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RESEARCH ARTICLE

Interaction of Local Flexibility with National Ancillary Services Markets: Paving the Way for Türkiye's Sustainable Grid

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ABSTRACT

This paper explores the complex interactions that exist between national ancillary service markets and local flexibility in Türkiye's changing power landscape. The significance of grid flexibility is escalating, especially with the country's transition from a predictable energy generation model to one predominantly fueled by intermittent renewable sources, coupled with the imminent integration of nuclear power. Ancillary services, encompassing functions such as frequency control, voltage regulation, and system restart, play a pivotal role in upholding grid stability. The study particularly underscores the significance of frequency-related ancillary services in preserving grid equilibrium. Moreover, it emphasizes how important electricity distribution businesses are as major players in improving grid stability. These businesses can actively participate in ancillary service markets and support grid stability by utilizing local flexibility solutions like distributed generation, energy storage, and demand response. This benefits the grid as well as consumers. The central objective of the study is to explore the synergies between local flexibility solutions and national ancillary markets. A case study is employed to evaluate the potential benefits and profitability associated with the integration of these components for an electrical distribution company. A combination solution utilizing solar panels, battery storage systems, electric vehicle charging infrastructure, and a natural gas turbine within the gearbox company's network is the subject of a case study that is presented. The concept of local flexibility and its mutually beneficial relationship with the national auxiliary service markets are also clarified in the study. The findings demonstrate the potential profitability and advantages of battery storage for the national energy grid. A substantial increase in prices for Frequency Restoration Reserve is imperative to render the natural gas turbine economically sustainable.

Index Terms—Ancillary services, flexibility, frequency regulation markets, local energy exchange, power generation, renewable energy

I. INTRODUCTION

For the electrical system to be stable, the electricity generation must constantly meet the consumption. This balance needs to be managed in different time periods. In order to keep the frequency in the system around 50 Hz in the short term, fast solutions are needed, inter-sectoral balance is needed in the medium term, peak demands must be met locally, and the determined capacity requirements must be met locally in the long term [1, 2].

With the exponential increase in electricity "consumption in recent years, Türkiye's electricity diversity has increasingly included intermittent energy (renewable sources), while grids and the electricity markets are facing new challenges [3]. Türkiye is moving from an electricity system with highly predictable energy such as natural gas-fired and hydro power, where hydroelectric power provides great flexibility, to an electricity mix in which other energy types such as wind and solar take a larger share. In addition, the first reactor of the nuclear power plant is planned to be put into operation in 2023 [4]. This places higher demands on flexibility in other parts of the system. Flexibility can be achieved through flexible generation, energy storage, or flexible consumption [5, 6].

Ancillary services are one way to meet the growing demand for flexibility in the system [7]. Ancillary services are the idea of separating the power system for use to keep it in balance [8]. Ancillary services are more than that; there are all the services required by the transmission and distribution system operators that would enable them to maintain the integrity and stability of their system, including transmission and distribution and power quality. Various ancillary services [9] can be categorized into frequency control, voltage control, and system restart. This study primarily emphasizes frequency-related services, which play a crucial role in maintaining system balance.

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There are different types of ancillary services to meet the needs of the grid, but in general, ancillary services are those that cost-effectively reduce the need to change grid capacity and support the efficient and secure operation of the distribution system [10]. Frequency-related and non-frequency ancillary services are available. Frequency-related [11, 12]: Automatic Frequency Restoration Reserve (AFRR), Inertia, and Frequency Containment Reserve (FCR). Non-frequency-related [13]: voltage control and reactive power and congestion management. Frequency-related ancillary services are aimed at helping to maintain the correct frequency in the system. Non-frequency ancillary services are services used by a transmission or distribution system operator for steady-state voltage regulation, fast reactive power input, and inertia. Ancillary services are used to maintain stability, short-circuit current, and island mode operation capability in local networks [14].

With the increasing demand for flexibility, actors such as power distribution companies can play an important role. Local flexibility allows distribution companies to increase electricity consumption for customers as the grid becomes increasingly loaded and can contribute to fewer lines that need to be expanded. Investments in local resilience can contribute resources to ancillary service markets and thus contribute to stability in the system at the national level.

Regarding the above-mentioned ancillary services, the basic goal of this paper is to investigate frequency control in Türkiye, taking as an example the ancillary services markets actively used in the Nordic countries [15, 16]. The Northern European electricity system [16] is considered, as it is a well-connected market and can therefore serve as an example of energy market design for Türkiye. Market price data has not yet been analyzed for Turkish ancillary services markets and its suitability for electric vehicle owners to make viable business decisions has not been investigated. Moreover, while some studies [12, 16] on ancillary services markets in the Nordic countries focus on their rules and requirements [15, 17, 18], for Türkiye, there is no focus on the development of control strategies for the operation of battery systems.

Main Points

- The article examines the transformation of Türkiye's electricity system as it shifts from traditional, predictable energy sources to intermittent sources such as wind and solar. This change reflects a growing interest in renewable energy, which requires greater flexibility in the electrical grid.
- The need for flexibility and adaptability in the management of intermittent renewable resources is satisfied.
- The building of a gas turbine and its profitability is assessed in the case study in relation to varying gas price revenues.
- The study finds that implementing a battery storage system can be profitable, help reduce power peaks, and benefit the national energy system.
- For electric vehicles, flexible options like battery storage and well-planned charging schedules can be extremely important in effectively controlling power peaks.
- Limited operation hours and unpredictable market conditions further cast doubt on the gas turbine's viability; nevertheless, when combined with other solutions, the gas turbine can become more economically feasible.

