Research on the implementation of voltage control on MV busbars due to the influence of PV connection

Daniela F. NISTE
Department of Power Systems and Management
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
Daniela.Niste@enm.utcluj.ro

Silviu ȘTEFĂNESCU
Department of Power Systems and Management
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
Silviu.Ștefănescu@enm.utcluj.ro

Aurel BOTEZAN
Department of Power Systems and Management
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
Aurel.Botezan@enm.utcluj.ro

Sorin G. PAVEL
Department of Power Systems and Management
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
Sorin.Pavel@enm.utcluj.ro

Anca MIRON
Department of Power Systems and Management
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
Anca.Miron@enm.utcluj.ro

Horia G. BELEIU
Department of Power Systems and Management
Technical University of Cluj-Napoca
Cluj-Napoca, Romania
Horia.Beleiu@enm.utcluj.ro

***Abstract*— Voltage control is essential for optimizing power generation and management in photovoltaic (PV) systems. To minimize power losses and improve overall performance, a transformer plot reconfiguration scheme based on grid modeling is proposed. The grid model considers key parameters such as line impedance and local power consumption. By analyzing the model, the system identifies the optimal transformer plot configuration to reduce energy losses and improve power flow in the network. In order to achieve automatic voltage control (AVC), a control calculation was implemented to adjust the configuration of the transformer plots so that the voltage could be adequately optimized according to the load that is present in the electrical network. Implementing voltage control brings several benefits, including improving grid stability, optimizing power generation, and increasing flexibility. Successful implementation of this solution can significantly contribute to a sustainable energy transition and better integration of renewables into the electricity grid.**

Keywords*— *PV, voltage control, tap change, network modeling, AVC, power generation, energy management.

I. INTRODUCTION

Currently, energy research is a widely discussed and popular topic globally, with a focus on transitioning towards a low-carbon society. Electricity is a crucial source that ensures a high quality of life and supports the global economy. Energy comes in various forms, but renewable energy sources provide access to clean, sustainable energy in large quantities due to their self-renewing nature [1].

This paper presents issues related to connecting a photovoltaic power plant (PV) to the grid in accordance with legal provisions in the electricity sector, as the transition to green energy accelerates.

The power system comprises electricity generating units and consumers connected by an electricity grid consisting of power lines. Its purpose is to transmit electricity from production to consumption while maintaining acceptable reliability and quality of voltage and current for all connected loads, whether producers or consumers, at the lowest cost possible. Any sudden change in either the production process or electricity consumption could jeopardize the desired situation. Modern society heavily relies on the availability of both cheap and reliable electricity. Recent events, such as power cuts and sudden price increases, have highlighted this dependence. Deregulating the existing electricity market aims to facilitate the introduction of new electricity producers. This will improve market access, increase competition, and ultimately lead to lower prices [2].

Over the past century, electricity generation has expanded, utilizing both renewable and traditional energy sources. Despite the increase in electricity production, consumption has also risen, and the fact that PV are located far from consumers is a disadvantage.

Distribution networks consist of transmission lines and the part that supplies electricity to consumers. Transmission lines are designed to carry energy from PV to consumers. The new regulations allow for voltage to be raised on the high-voltage side, reducing energy losses during long-distance transmission. When supplying low-voltage consumers, several conditions for connecting PV to the grid are considered. Transformer stations are equipped with transformers to convert energy from high voltage (HV) to low voltage (LV). It is important to note that electricity flows in one direction only, from the power generation plant to the final consumers. However, PV handle a two-way flow of energy, allowing them to feed energy into the grid when a large amount is generated. Invertors are devices responsible for converting electricity from one form to another, including voltage conversion and power flow regulation.

