Cloud Induced PV Impact on Voltage Profiles for Real Microgrids

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Abstract— **Integration of renewable energy sources (RESs) into power systems has been a popular topic for a long time. Due to government policies and incentives, it will be more popular in the future since it is a free and environment-friendly nature. Besides its advantages, photovoltaic (PV) generation causes some serious problems to the grid. Since PV generation directly depends on the solar irradiance, cloud movements can cause sudden changes on the output of PV power and this results in some power issues in the system such as voltage violations, reverse power flow, voltage fluctuations. These types of issues complicate to maintain voltage within compulsory levels at customer sides. Thus, cloud-induced transients in PV power are seen as a potential handicap for the future expansion of renewable energy resources. This study investigates effects of instantaneous changes in PV power on the customer side voltage levels. Daily PV power output and voltage profiles were simulated using a real-world microgrid design that will be implemented in the Malta College of Arts Science and Technology (MCAST) Campus.**

Keywords— Cloud-induced transient, distributed power generation, microgrid, photovoltaic (PV) systems, power quality, PV generation, renewable energy resources, solar energy, solar radiation

I. Introduction

Since the beginning of life, energy is the primary need for the entire universe. Especially electrical energy has taken its place as the most popular energy source of humanity history. The demand for electricity grows exponentially day by day. However, the solutions applied to respond to this growth rate bring with important problems particularly for our planet. According to [1], %28 of the greenhouse gas emissions that causes global warming and climate changes emerges as a result of fossil fuels used in electricity generation. If conventional generation will be kept as now, the earth may become an uninhabitable place in a much shorter period than predicted. The idea of meeting all of the energy needs from renewable energy resources seems to be the most effective and appropriate solution so far. In recent years, there has been a significant increase in the use of renewable energy resources with the help of public pressure and government incentives. Solar energy is the type of energy that has the most striking growth rates among renewable energy resources. As seen in Fig. 1, with a growth rate of 438 GW expected until 2022, PV power is the most popular type of renewable energy. PV generation is expected to be followed by wind energy with a growth rate of 321 GW.

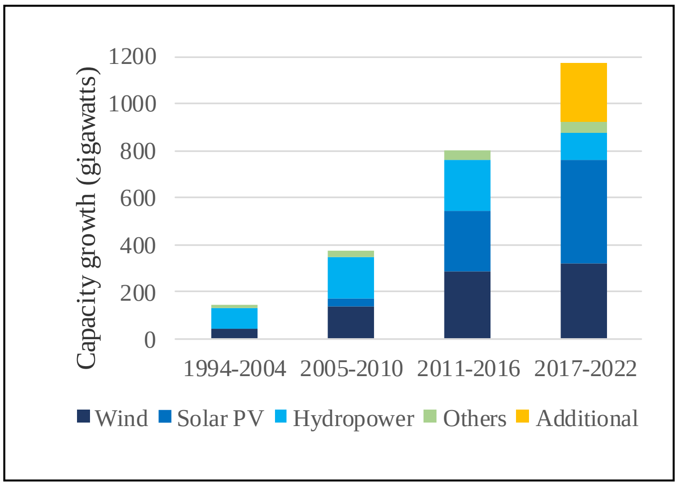

Fig. 1. Renewable electricity capacity growth by technology [2]

Besides many advantages of renewable energy resources, they have serious problems need to be addressed, particularly in the integration of the electricity grid. Among these issues, the most chaotic and unpredictable one is the voltage problems that occurs because of solar radiance interruptions caused by cloud movements. Such problems can be much more dangerous, especially in low voltage networks.

In 1989, [3] focused on the impact of interruption of solar irradiance caused by cloud movements on voltage levels. [4] ascertained significant increase on transformer tap changes according to sudden changes on PV output profile. [5] claims that if 40% of the required energy of the grid comes from photovoltaic power, clouds can be a serious threat for the voltage levels. Also, in [6], [7] Volt-VAR control, constant power factor control, PV inverter voltage control were compared to reduce harmful effects of sudden changes in PV generation due to clouds' movements. [8] presents future cases for PV penetration effects and [9] examines impacts of the specific properties of the clouds (speed, width etc.) on voltage levels. [10-11] analyze the effects of intermittent PV production on microgrids and residential areas and give advice for system settings. In [12], as a more novel study, the effects of line characteristics on voltage levels due to changes in the PV generation have been examined. [13] presents ways to continue to work smoothly by protecting the network from PV transients. [14] compares the effects of dynamic load and static load models on voltage levels in networks where the use of PV power is intense. As successful reviews of this issue, [15] [16] provide detailed analyzes on the integration of renewable energy resources into the grid, and on smart microgrids, respectively.

