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Investigation the effects of photovoltaic systems on electricity distribution networks and determining the optimum network structure

Fotovoltaik sistemlerin elektrik dağıtım şebekelerine etkilerinin incelenmesi ve en uygun şebeke yapısının belirlenmesi

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Abstract

Distributed generation models have started to be seen intensively in distribution networks with technological developments. The increase in distributed generation resources has brought changes in the grid. Problems such as improper operation of grid protection systems and imbalances in load flow have emerged. In this article, short circuit and load flow analyses of a low voltage distribution network with a distributed generation source are performed and the effects on the network are predicted. Results and predictions regarding the optimum operating conditions of distribution networks in the presence of distributed generation resources have been obtained. Real-time analyses are performed with a power quality measurement device. Scenarios are created in different situations in the presence of distributed generation resources. These scenarios are analysed using a network simulation program. The simulation programme analysed the effects of seasonal conditions and changes in power generation and loads on distribution transformers. In the light of the data obtained, the changes that are required to be made in the inventories in the network topology considering the changes in energy generation time and voltage levels outside the energy generation time are specified. Applications such as automatic tap switching of distribution transformers after a certain power level are proposed.

Keywords: Distributed generation resources, Load flow analysis, Photovoltaic, Short circuit analysis

Öz

Teknolojik gelişmelerle birlikte dağıtım şebekelerinde dağıtık üretim modelleri yoğun olarak görülmeye başlanmıştır. Dağıtık üretim kaynaklarının artması şebekede değişimleri de beraberinde getirmiştir. Şebeke koruma sistemlerinin hatalı çalışması ve yük akışındaki dengesizlikler gibi sorunlar ortaya çıkmıştır. Bu makalede, dağıtık üretim kaynağı içeren alçak gerilim seviyesinde bir dağıtım şebekesinin kısa devre ve yük akış analizleri yapılmış ve şebekenin nasıl etkileneceği tahmin edilmiştir. Dağıtık üretim kaynaklarının varlığında dağıtım şebekelerinin optimum işletme koşullarına ilişkin sonuçlar ve öngörüler elde edilmiştir. Güç kalitesi ölçüm cihazı ile gerçek zamanlı analizler yapılmıştır. Dağıtık üretim kaynakları varlığında farklı durumlarda senaryolar oluşturulmuştur. Bu senaryolar şebeke benzetim programı kullanılarak analiz çalışmaları gerçekleştirilmiştir. Benzetim programı mevsimsel koşullar ile enerji üretim ve yüklerdeki değişimlerin dağıtım trafoları üzerindeki etkileri incelenmiştir. Elde edilen veriler ışığında enerji üretim zamanı ve dışında gerilim seviyelerindeki değişiklikler göz önüne alınarak şebeke topolojisindeki envanterlerde yapılması gereken değişiklikler belirtilmiştir. Dağıtım transformatörlerinin belirli bir güç seviyesinden sonra otomatik kademe değiştirmesi gerekliliği gibi uygulamalar önerilmiştir.

Anahtar kelimeler: Dağıtık üretim kaynakları, Yük akış analizi, Fotovoltaik, Kısa devre analizi

1 Introduction

Energy demand is increasing with the development of industry and technology day by day. The high demand for energy requires the search for new resources for the efficiency of energy production. In terms of energy efficiency, research on renewable energy resources (RER) is increasing [1]. Wind and solar energy are the most widely used resources among RER. In the last 10 years, solar energy has reached 10.2 GW and wind energy has reached 12 GW energy generation capacity. Increases in generation capacity also lead to significant increases in raw material prices [2]. In order to implement the distributed generation model in the system, structural modifications are required in electricity distribution networks. These structural modifications create technical problems with the increase in RER at both high voltage (HV) and low voltage (LV) levels. This problem is caused by the fact that distribution networks are not suitable for the transition from unidirectional energy flow to bidirectional energy flow [3, 4]. In the existing literature, the effect of bidirectional energy flow on the changes in voltage and current levels during and outside of generation has been analysed. These modifications indicate the need to focus on short circuit protection and selectivity [5].

In the existing literature, the distribution system model created in real-time and DigSilent Power Factory has been analysed. In accordance with the IEC 60909 standard, a literature review has been carried out on the effects on the

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network in the presence and absence of distrubeted generation resource (DGR) [6]. It is a study on the effects of solar power plants on short circuit in the presence of HV networks, elimination of these effects and short circuit protection. Distribution network topology is created and analysed in order to simulate short circuit conditions on the network [7, 8]. The network structure has evolved into a bi-directional energy flow with the addition of DGRs to the distribution networks. Before these transitions, the cost differences caused by the changes to be made in the network are analyzed [9, 10]. As a result of the increase in RERs, load flow problems have emerged. Load flow analysis and projection study are performed in 10 busbar system by using Newton-Raphson Method (NRM) in ETAP programme [11]. Distributed generation sources are increasing in distribution networks at LV level. This increase has raised the issue of transition to smart grid and grid management. Studies have been carried out on SCADA structure and architecture for grid management [12]. In another study, a general examination of micro-grid structures is made and the results of the situations are seen [13]. Increasing the presence of DGRs in microgrids leads to power outages and grid integration problems. A smart structure is needed in order for the network to minimise the failure in the fastest way during power outages [14, 15, 16]. Microgrids have helped to reduce the areas affected by power outages and energy shortages. The researches have examined the conditions of microgrids together with smart management systems [17, 18, 19].

This literature review shows that increasing the presence of distributed generation resources in electricity distribution networks is an important requirement for the change of inventories used in network management.

In this study, load flow analysis has been performed with Newton-Raphson method in the grid with DGR. Short circuit analysis was performed at LV level using Digsilent Power Factory programme. In the study, the changes in the voltage levels of the bidirectional flow during generation and non-generation hours in real time and simulation programmes are examined. This change brings along the need for effective short circuit protection as a result of the rise and fall of the current level [20, 21]. As a result, this study aims to ensure that the need for variable value fuses in short circuit protection in terms of interoperability of distributed generation and electricity distribution network and the necessity of distribution transformers with automatic tap adjustment in the management of changes in voltage level meet at the optimum point [22, 23].

