Flexibility adequacy assessment in the SEE region with new technology integration

V. VITA[1], C.A. CHRISTODOULOU[1], E. ZAFEIROPOULOS[1], V. MLADENOV[2], V. CHOBANOV[2], M. ASPROU[3], E. KYRIAKIDES[3]

[1]Institute of Communications and Computer Systems,
9 Iroon Polytechniou Street, 15780 Athens, GREECE

[2]Department of Theoretical Electrical Engineering, Technical University of Sofia,
blvd. Kl. Ohridski 8, 1000 Sofia, BULGARIA

[3]KIOS Research and Innovation Center of Excellence, University of Cyprus,
1 Panepistimiou Avenue, Nicosia 2109, CYPRUS

Abstract: - In this paper, a flexibility adequacy assessment of the South East Europe region countries is being presented. Novel technology integration is being considered in order to provide more flexibility resources to the power system to absorb more renewable energy. A flexibility analysis based on the International Energy Agency methodology provided an overall estimation of the flexibility needs and resources of the Bulgarian and Cypriot power systems. Additionally, several flexibility indices have been calculated providing indications of the potential that both systems have to serve more volatile renewable energy sources without jeopardizing the balancing requirements for frequency regulation and security of supply. A detailed algorithm has been developed, in close cooperation with the national stakeholders in Bulgaria and Cyprus, in order to simulate the variations in demand and generation for the following years and calculate statistical indices for flexibility, such as the Insufficient Ramping Rate expectation and Flexibility Residual, apart from the traditional Loss of Load Expectation used in adequacy studies.

Key-Words: - Flexibility adequacy, Insufficient Ramping Resource Expectation (IRRE), system planning, flexibility residual.

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Abbreviations

AF	Available Flexibility	*IRRP*	Insufficient Ramping Resource probability
AFD	Available Flexibility Distribution	*LOLE*	Loss of Load Expectation
CF	Capacity Factor	*NLR*	Net Load Requirements
COPT	Capacity Outage Probability Table	*NTR*	Net Technical Resource
EFR	Existing Flexibility Requirement	*PD*	Peak Demand
FIX	Flexibility Index	*PFCs*	Power Factor Correction Systems
FR	Flexibility Residual	*PVP*	Present VRE Penetration Potential
GD	Gross Demand	*SEE*	South East Europe
KPI	Key Performance Indicator	*TR*	Technical Resource
IEA	International Energy Agency	*VRE*	Variable Renewable Energy
IRRE	Insufficient Ramping Resource Expectation		

1 Introduction

During the latest years, there has been an on-going discussion on introducing systematic flexibility assessment studies in the TSOs system planning process, basically alongside the system adequacy and balancing reserves portfolio evaluation [1-2]. The provision of market incentives for flexibility services has been a major concern of stakeholders and this need has been driven by:

(a) the augmenting penetration of volatile clean energy generation [3],

(b) the phase out of old conventional generation plants, disrupting significantly the generation mix and characteristics in many countries [4],

(c) the capital-intensive nature of transmission investments, long implementation time, public dissent and uncertainty of investment reimbursement schemes for both: fast conventional generation and new transmission infrastructure [5, 6].

In this context, the Horizon 2020 funded project FLEXITRANSTORE is proposing ways to study the flexibility needs and resources of the power system by a flexibility adequacy simulation study, i.e. an upgraded generation adequacy study analysing security of supply as well as balancing challenges.

The aim is to provide a testbed for (i) assessing the current and forecasting the future flexibility needs and resources of transmission systems (ii) evaluate the effects of innovation technology (i.e., batteries, controllers, PFCs, sensors) into the transmission systems through a systematic way with specific KPIs, to provide an alternative strategic decision-making method for integrating new technology into the grid [7-9]. In this paper the flexibility assessment studies conducted for the Bulgarian and Cyprus power system will be presented and the scenarios for future integration of renewable sources will be evaluated.