Let's discuss the subject of this study on the chart as shown in Fig. 1. What is shown at the top of the chart is the frequency in any country in Europe, and as you can see the target value is 50 Hz. Somehow something happens at a certain moment, we call it an event, and it actually creates an imbalance between production and consumption. In this case, there is not enough generation or too much consumption and a situation occurs that causes the frequency to decrease. The frequency must remain at 50 Hz, otherwise, there may be a major deterioration in the functioning of all electrical devices. The first thing that happens is that when the frequency goes down, a first reserve, called the primary reserve, which is now called frequency containment reserve, acts as a proportional controller and essentially stops the frequency in its drift. As seen in Fig. 1, when the primary reserve or FCR is activated, the frequency stops drifting, but the frequency does not return to the target value. This is actually the role of AFR, which stands for automatic frequency renewal reserve, and what used to be called secondary reserve. What this reserve does is that it acts as an integrated controller and essentially injects some energy into the grid to bring the frequency back to its target value of 50 Hz. It means AFR must have spare capacity and there will be a capacity payment for that. Electricity producers or project owners can earn income in this regard. On the other hand, it also means that energy must be brought to the grid, so there will be payment for energy or at least some energy transactions will be made. In other words, the subject of this study is the effective use of ancillary services on the frequency limitation reserve flexibilization.

The frequency response service is absolutely vital in the activities to achieve frequency management and balance generation and demand. Because it helps achieve variations in generation or demand to help manage system frequency through a wide range of ancillary service providers. Fast frequency response is a very useful service that helps us keep the frequency close to 50 Hz. It is known that there are statutory frequency limits, which means that the system frequency must be kept between 49.5 and 50.5 Hz. There are also operational limits which are a kind of safety net and allow the frequency to be kept between 49.8 and 50.2 Hz. There are two flavors of Fast Frequency Reserve (FFR) that help do this. The first is a dynamic service that constantly responds dynamically to the system frequency to keep the frequency as close to 50 Hz as possible. The second flavor is a static service and that's a service which only operates when system frequency has either a low trigger level or a high trigger level with a minimum dynamic for FFR and it vary depending on whether it's daytime or nighttime. For example, at night when demand is lower and there are fewer generation plants on the system; it may have to hold more FFR than our minimum dynamic to keep the frequency within 50 Hz because the system is a bit lighter at that time. Any deviation caused by increased demand or a shortfall in generation can have a bigger effect over nights. The situation is similar when summer and winter months are compared; in winter only of higher demands and much more generation plants on the system to meet those demands then less FFR is needed. In the

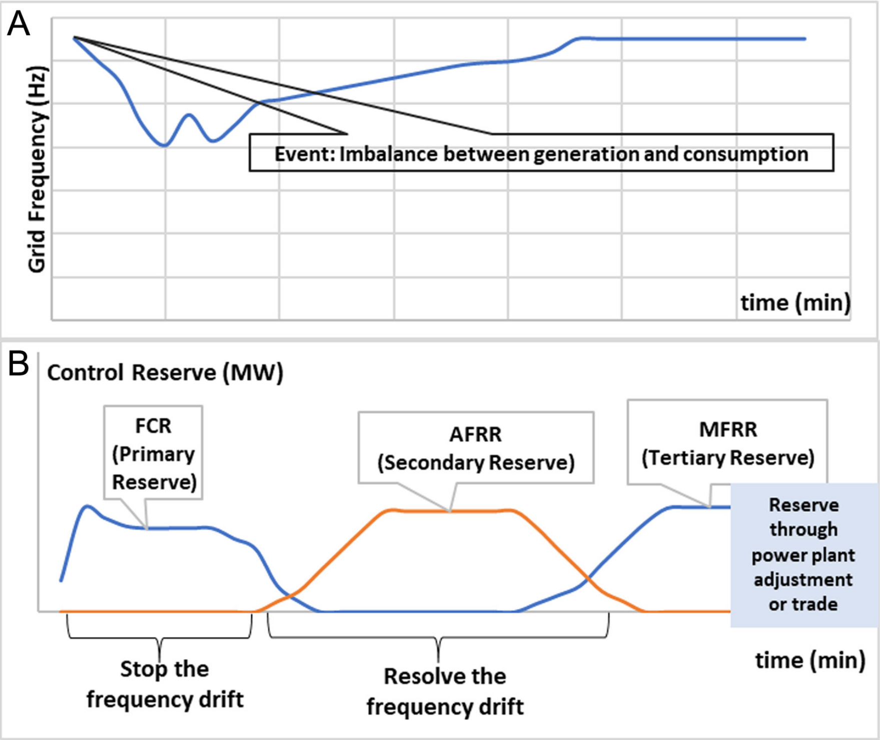

Fig. 1. Example frequency curve (a) and ancillary services (b) power type responsibilities.

summer months, with a much lighter system, a little more effort is needed to manage frequency fluctuations.

For the above-recognized reasons, the aim of this study is to evaluate how local flexibility, together with national ancillary service markets, it can provide profitability and benefits for electricity distribution companies and their customers. Two cases were examined in this study; a combination solution based on a natural gas turbine with electric vehicle charging, solar cells, and battery storage systems. The initial point of the study has the following questions:

- How can ancillary services be used to compensate for more intermittent renewable energy sources and increased electricity consumption in an economically beneficial way for the energy distribution company and its customers?
- How can ancillary services increase profitability?
- What are the ancillary service's needs?

II. FLEXIBILITY IN THE ELECTRICITY SYSTEM

The interaction of local flexibility with national ancillary service markets is an important aspect of modern electricity grids and energy systems. Local flexibility refers to the ability of distributed energy resources and demand-side resources to adjust their energy consumption or generation in response to grid needs or market prices. The role of a transmission system operator has 5 important steps, and the system operation shall be done at the lowest achievable cost.

1. Balancing between generation and consumption,
2. Maintain voltages throughout the power system,
3. Control power flows and avoid congestions (to make sure the power can be transported A to B),
4. Maintain the rotor angle stability (to make sure that no have oscillations),
5. Restore the system after blackout.

Ancillary services are the various support services that are essential for maintaining the reliability and stability of the electrical grid. Here is how local flexibility and national ancillary service markets can interact:

Grid reliability and stability [19, 20]: ancillary services, such as frequency regulation, voltage support, and spinning reserves, are crucial for ensuring the reliability and stability of the grid. Local flexibility resources can contribute to these services by responding to grid imbalances and helping to match supply and demand in real-time. The frequency regulation is typically handled in three different steps as in Fig. 2.

