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Evaluating the Flexibility Benefits of Smart Grid Innovations in Transmission Networks

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Abstract: The decision-making process during system planning of power systems is something that requires integrated tools that evaluate technical parameters, environmental impact, and overall costs and benefits with various performance indicators (i.e., key performance indicators KPIs). Several cost–benefit analysis approaches have been presented worldwide, providing analytic procedures to quantify the impact and practical effects of specific electricity projects. The implementation of innovation technology into the electricity networks play a critical role to optimizing overall costs. The targets set by the Clean Energy Package have been the main driver for the disruption occurring in the electricity sector, setting electrification of sectors and digitalization as additional emerging challenges. In the present paper, an evaluation approach for the flexibility benefits of smart grid innovations will be presented, as it has been developed and implemented in the context of the Horizon 2020 Research and Innovation project FLEXITRANSTORE. Flexibility is a prerequisite in an effort to achieve an electrical system of low CO_2 emissions. Moreover, flexibility contributes to the increase of renewable energy sources penetration, to the network investments deferral and to the enhancement of the efficiency of the system operation, avoiding generation capacity oversizing. Thus, flexibility has been the scope of many projects lately. FLEXITRANSTORE pilot projects are implemented in various sites across Europe and are briefly presented and the respective technologies are propagated on system level approach, evaluating the respective benefits on a specific use case for the power system of Cyprus, where the one of the pilots is located. The paper tries to show the big picture of the project and presents system study use case to highlight the system impacts of the technologies. To this direction, the installation of a BESS to the Cypriot power system is studied, in an effort to examine its impact to the enhancement of the system's flexibility, considering IRRE as an indicator.

Keywords: flexibility; cost–benefit assessment; batteries; power flow controllers

1. Introduction

Electricity infrastructure projects are capital intensive and face several public objections before and during their implementation phases [1]. Decision-making during planning phases is something that requires comprehensive tools to evaluate costs and benefits with various KPIs (key performance indicator). In this context, CBA (cost–benefit analysis) approaches have been introduced worldwide, providing analytic methodologies to quantify the effects of specific electricity projects [2–4]. The implementation of innovation technology into the electricity networks is a complex issue and can be expressed in different ways [5,6]. Clean energy targets have been the main driver for the disruption occurring in the electricity sector the last couple of decades. Electrification and digitalization are emerging as additional major challenges for the future years, dictating the maximization of assets capacity and controllability, so as to defer costly infrastructure investments with significant footprint on the environment, i.e., new OHLs (overhead line), substations, fossil fuel plants [7,8].

With more and more intermittent or variable sources from renewable energy and new patterns of demand resulting from electric vehicle charging, power systems critically need different flexibility means to maintain security of supply [9,10]. The need for flexibility in a decarbonizing electricity sector was consistently and broadly understood. Without an increase in flexibility, likely situation of power balance violates and increases levels of renewable energy curtailment. There are also needs for conventional reinforcement to deal with congestion, and a greater reliance on cross border trading and energy flows to accommodate regional power fluctuations [11,12].

An increase in system risk is also highlighted, which is associated with increasing the breadth of participation in system services, and with applying commercial pressure to that participation. Overall, by increasing the number of participants, the system will become more difficult to manage which may result in a less secure or a less stable grid configuration. There is also increased uncertainty in the network's ability to deal with infrequent but high impact events, such as storms or floods. Mechanisms should be put in place to ensure that the system can deal with such events without passing unnecessary costs onto consumers [13].

Flexibility is a necessary part of a low carbon electricity network, rather than an end in itself. Benefits resulting from increased flexibility lie in different aspects such as the ability to have a greater proportion of distributed renewable generation on the network without incurring significant additional network reinforcement costs and increased efficiency of electricity grid operation without oversizing generation capacity [14–16]. This was highlighted as an important aspect for grid owners and system development planners, as they focus on keeping electricity bills at reasonable levels. Electrical energy storage was seen as a key enabler for flexibility [17–19]. Note that flexibility resources can include both centralized resources connected to the transmission system, as well as distributed resources connected to the distribution network. In the latter case, aggregation will be required, as well as appropriate coordination, in order to provide flexibility services from the distribution network to the transmission system.

