UDC 621.316

# THE IMPORTANCE OF THE POWER SYSTEM FLEXIBILITY AND ITS EVALUATION

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Generation units are changing crucially in many power systems worldwide. The concern for the environment and energy security, as well as rising fuel prices, have led to significant, sustainable growth of wind and solar electricity generation capacity worldwide. Long-term transmission and generation planning face numerous challenges to accommodate the integration of a high penetration of variable generation. The system flexibility, or the ability of a system to meet changes in demand and variable generation production, is one such issue receiving much attention. An emerging challenge in power system planning is to evaluate the ability of an existing system to successfully integrate a targeted penetration of variable generation. As system planning techniques evolve with the demands from variable generation, the flexibility of a system to manage the periods of high variability will need to be assessed. The energy system flexibility has a very important role in ensuring the sustainability of the system. As a result of the integration of renewable energy sources, the problem of ensuring additional flexibility of the system becomes even more important. This article aims to discuss the issues on flexibility in the system, as well as the need for additional flexibility, resulting from the integration of variable sources such as wind and photovoltaic energy. Besides, in the article, the assessment of the flexibility of the energy system is given based on the visualization principle.

***Keywords:*** renewable energy, integration of power plants, system flexibility, flexibility asessment.

***Introduction.*** Renewable energy is rapidly developing around the globe. Solar energy is one of the most important and fast growing industries, one of the most essential part of renewable energy industry of the 21st century with its inexhaustible resources and ecological purity. In the 21st century many other types of renewable energy have been developing steadily. Figure 1 illustrates the growth rate of renewable energy globally by the end of 2015 [1].

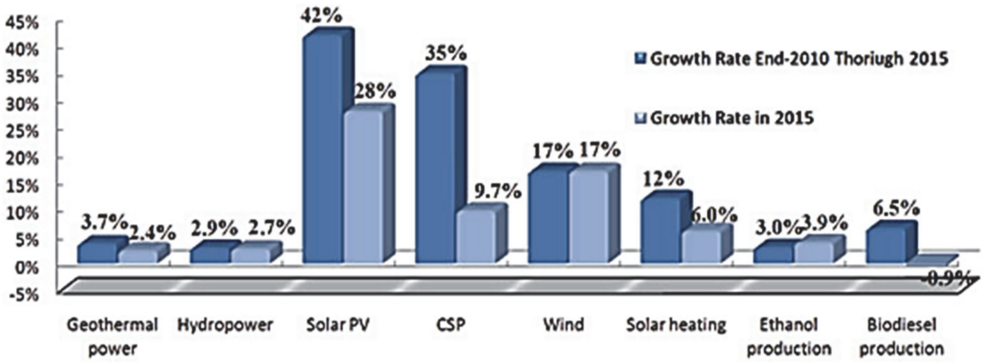



*Fig. 1. Average annual growth rates of renewable energy capacity and biofuel production, end-2010 to end-2015. Adapted from Renewable 2016 Global status report (p 29)*

The interconnected photovoltaic solar technology was the one with the highest growth, with an annual average of 42% for the 5-year period between 2010 and 2015. Other technologies that showed a high growth were concentrated solar power (35%), wind energy (17%), and solar energy for heating (12%). In conclusion, the renewable energy growth is much greater than that of hydropower (2.9%), geothermal (3.7%), ethanol (3%), and biodiesel (0.9%) for the same period of time [1].

***System flexibility requirements***. Many countries around the world have instituted policies with the aim of increasing the amount of installed variable generation (VG), such as wind and solar. A consequence of increased penetrations of VG is that changes in their output must be met by the remainder of the system's resources so that the demand-generation balance is maintained. In this context, flexibility is the ability of a power system to deploy its resources to meet changes in the system demand and that of variable generation [2]. Flexibility in power systems is mainly required to balance unpredictable variations in demand and generation. Such variations may be due to, for example, load forecast errors, forced power plant and transmission outages, and wind forecast deviations. Variations in supply and demand are compensated by drawing on short-term balancing services provided by so-called operating reserves. These usually consist of power plants that can adjust their generation at fast ramp rates or at loads that can be increased or decreased at short notice. Numerous denominations for these balancing services exist, yet the same term might entail different technical requirements in different countries [3]. The ISO (Independent System Operator) has identified through technical studies the need for flexible resources to be committed with sufficient ramping capability to balance the system within an operating hour and between hours for scheduled interchange ramps. System operators must rely on the ramping capability in both speed and quantity to balance the VERs' production change. Also, any underforecasting or overforecasting of demand requires dispatching flexible resources at higher or lower levels, respectively, to minimize inadvertent energy flows with neighboring balancing authorities [4]. As shown in figure 2, the typical ISO load (curve 2) during the spring months has ramps that extend across multiple hours. As the penetration of VERs increases, the net load (curve 2) is the trajectory non-VERs would have to follow through RTM dispatches [5]. The net load comprises ramps of significant capacity and shorter duration, and on days with high VER production and light load, the minimum net load occurs during the middle of the day. Figure 2 also shows that neither wind nor solar peak production coincides with the system peak load. During the spring months, the ISO may have to cycle resources on and off more than once a day to meet the double peak shown. At times, this may not be possible because the down time between resource shutdown and start-up may be too long, which may prevent the resource from being restarted in time for the morning load ramp that begins around 4:00 a.m., or meeting the system peak demand around 7:00 p.m. [4].