As shown in Fig. 3, the frequency regulation is divided into three groups based on their purpose:

1. The regulation with automatic reserves to stabilize the frequency by the FCR.
2. Restoring the frequency with the AFRR, which also is handled automatically.
3. The manual correction by MFRR, to release strain on and replace the already activated reserves in order to maintain the existing level of automatic reserves.

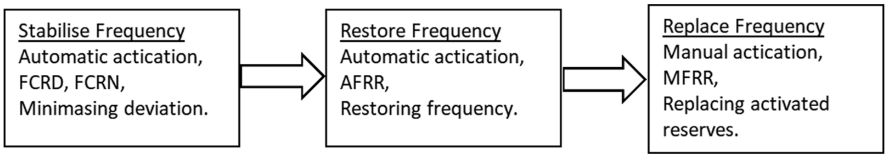

Fig. 2. Frequency regulation steps.

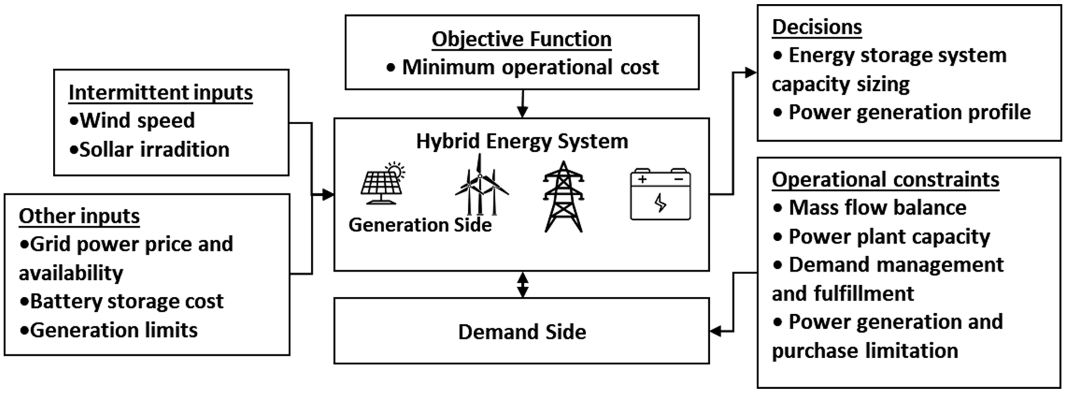

Fig. 3. Schematic representations of the typical hybrid system inputs and uncertainties.

Demand response [21, 22]: Demand-side resources, including smart appliances, industrial loads, and electric vehicles (EVs), can participate in demand response programs. When the grid faces stress, these resources can reduce their electricity consumption or shift it to other times when there is an excess of renewable energy generation, helping to balance the grid.

Distributed generation [23-25]: Distributed energy resources (see Fig. 3) like rooftop solar panels and small-scale wind turbines can provide local generation capacity. When integrated with advanced controls and grid communication systems, these resources can respond to grid demands and provide ancillary services, such as voltage support or reactive power.

Market participation [25-27]: Local flexibility resources can participate in national or regional ancillary service markets. These markets offer opportunities for resource owners to monetize their flexibility by providing services like frequency regulation, load following, or capacity reserves. These resources can bid into these markets to offer their services when needed.

Grid management [28, 29]: Grid operators and utilities can use local flexibility resources as part of their grid management strategies. They can dispatch these resources to address local grid constraints, alleviate congestion, and optimize grid operations, reducing the need for centralized investments in grid infrastructure.

Technological advancements [30, 31]: Advanced grid management systems and smart grid technologies enable better coordination between local flexibility resources and national ancillary service markets. Real-time data, predictive analytics, and automation help ensure that these resources are dispatched effectively and efficiently to meet grid needs.

Regulatory and market design [32, 33]: Regulatory frameworks and market designs play a critical role in facilitating the interaction between local flexibility and ancillary service markets. Clear rules, pricing mechanisms, and market incentives are needed to encourage the participation of local flexibility resources.

Resilience and decentralization [34, 35]: The interaction between local flexibility and national ancillary service markets can enhance grid resilience by reducing dependencies on centralized generation and transmission infrastructure. It promotes a more decentralized and adaptable grid that can better withstand disruptions.

In summary, the integration of local flexibility resources into national ancillary service markets is a key strategy for enhancing grid reliability, incorporating renewable energy sources, and optimizing grid operations. It requires a collaborative effort between grid operators, utilities, regulators, and technology providers to develop the necessary infrastructure, market mechanisms, and policies to enable this interaction effectively.

Technologies included in this study are battery storage, vehicle-to-grid (V2G), gas turbines, and smart charging. Vehicle-to-grid, batteries, and smart charging cases are best in the short to medium term because these are technologies that launch relatively quickly but do not have the staying power for that long. All are limited by battery capacity and V2G, and smart charging is also limited by vehicle usage. Vehicle batteries can only offer flexibility if they are stationary and connected to the grid. Natural gas turbines can solve the imbalances in the long term. They take longer to start up than batteries, for example, so they cannot handle quick, low-frequency adjustments, but they can handle longer blackouts. Therefore, a local distribution company has opportunities to contribute in all time periods and in all three areas of generation, consumption, and energy storage. Generation facilities do not compete with each other in any way, they complement each other.

In Türkiye, there are responsible companies for the balance in the frequency regulation ancillary service markets carried out under the auspices of regional distribution companies [36]. There are different ancillary service markets to meet different demands at different times. These are defined by different requirements regarding capacity, availability, location, and recovery time. The categories of ancillary services are Frequency Containment Reserve (FCR) [11], FFR [1], and Frequency Restoration Reserve (FRR) [11]. Fast Frequency Reserve is the fastest support service category, and the automatic activation time required by FFR is up to 1.3 seconds. Frequency Containment Reserve-Normal market works when the frequency is in the range of 49.9–50.1 Hz, under normal conditions. Frequency Containment Reserve for Disturbances (FCRD) handles the frequency when it is outside 49.9–50.1 Hz.

