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RESEARCH ARTICLE

Variable Feed-In Tariff Algorithm for Renewable Energy in Smart Grids

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ABSTRACT

In today's world, new solutions are constantly needed to meet the ever-increasing energy demand. One of the methods of meeting energy needs is to support renewable energy. In order to support renewable energy, globally accepted feed-in tariff (FiT) applications are used effectively. Feed-in tariff support policies differs from country to country. With the continued development of smart grid infrastructures, it has become necessary to reorganize renewable energy support policies. The determined conditions of the FiT application completely affect the renewable energy investments and productions in that region. Turkey has a number of economic and geographical advantages, the majority of which are renewable energy resources. Over the last decade, Turkey has made significant progress in renewable energy development and manufacture. The relevant legislation to renewable energy has been improved. Many studies have been conducted on the use of smart grids to increase energy efficiency and to obtain electrical power systems that provide different opportunities to users. In this study, a new variable FiT algorithm has been developed. The aim of this new variable support mechanism is to provide more benefits for both the investor and the electric power system of renewable energy investments. The results obtained with the proposed algorithm are explained. With this algorithm, the importance of more accurate planning and investment has been tried to be revealed.

Index Terms—Feed-in tariff, renewable energy support, smart grids, solar energy

I. INTRODUCTION

Energy consumption is one of the indicators that helps to understand the state of social and economic life. Energy resources such as oil and natural gas are not sufficient to meet the rapidly increasing energy demand in the world. Air pollution is one of the problems that must be constantly monitored for a sustainable and livable world, and the use of renewable energy is one of the best solutions to this problem [1]. The negative impacts of renewable energy on the environment are mostly negligible. Renewable energy can be used to contribute to countries' policies for safe, affordable, and sustainable energy. Turkey is in a unique position in the world in terms of the abundance of renewable energy sources (RESs) such as biomass, geothermal, solar, and wind energy. Turkey must reduce thermal power output due to scarcity of known fossil fuel sources and create more electricity from renewable sources due to the country's high renewable energy potential. Main problems in the use of renewable energies, however, are their availability, accessibility, and cost; unlike conventional sources of electricity, renewable energies are not available when and where they are needed [2]. Smart grids can help with renewable energy integration, and these networks will give additional benefits as well [3]. In the future, smart grids will seek to guide customers and utility companies to make better energy management decisions. Some of the purposes of this article are to emphasize the importance and benefits of renewable energy, as well as to try to reduce the barriers to integrating renewable energy into Turkey's smart grid.

A. Feed-In Tariff

Several support mechanisms are already in place around the world to encourage further investment in RESs. The feed-in tariff (FiT) is a long-term purchase arrangement between government agencies and companies that generate power from RESs. Producers are offered long-term contracts ranging from ten to twenty-five years, and the price per kilowatt-hour (kWh) of electricity is set by governments. Feed-in tariff, according to several research, is the optimum support mechanism for enhancing and extending the use of RESs [4-6]. Investors' perceived risk is reduced as a result of the long-term purchase agreement, and corporations choose to invest in renewable energy and research and development (R&D). Another benefit of FiT is that each country can customize the mechanism to suit its own circumstances. Various FiT applications have been put into use to encourage "RES" investments in many countries so far [7-9]. Depending on FiT, technical and financial analysis also needs to be done correctly [10].

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RES investments supported by FiT policy may receive an additional payment from governments. Today, providing additional price support to renewable energy has turned into a situation of determining renewable energy prices. In the long and medium term, the FiT policy is highly advantageous to increase the rate of use of renewable energy. The biggest disadvantage is the inequality of opportunity compared to other energy investors.

Due to large price fluctuations in the electricity market, investors may not be able to set an exact price for renewable energy. Renewable Portfolio Standards (RPS) mandatorily sets the percentage of renewable energy power generation, technically guiding progress [11]. However, current competition in the market favors renewable energy, which provides economic efficiency. RPS does not apply in countries that are in the early stages of renewable energy development [12].

