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Two methods for decreasing the flexibility gap in national energy systems

Ilija Batas Bjelić [a, *], Nikola Rajaković [a], Goran Krajačić [b], Neven Duić [b]

[a] School of Electrical Engineering Belgrade, University of Belgrade, Belgrade, Serbia
[b] Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Zagreb, Croatia

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ABSTRACT

More variable renewable energy sources and energy efficiency measures create an additional flexibility gap and require a novel energy planning method for sustainable national energy systems. The firstly presented method uses only EnergyPLAN tool in order to decrease the flexibility gap in a national energy system. Generic Optimization program (GenOpt®) is an optimization program for the minimization of a cost function that is evaluated by an external simulation program, such as EnergyPLAN, which was used as the second method in this research. Successful strategies to decrease the flexibility gap are verified on the case of the Serbian national energy system using two methods for its structure design: (1) the iterative method, based on heuristics and manual procedure of using only EnergyPLAN, and (2) the optimization method, based on soft-linking of EnergyPLAN with GenOpt®. The latter method, named EPOPT (EnergyPlan-genOPT), found the solution for the structure of the sustainable national energy system at the total cost of 8190 M€, while the iterative method was only able to find solutions at the cost in the range of 8251–8598 M€ by targeting only one sustainability goal. The advantages of the EPOPT method are its accuracy, user-friendliness and minimal costs, are valuable for planners.

1. Introduction

The transformation of national energy systems faces two challenges: (1) maintaining the positive and (2) reducing the negative outcomes of secure energy supply [1]. Energy system flexibility is constrained by the flexibility of its demand and generation [2]. The introduction of variable renewable energy sources such as wind and solar energy, or energy efficiency measures in line with EU 2030 energy policy goals, will at the same time increase the *flexibility gap* and reduce the availability of flexible resources in energy systems [2,3]. However, this should not be perceived as an obstacle in the planning phase. A study shows that up to 80% of variable renewable energy sources (RES) can be integrated [4] into a national energy system when all flexibility options are included. Another study shows that it is not feasible to integrate 100% renewable energy sources into a power system without demand flexibility [5]. Further, Stadler [6] sees no theoretical upper limit for the integration of renewable energies into electricity networks that can be explained by missing control power. Wind power yearly penetration of above 40%, monthly above 61.7%, daily above 102% and hourly above 135% has already been recorded in the front-runner Danish energy system [7,8].

The solution to the well-known sustainable energy system planning problems lies in further integration of electricity, transport and heating systems into one system with increased flexibility [9–12]. Mancarella [9] identified advantages of smart energy systems through their “multi-energy” perspective which increases systems efficiency and flexibility. The *flexibility* of a power system [13,14], positive to increase and negative to decrease available energy [15], an inherent feature of their design and operation, is defined as the ability to: (1) “cope with events of imbalance between electricity supply and demand while maintaining the system stability in a cost-effective manner” [3,16]; (2) “maintain that balance even during times when demand or supply change rapidly or widely” [17,18]; (3) “benefit from variability in production without generation of excess electricity production” [19] which one will be used.

The *flexibility gap* [3] on the system and local scale [20] might be covered by sixteen other *flexibility options* grouped in five categories: supply, demand, energy storage, grid and system operation principles or their mix [2]. Flexibility options are found within the

* Corresponding author.
E-mail addresses: batas@etf.rs (I. Batas Bjelić), rajakovic@etf.rs (N. Rajaković), goran.krajacic@fsb.hr (G. Krajačić), neven.duic@fsb.hr (N. Duić).

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Abbreviations

BMS	Biomass
CAES	Compressed Air Energy Storage
CHP	Combined Heat and Power plant
DH	District Heating
EE	Energy Efficiency
FOC	Fixed Operation Costs
GenOpt	Generic Optimization program
PHEV	Plug In Hybrid Vehicle
PHSPP	Pumped Hydro Storage Power Plant
PV	Photovoltaic
RE	Renewable energy
RES	Renewable Energy Sources
RES-E	Renewable electricity sources
SHPP	Small Hydro Power Plant
TPES	Total Primary Energy Supply
TPEScor	Export/import corrected TPES value
TPP	Thermal Power Plant
TVC	Total Variable Costs

electricity sector (dispatchable power plants, demand response, energy storage and grid interconnection), including renewables themselves, and outside the electricity sector, in the area of transportation and heating [17]. Flexibility options may be summarized as in Ref. [21] but concurrent flexibility options [22–25] are sorted as a supply curve, analogous to the generation supply curve. Another flexibility source prioritization can be found in Refs. [26,27], including overgeneration from renewable energy sources [28].