The paper is structured into five main sections. The first section contains general aspects about the conditions for connecting PV to the electricity grid, as well as the impediments that arise through their integration into the grid. In the second section, a short state of the art is presented regarding the determination of energy losses in the grid and the analysis of the consequences of introducing PV into the grid. Section III introduces general concepts regarding the configuration of power grids, as well as methods for reducing voltage. Section IV describes the application method of the proposed case study and presents the model implemented in the steady-state calculation program for determining the values of interest. In Section V, tables are presented with detailed results following the proposed calculation, as well as the implementation of a voltage control method by automatic voltage control and changing transformer plots to reduce voltage and decrease losses. Finally, the conclusions of the

979-8-3503-4929-0/24/$31.00 ©2024 IEEE

work were recorded, and a further direction of development of the implemented case study was proposed.

II. STATE OF THE ART

Research studies have shown that placing PV systems in overloaded distribution systems can cause stability issues, voltage fluctuations, and even power failures that can lead to equipment damage. This is because some power grids are not designed to handle a bi-directional power flow [3].

Previous studies on optimizing voltage control have primarily focused on using inverters to manage reactive power. Voltage control solutions have been implemented to address the imbalance caused by connecting a PV [4].

In another study on voltage analysis the authors conducted in [5] an extensive study on effective voltage and accent voltage by developing end-user influencing variables. Therefore they extended the analysis by clearly highlighting the voltage levels in a distribution network of the system considered in the study. At the basis of the study were the determination of the indicators that cause voltage drop.

Because of the problems arising from the connection of new production and new consumers to the electricity grid, voltage fluctuations have also increased, which is why in [6] the authors Iker Garcia and Roberto Santana conducted a study on the implementation of the transformer pad control method, obtaining positive results. In [7] the authors conducted a study to determine a voltage control to more easily integrate electric vehicle charging into grids.

In [8], an optimization study was performed using a nonlinear back-stepping controller. This technology proposes the use of the mentioned controller to achieve adaptive control of the inverter. To enhance the system's robustness, also was executed the control method for a finite time when introducing the controller.

In a study aimed at reducing losses in the medium voltage power grid, several scenarios were tested to determine the optimal debottlenecking method [9]. Additionally, in [10], authors Gautham Ram and Eva-Maria Bärthlein conducted a comparative analysis of different power transformer types, comparing them based on criteria such as voltage control and rated winding current. The analysis focuses on the classification and optimal placement of voltage-regulating transformers based on network power. In a study on voltage control, referenced in [11], the authors determined the significance of automatic transformer tap modification in reducing created imbalances and maintaining voltage within acceptable limits. Therefore, in their case study, they achieved positive outcomes by interchanging the plots within the range of 0.95 and 1.05 p.u.

III. GENERAL CONSIDERATIONS

A. *Electrical power network*

The electricity grid must be able to supply energy as reliably as possible, so it is imperative that distribution operators have real-time information containing data on the amount of energy that is produced by the PV [12].

The grid connection of systems that generate electricity based on solar energy conversion takes into account the following reference points:

- Location and distance from the nearest transformer station;
- Installed power of the PV;
- Configuration of the PV;
- Connection scenario to the distribution grid;
- Power line loads;
- Consumption scenario of consumers connected to the distributor.

Because PV systems are integrated into the grid, there is a risk of problems such as voltage surges, reverse power flow and other issues. Therefore, connecting these power generation systems to the grid can create various challenges and impacts that need to be carefully considered.

One of the challenges encountered when integrating PV into the electricity system is the variability of solar radiation, which often leads to high instability at the common coupling point in terms of voltage and frequency fluctuations.

In order to ensure the supply of electricity generated by PV, it is necessary to meet the requirements for connection to the distribution grid. To this end, several studies have been carried out to analyze the requirements in force regarding the conditions for connecting PV to electricity systems. These requirements are based on the response of the designed PV system in the event of a fault.

The conditions for connecting a PV to the distribution grid differ from one distribution operator to another, so each one has certain connection rules that need to be taken into account when carrying out the case study.