Feed-in tariffs were initially established in Turkey in 2005 as part of the renewable energy legislation. This legislation favored renewable energy for power generation to diversify primary energy sources, minimize emissions, and strengthen domestic manufacturing sectors. Feed-in tariffs have a 10-year period, and renewable energy installations must be operational before 2011 [13, 14]. However, this study was not completely satisfactory for both consumers and producers. Consumers purchasing electricity from distribution companies under renewable energy contracts saw their prices rise. Manufacturers were also dissatisfied with the current base price. Participation in the FiTs mechanism has lost its appeal as the average market price is higher than FiTs, and setup costs have started to rise [15]. In addition, compared to other countries such as Germany, France, Japan, and the United Kingdom, Turkey's FiTs are late in implementation, but some lessons have been learned from the problems experienced in these countries [13, 16-19]. Many countries around the world have developed different types of FiT applications to take advantage of the current solar and wind energy potential [20]. After the introduction of different FiT policy implementations, it has been observed that the installed renewable energy capacity in many countries has increased significantly [21, 22].

Turkey supports the establishment of renewable energy power plants to meet the ever-increasing electricity demand. For this reason, the Law regulating Electricity Production with Renewable Energy Resources [23] has been put into effect [24]. Turkey's FiT for renewable energy provides a 10-year purchase guarantee.

Main Points

- The effects of different feed-in tariff (FiT) applications on renewable energy are compared.
- The advantages and disadvantages of FiT policies are stated.
- Decisions that can be taken to regulate the load flow in smart grids are explained.
- Feed-in-tariff examples, which offer more economically suitable solutions, are given, and a new FiT algorithm is proposed.
- The benefits obtained with the proposed algorithm are presented.

II. SMART GRIDS

An electrical grid has to keep the frequency and voltage under control while supplying energy to the loads in order to ensure sustainability. Any failure in the interconnected system leads the entire system to collapse, disrupting all countries connected to it. The network uses branch nodes fed by a single source at the distribution level, and any failure of a single energy supply source affects the entire system. To overcome these issues, ring lines between centers are now used. The existing grid has a number of significant flaws. The following are some of these issues: bidirectional energy flow causes problems with reactive power control [25]. Voltage fluctuations in the grid as a result of unpredictable changes in reactive and active power, an increase in the impacts of short-circuit currents, as well as a shift in relay selection criteria based on the connection of groups of transformers in the grid may occur. Short-circuit current limits enforce the thermal withstand capability of existing grid components. The amount of flicker and harmonic generation will be higher than normal. Network stability is not within the limit values in transient situations such as switching and instantaneous tripping. Smart grids reduce transmission and distribution losses by incorporating complex technologies into network control systems. According to its definition, the smart grid is "a power system that responds to the needs of generation/transmission/distribution systems and the energy market, and also has the capacity to solve its own problems in emergencies" [26].

A smart grid is an electricity network enabling a two-way flow of electricity and data. Smart grid applications have a lot of benefits, and the technology is getting better, but there are still a lot of unknowns in the industry. Funding, consumer engagement, government assistance and taxation, legislation, and new entrants to the industry are the primary challenges for an electrical company [27]. As a result, before smart grid implementations, the difficulties and potential of smart grids must be properly studied, and a revenue-generating business model must be developed. Since smart grids are a new technology that requires changes in transmission and distribution infrastructure, electricity distribution companies may not be ready for these changes yet. All of these issues can be addressed by energy policies and regulatory frameworks that include and encourage smart grids; however, energy policies may force some of the market players from time to time [28]. Many countries' energy strategy plans include smart grids, because smart grids may play a large role in integrating renewable energy into electricity [3]. These countries include China [29], the United Kingdom [30], and Turkey [31]. One of the most common tactics in countries' implementation plans is the adoption of smart metering, which is a component of smart grid [32].

Energy infrastructure is a key factor of economic growth. Technological advancements, as well as increasing social interdependence and environmental consciousness, necessitate a major shift in the future energy system. Smart grids are one of the most vital parts of a secure, sustainable, long-term, environmentally friendly, and competitive economic future.

Turkey aims to replace imported fossil fuels with nuclear energy and RESs in the near future in order to meet its rapidly increasing energy needs [33]. That's why the support policies were updated continuously until the last date of August 11, 2022 [24].