2 Materials and methods

In this section, virtual analyses are performed for the values that cannot be measured instantaneously, as well as real-time measurements in order to create the most suitable structure for the distribution network containing DGR.

2.1 Network topology

Real-time measurements have been taken for the simulation studies to create the distribution network structure with the most appropriate DGR presence. Actual data from the national electricity distribution network are used during the selection of the region and network. Fault diversity, suitability of the site for distributed generation installation and load conditions are determined as the first priority. In this framework, the national electricity distribution network structures are modelled by simulation with DigSilent Power Factory application considering fault diversity and load conditions.

In this research, an analysis is performed by modelling a 1000 kVA internal type transformer model with 5 outputs in the urban underground network topology. In addition, 1 lighting output with a power of 20 kVA is added. The main distribution panel (MDP) used in TEDAŞ type project is used as the distribution panel. The supply of the distribution transformer is aluminium XLPE cable. Transformer voltage level is 31.5/0.4 kV and transformer connection group is DYN11. There are 6 stages in the HV part of the transformer. The percentage uk value of the distribution transformer is 5.92%. The type of cable between the transformer LV output and busbar is NYY YVV. The busbar part of MDP is 100x10 mm² copper busbar. There are 5 distribution line outputs from MDP. Field distribution boxes (FDB) are TYPEB_400_400_400_5C specified in TEDAŞ MYD type project. In Table 1, power information of the energy outputs from MDP, NH fuse values used as short circuit protection element, cable cross-section information of the outputs are given. NYY YVV is used as cable type in all outputs.

Table 1. 1000 kVA transformer MDP equipment list

MDP Outputs	Power	Fuse Value	Cable Cross-Section
Output 1	250 kVA	400 A	3×185+95 mm²
Output 2	250 kVA	400 A	3×185+95 mm²
Output 3	250 kVA	400 A	3×185+95 mm²
Output 4	160 kVA	250 A	3×150+70 mm²
Output 5	100 kVA	160 A	3×150+70 mm²

A total of 15 TYPE B FDBs are used in the network modelling. In the substation area, 52 real load structures are simulated by sampling from the national electricity distribution network. Load types of 3, 5, 8, 13, 13, 20, 65 and 93 kW are created and modelling was performed. The modelling study was carried out by using 5 TYPE B FDBs on output 1, 3 FDBs on output 2, 4 FDBs on output 3, 2 FDBs on output 4 and 1 FDB on output 5.

The FDB information on the energy outputs determined in the network modelling are given in Table 2, Table 3, Table 4, Table 5 and Table 6. Power information on the power outputs, short circuit protection element NH fuse values and cable cross-section information of the loads are given in the tables as well as FDB information. Cable type NYY YVV is used as cable type in all outputs.

Table 2. Equipment list of network model output 1 field distribution boxes

Output 1	Load No	Power	Fuse Value	Cable Cross-Section
DB 1	Load 1	93 kW	160 A	4×50 mm²
	Load 2	8 kW	16 A	4×6 mm²
DB 2	Load 3	20 kW	40 A	4×10 mm²
	Load 4	8 kW	16 A	4×6 mm²
	Load 5	8 kW	16 A	4×6 mm²
	Load 6	8 kW	16 A	4×6 mm²
	Load 7	8 kW	16 A	4×6 mm²
DB 3	Load 8	13 kW	32 A	4×10 mm²
	Load 9	8 kW	16 A	4×6 mm²
	Load 10	3 kW	10 A	2×6 mm²
DB 4	Load 11	8 kW	16 A	4×6 mm²
	Load 12	8 kW	16 A	4×6 mm²
	Load 13	13 kW	32 A	4×10 mm²
	Load 14	8 kW	16 A	4×6 mm²
DB 5	Load 15	13 kW	32 A	4×10 mm²
	Load 16	13 kW	32 A	4×10 mm²
	Load 17	13 kW	32 A	4×10 mm²

Table 3. Equipment list of network model output 2 field distribution boxes

Output 2	Load No	Power	Fuse Value	Cable Cross-Section
DB 6	Load 18	65 kW	125 A	4×35 mm²
	Load 19	13 kW	32 A	4×10 mm²
	Load 20	65 kW	125 A	4×35 mm²
	Load 21	13 kW	32 A	4×10 mm²
DB 7	Load 22	20 kW	40 A	4×10 mm²
	Load 23	3 kW	10 A	2×6 mm²
	Load 24	20 kW	40 A	4×10 mm²
	Load 25	20 kW	40 A	4×10 mm²
DB 8	Load 26	13 kW	32 A	4×10 mm²
	Load 27	20 kW	40 A	4×10 mm²
	Load 28	8 kW	16 A	4×6 mm²

Table 4. Equipment list of network model output 3 field distribution boxes

Output 3	Load No	Power	Fuse Value	Cable Cross-Section
DB 9	Load 29	93 kW	160 A	4×50 mm²
DB 10	Load 30	93 kW	160 A	4×50 mm²
DB 11	Load 31	8 kW	16 A	4×6 mm²
	Load 32	13 kW	32 A	4×10 mm²
	Load 33	8 kW	16 A	4×6 mm²
	Load 34	5 kW	16 A	4×6 mm²
DB 12	Load 35	8 kW	16 A	4×6 mm²
	Load 36	13 kW	32 A	4×10 mm²
	Load 37	8 kW	16 A	4×6 mm²

Table 5. Equipment list of network model output 4 field distribution boxes

Output 4	Load No	Power	Fuse Value	Cable Cross-Section
DB 13	Load 38	8 kW	16 A	4×6 mm²
	Load 39	65 kW	125 A	4×35 mm²
	Load 40	8 kW	16 A	4×6 mm²
	Load 41	8 kW	16 A	4×6 mm²
	Load 42	8 kW	16 A	4×6 mm²
DB 14	Load 43	20 kW	40 A	4×10 mm²
	Load 44	8 kW	16 A	4×6 mm²
	Load 45	8 kW	16 A	4×6 mm²
	Load 46	8 kW	16 A	4×6 mm²
	Load 47	8 kW	16 A	4×6 mm²