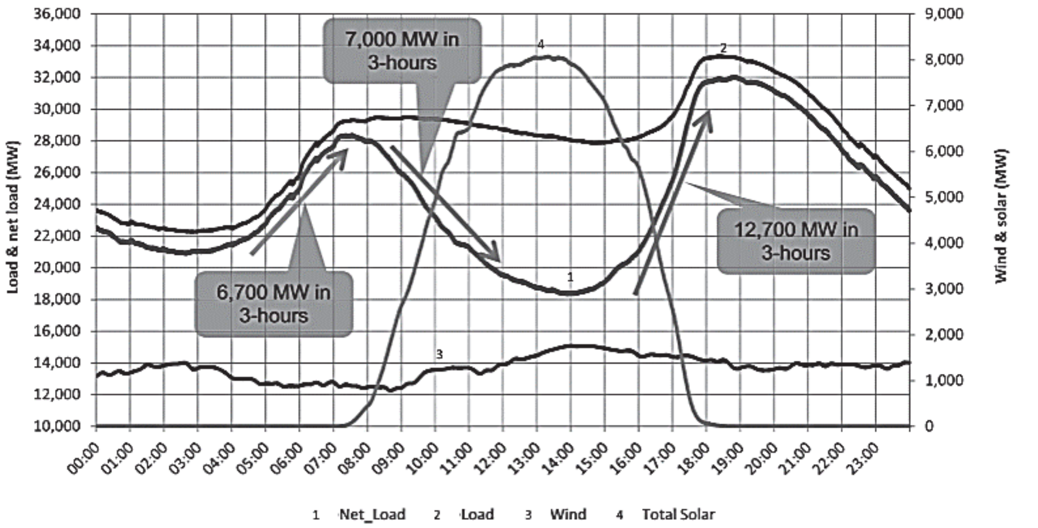



*Fig. 2. Illustration of increasing the system flexibility requirements along with wind and solar energy penetration*

In order to meet power ramps while integrating RE, we should somehow evaluate the system flexibility. The flexibility of a power system is defined as the ability to meet these ramps. To make assumptions on future portfolios and the integration of renewable energy sources without losing in the system reliability, it is crucial to measure and evaluate the existing amount of flexibility in the system [6].

***Power system flexibility assessment***. Power systems have at all times had to cope with variability and uncertainty in load and unit outages, so the need for flexibility in these systems is not an entirely new issue. However, with higher penetration of variable generation (VG), the netload ramps (NLR) become more frequent and show higher values [7]. In this chapter, we will make a rough estimate of the network's flexibility according to GIVAR visual flexibility assessment tool [8] as well as the "flexibility chart" [9]. The purpose is to evaluate the operation supply flexibility during different seasons. The main feature of the assessment method is that it ignores the storage and demand response. Thus we need to obtain data on dispatchable power plants and interconnections. The second feature is that we can evaluate the flexibility through visualization.

Figure 3 illustrates some features of dispatchable power plants [8]:

- how fast can it change output?
- how long does it take to start up and shut down?
- what is the minimum stable operating level?