There are different ways to provide flexibility to relieve the electrical grid. Two perspectives on this issue are whether flexibility occurs in front of or behind the meter. Flexibility behind the meter means flexibility within the operation. An example of flexibility behind the meter is installing solar panels on a home and then transferring excess energy to a battery to reduce power peaks. Flexibility before the meter is the flexibility that is traded between actors, such as ancillary service markets or local flexibility markets. In this study, Turkish ancillary services, AFRR and MFRR energy activation, are processed at 15-minute intervals, and they are planned to be integrated into the European market. Table I [37-43] summarizes the requirements and features of the various ancillary services used in this study.

The natural gas turbine, another piece of equipment in this study, starts generation in a relatively few minutes but does not start as fast as batteries. Batteries and gas turbines therefore meet different flexibility needs. Batteries are good for frequency regulation, flexible, and fast but have limited durability [1]. On the other hand, combustion turbines have a slightly longer start-up time but can be run as long as needed, meaning they can handle longer power outages. However, gas turbines have very expensive variable operating costs because gas turbines have relatively low efficiency and fuel is expensive. Therefore, it is not profitable to operate combustion turbines only when the electricity price is high, rather than operating them always. This issue has come to the fore in recent years when most of the diversity of electricity generation sources has become intermittent, as Türkiye has a plannable power-based system. The frequency-related ancillary service market deals with imbalances in the system over a longer period of time, not just in the short term.

III. METHODS

This study consists of two case studies with slightly different perspectives. The first case concerns a customer of a transmission company that will electrify its fleet of vehicles and combine it with a solar cell facility and energy storage. The aim of this study is how flexibility and ancillary services can contribute to the electric vehicle fleet. The second case concerns the addition of a combustion gas turbine in the transmission company's network. The case study considers how a gas turbine can add flexibility to the grid and how it can contribute to ancillary services at FRR.

For case study, a customer of a transmission company is examined. Part of the transmission company's sustainability roadmap is to electrify some of the company's vehicles. This means increased demand for electricity, a challenge many companies will face in terms of energy consumption. Part of the increasing electrification is flexibility, which is the focus of this study. By mapping the system, flexible solutions can be compared and optimized, reducing both customer and transmission company costs. The initial point for evaluating flexibility is the energy consumption in hourly series, and then a model is established in which solar photovoltaic cells and EVs are added.

TABLE I.
VARIOUS ANCILLARY SERVICES USED IN THIS STUDY

	Description	Price (€/MWh)	Activation Time and Endurance	References
FFR	Fast Frequency Reserve	39	0.7–1.3 seconds depending on frequency, 30 seconds or 5 seconds	[37–39]
FCRN	Frequency Containment Reserve - Normal	19	63% within 60 seconds and 100% within 3 minutes, 1 hour	[40, 41]
FCRD up	Upward Frequency Containment Reserve - Disturbance	2.81	50% within 5 seconds and 100% within 30 seconds, About 20 minutes	[40, 42]
FCRD down	Downward Frequency Containment Reserve - Disturbance	9.99	50% within 5 seconds and 100% within 30 seconds, About 20 minutes	[40, 42]
AFRR	Automatic Frequency Restoration Reserve	43	100% within 120 seconds, 2 hours	[17, 41, 43]
MFRR	Manual Frequency Restoration Reserve	40	100% within 15 minutes, 1 hour	[17, 18]

It is interesting to study for January, as energy use peaks in this month, and it is used to analyze power peaks and plan how and when EVs should be charged. Then, a solar cell facility is simulated and the generation of solar cells is calculated. The solar panels used in this study are Sunket monocrystalline module SKT550M10-144HB, and they are angled to the southeast. Each panel measures 22685 × 1134 mm and can provide 550W of power [44].

A battery model was developed where the battery is not only charged by overgeneration but also used for accumulation. The battery is charged when the consumption drops below a certain threshold power and discharged when the consumption rises above this level; in this way, peaks in consumption can be reduced.

When more loads are connected in the form of electric vehicle charging, the existing subscription and physical conditions in the form of wires may not be sufficient. The battery reduces power peaks and the installation costs of a new grid connection can also be avoided. Here are the incomes and savings used to optimize battery capacity:

- Income frequency containment reserve,
- Savings from decreasing power peaks,
- Cost of electricity purchased for load balancing,
- Battery cost.

The coulomb counting method, also known as ampere-hour counting and current integration, is the most common technique for calculating the state of charge. The state of charge ($SOC(t)$) of the batteries is calculated for each time cycle by (1-2):

$$SOC(t) = SOC(t-1) + \frac{1}{C_{rated}} \int_{t-1}^{t-1+\tau} (I_b - I_{loss})\,dt \qquad (1)$$

$$SOC(t) = SOC(t-1) \cdot (1 - S_{dis}) + \frac{\sum C(t) \cdot \eta}{B_c} \qquad (2)$$

where

SOC—state of charge,

C_{rated}—the rated capacity,

I_{b}—the battery current,

τ—time instant,

I_{loss}—the current consumed by the loss reactions,

S_{dis}—the self-discharge of the battery,

C—the consumption,

η—the efficiency of the battery,

B_{c}—the battery storage capacity,

t—the time.

Battery capacity (B_c) is the actual energy storage capacity of the battery, while rated capacity (C_{rated}) is the standard capacity specified by the manufacturer for the battery. Mostly, the actual capacity of a battery may vary slightly because the battery may perform differently under different conditions. In order to make power diagrams with and without a battery, the charge and discharge power are calculated for the time series. The charge is calculated by (3):

$$P_{ch} = P(t) - C(t) \qquad (3)$$

Subject to: $P_{\text{ch}} \leq P_{\text{max}}$

The battery model data consists of electricity consumption and simulated future consumption. For the future scenario, besides solar cells, EVs and their charging systems are also added to the model. The energy demand of EVs when they arrive at the parking area is calculated as follows (4):

$$\sum E_{EV} = T_d v EV_{cons} (1 - SOC_{arr}) \qquad (4)$$

E_{EV}—energy demand of EVs,

T_{d}—the driving time,

v—the average EV speed,

EV_{cons}—the energy consumed per kilometer,

SOC_{arr}—SOC at arrival.