Table 6. Equipment list of network model output 5 field distribution boxes

Output 5	Load No	Power	Fuse Value	Cable Cross-Section
DB 15	Load 48	20 kW	40 A	4×10 mm²
	Load 49	8 kW	16 A	4×6 mm²
	Load 50	8 kW	16 A	4×6 mm²
	Load 51	8 kW	16 A	4×6 mm²
	Load 52	8 kW	16 A	4×6 mm²

2.2 Real-time energy analysis on distributed generation

In this research, the effect of the real-time DGR system on the distribution system is analysed together with the simulation of the distribution network. In this context, real-time measurements are made in the distribution network, which is established with the network model defined in the research and which includes a DGR. The sustainability of the distribution network, energy supply security and energy quality depend on certain criteria. These criteria are that power quality data such as voltage, current, active power, reactive power must be at values determined by standards. These values need to be measured and analysed in cases where there is a DGR connected to the network and there is no presence of DGR. Energy analysers and power quality measurement devices (PQMDs) are used to perform the measurement process. In the framework of the research, A-Eberle brand PQI-DA smart model energy analyser and energy analysis set are used to measure and transfer the data to the computer environment. Figure 1 shows the PV panel photographs of the rooftop solar power plant (SPP) located at the real-time measurement point with grid model DGR. The measurement process is performed with the PQMD shown in Figure 2. Figure 3 shows a simulated real-time distribution grid with distributed generation resources.

Figure 1. Real time measurement point rooftop SPP facility

Figure 2. Power quality measurement device with A-Eberle energy analyser

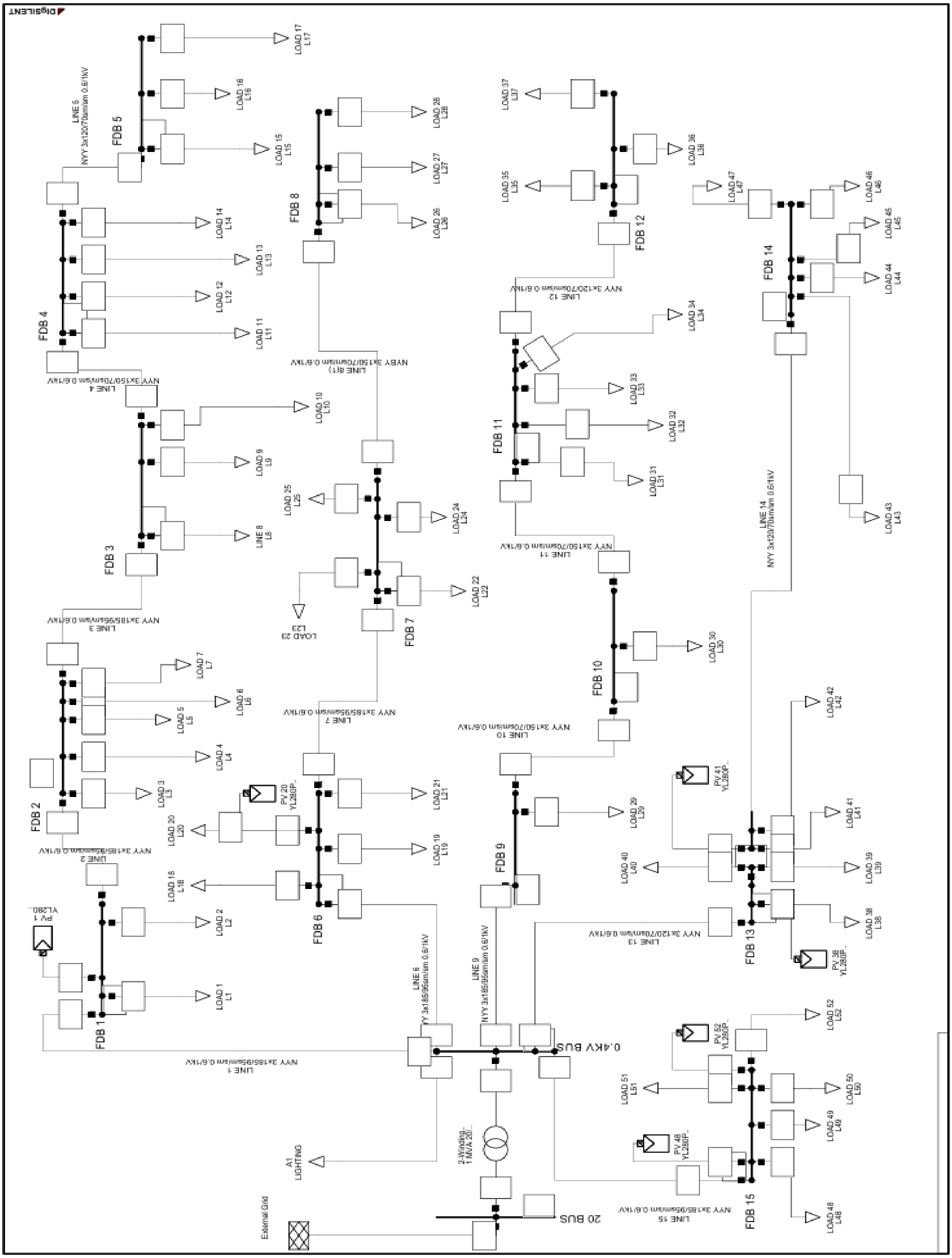

Figure 3. Network model drawing in the presence of DGR

2.3 Load flow analysis with newton-raphson method

In power systems, Newton-Raphson method is used for load flow analysis. The aim of the Newton-Raphson method is to reduce the error phenomenon to zero. For this situation, Taylor series expansion of functions is required. The Taylor series expansion of the function with n variables defined as y=f(x) can be formulated as follows in Equation (1);

$$y = f(x_0) + \left.\frac{df}{dx}\right|_{x=x_0} (x - x_0) \qquad (1)$$

In Equation (2), our matrix called J(i) is the Jacobian matrix and this matrix is defined as follows.