The main goal of this study is analyzing impacts of clouds on PV power generation that results in voltage drop on the customer side. During the acquisition of the results, two different case studies were used such as voltage variations with and without energy storage system (ESS). The microgrid design used in this paper belongs to the real field design to be installed in the Malta College of Arts Science and Technology (MCAST) Campus. In addition, the solar radiation used during the analysis is the data of the Mediterranean Region. The remainder of this paper is organized as follows. Section II presents the real field microgrid design details. Load, PV generation, ESS, diesel generator information are also given in this section. Section III shares used case studies and results. Section IV finalizes the study with conclusion.

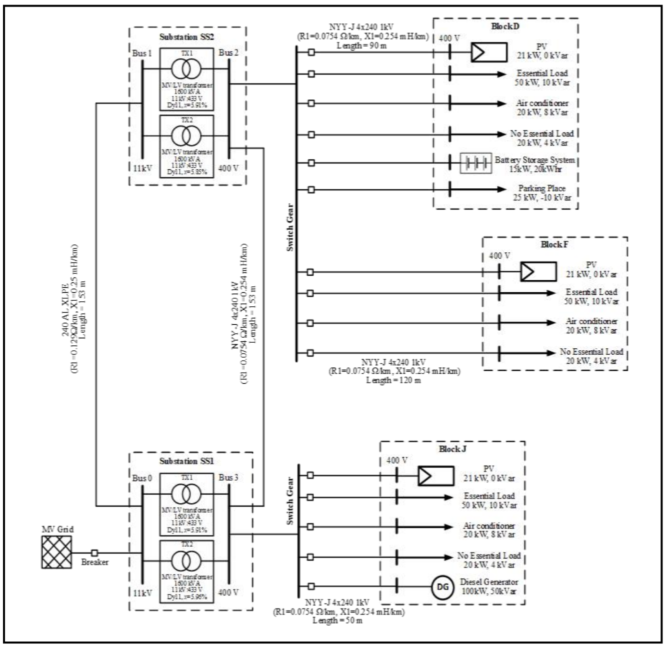

Fig. 2. Main architecture of microgrid design

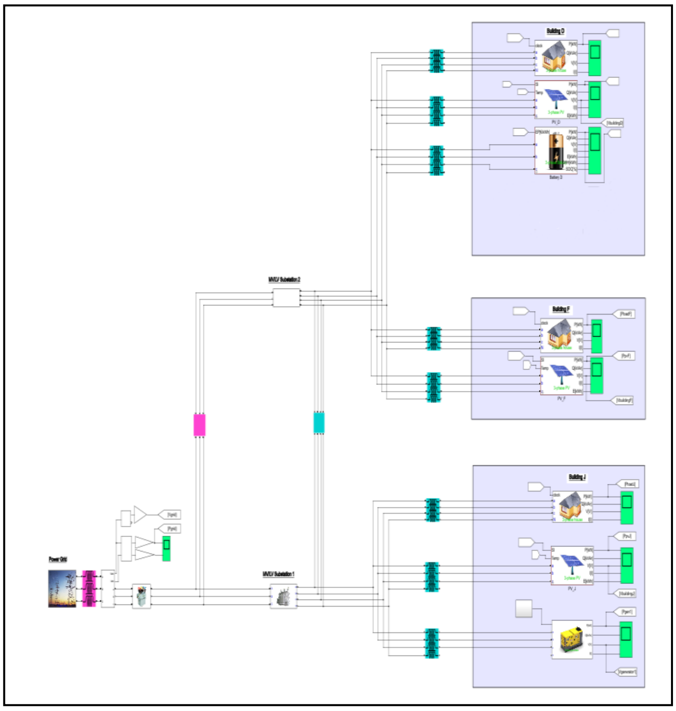

Fig. 3. MATLAB/Simulink model of microgrid design

II. System Description

Fig. 2 gives the detailed architecture of the microgrid designed for the MCAST Campus and Fig. 3 gives the MATLAB/Simulink model of it. In this study Microgrid design consists of two substations (SS1 and SS2) which serve three different buildings (Building D, Building F, Building J). Substations are in the closed room and they consist of a 20 MVA, 11 kV / 400 V connected transformers. Two switch gears control three different buildings.