The batteries in the EVs used in this study are assumed to be able to handle approximately 4 hours of driving time, corresponding to battery capacities of 300–500 kWh. The charging time of EVs is calculated by (5):

$$T_{ch} = \frac{EV_{cons}}{P_{ch}} \qquad (5)$$

where;

T_{ch}—the charging time of EVs,

EV_{cons}—the consumption of EVs,

P_{ch}—the charging power.

Due to the reality that EVs have traveled different distances in terms of driven time, speed, the capacity of the battery when arriving at the parking area, and energy consumption values in electric vehicles, in this study, it is assumed that the driven time is 4 hours, the average speed is 70 km, the battery capacity at the parking area is 50%, and the consumed energy is 1.5 kWh/km.

A. Combustion Turbine

This study examines a scenario where the transmission company has a combustion turbine power plant in its network that can withstand outages and sell energy in a MFRR market. It meets the MFRR specifications of the gas turbine because it does not require a very fast start-up time and electricity can be sold on the spot market during high-price hours. The case study is based on a 5 MW gas turbine with a cost of 2 million dollars and a gas price of 120 $/MWh. The electrical efficiency is assumed to be 45%. In order to calculate the income of the combustion turbine, hourly series are created for 8760 hours. The calculation is made if the amount obtained by dividing the gas price by the generation per hour is lower than the market price (6).

$$in_{cmb} = P_{gas} \cdot pr_m - \frac{pr_{gas}}{\eta} \tag{6}$$

where

in_{cmb}—income for combustion power facility,

P_{gas}—generated power by combustion turbine,

pr_m—electricity market price,

pr_{gas}—the price of natural gas,

η – the electrical efficiency of the turbine.

The ancillary services prices (MFRR price and FFR price) are calculated in $/MW (as shown in Table I) and the electricity market price in $/MWh, but since both markets are bought hourly, the prices in both markets are comparable. Market prices used in this study are taken from [45]. In the next section, various scenarios are compared regarding how much the energy market has changed. Since the transmission company considers that the electricity demand will increase, this study only considers cases where prices increase. Natural gas market prices are used in this study since natural gas prices have increased a lot in 2023 due to the war between Russia and Ukraine, and since it is difficult to predict, different prices will affect the result.

IV. RESULTS AND DISCUSSION

In this section, the results of the case study are presented. First, the results for the hybrid system are presented, then the results for the combustion turbine case. Fig. 4 shows the system's power generation before the vehicles are electrified. Hourly power output varies a lot but averages over 105kWh per month. In some months, solar energy generation is slightly higher; this generation meets the heating and cooling demand, which is an average of 1258.5 kWh.

Fig. 5 shows how the power output changes when solar panels are added to the system. During the year, the average generation decreases by 21 kW, especially in summer the solar cells have a large generation. On an hourly basis, all the energy consumed during the summer months can be met from solar energy, which means a surplus. Surplus means the opportunity to accumulate or sell electricity in different markets. All of the excess hours occur during the summer period. After the solar cells were added to the system, it is depicted that the energy obtained from the sun met a very small part of the energy consumption.

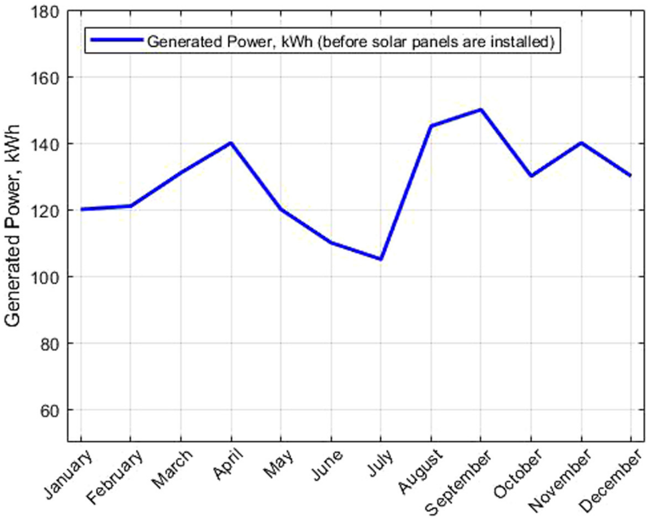

Fig. 4. Power consumption before vehicles are electrified and solar cells are adopted.

According to the sustainability roadmap of the electricity transmission company, 10% and 30% of the vehicles in the vehicle fleet should be electric in 2025 and 2030, respectively. In this case, if EVs are simultaneously charged with 6.6 kW, the power peaks will be around 600 kW, which is sufficient for the next day while the vehicles are charging overnight. During the night, 20 vehicles can be charged with 6.6 kW, and the load profile of 8 heavy vehicles with 6.6 kW is shown in Fig. 6. This means that approximately 1040 $ income can be generated from the FCRD-up through heavy vehicle charging.

By installing a battery storage system, it can reduce power peaks and thus create charging opportunities for more EVs. Fig. 7 illustrates all the factors that affect the company's power output. Fig. 7, prepared for July, shows all the factors affecting the company's power output. Load, consumption, solar cell generation, and battery storage resulting from EV charging are shown in different colors.

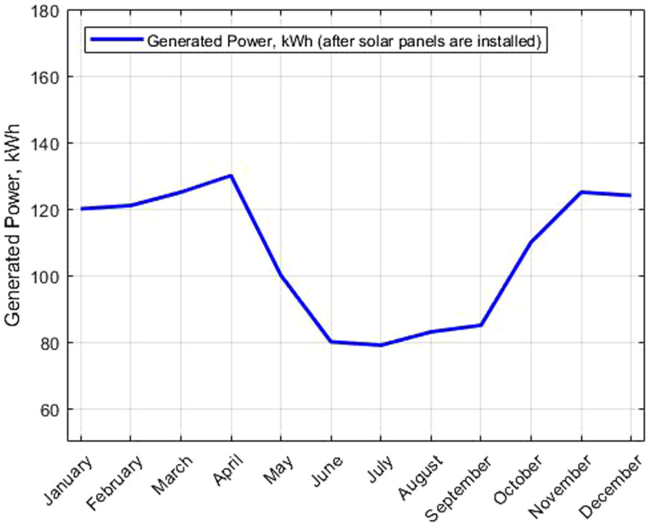

Fig. 5. Generated power after solar panels are adopted.