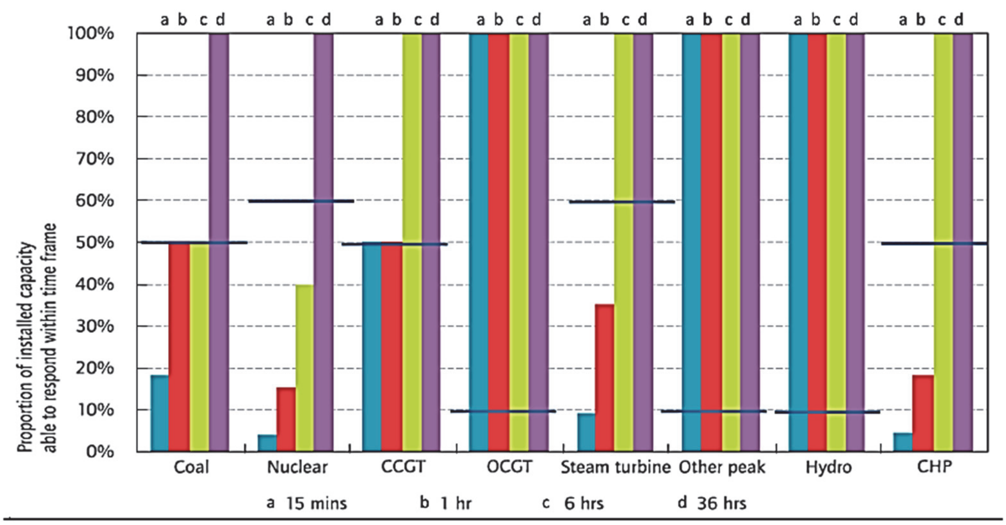
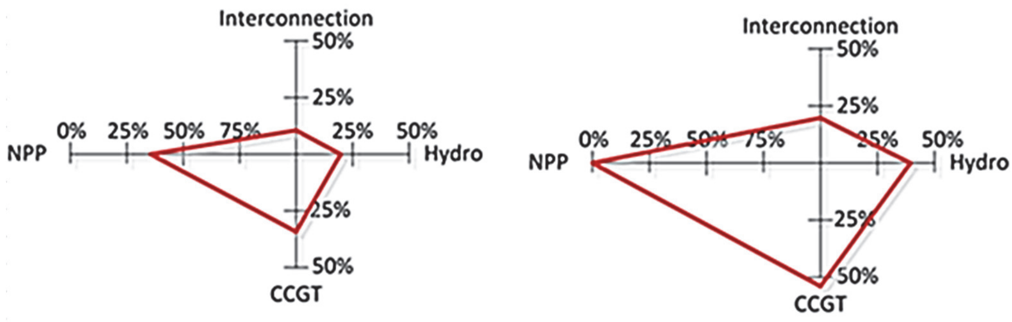



*Fig. 3. The proportion of the installed capacity able to respond within the time frame*




a) b)

*Fig. 4. a-online flexibility chart for January, b-online flexibility chart for July*

Analyzing the response capacity of dispatchable power plants we can visualize the System flexibility model of the Armenian power system according to the flexibility evaluation chart [9]. All data are taken from the Energy System Operator report of 2018 [10]. Figure 4 a and b illustrate online flexibility of the Armenian power system in January and July accordingly. As the output of the Nuclear Power Plant is not flexible it negatively influences the overall online flexibility. In July, when NPP is not involved in the power system operation, the overall online flexibility is much higher.

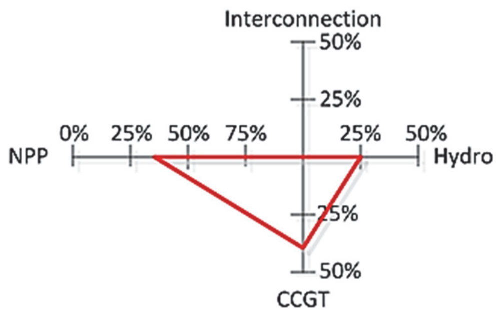



*Fig. 5. Online flexibility curtailment due to the interconnection loss*

Figure 5 illustrates how generation diversity can positively influence the online system flexibility. When the interconnection is lost, the overall curtailment of the system online flexibility is more than 6%.

In this example, simple summaries can be quick and insightful, but they have limitations. A limited number of characteristics can be measured, and the chart does not provide enough information to evaluate the overall level of flexibility. The flexibility chart restricts the comparison to capacities in order to employ common units across the variables, and excludes the aspects of flexibility that cannot be reduced to capacity (e.g., market designs). Using the flexibility chart, non-technical audiences (e.g., policy makers, journalists) can make quick comparisons of the countries' (or specific power systems') relative strengths in flexibility, and how much wind each country currently integrates with that flexibility [11].

***Conclusions.*** Flexibility has a very imoportant significance in the power system stability.

1. It helps to balance energy demand and supply.
2. It hepls to meet power rumps because of significant renewable energy curtailments.

