are in table Tab. II.

TABLE II. Setting the Automatic Simulating TRR

Parameters	**TRR+DE**	**TRR-DE**
Period konstant [s]	0.1	0.1
Measured value	ACE	ACE
Measured object	DE	DE
Requirement	LT	GT
P_{set} [MW]	-50	50
T_{KON} [s]	60	60
T_{BLOCK} [s]	300	300
Code of intervention	TURB	TURB
Object of intervention	DE	DE
Parameters of intervention	-0.003	0.003

The automatic device is monitors the balance value (SALD) of RO DE. If the set power (PNAST) is exceeded, the change of the turbine power (TURB) on the DE block is activated. For the model of this system, cases with TRR activation and deactivation are evaluated during both cloudy and clear day.

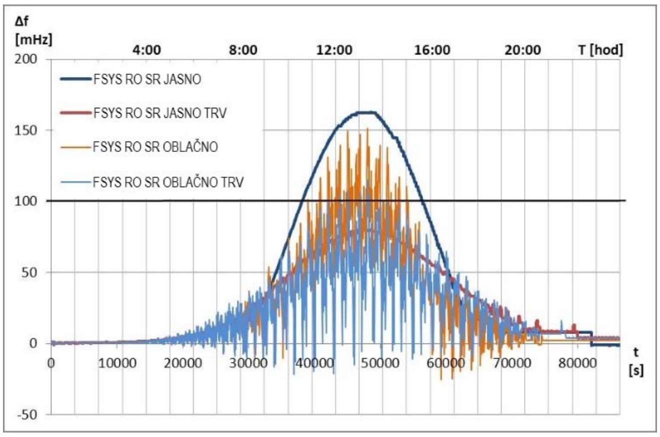


Fig. 4. Frequency deviation during cloudy day without activated TRR

Fig. 4 is the frequency deviation pattern for all four cases mentioned. The largest deviation of the frequency is in the modeled network in case of clear weather without TRR activated, the maximum deviation [9] in this case is ΔfMAX = 162.46 mHz. In the case of TRR simulation in the system, the maximum deviation XfMAXTRR = 79.8 mHz. The more significant frequency deviation in the case of inactive TRR is due to the lack of regulatory energy of the 2MEV11 unit connected to the SRR, whose SRP is unable to cover the increase in electricity supply from PVP.

During a cloudy day, the maximum frequency deviation is not as pronounced. In the system, however, there is a significant change in the power supplied from the PPP (which has to be fully purchased and fed into the grid) due to cloud transition and thus changes in frequency deviation. These deviations place high demands on the regulatory capabilities of the units involved in PRR and SRR. The PRR is activated throughout the interconnected system.

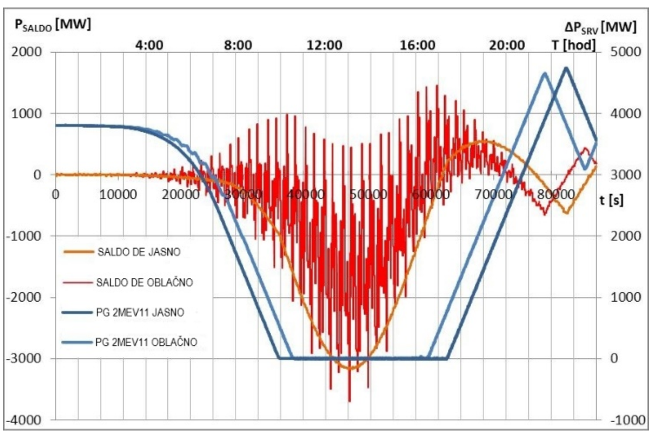


Fig. 5. Comparison of dynamic of cloudy day without TRR

The 2MEV11 block has a working point in the middle of the secondary control band (SRP) at the start of the simulation. The SRR on this block thus has a PSRR = 3800 MW. This capacity is not sufficient to cover the production from PVP. When the SRR is exhausted, the network frequency starts to increase (see Fig. 5) and reaches maximum values at around 1 pm. The observed deviation of the RO DE balance will start to change sharply due to increased production from PPP with a maximum deviation of approx. 3000 MW. The deviation of the balance and the CFR returns to their original values only with a decrease in PPP production.

The network model was subsequently supplemented by TRR. TRR is a modeled change in PVE power supply, which provides enough SRR for the SRR in the system. The deviation of the frequency, balance and power of the SRR modeling block in the interconnected system is shown in Fig. 6.

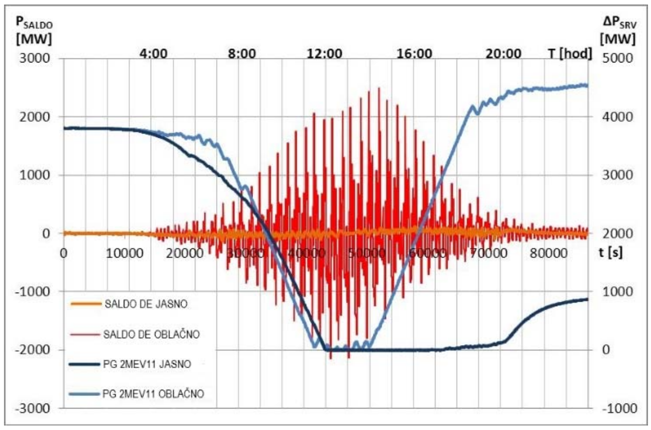


Fig. 6. Comparison od dynamics of cloudy and sunny days with activated TRR

At the time of the highest share of PPP production, the EMO failure is modelled. The second modeled scenario deals with power flows across border lines with RO SVK where the failure of one of the border lines is modelled.