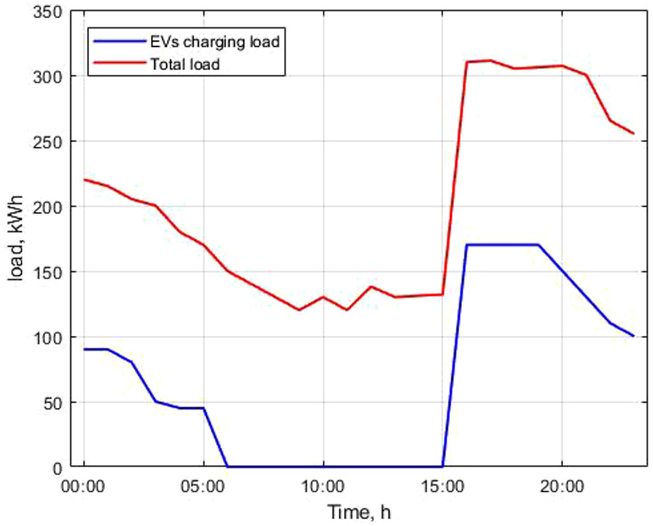

Fig. 6. Load profile for EVs charging with 6.6 kW.

When the combustion units are connected, the FRR capacity offered to the transmission system operators also depends on the generation unit's opportunity costs. This is different for almost every hour since this depends on the prices of natural gas (in the wholesale market). Fig. 8 shows how the total revenue from the combustion turbine changes depending on the gas price. Income decreases compared to the gas price increase, which means the natural gas price is having a significant impact. In this study, when the assumed price of gas is \$190/MWh, the revenue at 2023 prices for an investment of approximately \$6 million would be \$275 000 per year. The working hours vary between 54 hours at a gas price of 73\$ and 11 hours at a gas price of 190\$.

The company has a high energy consumption and despite a 250 kWp solar cell adoption, there are few hours during the day when the solar cells produce more than they consume. It is good if solar cells have a high utilization rate for the own consumption because it saves costs that would otherwise come from purchased electricity. In the future, as the consumption will increase with the EVs in operation, solar energy will meet an even larger portion of consumption. A battery storage can be used to increase the proportion of generated electricity, used for its self-consumption, but in this case, the ratio is already so high that a battery for this purpose becomes unnecessary. Instead, it is to move the peaks in consumption to smooth out the load profile, thereby staying at a lower electricity consumption and getting lower power tariffs.

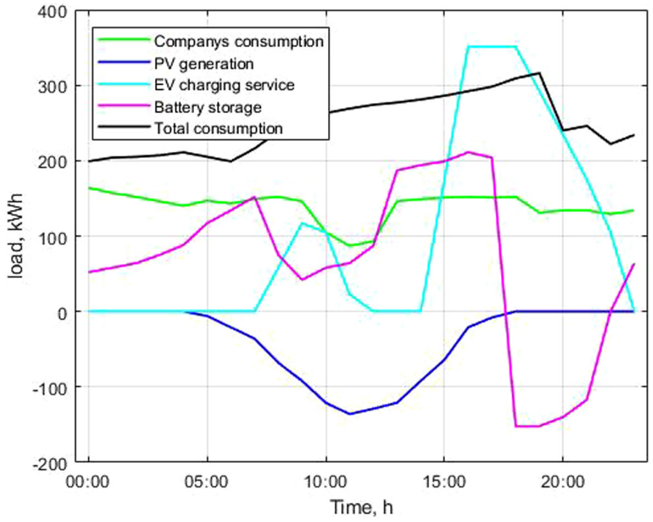

Fig. 7. The company's load profile linked to energy consumption and generation.

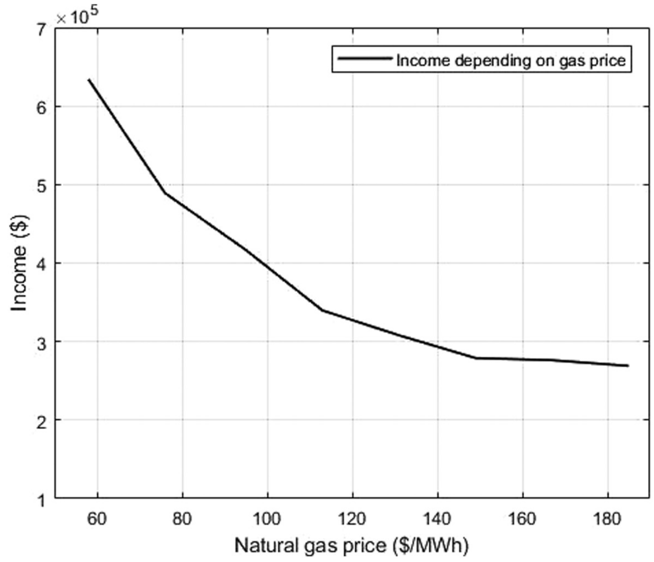

Fig. 8. Income depending on gas price.

The battery needs to be oversized, both to reduce the power peaks of consumption and to keep the energy that can be sold in the FCRD. There are many uncertainties in the combustion natural gas turbine case. Mainly this is based on the fact that the country's electricity system is changing and it will be under more pressure in the future if plannable energy sources decrease and intermittent ones increase, which will lead to increased revenue from MFRR. In addition to the prices in the market and the MFRR, it is the price of natural gas that shows how profitable a gas plant can be. Since the start of the Russia–Ukraine War, natural gas and coal prices in global markets have reached record levels. Gas prices reached a record high in Europe due to the supply–demand imbalance after the coronavirus diseae 2019 outbreak and supply constraints after the Russia–Ukraine War.

V. CONCLUSION

In the context of the evolving energy landscape in Türkiye, this study has explored the complex dynamics of the relationship between national ancillary service markets and local flexibility. Grid flexibility assumes paramount significance as Türkiye transitions from a traditionally predictable energy generation model to one characterized by intermittent renewable sources such as solar and wind power, coupled with the anticipated integration of nuclear power.