III. PROPOSED FEED-IN TARIFF ALGORITHM

The main purpose of the proposed algorithm is to contribute to obtaining the most accurate operation by making optimum pricing for RESs of different sizes in the power system. The investor, who has knowledge about pricing at the initial stage of the investment, can thus take more accurate and informed steps. The proposed FiT algorithm is given in Fig. 1. The FiT in the current applied regulation is named as current FiT (C-FiT). C-Fit has two basic rules; firstly, the RES power cannot exceed twice the installed power of the industrial firm, and secondly, the industrial firm can sell electricity as much as the production one year ago. If the industrial firm is newly established, the energy production values are evaluated monthly until one year. This study proposed a new FiT model that can be applied to the support policy. This model has been named as variable FiT (VFiT) like semifixed semiflexible FiT (SFFiT) that can be applied to all of RESs. Full flexible FiT (FFiT) support policies should apply only to high power RES (≥10 MW) due to their high contribution to the power system. Standard FiT (SFiT) should be applied to low-power RES (≤1 MW) to increase the number of investors benefiting from the support policy. Partial FiT (PFiT) should be applied to middle-power RES (1 MW < RES <10 MW) to balance the power market. The proposed VFiT and SFFiT models include SFiT, PFiT, and FFiT models. The single-line diagram of the applied power system is given in Fig. 2. Classifying the investors according to their power is to encourage them to invest and to make the most of the energy capacity that can be produced.

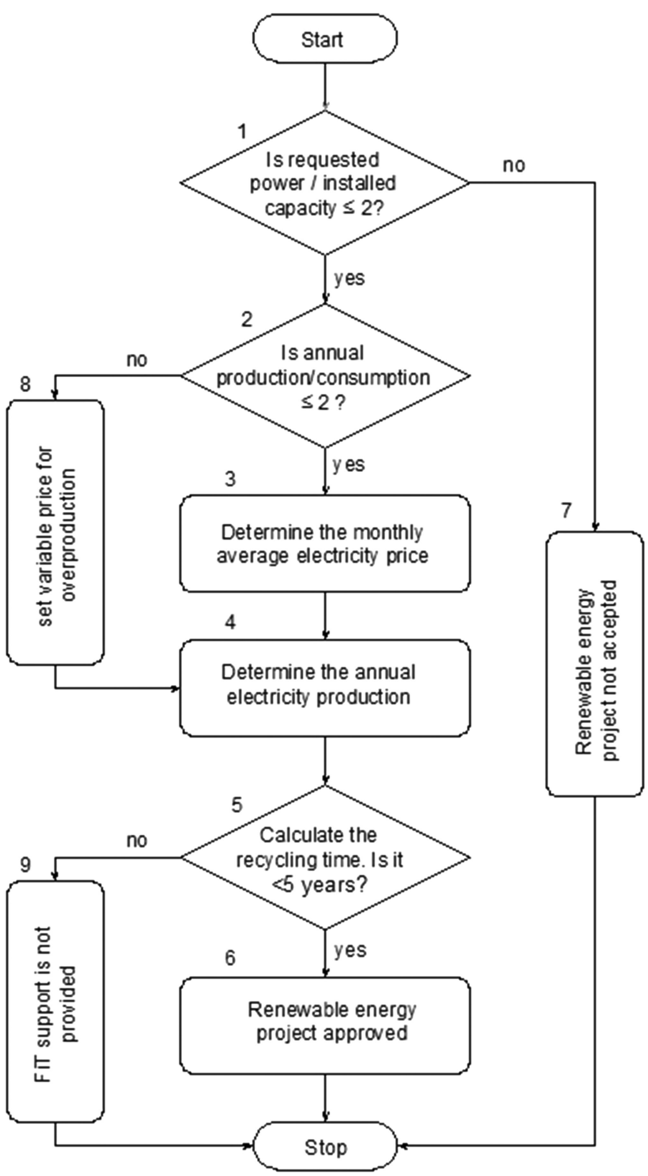

Fig. 1. Proposed feed-in tariff algorithm.

According to the proposed algorithm,

1) If the ratio of the renewable power plant capacity planned to be established to the installed power of the enterprise is greater than 2, the project is not accepted due to the current regulation. The most important reason for determining this ratio is to distribute production as much as possible and to ensure that possible future investments are minimized.
2) The annual energy production of the established power plant should be less than two times the consumption of the enterprise. Thus, the business is directed toward the right investment.
3) The electricity unit price is determined by considering the current economic conditions and production-consumption balances for the current month. In the current situation, companies can sell to the system at the price they have purchased.
4) The annual energy production of the renewable power plant to be established must be determined correctly. One of the tasks done in this study is the forecasting of annual production. Artificial neural network methods are used to forecast the energy produced from photovoltaics (PV). Fig. 3 shows the forecasting and actual values for each month of the year for a 1 MWe (1200 kWp) rooftop PV power plant.
5) Payback time is an indicator of how soon an investment will pay off. The shorter this period, the longer the investment will earn.