The current work deals with the assessment of the flexibility benefits coming from smart grid innovations, developed in the H2020 project FLEXITRANSTORE [20]. The project includes pilots in various sites across the Europe, where appropriate technologies have been developed in an effort to enhance the flexibility of the systems examined in the context of the project. To this direction, the paper focuses on a specific use case, considering a bulk system, i.e., the electrical power system of Cyprus and evaluates the benefits that the implemented technologies provide. Moreover, market and regulation aspects are also discussed.

2. Innovation Technology for Improving the Power System Flexibility: The FLEXITRANSTORE Project

FLEXITRANSTORE project commenced in 2017 and will complete its activities in 2021. It shall provide the technical basis to support the valorization of flexibility services through innovative smart grid technologies, enhancing the existing European Internal Energy Market (IEM). The strategic objectives of FLEXITRANSTORE are: to enhance and accelerate the integration of renewables into European energy systems and to increase cross border electricity flows across Europe. Flexibility is one of the keys to meeting these strategic objectives. A range of state-of-the-art ICT (Information and Communication Technologies) technologies/control improvements will be exploited to enhance the flexibility of this novel energy grid while increasing the utility of the existing infrastructure by integrating storage and demand response management. From a market perspective, state-of-the-art ICT technologies/control improvements will be applied to develop an enhanced market model on an integrated platform, for flexibility services and to support cross border auctioning and trading of energy. FLEXITRANSTORE deploys 8 pilot Demonstrations which will take place in 6 countries (Greece, Bulgaria, Cyprus, Slovenia, France, Spain), focusing on illustrating specific functions and serving real needs and existing challenges.

During the FLEXITRANSTORE project, a flexibility adequacy assessment method has been developed through a simulation platform and specific what-if scenarios add-ins have been developed, in order to evaluate the benefits of innovations into grid operation. Smart grid innovations and their impact on system operation is a common task of many R&D activities. The hereby strategic decision-making method proposed in the FLEXITRANSTORE is applicable by system operators (both TSO and DSO) with a wider scope for planning purposes. In many countries, DSOs operate HV levels 110/150 kV networks and formulate 5-year planning studies for the complete HV-MV-LV levels (i.e., in Slovenia ELJ, HEDNO in the 150 kV networks of Crete, Rhodes, and Lesvos Islands).

Flexible solutions are often considered to be best suited to managing short-term or real-time issues on power systems; thus, their long-term benefits in system planning may be overlooked. Cost–benefit analysis (CBA) approaches used by many utilities to support decision-making in the long-term investment planning process have gaps which can lead to suboptimum investment decisions. Benefits such as redeployability, deferral of investments modularity, and scalability are not clearly identified. If these areas are uncovered and an amendment is made to one or more best practice CBA methodologies, then the decision-making process will be better overall and lead to better decisions including the possibility of identifying flexible solutions that should be deployed in the long-term process. This will support the achievement of the Energy Union by increasing the efficiency of investments.

In the context of FLEXITRANSTORE, these benefits provided by smart grid innovations are taken under consideration. The project's area of focus is to enable the testing of flexibility services provided by innovative technologies and market design. FLEXITRANSTORE's approach targets the entire energy industry value chain by focusing on not only a stronger, more flexible infrastructure, but also the capabilities of demand side response, improved operations, more flexible generation, and the integration of storage to accelerate RES (renewable energy sources) integration and increase cross border flows from a market and system perspective. Everything is interconnected. Touching each of the flexibility services across the value chain shall result in a big impact on the overall system. PFC (Priority Flow Control) for flow redirections, short term solutions, leasing opportunities for noncapital intensive solutions, while DLRs (Dynamic Line Rating) and battery solutions retain an asset value after the completion of a project. The demonstrated technologies are presented in Figure 1.