PV grid integration entails a range of negative effects. The increase in system frequency instability is also caused by the increase in PV introduced into the power system. From this point of view, the stability of the angle with reference to the optimal radiation of the solar system and the generation time of inertia of the PV plants are of importance. When the plants are fed into the grid, the inertia of the whole power system decreases drastically, which leads to frequency instability. As a result, the power grid cannot handle frequency fluctuations caused by repeated changes in the load curve.

Connecting PV to the distribution system also entails high voltage instability. Thus, voltage instability occurs in the grid irrespective of the installed power of the PV and the power system can experience both negative and positive effects when calculating the steady state.

Therefore, voltage variations occur when the PV is connected to the grid, so that the calculated voltage changes from the one measured beforehand. The voltage level at the time of connection of the PV to the grid must not exceed the limit allowed by the regulations in force.

The integration of renewable energies into electricity distribution systems has led to some issues related to power quality and voltage stability according to new market standards and requirements. Connection via inverters distorts the voltage due to the way the inverter operates, an operating principle based on pulse width modelling.

The reduction in active energy due to solar generation gradually leads to a reduction in the amount produced by PV, resulting in electricity losses. For these losses to decrease, the principle of self-consumption of the energy produced needs to be introduced in order not to overload the system in a no-load scenario [13].

The control of reactive power is generally done according to the amount of active power generated by the installed PV. It is the grid element, namely the inverter that can inject or absorb reactive power in case of slow or fast voltage variations. Therefore, the inverter can control active and reactive power separately. If there are days when no power is produced at all, the inverter can generate a maximum amount of reactive power. Controlling the reactive power of a PV is typically aimed at reducing voltage drops and fluctuations to ensure reliable system operation [14].

B. *Voltage Control*

In a general sense, voltage control refers to the management of reactive power, which is characteristic of an electrical power system, whether generated or absorbed by component elements, both generation and transmission networks. Achieving voltage control in electricity transmission and distribution systems requires consideration of government regulations and distribution operator regulations. Voltage control aims to maintain standards at both the consumer and network levels, ensuring that voltage does not affect system reliability under three critical conditions. The first condition refers to maintaining voltages within an acceptable range for both final consumers and the proper functioning of equipment in the electrical system. The second condition involves the circulation of reactive power through electricity transmission networks, which can lead to congestion. The third condition to consider is the determination of reactive power circulation to prevent an increase in active power losses [15].

The aim of voltage control is to minimize voltage deviation in power distribution systems when a photovoltaic power plant is connected to the system under analysis. This is achieved by adjusting the position of the taps and switching them accordingly. On-load tap changers are commonly used to change the number of turns in the transformer primary coil. Regular manual checks of the equipment are necessary to verify that it is in technically functional condition. Voltage control is mainly performed to compensate for voltage variations that may occur in the network, caused by fluctuations in network consumption or due to the occurrence of element faults. Another reason for using plot adjustment is to adapt to different load and consumption patterns to achieve optimal functionality based on the consumption scenario. Therefore, a calculation is performed, depending on the topological information in the distribution systems, to determine the minimization of voltage deviations that occur in the system following the integration of a new energy-producing source [16].

IV. SYSTEM MODELING AND SIMULATION

The primary objective of this study is to investigate the impact on busbar voltage in a MV station when a PV is connected. To achieve this, a model of an electrical network based on the normal operating scheme of a distribution network is used as a case study.

Figure 1 presents the model implemented in the simulation software and, as it is a complex model, the figure represents a section of the total simulation performed.

The steady state calculation was used to determine the voltage variations and voltage drops, using Paladin Design Base modelling and calculation software [17].