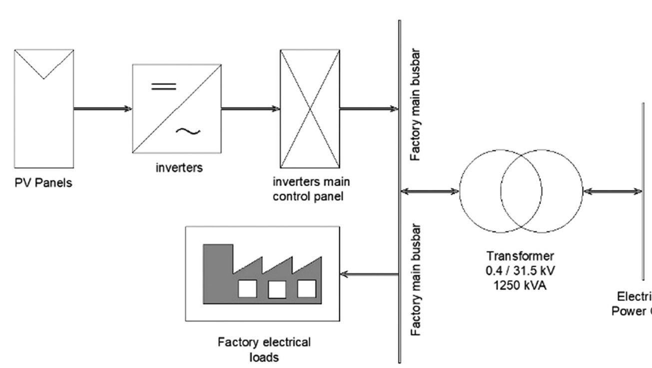

Fig. 2. Single-line diagram of the applied power system.

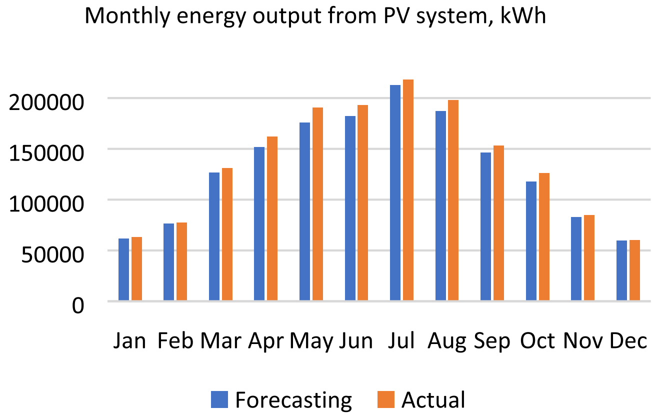

Fig. 3. Forecasting and actual values for a 1 MWe PV power plant.

Because the established power plant has a certain economic life, according to the panel manufacturers who give a 25-year linear reduction guarantee, the lifetime of a solar PV plant can be taken as approximately 30 years. However, it should never be forgotten that the production decreases linearly compared to the value of the first day.

6) Projects that fall below the specified payback time are approved. In this study, this period was defined as 5 years.
7) Demand power, if it is more than two times the installed power, the project will not be approved in any way. Thus, the investor starts by knowing his target.
8) A variable price is applied for the investor whose renewable energy generation consumption is more than two times. The monthly standard price is applied for up to two times the consumption. The amount between two times and three times the consumption is charged with standard price × 0.7. Price between three times and four times is charged at standard price × 0.5. Production made four times, or more, is not charged. The power system uses this energy for free. Thus, the more accurately the investor calculates how much electrical energy will use, the more earns.
9) The power plant can be installed, but FiT support is not provided. The investor can only build the power plant for his own energy needs and cannot get paid for the amount given to the grid.

The important characteristics of 1 MW solar PV power plant are shown in Table I. The most important values of the feasibility study are location, construction conditions, panel placement angle, panel efficiency, efficiency decrease (10 years 90%, 25 years 80%), and inverter prices that vary between 10% and 12% of the total plant cost. Grounding, lightning protection, data recording, and remote monitoring are included in the price of the PV power plant. In Table II, an example calculation is given for the C-FiT and VFiT to be applied to a facility with a monthly consumption of 50 MWh and a production of 210 MWh with a power of 1 MWe.