Given the locational characteristics of the buildings and customer preferences, various distributed energy sources have been optimally placed in the buildings. Each building has 21 kW PV installation. For flexibility, Building D has 15 kW battery storage system in addition to PV power. Also, Building J has a diesel generator that will pass to the master position when the microgrid operates at the islanded mode. All buildings have essential, non-essential and AC controllable loads. More detailed data are given in Fig. 2.

A. Loads and Solar Radiance Data

It was assumed during the analyzes that the solar radiation was interrupted by the clouds and the penetration level dropped to 20% (200 W/m2) from 100% (1000 W/m2) within one minute and remained at this level between 02:00 pm and 02:10 pm. Before the decline assumption in PV power generation, PV irradiance data are specific to the Mediterranean region. Sampling interval used during operation for PV radiance is 1 minute.

The load data used during this study is based on the real historical data measured from the MCAST Campus. Especially during the simulation, the daytime schedules of the load data are formed considering the actual selection characteristics of the customers. Resolution for load data also 1 minute.

B. *Operation Scenario of Microgrid*

Simulation scenario starts at 00:00, until 08:00 am microgrid operates in grid-connected mode, from 08:00 am to 08:00 pm the microgrid continue to work in islanded mode where the diesel generator is the master. After 08:00 pm microgrid switch to grid-connected mode again.

When the microgrid switches to islanded mode, the main responsibility for ensuring that the system continues to function smoothly is largely handled by the diesel generator rather than the battery and solar energy systems.

The battery charges itself between 00:00 - 08:00 am and 08:00 pm - 00:00 when the microgrid is connected to the grid. It uses stored energy to improve the voltage quality of the system when the microgrid operates in islanded mode and load increases. In the case study results mentioned in Section IV, the difference created by battery and battery-free microgrid designs is clearly shown.

Since PV systems are directly dependent on the solar radiance, as long as there is no interruption in the solar radiance, 21 kW PV system of each building helps to keep the network in balance throughout the daytime.

III. Case Studies and Simulation Results

Two different case studies were conducted to investigate the cloud effect on customer side voltage. In both cases, it was assumed that the solar irradiance was cut by the clouds and the production of PV power fell from 100% to 20% (4.2 kW) within a minute and remained at this level for 10 minutes. Fig. 4 Shows the 24 hours voltage profile for buildings. The analyzed 10 minutes section is indicated by an arrow.

The difference between the two cases is due to the use of the battery system in the Building D. In the first case study, while the microgrid was operating in islanded mode, we assumed there was 15 kW battery system in Building D to increase voltage quality of the grid. In the second case study, while the microgrid was operating in islanded mode, we assumed there was no battery system in Building D. With the help of these two case studies, the impacts of sudden drop in PV power production on grid voltage, and the influence of 15 kW battery usage on such scenarios were investigated.

A. *The case with Battery System in Building D*

Fig. 5 shows the characteristics of the voltage phases in Building D for the first case. As can be seen from Fig. 5, when the PV power drops due to the clouds, the behavior of voltage phases also varies. It is important to note that when the microgrid switch to the islanded mode, the power to ensure that the network continues to function smoothly comes primarily from the diesel generator. This means that when the PV power falls, the diesel generator takes on more responsibilities and prevents further voltage losses. It should be noted that Fig. 5 shows the average value of the voltage phases in Building D. When PV power penetration level drops to 20% in seconds, the maximum voltage fluctuation is only 0.18 V and this is a rather insignificant voltage loss. Even though Building D is the farthest building from the diesel generator, the main reason of negligible voltage drop in Building D, of course, existing of the 15 kW battery system.

Fig. 6 gives the average voltage profile of the all phases in Building F. Building F is located in the between of Building D and Building J which have a battery system and a diesel generator, respectively as shown in Fig. 2. Therefore, it can be expected to get benefits from two sources for Building F.