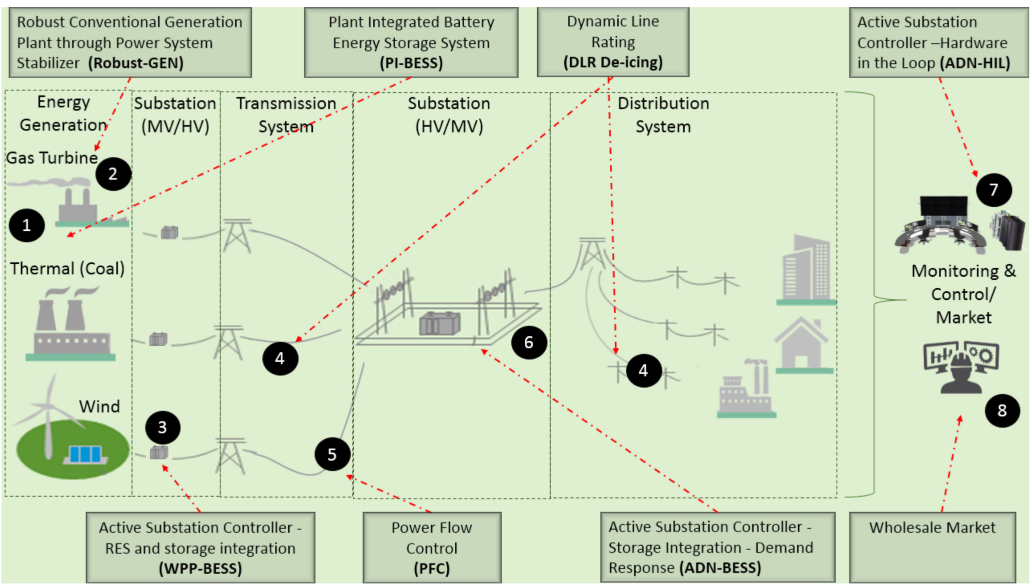


Figure 1. FLEXITRANSTORE project with different demos able to improve power system flexibility.

In order to quantify such benefits from tested technologies and solution, a set of 'priority' KPAs can be defined. When defining these priority KPAs (Key Performance Area), we consider these principles for the whole project:

- Strongly highlight benefits of demos of FLEXITRANSTORE project: relevance to the activities we implement within the project;
- Compatible and in line with CBA of ENTSO-E and other good practices of CBA calculation: to have common understanding when communication [21];
- Focus on around five essential KPAs: not to have many KPAs so that we lose focus and incur high calculation burden, but not to have few so that we cannot cover the major benefits.

Considering all aspects of KPAs analysis in the Section 3 and consultation with different demo leader, as well as TSO/DSO relevant, supporting the European energy targets of renewable energy target, competitiveness and security of supply, we came up with five KPAs:

- KPA1—Renewable integration;
- KPA2—Congestion reduction;
- KPA3—Flexibility indices improvement;
- KPA4—Improving reliability and stability;
- KPA5—Improved competitiveness of the electricity market.

These KPAs can be quantified through specific KPIs. Table 1 presents in detail the connection of each KPA (i.e., the integration of renewables, the reduction of congestion, the improvement of the flexibility indices, the improvement of the reliability and the quality of supply, and the competitiveness of the electricity market) with the proposed KPIs in the context of the project. Table 2 correlates each of the presented KPAs with the relevant technology of the eight demos.

Besides the KPIs list and their mapping in the Table 1, which are applicable for many technologies and demonstrations, an extra set of particular KPIs could be formulated to cover specific aspects, for instance:

- Power flow controller:
    - Extension of outage windows for construction and maintenance projects;
    - Time required to implement solution;
    - Value of scaling the solution size over time to meet emerging needs;
    - Value of the PFC assets being highly mobile and ability to be re-deployed to new locations to solve new issues as they emerge;
    - Flexibility in approach to capital spending (modular design and redeployability means that capital spending can be projected for much shorter time horizons);
- Storage with conventional GT power plant:
    - Primary response—increase of capacity and response time;
    - Increase of power plant electricity production;
    - EFR—capacity of response;
    - Black Start—validation of the service with the storage;
    - LVRT voltage support—quantity and BESS sizing;
    - ROI (return on investment).