2 General Principles of the Flexibility Assessment Process

A method has been proposed by the IEA [10] and has been followed in the present paper to provide the rough evaluation of the flexibility adequacy for the Bulgarian and Cypriot power systems. The flexibility requirement depends on two main aspects: the Variable Renewable Energy (VRE) variability and the uncertainty in the output forecast. The first parameter is expressed in terms of percentage of installed capacity per minute, considering both the extent of the maximum ramp and the maximum rate at which this ramp occurs in given time-frames. The latter one depends heavily on how far ahead of delivery the producer must commit to delivering a specific volume of energy, where in that case, the extent of the forecast error is maximized in the 36-hour time frame. The error itself is also expressed as error percentage per minute.

The ability to follow the variability in the net load is quantified, via the calculation of available flexible resources for all the time horizons, in both directions (upward/ downward regulation) [11-14]. The available flexible resources consist of the following: dispatchable generation, which comprises the bulk of the available flexibility in the power system, demand response, if available in each individual case, interconnections with neighboring countries and storage [15-18]. Regarding storage, only pumped hydro plants are considered in this study.

The flexible resource of the power system is calculated as following: when the power system is in a state of peak demand, we consider the 15min and 1h upward flexible resource, alongside the 6h and 36h downward flexibility. This is based on the reasonable assumption that if a power system is in peak demand it is highly unlikely that the net load will continue to rise for more than one hour. Respectively, for the state of minimum demand, the 15min and 1h downward are considered for downward regulation and the 6h and 36h horizon for upward flexibility.

Using this data, two indices have been calculated, the Flexibility Index (FIX) and VRE Present Penetration Potential (PVP) indices. The FIX represents how flexible the power system is on different time horizons, while the PVP index expresses how much additional VRE capacity can be reliably balanced by the system as it is presently configured and operated. These metrics are defined as follows:

$$FIX == \frac{AF - NLR}{PD} \tag{1}$$

$$PVP == \frac{AF - NLR}{VRE\ requirements} \cdot \frac{CF}{GD} \tag{2}$$

where: “AF - Available Flexibility” value represents the total available flexibility from the various resources, “NLR - Net Load Requirements” value is calculated from the upward and downward ramps in the net load time series. “PD - Peak demand” and “GD - Gross demand” are estimated from the data provided by the TSOs, whereas “VRE requirements” and “CF - Capacity factor” (of VRE technologies in each country) are either calculated directly from actual data of VRE generation, if available, or estimated based on VRE capacity and approximate capacity factors. In this work, VRE variability is estimated by calculating separately the requirements for wind and solar generation and, finally, adding the results. For this purpose, is assumed that wind and solar generation is uncorrelated. The capacity factor is calculated as the weighted average capacity factor of our actual VRE portfolio.

Following these rough estimations with the respective indices and in order to remain consistent with current system planning metrics applied by TSOs, it is desirable to expand or adapt existing planning concepts to consider flexibility. The most appropriate existing metric is the Loss Of Load

Expectation, which results in a temporal expectation of a system's inability to meet system load. By adapting the LOLE methodology, a similar expectation can be calculated for a system's inability to provide the required flexibility. The calculation process for the LOLE can follow the generic steps proposed in [7]. First, a resource model is built, called the capacity outage probability table (COPT), which employs unit characteristics (e.g., unit size and forced outage probabilities) to develop a probabilistic distribution of the unavailable generation capacity. From this distribution, the loss of load expectation can be calculated by summing the probabilities that there will be insufficient capacity to meet each observation in the system load time series.

The Insufficient Ramping Resource Expectation (IRRE) is the expected number of observations when a power system cannot cope with the changes in net load, predicted or unpredicted. So, the calculation of the IRRE follows a similar structure to the LOLE, however, rather than forming a distribution of the unavailable generation capacity, a distribution of the available flexible resources is formed for each direction and time horizon. Secondly, as with the LOLE calculation, the probability that the system has insufficient ramp resources at each observation, over each time horizon and direction, are calculated from the available flexibility distribution (AFD), which stands for the Insufficient Ramping Resource Probability (IRRP), from which the overall metric IRRE is computed. Calculation of the IRRE for all selected time horizons provides a picture of the ability of a system's resources to meet the variability requirements of its net load. The relevant equations are presented below [8]:

$$IRRE_{i,+/-} = \sum_{\forall t \in T_{+/-}} IRRP_{t,i,+/-} \quad (3)$$

where:

$$IRRP_{t,i,+/-} = AFD_{i,+/-}(NRL_{t,i,+/-}), \quad (4)$$

$AFD_{i,+/-}(X)$ is a function that provides the means by which the probability of insufficient ramping resources can be calculated at each observation in the time series,

$NRL_{t,i,+/-}$ is the net load ramp at observation t in either direction, and

$T_{+/-}$ is the entire time series for each direction.