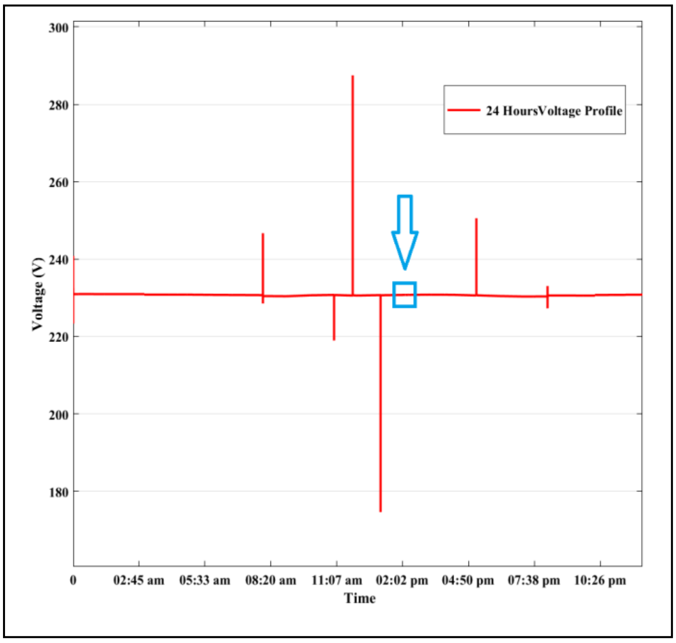

Fig. 4. 24 hours voltage profile of buildings

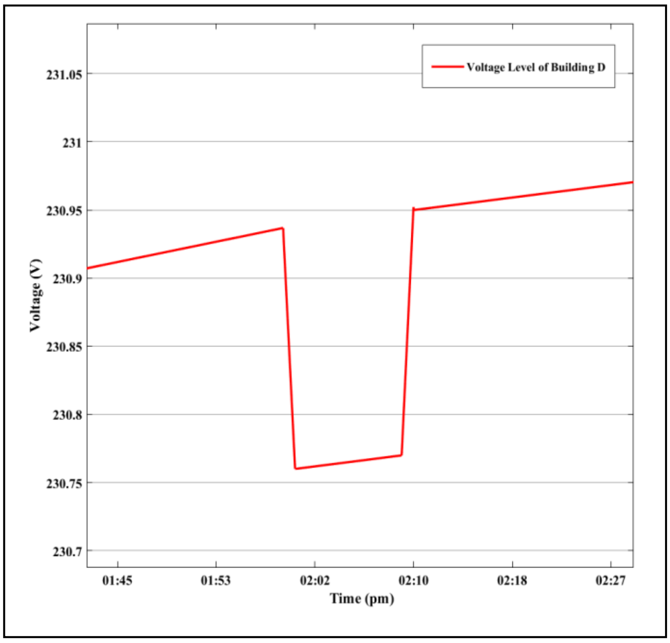

Fig. 5. Voltage profile of Building D for the case with battery

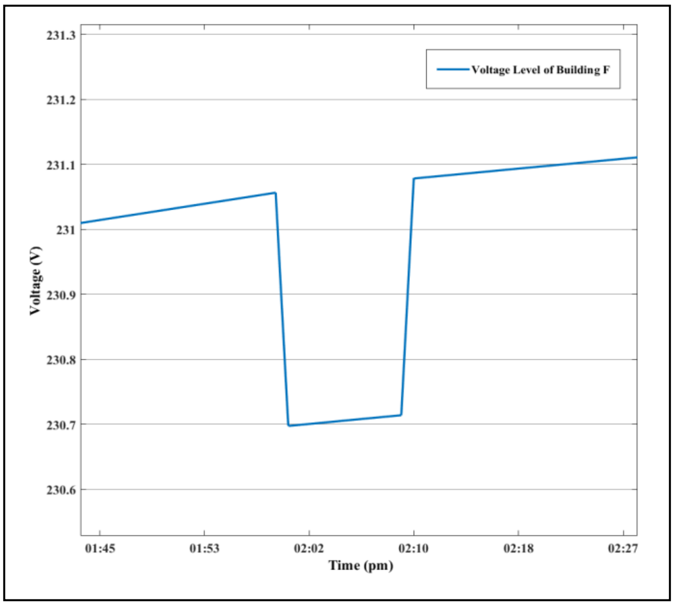

Fig. 6. Voltage profile of Building F for the case with battery

Before the voltage drop happens, the voltage level of the phases was 231.05 V, but this value decreases to 230.69 V in the analyzed range. So, the maximum voltage drop at the voltage level of this building is 0.36 V.

Fig. 7 shows voltage profile of Building J. Building J has a diesel generator that performs more than any other distributed energy sources so that the microgrid can continue its functions when it switches back to islanded mode. The voltage level of this building, which was at 231.13 V before the sudden decrease occurs in PV power, drop to 230.87 V within seconds in the analyzed interval. As a result, despite the fact that it has a powerful diesel generator, there is a small decrease in voltage levels in this building.