In the following Figure 2, an indicative flowchart of the stages to be integrated with the flexibility assessment of alternative technologies is presented.

Table 1. Proposed KPIs to be used in the FLEXITRANSTORE project.

No	System Benefits (KPAs)	Proposed KPIs of FLEXITRANSTORE
1	Renewable integration	- Reduction in renewable curtailment on existing generation facilities - Cost of enabling new renewable interconnections relative to conventional solutions - Share of electricity generated from renewable sources - Increased RES and DER hosting capacity - Reduced energy curtailment of RES and DER - Avoid redispatching
2	Congestion reduction	- Reduction in redispatching - Increased network capacity - Maximum transfer capacity - RES Energy unleashed - Reduced congestion costs
3	Flexibility indices improvement	- IRRE, FIX - Capacity of reserves increase - Maximum hourly ramp of residual load - Additional capacity (NTC) in relation to existing cross-border capacity - Grid expansion deferral by applying peak-shaving
4	Improving Reliability and Quality of Supply	- LOLE, LOR - EENS - Additional adequacy margin - VOLL - Average hourly load not r
5	Improved competitiveness of the electricity market	- Type of energy pricing/market products - Market services remuneration - Number of market actors per activity - Concentration ratio (CR)

Table 2. Mapping of system benefits with different demonstration and tested technologies of FLEXITRANSTORE.

Demo	Technology	Benefits				
		RES Integration	Congestion Reduction	Flexibility Indices Improvement	Improving Reliability & Stability	Improved Competitiveness of the Electricity Market
1	Active distribution node	√		√	√	√
2	Battery storage at wind power plant	√	√		√	√
3	Dynamic line rating			√	√	
4	Power flow controller	√	√	√		
5	Adapting wholesale market approach	√		√		√
6	Advanced controllers for grid services				√	
7	BESS for CC power plant	√		√		√
8	Advanced control for flexible synchronous generation				√	

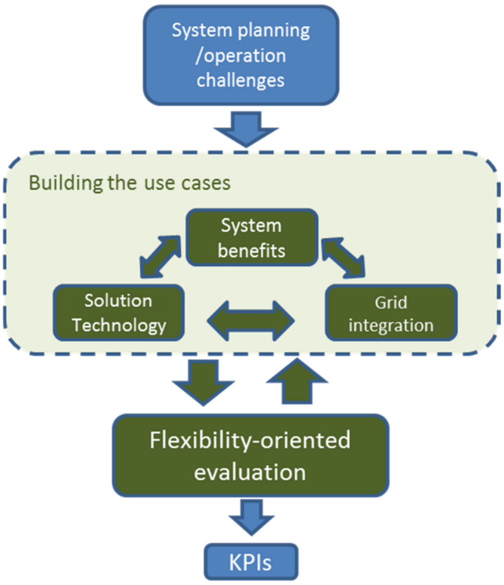


Figure 2. Flowchart for strategic decision-making through innovation integration.

3. Use Case Scenario: Battery Integration in the Cypriot Power System

The main source of flexibility in a power system was always the conventional generators, however during the last years, the Battery Energy Storage Systems (BESS) constitute a viable flexibility resource in the power systems. This is mainly thanks to cost reduction of the battery technology, the need for more environmentally friendly solutions, and the enhanced technical performance of BESS, i.e., fast ramp rates. Demand side management, interconnections with neighboring systems, grid strength and forecasting accuracy can also provide flexibility to the power system [22,23].

In this use case, a BESS is considered to be installed to the Cyprus power system along with the existing conventional generation plants. For this purpose, three sizes of 40, 80, 120 MWh were considered. The selection of the above battery capacity is based only on the nominal power of the wind parks. Considering the variation of the wind potential, the examination of various scenarios is demanded. Note that the optimization of the BESS size is not included in the goals of the current work. The use-case has been developed and studied in the context of FLEXITRANSTORE project, where a flexibility adequacy assessment platform has been developed in order to evaluate the flexibility indices of the power systems apart from the generation adequacy indices like LOLE. This will provide a more realistic view of the risks facing the electricity systems in the following years when the generation mix will consist mainly of variable renewables and additional balancing resources will be needed. Additionally, this FLEXITRANSTORE platform and the strategic decision-making method will evaluate the benefits of innovation technology in the power

3.1. IRRE without BESS

The BESS certainly enhances the flexibility of the Cyprus power system and therefore the insufficient ramping resource expectation (IRRE) metric was used for quantifying the enhancement of the Cyprus power system flexibility with the installation of the BESS. First, the IRRE for the years 2020–2025 without a BESS installed was calculated as a reference point (Figure 3). The results are based on the unit commitment resulting from the estimated load and RES generation provided by Transmission System Operator-Cyprus (TSOC).