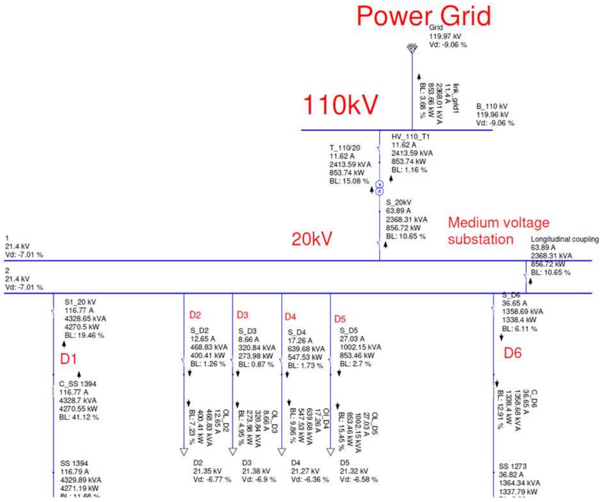

Fig. 1 Configuration of the electrical network implemented in the calculation program.

The scheme integrates a 16 MVA transformer, two distribution busbars connected by a longitudinal coupling, consumers, and newly introduced PV with a power of 4,5 MW, as shown in figure 2.

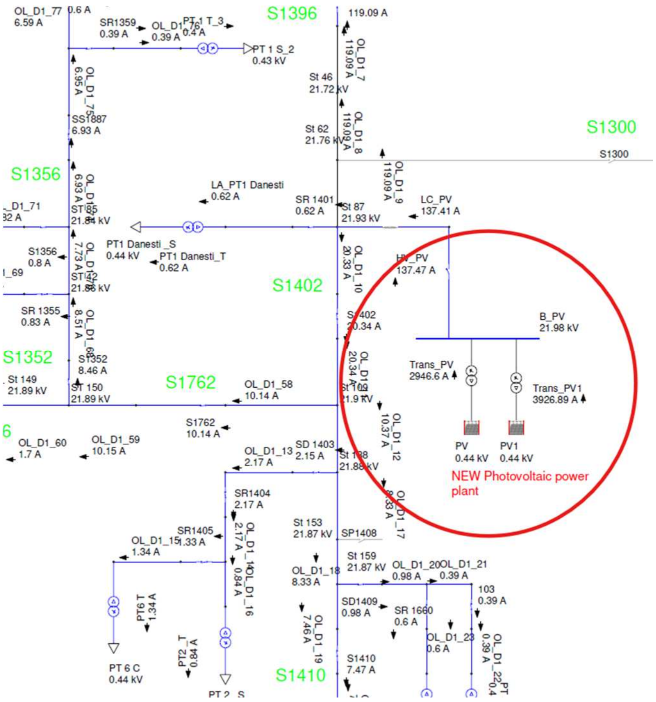

Fig. 2 New PV integrated to the MV network.

Figure 2 illustrates the connection of the PV to the grid and the voltage level on the PV busbar. To perform steady state calculations, a voltage of 21.4 kV was set before the PV was connected by raising the voltage in the HV side. Based on these assumptions, the effects of its introduction were analyzed.

A. *Initial system analysis*

In order to determine the values of voltages and currents in the network nodes, the steady-state calculation for the electrical network modeling software was carried out. Therefore, taking into account the network topology, generators, consumption and power line data, the voltage across the network nodes, the currents flowing through the power lines as well as the power and energy losses occurring are determined.

To determine these quantities of interest, the voltage study is considered in two different scenarios:

- *Scenario 1* - where the power generated by the new PV introduced into the system is entirely consumed within the MV grid.
- *Scenario 2* - where the power generated by the new PV is further distributed into the High Voltage (HV) grid.

In both implemented scenarios, the voltage is considered to be 21.4 kV at the MV substation busbars. In order to analyze voltage variations and voltage drops, the Newton - Raphson numerical iterative calculation method was used.

The results of the steady-state calculations for the two scenarios are presented in Tables I-III. These tables contain the values of power and energy losses, as well as voltage drops, recorded at the MV network nodes. The tables were compiled on the basis of the results obtained in the dedicated program and are presented in a centralized format.