When the results of the first case are examined, it can be said that the grid voltage drops experienced by all the buildings do not contain any violations. Since Building F does not have any auxiliary energy sources, there is more voltage drop in Building F than the other two buildings.

In the second case study, it is assumed that there is no battery system in Building D and it is investigated that how lack of battery system will have an impact on the voltage levels of the buildings.

B. The case without Battery System in Building D

Fig. 8 shows the voltage profile of Building D for the second case study. The voltage level in this figure is the average value of the three phases. When the battery system was removed from this building, voltage drop of the Building D increased to 1 V from 0.18 V. This increase indicates that the battery system has an important task in terms of voltage quality in the Building D. Especially since Building D is the furthest building to the diesel generator, the power that the generator provides to the grid is at the level that can't match the battery's lack of power for this building. However, considering international standards, even though it comes within seconds, 1 V lost is not a harmful drop for the grid [17].

Fig. 9 gives the average voltage profile of the Building F. As shown earlier in Fig. 2, Building F is located in the between of the Building D and J. These buildings have their own distributed energy sources. This means that Building F can be expected to get benefits from these two energy sources, even at low volumes. However, when the results are examined, at the voltage level of this building, it is observed a change that can be easily ignored, compared to the first case. This result shows that the battery system owned by Building D does not have the adequate power to increase the voltage quality of Building F and the supporting power supply unit for