10 MWh is given free of charge to the power system, as the energy production exceeds four times the consumption. According to this calculation, if the monthly consumption of the enterprise (investor) was 105 MWh, it would have made the most appropriate purchase by selling the remaining 105 MWh to the system at the standard price. A facility with an energy consumption of 50 MWh can sell to a 50 MWh system according to the current regulation. In this case, only 100 MWh of energy is evaluated in the relevant month. Another purpose of this algorithm is to make the investor aware of energy consumption. The investor will be able to use his capital more accurately, as the power of the plant, which is determined according to the real need, will also prevent excessive investment. In the example given above, if the investor establishes a 1.2 MWe facility instead of a 2 MWe facility, he will not have spent extra money for a 0.8 MWe facility and, at the same time, he will lose profit by selling below the standard price for more than double the production. The approximate cost of a 0.8 MWe rooftop solar PV plant is around €672 000 in today's conditions.

TABLE I.
CHARACTERISTIC OF PV POWER PLANT

Material/Technical Specifications	Value Ranges
Panel power	500 W
Panel efficiency	20,3%
Operating temperatures	−25/+60
Inverter power	100 kW AC
Inverter maximum input voltage	1000 VDC
Inverter efficiency	98%
Total PV plant power	1200 kWp

In the calculations made in Table III, the carbon emission for Turkey is assumed as 0.6488 [tCO_2/MWh] and the profit from one ton of carbon is taken as 40 €.

TABLE II.
AN EXAMPLE OF A FEED-IN TARIFF CALCULATION

Explanations	Energy	Calculations (C-FiT)	Calculations (VFiT)
Energy supplied to the power system	160 MWh	210-50	210-50
Sale at regular price	50 MWh	= monthly consumption	= monthly consumption
Sale at regular price × 0.7	50 MWh	= 0	= monthly consumption
Sale at regular price × 0.5	50 MWh	= 0	= monthly consumption
Free sale	160 – selling	110	10

FiT, feed-in tariff; VFiT, variable FiT.

TABLE III.
COMPARISON OF THE FIT CASE STUDIES

Proposed Models/Variables	Unit	C-FiT	VFiT	SFiT	PFiT	FFiT	SFFiT
Installed power	kWp	1200	1200	1200	6000	12 000	12 000
Unit cost	€/kWp	700	700	700	675	650	650
Total investment cost	K€	840 000	840	840	4050	7800	7800
Annual energy production	MWh	1600	1600	1600	8000	16 000	16 000
Annual energy profit	K€/year	142.59	175.06	190.13	893.44	1715.47	1758.38
Carbon emissions	ton/year	1038.08	1038	1038	5190	10 380	10 380
Annual carbon profit	K€/year	41.52	41.52	41.52	207.62	415.23	415.23
Average support price	€cent /kWh	11.88	10.94	11.88	11.17	10.72	10.99
Payback time	years	4.56	3.88	3.63	3.68	3.66	3.59

FiT, feed-in tariff; FFiT, full flexible FiT; PFiT, partial FiT; SFiT, standard FiT; SFFiT, semifixed semiflexible FiT; VFiT, variable FiT.

IV. CONCLUSION

Supporting renewable energy and the function of smart grid in renewable energy are presented in this study. Support policies of renewable energy and its current situation in Turkey are explained. The FiT application has been examined from different aspects and its necessity for meeting the future energy needs has been emphasized.

Smart grids are already in use in some countries and can be used for long-term development in other countries. One method of integrating renewable energy into smart grids is FiT applications.

Feed-in tariffs have been used continuously in Turkey as a renewable energy support mechanism and have been continuously developed depending on the current market conditions. As of August 2022, the share of power plants using solar and wind energy in the total installed power was 19.5%. If hydraulic energy is added to these, it can be said that 51.5% of Turkey's installed power consists of RESs.

In order for the FiT mechanism to work more effectively, the same electricity purchase and sale prices in the same distribution region are applied in the electricity market. Increasing the support period from 10 to 15 or 20 years can help ensure continuity in the electricity market. In particular, the inclusion of energy storage facilities in the scope of support is an important factor in increasing energy supply security. Compared to other countries, Turkey also actively updates a dynamic FiT application system in case electricity prices and renewable energy technology costs change continuously.

In this study, five different FiT applications were also compared to the current situation. The return periods of investments vary between 3.59 and 3.88 years while the C-FiT is 4.56 years. It is seen that the payback time obtained with the VFiT algorithm proposed in this study is longer. In order to reduce this period, the investor must establish the correct relationship between the real energy need and energy production. Feed-in tariff policies try to guide the investor more accurately in this way.

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