Table 1 displays the active power losses and own technology consumption (OTC) measured in kW and percentage for both scenarios analyzed. The calculations were made with and without the introduction of the PV into the system, taking into account the input characteristics.

TABLE I. ACTIVE POWER LOSSES IN BOTH SCENARIOS

Scenario	**Power losses [kW]**			
	Without PV		***With new PV***	
	ΔP, [kW]	***OTC, [%]***	**ΔP, [kW]**	***OTC, [%]***
Scenario I	69.331	1,63	175.302	3,89
Scenario II	69.331	1,63	232.95	5,17

As can be seen in the table, the actual and percentage values of power losses in the electricity grid increase when a new PV is introduced in the station. In scenario II, the power losses increase even more, as they are caused by the power flow through the HV transformer as well as bidirectionally across the power lines.

Table 2 displays the voltage values at the MV busbars and other significant nodes in the modeled grid for scenario I. It is important to note that all energy produced is consumed in the MV grid.

According to Table 2, the values of voltage drops and voltage levels in significant nodes of the power grid vary within the permissible limits of +10% and -10%, but at the same time changes in these levels can lead to grid instability and increased power losses.

TABLE II. VOLTAGE LEVEL IN SCENARIO I

BUS	**Voltage drops and voltage level**			
	Without PV		***With new PV***	
	V, [kV]	**Δ *V, [%]***	**V, [kV]**	**Δ *V, [%]***
1	21.4	-7	21.676	-8.38
B_PV	21.275	-6.38	21.89	-9.45
St 87	21.275	-6.38	21.855	-9.28
St 15	21.373	-6.86	21.498	-7.49
St 109	21.241	-6.21	21.822	-9.11
St 159	21.205	-6.03	21.787	-8.94
St 209	21.181	-5.9	21.764	-8.82
St 244	21.175	-5.88	21.758	-8.79

Further, in Table 3 the same quantities of interest are similarly shown for scenario II, where the power produced by PV is evacuated to the HV grid.

TABLE III. VOLTAGE LEVEL IN SCENARIO II

BUS	**Voltage drops and voltage level**			
	Without PV		***With new PV***	
	V, [kV]	**Δ *V, [%]***	**V, [kV]**	**Δ *V, [%]***
1	21.4	-7	21.861	-9.31
B_PV	21.275	-6.38	21.975	-9.88
St 87	21.275	-6.38	21.935	-9.67
St 15	21.373	-6.86	21.838	-9.19
St 109	21.241	-6.21	21.902	-9.51
St 159	21.205	-6.03	21.867	-9.34
St 209	21.181	-5.9	21.844	-9.22
St 244	21.175	-5.88	21.838	-9.19

Following the comparative analysis of the voltage level and voltage drops obtained in the two calculation scenarios, the following conclusions can be drawn:

- *In Scenario I* – higher voltage drops are recorded in areas with higher energy consumption.
- *In Scenario II* – injecting power into the HV grid leads to increased voltage values in almost all nodes of the grid.
- *In both scenarios* – PV deployment leads to increased voltage instability in neighboring nodes.

Taking into account the different consumption profiles that electricity users have, a new scenario has been developed according to consumption mode. Therefore, the third scenario shows the voltage variation at the MV station busbars according to the consumption step, analyzed at no load and peak load.

Figure 3 shows the graph of voltage level variation as a function of consumption steps. In the graph 4 consumption steps have been introduced, namely 25%, 50%, 75% and 100%. The lowest value indicates no load, the highest value indicates peak load, and two intermediate situations are also shown.