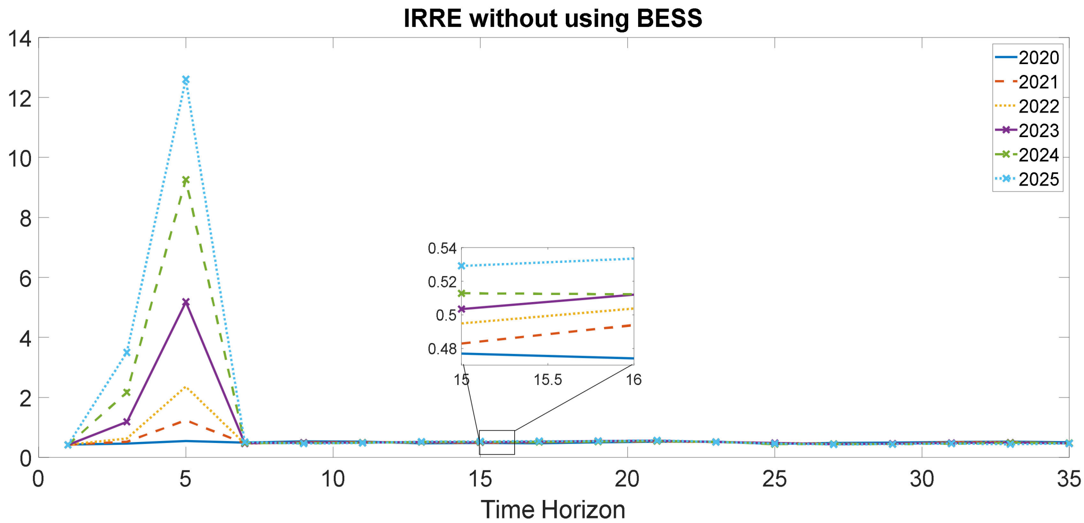
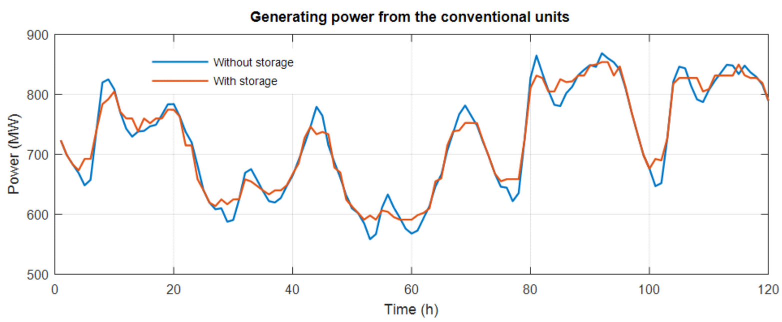
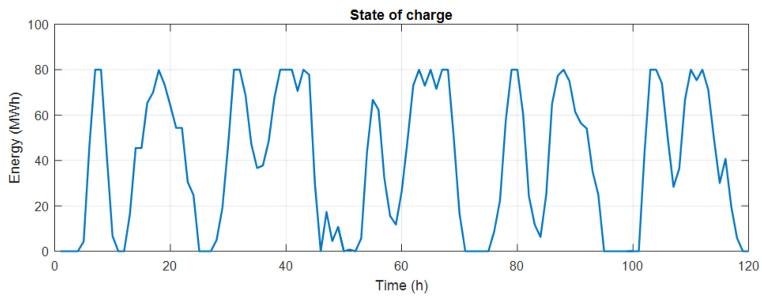


Figure 3. IRRE without a BESS installed for the years 2020–2025.