$$[J(i)] = \left[\left.\frac{\partial f}{\partial x}\right|_{x=x(i)}\right] = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \cdots & \frac{\partial f_1}{\partial x_N} \\ \vdots & \cdots & \vdots \\ \frac{\partial f_N}{\partial x_1} & \cdots & \frac{\partial f_N}{\partial x_N} \end{bmatrix}_{x=x(i)} \qquad (2)$$

In Equation (2), instead of calculating the inverse of the matrix J(i), the solution with a system of linear equations is preferred. Instead of writing the inverse of the J(i) matrix, it is preferred to rewrite it in Equation (3).

$$J = (i)\Delta x(i) = \Delta y(i) \qquad (3)$$

After that, the following 4 steps are applied for each convergence process and these steps are continued until the tolerable value is reached;

Step-1: Δy(i) is calculated,
Step-2: J(i) is calculated,
Step-3: Calculate Δx(i) by Gaussian elimination and back substitution,
Step-4: The value of x(i+1) is calculated.

2.4 Voltage drop calculation methods

The cross-sections of the network conductor, the load level on the HV or LV distribution network, the type of load, the length of the network to the resource and the branch structure create problems in distribution networks in the presence or absence of DGR. As stated in the electrical high current installations regulation (EKAT) regulation, voltage drop should not exceed 7% in HV installations. In LV installations, it should not exceed 5%. The calculation of the values given in Table 7 is calculated according to the network structure.

Table 7. Voltage drop calculation methods

Phases	Voltage Values	Formulas
3 phase	380	e% = 0,0124 (L.N.)/(S.)
1 phase	220	e%= 0,074 (L.N.)/(S.)

The definitions of the formulas given in Table 7 are e%= Voltage drop, N=Power (kW), U=Voltage (Volt), L=Line distance (metre), S=Conductor cross section (mm²), K=Conductivity coefficient (m/Ω mm²), K (Cu) 56 m/Ω mm², K (Al) 35 m/Ω mm².

2.5 Short circuit calculation methods in HV and LV networks

Short circuit faults occur as a result of the deterioration of the insulation of the conductors in the network with excessive current draw, aging of the insulating material, lightning strikes, contact of external factors (wood, zinc, long-winged birds, etc.) with the line. The current generated during this short circuit is called short circuit current. One of the main parts of the study is to ensure that the short circuits are eliminated by making the correct selectivity to ensure network security. Selectivity means that as a result of a fault occurring on a line, only the breaker that protects on that line opens and the energy continuity on other lines is protected. Selectivity is provided by the proper selection of the rated currents of the circuit breakers to be used in line protection. Overload protection is one of the most important issues with the increase of DGRs in LV network. Short circuit calculations are calculated around TSE-EN60909 standards. In the framework of this standard, it covers the calculation of HV and LV alternating current short circuits. Short circuit faults are divided into 2 as phase-phase short circuit and phase-earth short circuit. Short circuit calculation methods are given in Table 8.

3 Analysis methods and results

Analyses made with the materials used in the study and the results of the approaches are evaluated. The results are the output values that are necessary for the creation of the optimal network structure.

3.1 Load flow analysis with DIgSILENT power factory program

As a result of the measurements made with the analysis programme and energy analyser, the data in Figure 4 and Figure 5, where winter and summer months are simulated, are obtained. A comparison is made between the data obtained when the energy consumption rates are 20%, 50%, 80% and 100%.

Table 8. Short circuit calculation methods

Three-Phase Fault	Phase-Phase Fault	Two-Phase-Earth Fault	Phase-Earth Fault
$I_k'' = \frac{1.1U_n}{\sqrt{3}\lvert Z_1\rvert}$	$I_k'' = \frac{1.1U_n}{\lvert Z_1 + Z_2\rvert}$	$I_k'' = \frac{\sqrt{3}\,1.1U_n}{\lvert Z_1 + Z_0 + Z_0 . \frac{Z_1}{Z_2}\rvert}$	$I_k'' = \frac{\sqrt{3.1.1U_n}}{\lvert Z_1 + Z_2 + Z_0\rvert}$

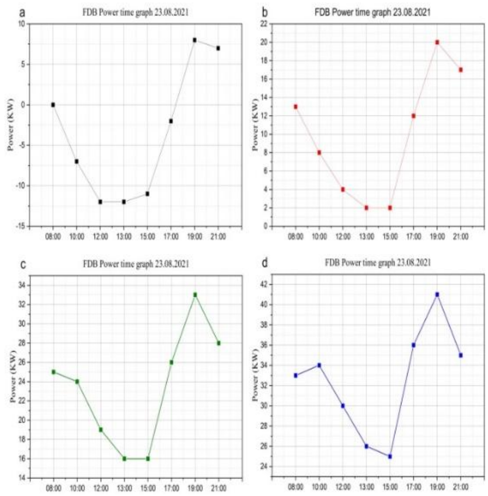

Figure 4. DB summer season power analysis a) 20% load usage case b) 50% load usage case c) 80% load usage case d) 100% load usage case

As a result of the load flow analysis performed in the analysis programme, it is simulated by considering the real-time data in the FDB to which the DGR is connected. As a result of this analysis, a value close to the real-time measurement on 23.08.2021 is obtained. As can be seen in Figures 4 and 5, it is concluded that the amount of energy produced from the SPP and the energy consumption rates of 20%, 50%, 80% and 100% are in line with the real-time power values. Generation is observed to be at maximum level due to the fact that it is summer month when energy consumption is 20%. Due to this situation, the energy production has seen negative values and it is seen that energy is pressed from the consumption point in the direction of the grid. In the summer months of the region, the use of temperature-induced air conditioning causes the installed power to be used by 50% and above. It is observed that the increase in consumption reduces the effect of energy production.