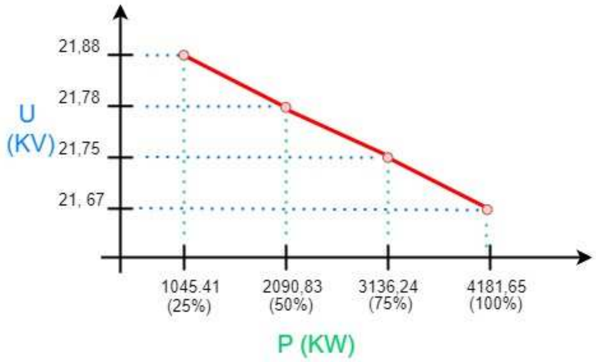

Fig. 3 Voltage variation depending on consumption.

As the voltage at the MV busbars can be significantly affected by reactive power in the system, an analysis was conducted based on a specific power factor level. Excessive reactive power in the network can cause a voltage decrease, while a lack of reactive power can cause an increase in voltage. In addition, reactive power in the distribution network causes additional losses in the electricity network, especially in elements such as cables and transformers. Insufficient reactive power can increase the risk of voltage swings, which can affect grid stability. It is important to maintain appropriate reactive power levels in the distribution network.

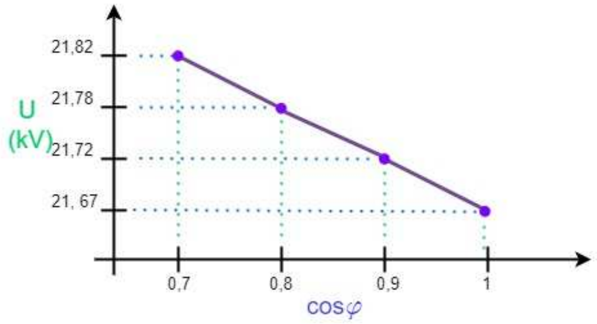

Fig. 4 Voltage variation depending on the power factor value.

Figure 4 displays a graph showing the variation of the voltage with the power factor value. The voltage at the MV busbars increases as the power factor decreases due to reactive power circulation.

B. *Voltage control using AVC*

The same initial scenarios considered were used to achieve voltage control using the AVC method. Therefore, the AVC was introduced to keep the voltage constant at a level of 21.4 regardless of variations in station consumption. Given the voltage fluctuation due to the introduction of PV into the system, determining a voltage control is necessary for grid efficiency and reducing power losses.

Voltage control was performed at the MV bars to measure the constant voltage. Thus, in the calculation program Automatic Tap adjustment was performed to set the plot in the correct position so that the voltage is maintained at the value 21.4 regardless of the power generated by the new PV. In order to achieve the most accurate control, a range of 0.90 and 1.05 p.u. was set for setting the plot according to the voltage value. Following the calculation by AVC input, the use of the transformer plot was set to 0.917 p.u. Therefore, the calculation for the two scenarios was performed according to the new value determined for the voltage control.

V. RESULTS AND DISCUTIONS

Following the AVC analysis to determine the transformer plot the desired effects are to maintain the voltage at 21.4 kV and therefore reduce power losses. In order to achieve the desired objective, aspects such as the stability of the power grid, the control action itself, the power losses were taken into account, in order to determine the real impact occurring at the nodes in the grid.

After performing the calculations according to the new input characteristics, the following results were obtained and are presented in the tables.

Tables IV, V and VI present the results following the implementation of the voltage control calculation in the dedicated software, and therefore have been arranged in tabular form.

TABLE IV. ACTIVE POWER LOSSES IN BOTH SCENARIOS, AFTER AVC

Scenario	**Power losses [kW]**			
	Without PV		***With new PV***	
	DP, [kW]	***OTC, [%]***	**DP, [kW]**	***OTC, [%]***
Scenario I	69.331	1,63	163.25	3,50
Scenario II	69.331	1,63	200.15	4,45

Table 4 shows the actual and percentage values of power losses following AVC. As can be seen the power losses decrease in both scenarios.

The voltage at the time of automatic voltage control in the power grid is fed back into the system as a re-gated voltage. By manually or automatically changing the number of turns in the transformer coils determined by calculation, this voltage is kept constant regardless of variations in load or power generation in the power grid analyzed in the case study. Therefore, the implementation of AVC is an essential action to ensure stable and reliable operation of the power grid.