The proposed flexibility chart is employed to visualize the dominant factors and compare the variety of solutions in different areas. The chart was designed as an "at a glance graph" that clearly shows the difference of flexibility strategies and provides an "easy to understand" tool, even for none technical experts including journalists and policy makers.

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*Recerved on 03.05.2018.*

*Accepted for publication on 05.06.2018.*

## ԷՆԵՐԳԱՀԱՄԱԿԱՐԳԻ ՃԿՈՒՆՈՒԹՅԱՆ ԿԱՐԵՎՈՐՈՒԹՅՈՒՆԸ ԵՎ ԴՐԱ ԳՆԱՀԱՏՈՒՄԸ

**Ս.Ն. Մոսոյան, Ժ.Ռ. Փանոսյան**

Ներկայումս բազմաթիվ էներգահամակարգերում շահագործվող տարբեր գեներացիոն միավորներ կրում են զգալի փոփոխություններ: Շրջակա միջավայրի և էներգետիկ անվտանգության խնդիրները, ինչպես նաև վառելիքի գների շարունակական աճը հանգեցնում են քամու և արևային էլեկտրաէներգիայի օգտագործման ծավալների մեծացման: Վերականգնվող և փոփոխական էներգիա արտադրող կայանների ինտեգրումը էներգահամակարգին բարդացնում է էներգիայի արտադրության և տեղափոխման պլանավորման խնդիրը: Դրա հետ մեկտեղ առաջանում են լրացուցիչ խնդիրներ՝ կապված համակարգի ճկունության անհրաժեշտ մակարդակի գնահատման հետ: Քանի որ էներգահամակարգի պլանավորման մեթոդները զարգանում են փոփոխական գեներացիայի ինտեգրման պահանջներին զուգընթաց, անհրաժեշտություն է առաջանում գնահատել համակարգի ճկունությունը, որը թույլ կտա կառավարել փոփոխական գեներացիայի ինտեգրման հետևանքով առաջացած բեռի բարձր փոփոխականությունը: Էներգահամակարգի ճկունությունն ունի շատ կարևոր դեր համակարգի կայունության ապահովման տեսանկյունից: Վերականգնվող փոփոխական էներգիայի ռեսուրսների ինտեգրման հետևանքով համակարգի լրացուցիչ ճկունության ապահովման խնդիրը դառնում է էլ ավելի կարևոր: Քննարկվել են համակարգի ճկունության ապահովման խնդիրները, ինչպես նաև փոփոխական ռեսուրսների ինտեգրման հետանքով առաջացող լրացուցիչ ճկունության անհրաժեշտության պատճառները: Բացի այդ, կատարվել է նաև տրված էներգահամակարգի ճկունության գնահատում տեսանելիության սկզբունքով:

***Առանցքային բառեր.*** վերականգնվող էներգիա, էլեկտրական կայանների ինտեգրում, համակարգի ճկունություն, ճկունության գնահատում:

## ВАЖНОСТЬ ГИБКОСТИ ЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ И ЕЕ ОЦЕНКА

**С.Н. Мосоян, Ж.Р. Паносян**

Единицы генерации существенно меняются во многих энергетических системах всего мира. Проблемы окружающей среды и энергетической безопасности, а также рост цен на топливо приводят к значительному и устойчивому росту мощности по производству энергии ветра и солнечной энергии во всем мире. Долгосрочное планирование генерации и передачи электроэнергии приводят к многочисленным проблемам в плане интеграции переменных источников энергии. Гибкость системы или способность системы реагировать на изменения спроса и производства энергии - одна из таких проблем. В связи с этим задачей планирования является оценка способности существующей системы успешно интегрировать источники переменной генерации. Поскольку методы системного планирования развиваются с учетом требований переменной генерации, необходимо оценить гибкость системы для управления периодами высокой изменчивости. Гибкость энергосистемы играет важную роль в обеспечении устойчивости системы. В результате интеграции возобновляемых источников энергии проблема обеспечения дополнительной гибкости системы становится еще более важной, поэтому обсуждаются вопросы гибкости системы, а также необходимость дополнительной гибкости в результате интеграции переменных источников, таких как энергия ветра и фотоэлектричества. Кроме того, дана оценка гибкости данной энергетической системы на основе принципа визуализации.

***Ключевые слова:*** возобновляемая энергия, интеграция электрических станций, гибкость системы, оценка гибкости системы.