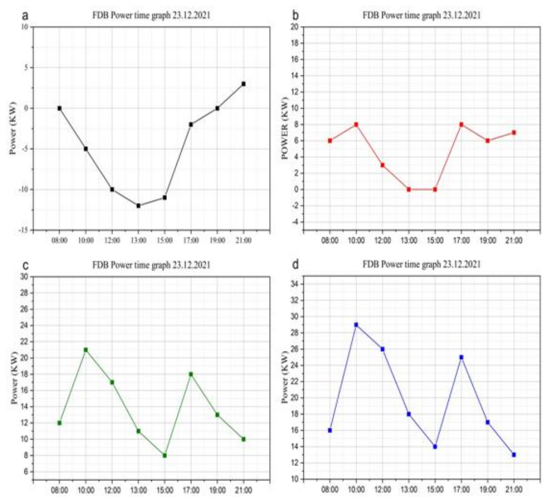

Figure 5. DB winter season power analysis a) 20% load utilisation case b) 50% load utilisation case c) 80% load utilisation case d) 100% load utilisation case

Figure 5 shows the comparison of real-time measurements and analysis data taken under winter conditions on 23.12.2021. Depending on the seasonal data, differences between energy production and consumption occur. These differences are observed in the study during the evening hours when energy consumption is intense and when a comparison is made with the summer season graphs.

3.2 *Real time load flow analysis*

It is seen that the results of the analyses in Figures 4 and 5 in the virtual environment and the results of the analyses in especially Figures 6 and 7 in real time match each other with a high degree of accuracy in a 20kWp SPP installed load.

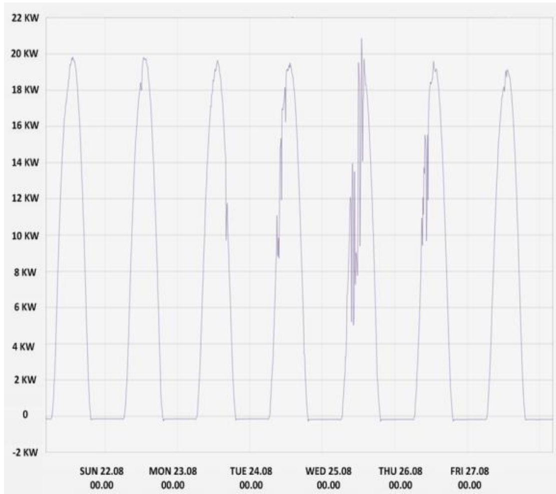

Figure 6. 21-27.08.2021 1 week total active power (kW) measurement

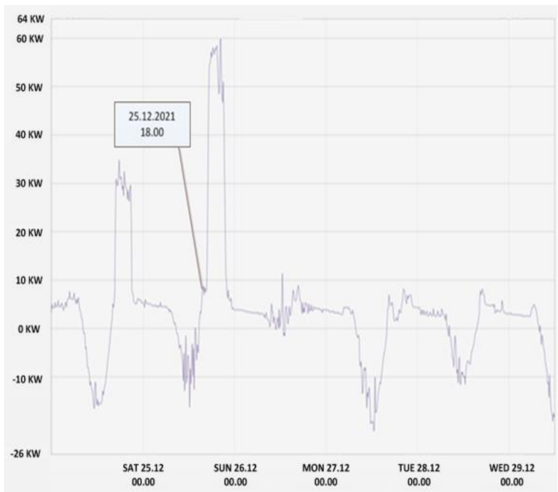

Figure 7. 25.12.2021 1 week load total active power (kW) measurement

The residential and commercial loads on the real-time measured FDB are analysed. In this analysis, the relationship between the energy utilisation profile and the generation profile, the results of which are shown in Figures 6 and 7, is examined. The current generation analysis using NRM and the real-time measurement simulation ratio is very similar as shown in Figure 7 dated 24.12.2021. In the real-time measurement, 2 commercial enterprises located in the analysed FDB make intensive energy consumption on weekends. Due to the fact that there are commercial centres, both production and consumption intensity is observed in the power graph in Figure 7 between 24.12-30.12, 24-25 and 26. Especially on 25 December, besides the production in the morning hours, it is measured that 2 commercial establishments consumed energy in the morning. It is observed that production and consumption complemented each other at a very high rate.

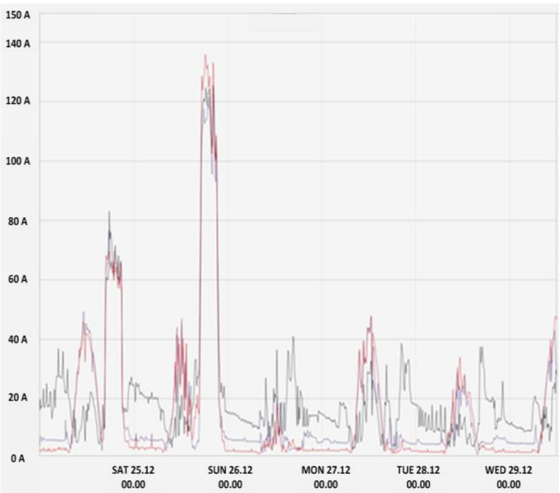

Figure 8. 25.12.2021 1 week total current (A) measurement

The measurements made at the FDB provide information about the single phase load density and the per phase effects of consumption and generation rates on the grid, as shown in Figure 8. The knowledge obtained in the study will provide speed gains in managing network losses, storage and voltage drop on the network. For example, when the maximum values seen during peak energy consumption hours such as 25.12.2021 and 26.12.2021 are compared with the maximum values seen during production hours, it will provide ease of design in the selection of protection systems. In addition, the knowledge of current values in the load panel and distribution panels will enable selectivity for overload and short circuit protection with these values.

3.3 *Real time analysis of the effects of DGRs on voltage*

The main problem of voltage regulation in distribution networks is the unplanned development of the construction speed. The rate of construction means that the power demand in the distribution network is realised far above the planned loads. This rapid development causes the power line to be longer than the optimum level. Therefore, the load ratio increases and the conductor cross-sections are not sufficient for this ratio. The effects of the network structure and loads on the voltage values are examined and analysed for the creation of the optimal network within the scope of the research.

