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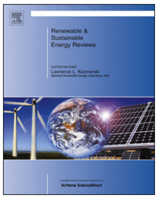

Flexibility in future power systems with high renewable penetration: A review

M.I. Alizadeh [a], M. Parsa Moghaddam [a,*], N. Amjady [b], P. Siano [c], M.K. Sheikh-El-Eslami [a]

[a] Faculty of Electrical & Computer Engineering, Tarbiat Modares University, Tehran, Iran
[b] Department of Electrical Engineering, Semnan University, Semnan, Iran
[c] Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, 132, Fisciano, SA 84084, Italy

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ABSTRACT

Renewables are going to make our planet a better place to live. These clean resources of energy can bring a handful of advantages to the future electricity industries. Nevertheless, the large percentage of renewables integration can cause some operational issues, in power systems, which are needed to be identified and coped with. This paper defines, classifies and discusses the latest flexibility treatments in power system based on a comprehensive literature study. The current work specifically considers the abilities, barriers, and inherent attributes of power systems' potential to deal with high integration of Variable Generations (VGs) in future flexible power systems.

Contents

1. Introduction

Certainly, the future is uncertain. Due to transforming of technologies, increasing concerns of the societies, and climate changes, dealing with flexibility issues seems crucial for almost all scientific fields. From communication network, manufacturing, oil extraction and transportation to defense systems and energy production, transmission and distribution, flexibility will be a must in near future. Hence, a wide range of stakeholders are involved with the matter [1]. Manufacturing, among all, due to

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[*] Corresponding author. Tel.: +98 21 82883369; fax: +98 21 82884325.
E-mail address: parsa@modares.ac.ir (M. Parsa Moghaddam).

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competitiveness in producing low cost and high quality products to respond quickly to the rapidly changing markets, flexibility, as one of the most sought-after properties, has been in the warmth of the spotlight for years [2]. Accordingly, flexible Manufacturing Systems (FMS) are introduced. FMS is a manufacturing system in which there is some amount of flexibility that allows the system to react in case of changes, whether predicted or unpredicted [2]. Similarly, flexibility, in transportation, is defined as "the adaptability of a system in response to external changes, while maintaining satisfactory system performance". System performance is characterized by parameters such as capacity, level of service, maintainability, and profitability. External changes are referable to uncontrolled conditions of a system, including deviations in level of demand or use, changes in spatial traffic patterns, infrastructure loss and degradation, and volatilities in the price and availability of important resources such as fuel, etc. [3]. As it can be seen, flexibility has no general definition and is highly dependent on the system under study. Accordingly, is seems irrational to state a same definition for power system flexibility or any other engineering subjects. The general flexibility terms for different industries, however, can be applied to the power system flexibility assessment. The current paper tries to gather general flexibility terms applied in many different industries to be adopted in power system flexibility assessments.

Due to the increasing penetration rate of variable generation resources integration into the power generation portfolios, a flexibility assessment looks necessary because of the rising issues in both operational and planning horizons of the power system. Accordingly, these fields are studied separately. Hence, to cover versatile aspects of flexibility in power systems the following tasks are done. First, flexibility from multi-carrier energy systems' point of view, as a general system is discussed in Section 2. A comprehensive literature review of recent researches in the field of flexibility in power systems is, then, presented in Section 3. The two subsequent Sections, 4 and 5, are dedicated to answer the two following major questions targeted to clarify the flexibility features in power systems: why flexibility assessment in power system is needed? and how can flexibility be improved through available resources? Finally, Section 6 is discusses the current barriers faced by power system operators and planners both to unleash the hidden potentials of the available flexibility resources and to plan for flexible future grids, respectively.

2. Multi-carrier energy systems

Multi (Carrier) Energy Systems (MES) as one of the premier systems dealing with energy in a wider range than power systems are involved with the flexibility in many features [4,5]. Reference [4] states that MES can enhance technical, economic, and environmental performance of energy systems through energy hubs, multi-energy microgrids, and Virtual Power Plants (VPP). Energy hubs can increase the flexibility of energy systems through coupling of supply and demand consistently for design purposes aimed at minimizing investment or life cycle costs [6]. Multi-energy microgrids can similarly enhance flexibility through versatile capabilities such as energy provision by trigeneration applications namely, electricity, cooling and heating for controllable multi-energy loads, different aggregation levels, namely local level, multiple building and power grid, and participating in distributed markets and power grid exchanges by making use of automatic iterative feedback signals [4,7].

VPPs are defined as flexible aggregations of coordinated distributed energy resources in an optimal pattern, capable to play in the energy markets, and offer services in the same way as conventional power plants. It is worth noting that VPPs, both of commercial and technical types, can deploy the synergies between electricity and other energy vectors for system balancing purposes in presence of fluctuating Variable Generations (VGs). As a result, it can be inferred that VPPs can be counted among the main flexibility providers of the future power grids. MES can increase the energy system flexibility for instance through allowing to take advance from the storage characteristics of thermal loads supplied by electricity, or by exploiting combined production of electricity, heat/steam [8], energy transportation [9], cooling and water with focus on agro-food industries [7]. In addition, MES can also offer the energy flexibility provided by Combined Heat and Power (CHP) plants buffered by thermal storages.

Generally, the flexibility improvements allowed by MESs are mainly due to the multiple alternatives they can offer such as versatilities from spatial, multi-service, multi-fuel, and network perspectives. According to [4], the goal of flexibility is to consider the robustness of optimal operation and design variables to changing boundary conditions. It is notable that flexibility does not mean the robust operation against any possible uncertainties and fluctuations. It, however, represents a compromise between flexibility worth and flexibility cost.

3. Literature review

Power system flexibility consideration has been around since the integration of VGs in bulk power generation mix. One of the premier definition is announced by [10], as "the ability of a system to deploy its resources to respond to changes in the net load, where net load is defined as the remaining system load not served by variable generation". Flexibility, however, remained negligible due to very limited penetration rate of non-dispatchable energy resources. The variability of the wind power and other renewables is presented in [11], as in other early reports released in this area. These reports indicate that non-dispatchable energy resources, due to their natural cycles, can fluctuate over short timescales intraday and intra-hourly and require different management strategies. These management strategies are briefly aggregated as follows; increasing grid capacity and cross border connections, developing cost-effective balancing and regulating markets with transparent gate-closure times also reflecting the technical and economic needs on the system, enhancing uptake of efficient demand-side response mechanism, installing more flexible generation capacity, utilizing a mixture of different renewable energy resources, improving forecasting and modeling of natural fluctuations and increasing utilization of communication technologies to disseminate this information between grid operators and markets [11]. The term power system flexibility is also used in [12]. According to [12], a power system is called flexible if it can – within the economic boundaries – rapidly respond to large fluctuations in demand and supply, both scheduled and unforeseen variations and events, ramping down production when demand decreases, and upwards when it increases. The report also suggests that in order to have a flexible power system three main steps must be accomplished namely, flexibility resource identification, accounting the existence flexibility requirements, and considering the Net Flexibility Resource (NFR). It adds that, once the existing flexibility requirement has been accounted for, the remaining net flexibility resource can be considered to be available for use in balancing the additional fluctuations introduced by additional VGs output.

As it was mentioned in the first section, flexibility needs to be measured. In this regard, [13] presented a framework to measure flexibility for the first time. Reference [13] declares that magnitude, ramp response, frequency, and detecting available flexible resources characterize the supply and demand imbalances, which