Flexibility is also provided by larger balancing areas, access to neighboring markets, fast energy market, improved market design, demand response, strategic renewable energy curtailment, new ancillary services and products, flexible conventional generation units, and storage [29]. The flexibility served at the local level has been simulated and verified using an operation optimization model in Ref. [30]. Selling excess productions to the European grid may look as a solution but the problem will remain if each country adopts the same policy [19].

There are different metrics for flexibility, such as “net flexibility resource” [31], storage capacity, maximum positive residual load, and excess energy production [19,32]. The excess energy production duration curves are characterized by the annual value, maximal hourly value, duration over the year and the slope. Looking at duration curves, one can compare the flexibility of different national energy system scenarios. Alternative flexibility options can be analyzed with generation simulations [29] and this gap can be quantified with CEEP using the EnergyPLAN tool. EnergyPLAN has been validated in many studies explained in detail in Ref. [33]. GENOPT® has also been validated e.g. Refs. [34–37] and well documented [38].

Utilization of capacities obtained from optimal operation during one year hour by hour simulation becomes the main decision driver in the investment optimization. Flexibility is then obtained as a positive side effect of cost minimization [15], which might be a feature of the EPOPT method. The iterative method, based on heuristics presented in Ref. [19] has been standard for EnergyPLAN users in the process of performing national energy analysis and recommendation of the strategies in South East Europe [39], Romania [40], Serbia [41], Croatia [42] and many other countries [43]. In this article the heuristic method is compared to a new optimization method (EPOPT) to look at how they reduce the flexibility gap and costs in sustainable national energy systems. In other words, we first look at how the planner community uses heuristic methods with EnergyPLAN to design technically flexible smart national energy systems and then how an optimization method may be applied to help planners avoid repetitive tasks and obtain more accurate solutions. The article shows how an energy system can benefit from large-scale integration of variable renewable energy sources and energy efficiency measures applied to the optimal amounts. EnergyPLAN simulations have been carried out to quantify the annual total system costs (annual financial balances), annual energy balances and annual operation of selected flexibility options. The obtained result in one case study indicates that the EPOPT method has advantages over the iterative method in improved accuracy, shorter duration (also user-friendliness for the planner) and further cost reduction based on better utilization. The planner community is kindly invited to use the EPOPT method in more case studies in other counties and to validate its quality against state of the art methods for national energy system optimal planning. Based on these advantages the EPOPT method may become the most popular among national energy systems planners in the EU or other sustainable governance frameworks, boosting the usage of EnergyPLAN and GENOPT®. Ultimately, the European Commission, governments and citizens will be key beneficiaries.

2. Method

2.1. Measures for energy system transformation

Smart energy system measures refer to technically optimal mixing of variable renewable energy sources, using multi-energy carrier flexibility options, using design and operation of energy system differently and using all smart grid technologies for grid stabilization. A different design of an energy system means the utilization of different generation options. On the other hand, different operation of the energy system means choosing: (1) the operation optimization strategy (market or technical), (2) grid stabilization requirements, (3) critical excess electricity production (CEEP) balancing strategies, etc. Measures towards smart energy systems have potential to replace fossil fuels, to improve fuel efficiency and they should be combined with energy conservation measures and system efficiency improvements in order to become relevant for the future energy systems [10]. Furthermore, their mix has an impact on the flexibility requirements [14], which has to be minimized. Therefore we search for a techno-economically optimal mix between wind and solar photovoltaic (PV). Future national energy systems in year 2030 should be designed to meet indicative EU level designated targets of at least 27% energy from renewable energy sources in final energy consumption, 40% CO_2 emission reduction in comparison to 2009, and energy efficiency improved by 27% [44] in comparison to the current outlooks [45]. Fuel consumption and CO_2 emissions reductions are already shown possible in the case of the Danish national energy system [46]. Although much research has been done in the area of optimal energy systems, it is still an open question which energy sources and which types of efficiency measures will be used in an energy master plan in order to reach the designated targets. All conventional and new supply side technologies can create the flexibility gap, since they are characterized by a flexibility coefficient [47]. Apart from adding variability to the supply side, the demand side energy efficiency measures also create the flexibility gap [20]. For example, these measures can narrow down electricity consumption, which may be used for demand response. This means that all flexibility options have to be coordinated because their benefits are related to the whole energy system [48]. Each technical measure project (for