3 Flexibility Assessment for the Bulgarian Power System

Based on the aforementioned methodology, a flexibility assessment study has been conducted in Bulgaria during the activities of FLEXITRANSTORE project. As already seen, the most important parameters are the maximum ramp and the maximum rate, which the installed capacity, can provide in a 36-hour period.

In the study for Bulgarian power system, the VRE statistics have been evaluated, including maximum variability and uncertainty of VRE, the share of each VRE technology, the location relative to load, the frequency of extreme ramping events and the capacity factor of each technology. The possible errors have been calculated as error percentage per minute. Renewable forecast error is used to evaluate uncertainty that VRE provide to the system operator. Parameter' calculation is done using historical data given by the ESO EAD the TSO of Bulgaria. Table 1 presents the maximum variability and uncertainty as well as the VRE portfolio flexibility requirement based on 4-time frames- 15min, 1hr, 6hrs, 36hrs. The values of the first 2 parameters are derived from historical data. VRE portfolio flexibility requirement is simplified as the sum of the above to ensure maximum certainty in the system.

Table 1 VRE flexibility requirement

Time horizon	15 m	1 hr	6 hrs	36 hrs
Maximum variability (% inst. capacity)	2.0%	7.0%	22.0%	30.0%
Maximum uncertainty (% inst. capacity)	1.0%	2.4%	12.0%	28.0%
VRE portfolio flexibility requirement	3.0%	9.4%	34.0%	58.0%

Many generation technologies can provide system flexibility. Unfortunately, few of these possibilities are actively used in Bulgaria. The main flexible resources are provided from coal and hydro power stations. The available flexibility from the above resources is calculated in the 4-time horizons as described in the previous section.

The needs for flexibility, called existing flexibility requirement, are calculated based on the sum of the demand fluctuations and the VRE variability and uncertainty. This is a conservative approach because it regards changes in demand and VRE generation to be negatively correlated at all times. Net load data offers a more realistic approach because it incorporates the time that ramps occurring in demand coincide with changes in VRE output. Most prominent example, is the morning ramp in demand which starts at around 7:00 am, which is the time that the PV generation starts to ramp up. Since the historical net load was available the flexibility needs were calculated based on it and are presented in Table 2. VRE flexibility requirement is calculated as a percentage of the total VRE capacity in the grid. The available flexible capacity is calculated by subtracting the flexibility requirement from the technical resource. The result is then divided by the total system capacity to get the system flexibility percentage. The potential for integrating VRE energy is calculated by dividing the flexible capacity to the VRE flexibility requirement. We can conclude that there exists a possibility for integrating a large amount of VRE capacities without hurting the stability of the electrical grid.

The next metric calculated in this section is the present VRE penetration potential (PVP), which shows the extent that the flexible resource available can accommodate the existing VRE portfolio, as % of VRE in gross electricity demand. The results for Bulgaria are shown in Table 3.

Table 2 Net Load Flexibility Requirement and Flexibility Index in Bulgaria

Time horizon	Technical Resource (MW)		Net Load Flexibility requirement (MW)		Flexibility Index (FIX)	
	Up	Down	Up	Down	Up	Down
15min	2781	3448	73	66	42.8%	48.9%
1h	3451	4528	209	188	41.2%	59.9%
6h	3730	7294	731	658	34.9%	86.3%
36h	4341	7294	1183	1065	19.1%	71.7%