The generating power from the conventional units with and without the integration of the battery is illustrated in Figure 4a for the 80 MWh BESS capacity for 5 summer days in 2020. Also, the state of charge of the battery is presented in Figure 4b. Initially, it is assumed that the battery is fully discharged. Note that 80 MWh is the usable capacity of the battery, and we assume that there are no limitations about the minimum state of charge of the battery. The valley filling and peak shaving applications of the battery storage are obvious in Figure 4a. The integration of the battery storage manages to reduce the range between the maximum and the minimum produced power, with a great benefit on the operational cost of the system due to the fact that less generating units need to be committed and de-committed in order to satisfy the security and the technical constraints of the system.



(**a**)



(**b**)

Figure 4. (**a**) Generating power from conventional power plants with and without the use of storage and (**b**) State of charge of the 80 MWh battery.

As illustrated in Figure 3, the IRRE follows an increasing trend over the six years. This is mainly due to the constantly increasing RES capacity in the 6 years as it is shown in Figure 5, which demands higher flexibility to compensate the bigger fluctuations of the net load. It is worth noting that no new conventional units are considered to be installed in this study.

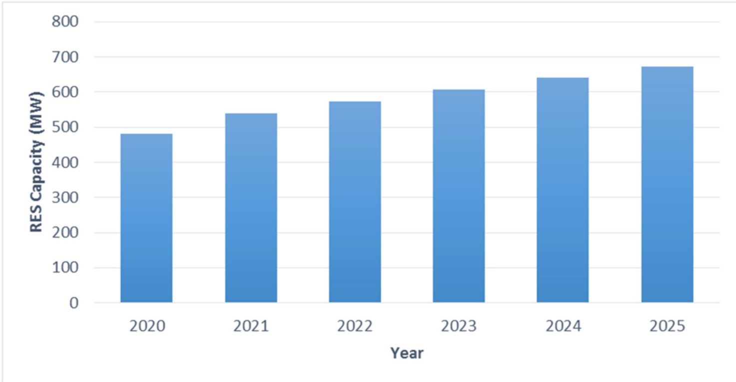


Figure 5. Estimated RES capacity for the years 2020–2025.

3.2. IRRE with BESS

In order to investigate the impact of the BESS to the Cyprus power system flexibility for 2020–2025 the IRRE for the six years was calculated again, considering the three different BESSs. Although a BESS is a very expensive asset (especially for BESS with large capacities), it is essential to assess the benefits of such systems to the overall power system operating condition in terms of flexibility improvement and operating cost decrease [24]. The integration of BESS capacity into the network is related to the market incentives provided to the energy actors and the respective business models created (i.e., aggregators, battery-RES installations, ESCO/flexibility providers), a subject very well elaborated in WP3. Note that aim of WP3, entitled “Regulatory frameworks, market designs and novel business models for flexibility services” is to develop a proposal for an enhanced market design focusing on the integration of renewables, the promotion of regional collaboration to accelerate market coupling activities in the SEE region (including the establishment of a liberalized electricity market in Cyprus). In addition, WP3 shall explore the suggestion that an enhanced market design incorporating flexibility could help relieve internal congestion issues between SEE region grids and thereby contribute to the available cross-zonal capacity in the region. New business models for market players and TSOs/DSOs where appropriate will be developed, incorporating flexibility services and thereby helping Europe achieve global leadership in renewable energies.

In this sense, the IRRE for each BESS capacity (40, 80, and 120 MWh) was calculated for the whole period. Figures 6 and 7 illustrate the IRRE (with BESSs) for the years 2020 and 2021, respectively.

In both years, the IRRE was significantly decreased when a BESS was integrated to the generation portfolio. The behavior of the IRRE is the same for the other 4 years leading to the conclusion that the use of the BESS benefits the system and provides a huge amount of flexibility, due to its ability to provide or absorb large amounts of power almost instantly. Normally, in the absence of a BESS, the required flexibility is provided by dispatchable thermal generation units, which are very expensive to operate for regulation. In this sense, the BESS may limit the use of those generators, while providing that extra flexibility needed, instantly. Furthermore, the RES-battery integration business model can provide multiple revenue streams through the provision of flexibility services, as this is very well described in the activities of FLEXITRANSTORE related with business models. These new market opportunities result in lower cost of operation, lower emissions, and increased stability and power quality.