VI. PRR QUALITY ASSESSMENT

The total PRR represents 3% of the installed capacity of the system, which is in absolute numbers 9900 MW. Replacement blocks representing production in a given RO have the same name as the RO in which they work [10].

TABLE III. LIST OF PRR ANALYSIS FOR EWIS SINGLE BLOCKS

Blok	**Kód Reg.**	**PRR+ [MW]**	**PRR- [MW]**	**N_{tmin} [MW]**	**N_t [MW]**	**N_{tmax} [MW]**	**N_{tN} [MW]**
TG31	CoNF	10	-10	99	150	249	207
TG32	CoNF	10	-10	99	150	249	207
TG41	CoNF	10	-10	99	150	249	207
TG42	CoNF	10	-10	99	150	249	207
1MKZ1	CoNF	10	-10	119	169	219	207
1MKZ2	CoNF	10	-10	119	169	219	207
2MKZ1	CoNF	10	-10	119	169	219	207
2MKZ2	CoNF	10	-10	119	169	219	207
TG1	PoCF	4	-4	40	54	110	110

TG2	PoCF	4	-4	40	54	110	110
TG5	PoCF	4	-4	40	54	110	110
TG6	PoCF	4	-4	40	54	110	110
TG21	PoCF	5	-5	40	75	110	110
TG22	PoCF	5	-5	40	75	110	110
TG23	PoCF	5	-5	40	75	110	110
TG24	PoCF	5	-5	40	75	110	110
PPC Mal	PoCF	0	-29	0	29	427	481
ENOA	PoCF	3	-3	10	42	59	62
ENOB1	PoCF	5	-5	69	75	110	110
ENOB2	PoCF	5	-5	69	75	110	110
ENOB3	PoCF	5	-5	69	75	110	110
ENOB4	MaCF	4	-4	70	63	110	92
OST	PoCF	442	-293	100	293	700	4423
AT	Speed	1629	-4270	0	4270	5900	6216
BA	CoCF	103	-103	0	1781	1999	2076
BE	CoCF	495	-495	0	9449	9921	9915
BG	SCoCF	65	-65	0	5820	6600	6572
CH	CoCF	266	-266	0	4400	5699	5338
CZ	SCoCF	104	-104	0	8304	10500	10423
EON	SPoCF	229	-20075	0	20075	22999	22959
DE	SPoCF	365	-33999	0	33999	36999	36564
VET	SPoCF	153	-13383	0	13383	16000	15306
DKW	CoCF	161	-161	0	2773	3200	3220
FR	SCoCF	1204	-1204	0	112748	120999	120423
GR	CoCF	363	-363	0	5854	7200	7264
HR	CoCF	84	-84	0	1060	1699	1694
HU	SPoCF	38	-2735	0	2735	2999	3830
IT	CoCF	1906	-1906	0	32252	37999	38135
NL	CoCF	762	-762	0	13499	15000	15254
PL	CoCF	936	-936	0	15310	18800	18728
RO	SCoCF	93	-93	0	7695	9000	9322
JIE	SCoCF	95	-95	0	6740	9500	9515
SI	CoCF	105	-105	0	1649	2099	2118
UA	CoCF	109	-109	0	1908	2199	2190
LU	CoCF	67	-16	0	16	1200	1343

The PRR quality assessment was carried out according to the condition given in [3]. According to (1), a linear regression line is calculated for every 15-minute interval at which the absolute value of the frequency deviation (| Δf |) has reached a value of at least 0.1 Hz (the deviation boundary is highlighted in solid line in Fig. 5. The calculation is performed for a given trading hour from the average of the direct values of the linear regression slopes from 15 minute intervals when the minimum frequency deviation condition is met.

TABLE IV. LIST OF QUALITY ASSESSMENT OF PRR

$\lvert B_{Hour} \rvert$	EBO	EMO	EVOI	EVOII	ENOA	ENOB
B_{10}	37,99	36,86	6,047	39,57	5,630	22,54
B_{11}	34,25	34,02	16,49	29,42	22,91	14,94
B_{12}	26,51	26,56	21,20	21,94	16,55	16,74
B_{13}	29,14	29,36	14,63	17,03	12,14	8,327
B_{14}	31,25	32,13	13,89	24,36	15,08	22,63
B_{15}	31,6	31,1	23,5	47,28	36,26	12,09
P_{VYP} [MW]	25,0	25,0	10,0	12,5	7,5	12,5
PRR+ [MW]	10	10	4	5	3	5

VII. ANALYSIS OF RESULTS

The EWIS model is a system designed to model the impact of RES. Designed for long-term dynamics modelling, the system has been significantly simplified to reduce the dynamics calculation requirements. For the purpose of modelling the impact of RES on support services, which this work deals with, the simplified model of the EWIS network was supplemented by a detailed model of the WG SR. Thus, a system was created that modelled RO SVK in detail as part of a complex interconnected system. The whole interconnected system represents a model suitable for dynamics modelling over a wide time interval.

In this case, the effect of the modelling of the surrounding RO on the SVK RO itself is compared. However, there was a problem in the synthesis of systems that arose on the basis of different modelling of resources working into the system in individual systems, which caused the machines to swing in the system. This swinging did not compromise stability and modelling of the PPP effect on long-term dynamics could be analysed.

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