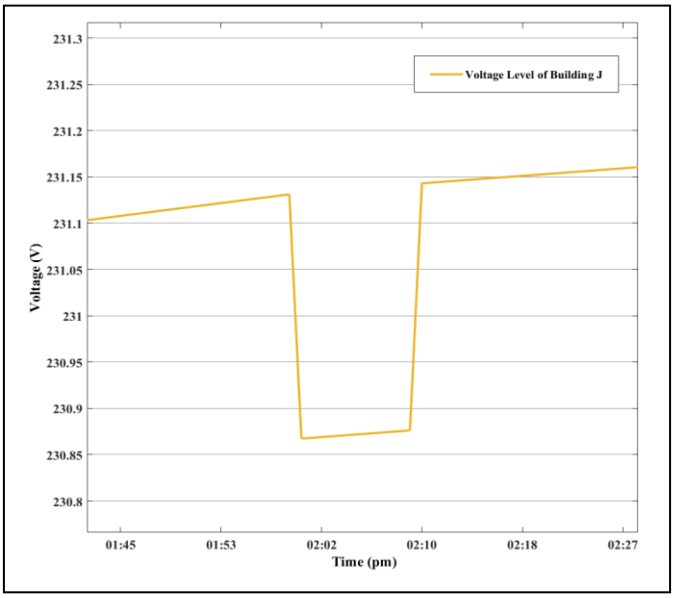

Fig. 7. Voltage profile of Building J for the case with battery

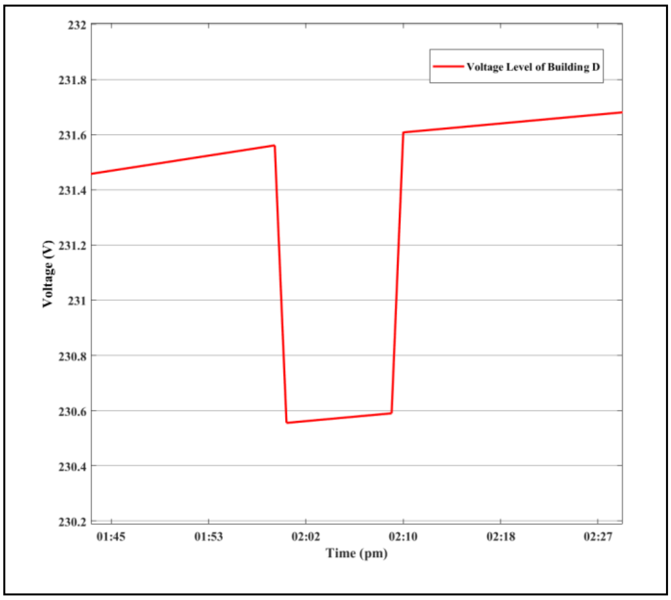

Fig. 8. Voltage profile of Building D for the case without battery

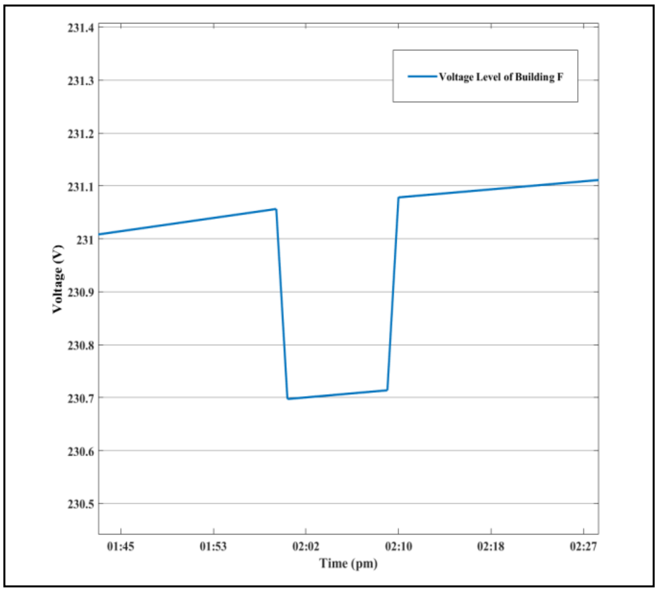

Fig. 9. Voltage profile of Building F for the case without battery

Building F is the diesel generator.

Average voltage profile of the Building J is given in Fig 10. When the results that are obtained for Building J are examined, since Building J has a powerful diesel generator, it seems logical opinion that the battery system in Building D does not make any differences for this building. Compared to the first case, just as in Building F, the amount of loss in this building is also negligible.

In addition to the two cases examined in this study, the voltage drop amounts of all buildings for different PV penetration levels such as % 0, %20, %40, %60 and %80 are given in Table I.

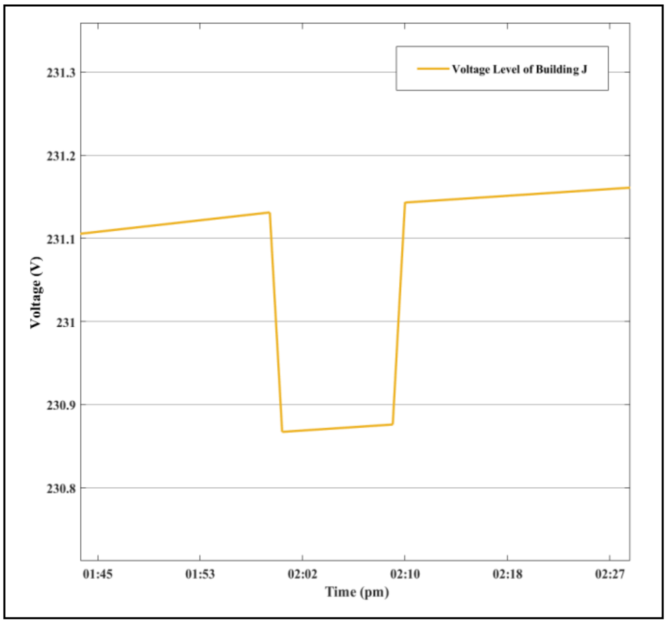

Fig. 10. Voltage profile of Building J for the case without battery

TABLE I. VOLTAGE DROPS FOR DIFFERENT PV PENETRATION LEVELS

	Building D		**Building F**		**Building J**	
Penetration Levels	***With Battery***	***Without Battery***	***With Battery***	***Without Battery***	***With Battery***	***Without Battery***
%0	0.22 V	1.26 V	0.45 V	0.46 V	0.33 V	0.33 V
%20	0.18 V	1 V	0.35 V	0.36 V	0.26 V	0.26 V
%40	0.13 V	0.75 V	0.26 V	0.27 V	0.2 V	0.2 V
%60	0.09 V	0.5 V	0.17 V	0.18 V	0.13 V	0.13 V
%80	0.04 V	0.24 V	0.08 V	0.09 V	0.6 V	0.6 V

IV. CONCLUSION

In this study, the effects of cloud-induced PV power on customer side voltage levels for a microgrid design, which will be integrated into the MCAST Campus, has been investigated with the help of storage cases. Simulation results showed that none of the cases examined had voltage drops that violate acceptable standards. It has been determined that the use of the battery positively affects the grid voltage quality of Building D. However, battery system in Building D has no effect on voltage quality of Building F and Building J. In addition, the diesel generator does not allow significant drops in voltage levels of Building J and Building F by filling a gap of the lack of PV power generation.

Future works can focus on efforts to reduce energy sources that are conventional generation that are not environment friendly, such as diesel generators, by increasing the share of renewable energy resources in microgrids.

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