As the study's findings demonstrate, ancillary services are essential to preserving the stability and dependability of the electrical grid. Notably, frequency-related ancillary services have been accorded particular attention within the ancillary services domain due to their pivotal role in maintaining the equilibrium of the grid. The gas turbine system deals with large distortions in frequency, affecting the MFRR market, but for this to be investable, the value of the MFRR market must increase in the coming years. However, for this aspect to become a viable investment, the market's valuation must experience an upward trajectory in the ensuing years. The article underscores the escalating demand for flexibility and posits that influential entities, such as power distribution firms, play a pivotal role in this landscape. Distribution companies can improve grid stability, minimize the need for expensive infrastructure expansions, and actively participate in ancillary service markets by utilizing local flexibility through strategies such as demand response, distributed generation, and energy storage. These actions ultimately contribute to the stability of the national grid. The main goal of the study has been to assess how local flexibility might benefit and be profitable for energy distribution firms and their customers when combined with national ancillary service marketplaces. A specific case study was undertaken, encompassing a combined solution involving solar panels, battery storage systems, electric vehicle charging infrastructure, natural gas turbines, and their integration within the network of the transmission company.

Notably, the potential of individual resilience resources was not explored further in this study. Therefore, it would be worthwhile to research in future studies the potential of different sources of flexibility in an ancillary market (e.g., battery storage, and charging infrastructure for EVs). Also, it will be interesting to conduct a socioeconomic evaluation between grid expansion and the use of ancillary services in the future to determine which solution is most suitable when capacity problems arise in local electricity networks.

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REFERENCES

1. L. Meng *et al.*, "Fast frequency response from energy storage systems—A review of grid standards, projects and technical issues," *IEEE Trans. Smart Grid*, vol. 11, no. 2, pp. 1566–1581, 2020. [CrossRef]
2. V. Z. Gjorgievski, N. Markovska, A. Abazi, and N. Duić, "The potential of power-to-heat demand response to improve the flexibility of the energy system: An empirical review," *Renew. Sustain. Energy Rev.*, vol. 138, p. 110489, 2021. [CrossRef]
3. C. Amil, and M. Z. Yılmazoğlu, "The importance of hydrogen for energy diversity of Turkey's energy production: 2030 projection," *Int. J. Hydrog. Energy*, vol. 47, no. 45, pp. 19935–19946, 2022. [CrossRef]
4. K. A. Kyriakides, "The Akkuyu nuclear power plant in turkey: Some causes for concern," *J. Balk. Near East. Stud.*, vol. 25, no. 3, pp. 340–377, 2023. [CrossRef]
5. P. Denholm, and R. Margolis, *Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California*. Golden, CO (United States), 2016. [CrossRef]
6. D. Mohler, and D. Sowder, "Energy storage and the need for flexibility on the grid," in *Renewable Energy Integration*. Amsterdam: Elsevier, 2017, pp. 309–316. [CrossRef]
7. D. Ribó-Pérez, L. Larrosa-López, D. Pecondón-Tricas, and M. Alcázar-Ortega, "A critical review of demand response products as resource for ancillary services: International experience and policy recommendations," *Energies*, vol. 14, no. 4, p. 846, 2021. [CrossRef]
8. A. Zobian, and M. D. Ilic, "Unbundling of transmission and ancillary services. I. Technical issues," *IEEE Trans. Power Syst.*, vol. 12, no. 2, pp. 539–548, 1997. [CrossRef]
9. Y. G. Rebours, D. S. Kirschen, M. Trotignon, and S. Rossignol, "A survey of frequency and voltage control ancillary services—Part I: Technical features," *IEEE Trans. Power Syst.*, vol. 22, no. 1, pp. 350–357, 2007. [CrossRef]
10. V. Adetola, F. Lin, S. Yuan, and H. Reeve, "Building HVAC flexibility estimation and control for grid ancillary services," in International High Performance Buildings Conference, 2018, pp. 1–10.
11. J. Marchgraber, W. Gawlik, and G. Wailzer, "Reducing SoC-Management and losses of battery energy storage systems during provision of frequency containment reserve," *J. Energy Storage*, vol. 27, p. 101107, 2020. [CrossRef]
12. A. Alahaivala, and M. Lehtonen, "Coordination strategies for distributed resources as frequency containment reserves," in *IEEE Innovative Smart Grid Technologies*. Asia Publishing, 2015, pp. 1–6. [CrossRef]
13. R. Faia *et al.*, "A simulation of market-based non-frequency ancillary service procurement based on demand flexibility," *J. Mod. Power Syst. Clean Energy*, vol. 11, no. 3, pp. 781–792, 2023. [CrossRef]
14. Y. Krim, D. Abbes, S. Krim, and M. F. Mimouni, "Intelligent droop control and power management of active generator for ancillary services under grid instability using fuzzy logic technology," *Control Eng. Pract.*, vol. 81, pp. 215–230, 2018. [CrossRef]
15. "'Reserves and balancing power,' *Fingrid*,", 2023. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/#reserve-obligations-and-procurement-sources.
16. L. Ravudd, and G. Kristoffer, *An Approach for Detecting Potential Market Anomalies in the Balancing Power Market Using Screening Analysis and Regression Analysis*. KTH Royal Institute of Technology, 2019.
17. "'European aFRR and mFRR activation market,' *Nordic balancing model*,", 2023. Available: https://nordicbalancingmodel.net/roadmap-and-projects/european-afrr-activation-market/.
18. "'Balancing energy and balancing capacity markets (mFRR),' *Fingrid*,", 2023. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/balancing-energy-and-balancing-capacity-markets/.
19. M. Morjaria, D. Anichkov, V. Chadliev, and S. Soni, "A grid-friendly plant: The role of utility-scale photovoltaic plants in grid stability and reliability," *IEEE Power Energy Mag.*, vol. 12, no. 3, pp. 87–95, 2014. [CrossRef]
20. G. D. Rodriguez, "A utility perspective of the role of energy storage in the smart grid," in IEEE PES General Meeting, IEEE, 2010, pp. 1–2. [CrossRef]
21. M. H. Albadi, and E. F. El-Saadany, "Demand response in electricity markets: An overview," in Engineering Society General Meeting, IEEE, Power: IEEE PUBLICATIONS, 2007, pp. 1–5. [CrossRef]
22. O. Ma *et al.*, "Demand response for ancillary services," *IEEE Trans. Smart Grid*, vol. 4, no. 4, pp. 1988–1995, 2013. [CrossRef]
23. G. Joos, B. T. Ooi, D. McGillis, F. D. Galiana, and R. Marceau, "The potential of distributed generation to provide ancillary services," in Summer Meeting (Cat. No.00CH37134). Power: Engineering Society. IEEE Publications, 2000, pp. 1762–1767. [CrossRef]
24. P. Kotsampopoulos, N. Hatziargyriou, B. Bletterie, and G. Lauss, "Review, analysis and recommendations on recent guidelines for the provision of ancillary services by Distributed Generation," in IEEE International