Table 3 Present VRE Penetration Potential in Bulgaria

PVP Calculation						
Time horizon	**VRE Flexibility requirement (MW)**		**Potential for VRE capacity with NTR (MW)**		**PVP with NTR (MW)**	
	Up	Down	Up	Down	Up	Down
15 min	130.50	134.25	31857.88	38806.97	132.85%	161.83%
1 h	522.00	537.00	9264.01	12102.15	38.63%	50.47%
6 h	1225.00	1236.00	3536.84	7767.68	14.75%	32.39%
36 h	1356.00	1375.00	2981.41	5820.36	12.43%	24.27%

The flexibility requirement of VRE is very small relative to the available flexible resources on the 15-minute and 1-hour horizon, therefore as one can observe from Table 3 high amounts of VRE capacity could theoretically be enabled on these timeframes. It is only the most constrained occasion, i.e., when the extent of variability is largest relative to the extent of flexible resource (in this case, downwards flexibility at 36 hours) that truly reflects PVP.

In Bulgaria, from a technical perspective, an additional 12.43% penetration of VRE in mean net load demand could be balanced by the existing flexible resources, after existing requirements for flexibility are taken into account. However, while both the FIX and PVP metrics provide a useful indication of what is technically possible, the full range of power area constraints that will affect the availability of flexible resources should also be examined. These relate to operation of the system and market in the area. As a result, flexible resources are unlikely ever to be completely available when needed.

A more detailed flexibility assessment study was carried out. Residual load can be defined as the difference between the available load of the power system and the flexibility requirements yielded from the net load ramps for different time horizons Residual load in this study case has been calculated on the basis of 2018 data.

In Table 4 specific fictitious RES penetration values are identified and studied. The most common metric used to quantify the available ramp resource of the conventional generation in a power system is the index called Insufficient Ramp Resource Probability – IRRP. As already mentioned in the previous SEE countries studies, it is the probability that a system will not have sufficient ramping capability in a given direction over a year.

Table 4 Penetration scenarios of RES

Increase (%)	0	25	50	75	100
Wind (MW)	700	875	1050	1225	1400
PV (MW)	1040	1300	1560	1820	2080

Table 5 Values of IRRP and IRRE as number of hours for the various RES penetration scenarios

	IRRP	IRRE (h)
Zero RES	0.0239	209
now RES	0.0272	238
RES +25%	0.0305	267
RES +50%	0.0347	304
RES +75%	0.0396	347
RES +100%	0.0453	397

Therefore, the IRRP needs to be specified over different time intervals and in both the positive and negative direction. So, the reliability of a power system with respect to ramping is measured by IRRP. The insufficient ramping resource expectation (IRRE) is the expected number of observations when a power system cannot cope with the changes in net load, predicted or unpredicted. The extreme total hourly generation of thermal and hydro units in Bulgarian power system are estimated as follows: minimum hourly generation 1350 MW and maximum 5400 MW. The corresponding to 1350 MW online capacity value of total ramp rate for 30 minutes interval is 420 MW. The following values of IRRP and IRRE are calculated and presented in Table 5.

4 Flexibility Assessment for the Cypriot Power System

In case of an islanded power system as in the case of Cyprus, the enhanced flexibility of the system should be among the main priorities of the power system operators in order to ensure the proper operation of the Cyprus power system in the view of an increased share of renewables in the energy mix. For the assessment of the flexibility through the FAST method the PVP (Present VRE Penetration Potential) is calculated. The following steps were followed in this study for extracting the PVP of the Cyprus power system for 2018:

1) Calculation of the technical flexibility of the dispatchable power plants,
2) Calculation of the flexibility requirement of VRE,
3) Calculation of the Existing Flexible Requirement of the system (EFR), and
4) Calculation of the Flexibility Index (FIX) and Present VRE Penetration Potential (PVP).

The flexibility of each dispatchable power plant type which is calculated based on the installed capacity, the ramp rates, the start-up time, the shut-down time, and the minimum stable operating levels. In the case that the time horizon is bigger than the start-up time of a power plant, the upward flexibility is calculated from the multiplication of the upward ramp rate and the time, where the time is equal to the time horizon minus the start-up time of a power plant. Otherwise, the upward flexibility is calculated from the multiplication of the upward ramp rate and the corresponding time horizon.