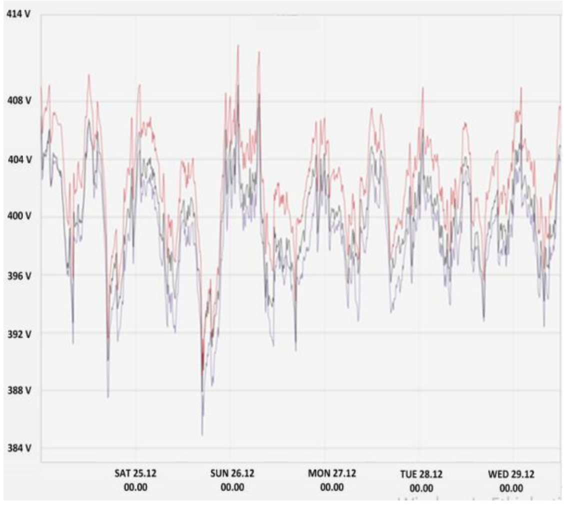

Figure 9. 25.12.2021 1 week voltage change

Figures 9 and 10 show the changes in voltage values in real time measurements. It has been analysed that these changes increase in loads and SDCs during power generation times, while they show changes depending on the demand power density during non-generation times. In these examinations, a decrease in voltage values occurs as a result of the increase in energy consumption in the evening hours and the lack of production due to the energy production with SPP. Voltage values are examined on 24-25 and 26 December. In the analysis, it is observed that the increase in the percentage of the load ratio in the power section in the network caused an intense decrease in the voltage value.

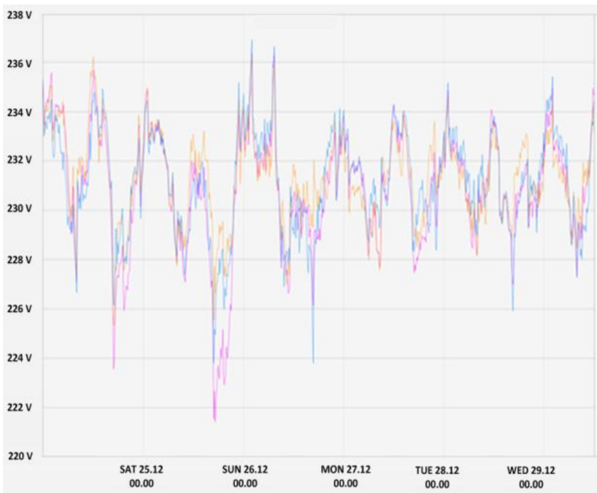

Figure 10. 25.12.2021 1 week load voltage change

Load flow analyses are performed on the network topology with 1000 kVA DGR, which is created by sampling global and national network structures. The voltage values are taken from the loads that are close to the resource in the network, i.e. the loads selected as primary. In Table 9, there are certain changes in the voltage values in the network structure when the load ratio increases 5 times, i.e. from 20% to 100% load ratio.

Table 9. Distribution network model underground urban network voltage analysis table with DigSilent PF

1000 kVA without DGR			Voltage Values					
			Load 48	Load 2	Load 9	Load 22	Load 17	Load 33
Transformer Loading Rate	Time: 13.00	20%	399 V	397 V	394 V	395 V	392 V	394 V
		50%	396 V	391 V	385 V	386 V	380 V	384 V
		80%	394 V	385 V	375 V	377 V	367 V	374 V
		100%	392 V	380 V	368 V	371 V	357 V	366 V
	Time: 20.00	20%	399 V	397 V	394 V	395 V	392 V	394 V
		50%	396 V	391 V	385 V	386 V	380 V	384 V
		80%	394 V	385 V	375 V	377 V	367 V	374 V
		100%	392 V	380 V	368 V	371 V	357 V	366 V

Table 10. Voltage analysis table with distribution network model DigSilent PF

1000 kVA DGR At First Side			Voltage Values					
			Load 48	Load 2	Load 9	Load 22	Load 17	Load 33
Transformer Loading Rate	Time:13.00	20%	400V	401V	398V	399V	396V	394V
		50%	398V	396V	390V	386V	385V	385V
		80%	396V	390V	380V	382V	372V	375V
		100%	394V	386V	373V	376V	363V	367V
	Time: 20.00	20%	399V	397V	395V	395V	393V	394V
		50%	397V	393V	387V	388V	382V	384V
		80%	395V	388V	378V	380V	370V	374V
		100%	393V	384V	372V	374V	361V	367V

Thus, a 2% change is observed on the load close to the source and an 8% change is observed on the load at the end of the network. Although the voltage values at the beginning of the network remain within the limit values, it is observed that the voltage drop at the point furthest from the source approaches the limit values.

In the analyses performed in the 1000 kVA DGR underground urban network structure, the changes in voltage values are examined in Table 10. There is no change in the percentage changes in voltage values compared to the network structure without DGR. Considering the installed capacity of the DGR density in the network, it is observed that being close to the source had little effect on the decrease in the voltage values in the network.

Table 11. Distribution network model DGR head SPP installed loads

Load	DGR Installed Power Value			
	8 kW	20 kW	65 kW	93 kW
Load 1				×
Load 20			×	
Load 38	×			
Load 41	×			
Load 48		×		
Load 52	×			

In Table 11, the sum of the power value of the loads with DGRs corresponds to 20% of the grid installed capacity. Voltage values are measured and voltage drop analysed in the above 1000 kVA transformer zone in the presence and absence of DGR. Comparative analyses of voltage responses are made with the results in Table 9 and Table 10. The relationship between load status and production hours is analysed in the study. During the hours when the load is low and the production is intense, the rate of change between the voltage values is very low and the voltage level is within the desired value range at the end of the line. In cases where the load ratio is above 60% and the power plants are located at the head of the network, the voltage values fall below the 10% value specified in the standards. Due to the fact that the majority of the power plants at LV level are SPPs, intense voltage drops are experienced during non-production hours in regions such as the Mediterranean region where electric heaters are used as a heating method in winter.

3.4 Simulation analysis of the change of voltage values in distribution transformer tap adjustment

Load analyses are initially performed at transformers in the real-time network at step 3, which is known as HV 31.5 kV and LV 0.4 kV. In the network management, the LV voltage level is increased in the secondary part by lowering the tap where the rate of decrease in voltage values is high. Considering this situation, voltage analyses are performed with tap adjustment at various load ratios and dates. The results of these analyses are shown in Table 12.