Table 5 illustrates the new values obtained in the different nodes of the electrical network after setting the power transformer to the 0.917 p.u. plot. Therefore, this determined value keeps the voltage constant and minimizes electrical losses.

TABLE V. VOLTAGE LEVEL AND DROPS IN SCENARIO I, WITH AVC

BUS	**Voltage drops and voltage level**			
	Without PV		***With new PV***	
	V, [kV]	**D *V, [%]***	**V, [kV]**	**D *V, [%]***
1	21.4	-7	21.4	-7
B_PV	21.275	-6.38	21.86	-9.28
St 87	21.275	-6.38	21.776	-8.88
St 15	21.373	-6.86	21.493	-7.46
St 109	21.241	-6.21	21.756	-8.78
St 159	21.205	-6.03	21.706	-8.53
St 209	21.181	-5.9	21.515	-7.58
St 244	21.175	-5.88	21.409	-7.04

Table 6 also shows the new values obtained in the different nodes corresponding to the second scenario considered.

TABLE VI. VOLTAGE LEVEL AND DROPS IN SCENARIO II, WITH AVC

BUS	**Voltage drops and voltage level**			
	Without PV		***With new PV***	
	V, [kV]	**D *V, [%]***	**V, [kV]**	**D *V, [%]***
1	21.4	-7	21.4	-7
B_PV	21.275	-6.38	21.852	-9.26
St 87	21.275	-6.38	21.778	-8.89
St 15	21.373	-6.86	21.759	-8.79
St 109	21.241	-6.21	21.818	-9.09
St 159	21.205	-6.03	21.806	-9.03
St 209	21.181	-5.9	21.754	-8.77
St 244	21.175	-5.88	21.706	-8.53

The results presented in the above tables allow for a detailed comparison of the behavior of the power grid before and after the implementation of a voltage control system. Tables V and VI include information on the reduction in power losses and voltage drops in the case of voltage control compared to the initial version, with the values approaching the nominal voltage value. Consequently, the implementation of the AVC system resulted in a considerable reduction in the average deviation from the considered voltage of 21.4 kV, with a decrease of approximately 3.7% at the busbar of the newly connected PV.

The results presented in this table clearly demonstrate the significant benefits of implementing automatic voltage control in electricity grids. The implementation of this system has led to a significant improvement in power quality, thereby reducing the risk of damage to existing equipment.

VI. CONCLUSIONS

Controlling voltage by adjusting the position of power transformer taps is an essential part of ensuring the correct functioning of modern electrical systems. This method of control and automation provides significant benefits, primarily by reducing large voltage variations and minimizing power and energy losses.

Voltage drops and variations are two of the most common issues encountered in power grids, and they appear as voltage drops at specific nodes of the power system. Voltage variations can be caused by factors such as distance from the power source or sudden increases in consumption.

One effective solution to overcome voltage fluctuations is to automatically control the voltage by adjusting the position of the voltage taps, which maintains the voltage at a certain level on the medium-voltage busbars of the network. This implementation also ensures a constant voltage at the consumer level, regardless of the distance to the new power source integrated into the system or if the load varies. The implementation of AVC also has the important benefit of reducing power and energy losses. The control achieved optimizes power distribution, resulting in a significant reduction in power losses.

In conclusion, the case study carried out on the MV power grid shows positive results in terms of reducing power losses and voltage variations by automatically determining the transformer tap position. Additionally, the benefits extend beyond the technical aspects, with significant economic and social impact.

A more detailed analysis of this case study can be carried out by implementing calculations to quantify the savings achieved by reducing energy losses and the costs to power network operators. At the same time, advanced algorithms based on artificial intelligence elements can be integrated to determine the energy efficiency and stability of energy networks.

REFERENCES

[1] STANLEY R. BULL in “Renewable Energy Today and Tomorrow”.