The calculation of the overall flexibility requirements for the VRE technologies is based on the maximum variability and the maximum uncertainty in each time frame (15min, 1hr, 6hr, 36hr). The calculation of the maximum variability and the maximum uncertainty for each time frame is based on data (for the 15min actual and forecast generation of the RES technologies) that has been received from the Transmission System Operator of Cyprus (TSOC).

The Existing Flexibility Requirement (EFR) of the Cyprus power system corresponds to the scenario of losing the largest generator that is committed to the system for all the time frames. Further both the upward and the downward EFR in each time frame are assumed equal to 131.38 MW. The Net Technical Resource (NTR) is calculated by finding the difference between the Technical Resource (TR) and the EFR. For the calculation of the Flexibility Index (FIX), the NTR is divided by the peak demand that is observed over the year 2018 (1089.2 MW) which is found by the sum of the VRE technologies generation and the dispatchable power plant generation every 15 minutes (Table 6). Therefore, the maximum summation value is considered as the maximum demand for 2018. In order to calculate the Present VRE Penetration Potential (PVP), the NTR is divided by the flexibility requirement of VRE. Table 7 shows the Present VRE Penetration Potential (Cyprus). For instance, based on Table 7, if the biggest flexibility requirement of a VRE portfolio in the 6-hour time frame is 89.57% of installed VRE capacity, and the minimum net technical resource on that time horizon is 326.53 MW, then the system can balance 364.54 MW from VRE technologies (on that time horizon).

The flexibility adequacy assessment for the power system of Cyprus for 2020-2025 is based on the aforementioned two flexibility indices, namely the Insufficient Ramping Resource Expectation (IRRE) and the Flexibility Residual (FR). Both indices are calculated for different time horizons ranging from 1 to 36 hours, in order to evaluate the capability of the flexible resources of the Cyprus power system to satisfy the net load in the different time horizons. It should be noted that in the flexibility adequacy assessment the envisioned Renewable Energy Sources (RES) generation is also taken into consideration.

In order to evaluate the flexibility of the Cyprus power system for the upcoming years the forecasted total load of the Cyprus power system as well as the renewable energy generation for the years 2020-2025 are provided by the TSOC. As it is indicated in Figure 1, a continuous increase of the total load of Cyprus is expected until 2025. This is more obvious in the summer period where the average load demand in 2025 is expected to reach almost 1000 MW in comparison to 2020 where the average summer period demand is below 900 MW. This fact indicates the need for accurate planning of the flexible resources to meet the expected increase of the demand in the upcoming years.

Based on the total load for each year and the envisioned RES generation, a unit commitment problem is formulated for determining the committed generation units (every half hour interval). In the unit commitment problem, except of the technical characteristics of the generators (i.e., ramp up and ramp down rates, start-up and shut down times, etc.), the reserve power is also considered according to the expected RES generation in each half hour interval. It should be noted that the unit commitment solution is necessary for calculating both flexibility indices and determine the time horizons that the flexible energy sources are likely to fail satisfying the net load ramps.

The Flexibility Residual (FR) is defined as the difference between the available flexibility of the power system and the flexibility requirements yielded from the net load ramps for different time horizons [8]. The Flexibility Residual for the Cyprus power system for 2020-2025 is depicted in Figure 2

Table 6 Net Technical Recourse and Flexibility Index in Cyprus

Time horizon	Technical Resource (MW)		Existing Flexibility Requirement (EFR) (MW)		Net Technical Resource (MW)		Flexibility Index (FIX)	
	Up	Down	Up	Down	Up	Down	Up	Down
15min	337.73	457.91	131.38	131.38	206.35	326.53	19%	30%
1h	748.36	457.91	131.38	131.38	616.98	326.53	57%	30%
6h	748.36	457.91	131.38	131.38	616.98	326.53	57%	30%
36h	1006.30	457.91	131.38	131.38	874.92	326.53	80%	30%

Table 7 Present VRE Penetration Potential in Cyprus

Time horizon	Flexibility requirement of VRE (% of installed VRE)	Net Technical Resource (MW)		PVP (MW)	
		Up	Down	Up	Down
15 min	54.95%	206.35	326.53	375.52	594.22
1 h	52.37%	616.98	326.53	1178.15	623.52
6 h	89.57%	616.98	326.53	688.80	364.54
36 h	81.39%	874.92	326.53	1074.95	401.18