Table 12. Distribution network model transformer step adjusted voltage analysis at DGR at first side

1000 kVA DGR At First Side			**Voltage Values**					
			Load 48	**Load 2**	**Load 9**	**Load 22**	**Load 17**	**Load 33**
Transformer Loading Rate	23.08.2021 %20	1	421V	421V	419V	419V	417	415
		2	410V	411V	408V	408V	407V	405V
		3	400V	400V	398V	398V	396V	394V
		4	391V	391V	388V	388V	386V	384V
	23.08.2021 %80	1	417V	411V	402V	403V	394V	396V
		2	406V	400V	391V	392V	384V	386V
		3	396V	390V	382V	383V	375V	376V
		4	386V	381V	373V	373V	366V	367V

In the analysis results shown especially Table 12, the load ratio and seasonal data present the necessity of tap adjustment as a finding. The existence of DGRs in the distribution network increases the voltage values at the busbars. This situation causes device failures in loads connected to the network due to overvoltage. In order to prevent this situation, real-time network monitoring and automatic tap adjustment are required.

3.5 Short circuit simulation results in the presence and absence of DGR

Short circuit methods that may occur in electricity distribution networks are simulated with the analysis programme and examined in a virtual environment. In accordance with the IEC 60909 standard, investigations are carried out in the presence and absence of DGR and analyses are made on the effects on the network and fuse selectivities. The results are analysed for the impedances of short circuit faults at the time of failure and when the impedance is zero. The results of the network responses in certain regions of the network, at certain loads and at various NH blade fuse values are obtained. Short circuit interruption times of the fuse values are examined by using the short circuit analysis regulation using the analysis programme. In this part of the study, analyses are performed at 0 ohm, 0.5 ohm and 1 ohm impedance values at 20%, 50%, 80% and 100% load conditions determined in the network. IEC curve responses of 16 A, 50 A, 80 A and 100 A NH blade fuses are analysed. Considering that the current value of the short circuit fault on the busbar does not change with the load ratio, the effect of impedance on the short circuit current is analysed.

As shown in Figure 11, the NH blade fuse used as circuit breaker reacts in a short time as 10 ms against 7557 A, which is the highest short circuit current that can occur on the busbar. This condition is tested against a 16 A NH blade fuse when the existing network is operating at 20% load. At 0 ohm impedance value, it is observed that all the loadings gave the same response time and went to tripping. However, the max. short circuit current is realised only at 0 ohm short circuit impedance. In other cases, the circuit response of the fuses is as shown in the current-time curves below.

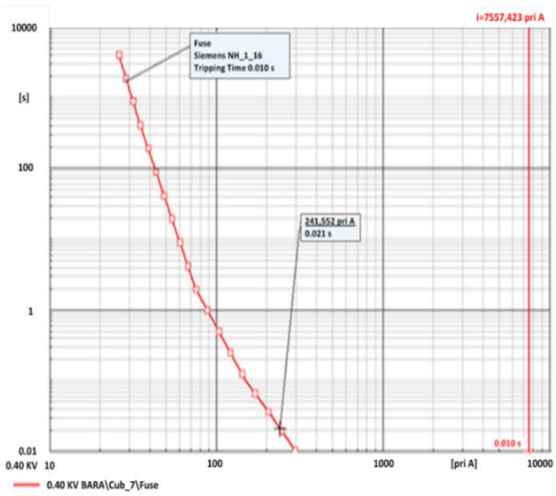

Figure 11. NH 1 size 16 A blade fuse IEC curve and behaviour during short circuit Z=0 ohm

In the short circuit analysis at Z=0.5 ohm, NH fuse responses at 16 A and 100 A values are analysed. As a result of the analyses, the circuit breaking response to 464.29 A short circuit current is shown in Figure 12 and Figure 13. In these investigations, the effects of the short-circuit nominal current in the busbar during load conditions on the network are focused on the effects of the disconnection time on the network. The unbalance of the circuit breaking times is especially caused by the proportional mismatch between the load ratio of the network and the nominal value of the fuse. Especially when Figure 13 is considered, it is seen that the exposure time of the circuit to short circuit is very long. This will cause deterioration in the structure of the network elements and cause the device to burn as a result of short circuit failure.

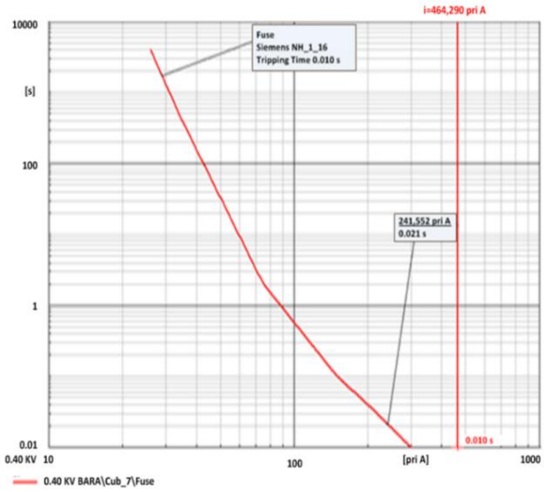

Figure 12. NH 1 size 16 A blade fuse IEC curve and behaviour during short circuit Z=0.5 ohm

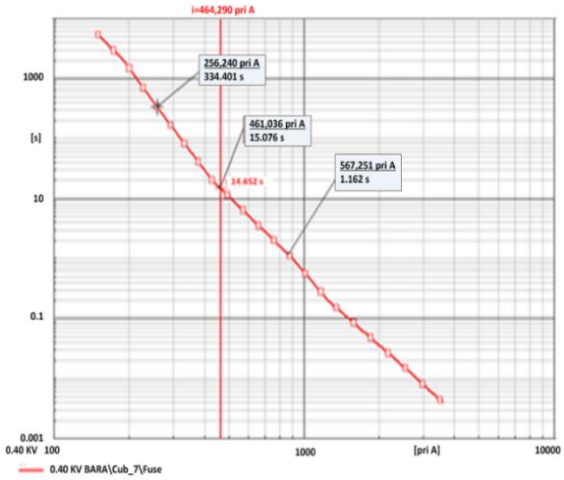

Figure 13. NH 1 size 100 A blade fuse IEC curve and behaviour during short circuit Z=0.5 ohm