[2] Bollen, M. H. J., & Hassan, F.”Integration of distributed generation in the power system.” John Wiley & Sons.

[3] El-Khattam, W., and M. M. A. Salama, “Impact of Distributed Generation on Voltage Profile in Deregulated Distribution System Key Terms :,” pp. 3–8, Proceedings of the Power Systems 2002 Conference, Impact of Distributed Generation, Clemson, SC, USA. 2002.

[4] Dubravac M, Fekete K, Topić D, Barukčić M. Voltage “Optimization in PV-Rich Distribution Networks – A Review”, Applied Sciences. 2022.

[5] Leşe, D., et al. "Voltage quality analysis in a network point of interest." Proceedings of CIE 2012 Conference. Vol. 7. No. 9. 2012.

[6] I. Garcia and R. Santana, "Unified Framework for the Analysis of the Effect of Control Strategies on On-Load Tap-Changer’s Automatic Voltage Controller," in IEEE Transactions on Automation Science and Engineering, vol. 21, no. 2, pp. 1539-1548, April 2024.

[7] J. Chen, R. Popova, A. F. Raab, H. Graute, M. Rojas and K. Strunz, "Coordinated Voltage Control of Microgrids With Integrated Electric Vehicles in Real-World Experiment and Application: Industrial Design and Implementation on EUREF-Campus in Berlin," in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, vol. 5, no. 2, pp. 359-368, April 2024.

[8] Feng Xuan, Mengyang Han, Avinash Kumar, Satyendra Vishwakarma, Nithiyananthan Kannan, Rituraj Jain, "Optimization of Grid-Connected Photovoltaic Power Generation Technology Based on Nonlinear Back-Stepping Controller", Mathematical Problems in Engineering.

[9] T. Pavel, D. Micu, S. Pavel, H. Beleiu and S. Ungureanu, "Contributions to the optimization of the Electrical Power Distribution in the Station Centru From Cluj, in the Context of Updating Its Medium Voltage Network," 2022 International Conference and Exposition on Electrical And Power Engineering (EPE), Iasi, Romania, 2022, pp. 545-549.

[10] G. Ram, V. Prasanth, P. Bauer and E. -M. Bärthlein, "Comparative analysis of on-load tap changing (OLTC) transformer topologies," 2014 16th International Power Electronics and Motion Control Conference and Exposition, Antalya, Turkey, 2014, pp. 918-923.

[11] I. Kim, "A Method of Modeling Tap-Changing Transformers for Power-Flow and Short-Circuit Analysis Studies," TENCON 2018 - 2018 IEEE Region 10 Conference, Jeju, Korea (South), 2018, pp. 0772-0775.

[12] Office of ENERGY EFFICIENCY & RENEWABLE ENERGY, Solar Systems Integration Basics, [Available] https://www.energy.gov/eere/solar/solar-systems-integration-basics.

[13] Mansouri, N.; Lashab, A.; Sera, D.; Guerrero, J.M.; Cherif, A. “Large Photovoltaic Power Plants Integration: A Review of Challenges and Solutions”, Energies 2019.

[14] Tu Van Dao and Hanh Thi Nguyet in „Local Reactive Power Control of PV Plants for Voltage Fluctuation Mitigation” University of Science and Technology Hanoi, Vietnam Surachai Chaitusaney and Rongrit Chatthaworn Department of Electrical Engineering Chulalongkorn University Bangkok, Thailand.

[15] Kirby, B, and Hirst, E. 1997. "Ancillary service details: Voltage control". United States.H. Xu, A. D. Domínguez-García and P. W. Sauer, "Optimal Tap Setting of Voltage Regulation Transformers Using Batch Reinforcement Learning," in IEEE Transactions on Power Systems, vol. 35, no. 3, pp. 1990-2001, May 2020.

[16] *** Paladin DesignBase, Technical Documentation.