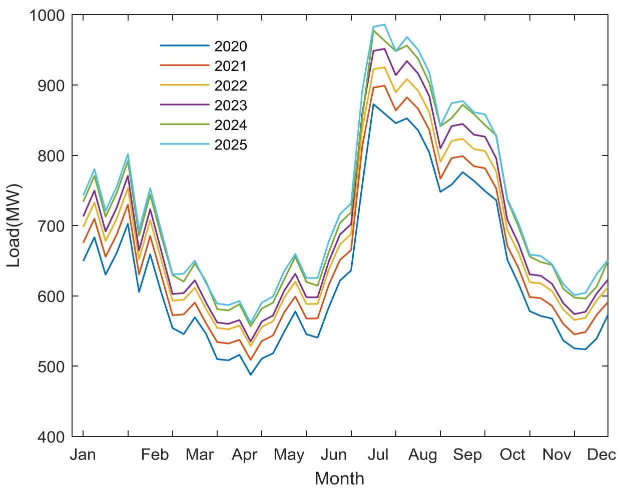

Figure 1 Total forecasted load in the Cyprus power system for the years 2020-2025.

for time horizons of 1 hour until 36 hours. According to the load forecasts of 2020-2025 and the RES generation forecast for the same years, the Cyprus power system is more likely to run out of flexible resources in years 2023 and 2025, since the FR is much larger than the other years. It is also indicated that between 1 hour and 7 hours the system is more prone to fail to satisfy the net load ramp of the system.

Following the previous steps, the IRRE for the case of the Cyprus power system for the years 2020-2025 is shown in Figure 3. As in the case of the FR (Figure 2), the IRRE has larger values in the years 2023 and 2025. Both indices stress the need for enhancing the Cyprus power system flexibility in 2023 and 2025 according to the forecasted load and RES generation in these two years. Further, both metrics indicate that the Cyprus power system is likely to lack flexibility for the time horizons between 1 hour to 7 hours.

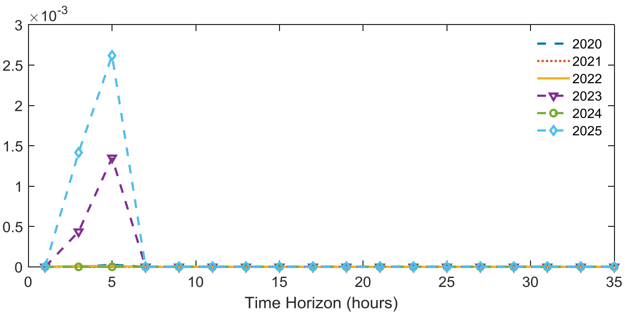

Figure 2 Flexibility residual of the Cyprus power system for years 2020-2025.

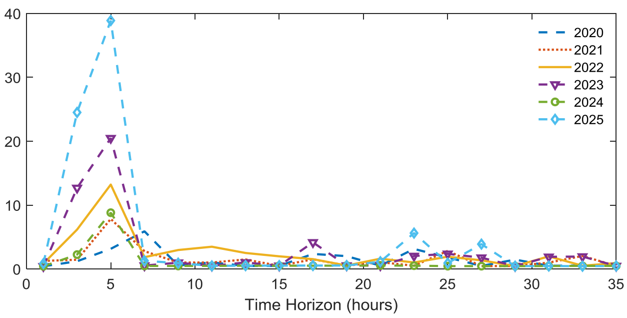

Figure 3 IRRE of the Cyprus power system for years 2020-2025.

5 Conclusion

In the context of FLEXITRANSTORE project, flexibility assessment studies took place for the Bulgarian and Cypriot power systems and the main results have been presented in this paper. These analyses present the landscape for the implementation of innovation technologies for improving the flexibility of power systems. Investigation of wind – storage configurations for ancillary services provision and smoothing of variability would be very beneficial to limit the effects of RES penetration in the next decade.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

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