The short circuit analyses performed with the analysis program are examined at 0 ohm, 0.5 ohm and 1 ohm fault impedances. As a result of these analyses, it is seen that the short circuit current decreased as the impedance value increased from Figure 11 to Figure 15. Here, the increase and decrease in the values of the short circuit impedances is to accurately simulate the short circuits occurring in real-time networks. These analyses contribute to the selectivity of the network to be planned. It is found that the fuses determined in overload faults, which are called as the entanglement of the conductors of 2 phases, which will occur especially in overhead line dense networks with low load conditions, will cut the circuit in a very long time. In a 1000 kVA transformer zone, a moment is simulated when there is a 20% load presence at the point where protection is made with a fuse of 100 A, which is determined based on the DGR density under normal conditions. At this moment, the fault impedance is assumed to be 1 ohm. When the overload fault is simulated with this assumed impedance value, it is seen from Figure 15 that the 100 A NH blade fuse cuts the fault in 545 seconds. This time becomes longer with the increase in impedance value. If the load condition was 20% and circuit protection was made with a 16 A NH blade fuse, the fault would have been concluded in a very short time such as 10 ms as shown in Figure 11. Short circuit events similar to this situation affect the energy production conditions in the presence of DGR. Failure to ensure network supply security will cause material losses. Due to the regulation on the ability of rooftop SPPs to generate up to 25 kWp in RESs, it creates the situation that the load value used is much lower than the installed power. This situation means that there is load utilisation at a very low level than the determined load value outside the production times. It is found that the network needs variable fuse protections against short circuits that will occur according to the load condition. Considering the analyses to be made, fuse selections should be determined while planning the network structure. The necessity of designing a LV protection element that can automatically change itself in protection groups according to the network load change arises.

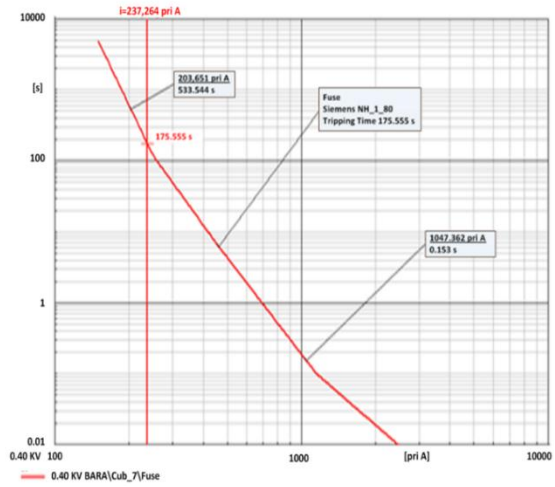

Figure 14. NH 1 size 80 A blade fuse IEC curve and behaviour during short circuit Z=1 ohm

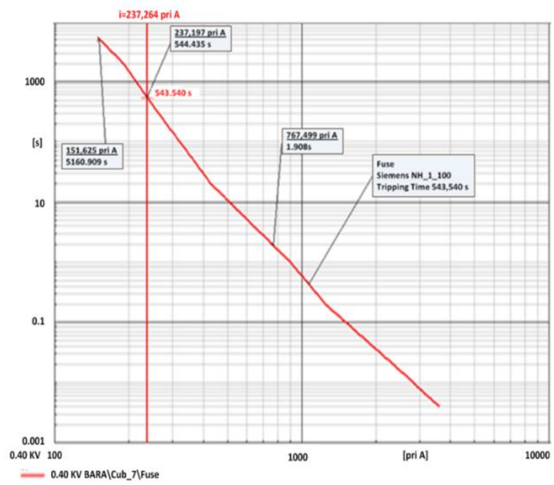

Figure 15. NH 1 size 100 A blade fuse IEC curve and behaviour during short circuit Z=1 ohm

4 Conclusion

The increasing number of RES-based generation plants in distribution networks brings some benefits as well as problems. These benefits and problems are analysed in this study. These analyses are evaluated with the changes of seasonal conditions on generation and load. The effect of the changes on the distribution transformer and the analyses for ensuring energy quality have been examined and results have been obtained. These results are intended to provide a projector for the future and to ensure that new network planning is more appropriate and economical. Within the framework of this study, the following contributions are aimed;

1. In the light of the measured and analysed values, the rate changes of voltage levels during generation and non-generation times are monitored. Due to the difference between the data, the distributed generation load ratio should also be taken into account in network planning. Distribution transformers should have an automatic tap change feature after a certain power level, taking into account the voltage changes between generation time and consumption time.
2. The fact that the load ratio due to distributed generation is very variable and the fuses in the protection systems are selected in accordance with the installed power creates selectivity and protection problems. In order to prevent this situation and to enable the protection elements to fulfil their duties correctly, protection elements that can change the nominal current value and adjust it according to the load condition should be designed and used for the optimum network.
3. The aim of this study is to find the necessary road signs for the optimal network configuration by applying the conditions specified in the first and second points to the network at the LV level of distribution networks.

The distribution of distributed generation resources in the grid affects the efficiency at voltage values. Step changes in the transformer create 8% improvement in voltage values. This change should be automatic according to the loads during the day. Considering the network load utilisation status, there is a 5% change in voltage values between 20% load and 80% load. This shows the importance of the effects of load distribution and distribution generation layout on efficiency.

The data obtained in the study are orientated towards the correct planning of DGRs in the grid and the correct installation of automatic controllable transformers and fuses of the grid management systems. These aims help to eliminate uncertainties in the management of grid protection systems and voltage variations. The newly proposed management model contributes to the realisation of the application at the most suitable point.

Conflict of Interest

The authors declare that there is no conflict of interest.

Similarity Rate (iThenticate): 15%

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