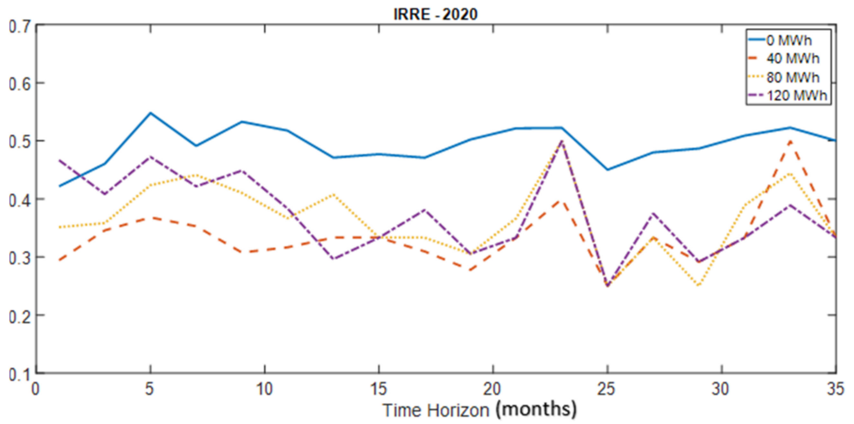


Figure 6. IRRE when a BESS is installed for 2020.

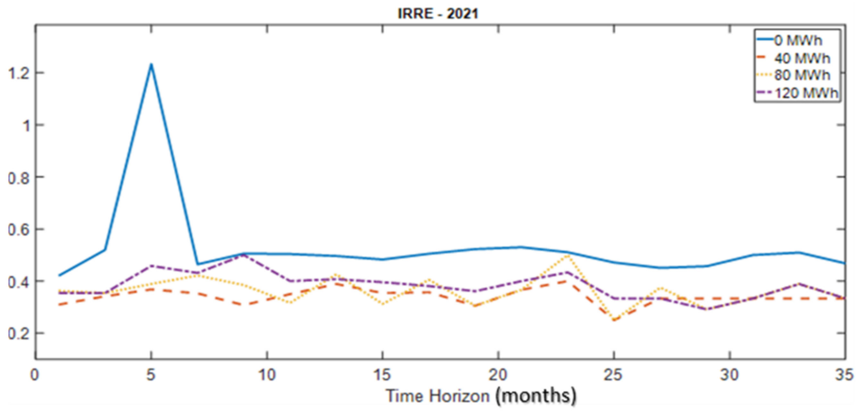


Figure 7. IRRE when a BESS is installed for 2021.

4. Conclusions

The current paper dealt with the study of the installation of a BESS to the Cypriot power system that operates along with the already existing conventional generators, in order to examine its impact to the enhancement of the system's flexibility. The presented work is included to the FLEXITRANSTORE H2020 project, where an advanced flexibility adequacy assessment platform has been processed, in an effort to review the flexibility indices of the electrical systems except form the generation adequacy indices. Indeed, in FLEXITRANSTORE project, an evaluation approach for the costs and benefits of integrating innovation technology into the electricity network for improving flexibility has been presented. A CBA framework has been developed, according to ENTSO-E CBA framework [21], leveraging several characteristics of methodologies put forward by international organizations (i.e., ENTSOe, US DoE), identifying specific KPIs and mechanisms. Note that the parameters considered for the evaluative analysis are similar with the adequacy studies. Related what-if studies have been conducted for the integration of batteries in the Cypriot system, studying the impact on flexibility indices like IRRE. The obtained results indicate that BESS ensures the upgrade of the flexibility of the Cypriot electric system, as the IRRE metric reveals, rendering the BESS as a reliable alternative instead of conventional generators.

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Conflicts of Interest: The authors declare no conflict of interest.

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