Workshop on Inteligent Energy Systems (IWIES), IEEE, 2013, pp. 185–190. [CrossRef]

25. A. S. Al-Bukhaytan, A. T. Al-Awami, A. M. Muqbel, and F. Al-Ismail, "Dynamic planning of active distribution network's wire and nonwire alternatives considering ancillary services market participation," *IEEE Syst. J.*, vol. 17, no. 2, pp. 2993–3004, 2023. [CrossRef]
26. T. Wu, M. Rothleder, Z. Alaywan, and A. D. Papalexopoulos, "Pricing energy and ancillary services in integrated market systems by an optimal power flow," *IEEE Trans. Power Syst.*, vol. 19, no. 1, pp. 339–347, 2004. [CrossRef]
27. M. Coppo *et al.*, "Ancillary services by DG and storage systems in distribution networks for energy market participation," in AEIT International Annual Conference (AEIT), IEEE, vol. 2016, 2016, pp. 1–6. [CrossRef]
28. S. Rahnama, T. Green, C. H. Lyhne, and J. D. Bendtsen, "Industrial demand management providing ancillary services to the distribution grid: Experimental verification," *IEEE Trans. Control Syst. Technol.*, vol. 25, no. 2, pp. 485–495, 2017. [CrossRef]
29. H. Liang, A. K. Tamang, W. Zhuang, and X. S. Shen, "Stochastic information management in smart grid," *IEEE Commun. Surv. Tutor.*, vol. 16, no. 3, pp. 1746–1770, 2014. [CrossRef]
30. K. Zhang, S. Troitzsch, S. Hanif, and T. Hamacher, "Coordinated market design for peer-to-peer energy trade and ancillary services in distribution grids," *IEEE Trans. Smart Grid*, vol. 11, no. 4, pp. 2929–2941, 2020. [CrossRef]
31. K. Schmitt *et al.*, "A review on active customers participation in smart grids," *J. Mod. Power Syst. Clean Energy*, vol. 11, no. 1, pp. 3–16, 2023. [CrossRef]
32. E. Ela, B. Kirby, N. Navid, and J. C. Smith, "Effective ancillary services market designs on high wind power penetration systems," in IEEE Power and Energy Society General Meeting, IEEE, 2012, pp. 1–8. [CrossRef]
33. J. H. Chow, W. De Mello, and K. W. Cheung, "Electricity market design: An integrated approach to reliability assurance," *Proc. IEEE*, vol. 93, no. 11, pp. 1956–1969, 2005. [CrossRef]
34. Y. Wang, C. Chen, J. Wang, and R. Baldick, "Research on resilience of power systems under natural disasters—A review," *IEEE Trans. Power Syst.*, vol. 31, no. 2, pp. 1604–1613, 2016. [CrossRef]
35. D. Manz, R. Walling, N. Miller, B. LaRose, R. D'Aquila, and B. Daryanian, "The grid of the future: Ten trends that will shape the grid over the next decade," *IEEE Power Energy Mag.*, vol. 12, no. 3, pp. 26–36, 2014. [CrossRef]
36. "Official gazette (30252), 26/11/2017," *Electr. Mark. Ancillary Serv. Regul., Ankara*, 2017.
37. S. Borenius, P. Tuomainen, J. Costa-Requena, M. Lehtonen, P. Hovila, and H. Kokkoniemi-Tarkkanen, "Mobile network multicast supported maintenance of frequency stability in low inertia power grids," in *CIRED*, Institution of Engineering and Technology, 2021, pp. 1288–1292. [CrossRef]
38. J. Markkula, V. Tikka, and P. Järventausta, "Local versus centralized control of Flexbile loads in power grid," in *CIRED*, Institution of Engineering and Technology, 2021, pp. 2294–2298. [CrossRef]
39. "'Fast Frequency Reserve,' *Fingrid*,", 2023. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/fast-frequency-reserve/.
40. F. Oyj, "Terms and conditions for providers of Frequency Containment Reserves (FCR),", 2021. [Online]. Available: https://www.fingrid.fi/globalassets/dokumentit/en/electricity-market/reserves/fcr-liite1---ehdot-ja-edellytykset_en.pdf.
41. K. Kölle *et al.*, "Towards integrated wind farm control: Interfacing farm flow and power plant controls," *Adv. Control Appl.*, vol. 4, no. 2, 2022. [CrossRef]
42. "'Frequency containment reserves (FCR products),' *Fingrid*,", 2023. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/frequency-containment-reserves/.
43. "'Automatic frequency restoration reserve (aFRR),' *Fingrid*,", 2023. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/automatic-frequency-restoration-reserve/.
44. "Wuxi sunket,", 2023, *JA Solar Module Mono Solar Panels*, Vol. 550W. Available: https://www.sunketsolar.com/half-cut-mono-solar-panel/58624283.html.
45. EPIAS, "Market clearing price,", 2023. Available: https://seffaflik.epias.com.tr/transparency/piyasalar/gop/ptf.xhtml. [accessed: Aug. 20, 2023].