Impact of distributed generation and energy storage systems on electrical power distribution systems

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Fecha de recepción: 25 de agosto de 2017 - Fecha de aceptación: 29 de septiembre de 2017

ABSTRACT

Worldwide is the concern about climate change and the impact on our planet indisputable. One of the aspects that enhances environmental problems is the generation of energy through conventional methods. Due to this, governments all over the world, and particularly Ecuador, opted for the implementation of renewable energy for the generation of electricity. This paper discusses possible technical impacts of distributed generation and energy storage of local distribution networks in Ecuador. Technical impacts on losses, voltages and reversed power flow are analyzed. OpenDSS software was used to model the networks. Different scenarios of photovoltaic (PV) penetration were analyzed. Also, the effect of the incorporation of storage in a high PV penetration network was examined.

<u>Keywords</u>: Battery energy storage system, distributed generation, low voltage, quasi-static time series, losses, reverse power flow.

RESUMEN

En la actualidad, la preocupación mundial sobre el cambio climático en nuestro planeta es indiscutible. Uno de los aspectos que influye en los problemas ambientales es la generación de energía a través de métodos convencionales. Debido a esto, los gobiernos de todo el mundo, y especialmente de Ecuador, han optado por la implementación de energía renovable para el suministro de electricidad. Este trabajo trata los posibles impactos técnicos de la generación distribuida y almacenamiento de energía en redes locales de distribución en Ecuador. Los impactos técnicos sobre el nivel de pérdidas, voltajes y el flujo inverso de potencia son analizados. Para el modelamiento de estas redes se utilizó el software OpenDSS. Se analizaron diferentes escenarios de penetración fotovoltaica. De igual manera, se analiza el efecto de incorporar sistemas de almacenamiento en una red con alta penetración de generación fotovoltaica.

<u>Palabras clave</u>: Sistema de almacenamiento de energía de la batería, generación distribuida, baja tensión, perdidas, flujo de potencia inversa.

1. INTRODUCTION

The energy sector is one of the main generators of greenhouse gases. The use of fossil-based energy resources causes the largest emission of greenhouse gases, which contributes to environmental problems. Population growth increases day by day along with electricity demand, contributing to more contamination. Building large power plants to supply the increase of electricity demand, could be a way out. However, this solution is only one possibility. Nowadays another solution is the use of Distributed Generation (DG), which combines renewable and non-renewable sources of energy to generate electricity. The Ecuadorian government, through the energy department, is implementing a program called "towards a new energy matrix" which consists of the implementation of new renewable technologies to produce electricity. This program considers incentive policies so that users can generate energy through renewable resources, for self-consumption or for sale of this energy to the grid. However, low voltage (LV) distribution networks were not designed to transport energy from the customer to the grid. Therefore, electricity distribution companies are carrying out analyses to know beforehand the impact on the grid parameters when customers decide to connect LV generation to the grid.

Several studies concerning the integration of DG into distribution systems have been carried over the last years. For example Begovic, Kim, Novosel, Aguero, & Rohatgi (2012) reviewed the impacts of utility scale PV-DG on power distribution systems, particularly in terms of planning and operating in steady state and dynamic conditions. A conclusion of this study is the improvement of voltage profiles when DG is considered. Furthermore, in this study mitigation measures such as distributed storage is discussed with the purpose of reducing the magnitude of voltage variation on the feeder. Broderick *et al.* (2013) conducted a time series power flow analysis for distribution with PV generation in three real feeders of a real network and on IEEE 8500 node feeder.

The main purpose of this study was to find out how using Quasi-static time series (QSTS) simulation and high time resolution data can quantify the impacts and the mitigation strategies to address voltage regulation operation, and steady state voltage. Chen *et al*. (2012) analyzed voltage problems due to DG penetration. These authors performed simulations under the worst network condition (minimum demand and maximum DG output power). The Monte Carlo method was used to allocate DG. This study also showed that a small amount of DG can produce voltage violations while very large amounts of DG allocated with adequate criterion do not affect the system operation. Navarro, Ochoa, & Randles (2013) assessed the impact of low carbon technologies in LV distribution systems. Firstly, a realistic 5-minute time series daily profile was produced for photovoltaic panel, electric heat pump, electric vehicles and micro combined heat and power units. After that, a Monte Carlo simulation was carried out for 128 real UK LV feeders. Results of this study revealed that photovoltaic (PV) panels technology produce problems in 47% of the feeders, electric heat pumps (EHPs) produce problems in 53% of the feeders and electric vehicles (EVs) produce problems in 34% of the feeders. For micro combined heat and power (uCHP) no problems were found. Another technical parameter to consider is losses when DG is added to the distribution system. Marra, Tarek, Thorsten, & Boštjan (2012) examined the technical impacts of microgeneration on low voltage distribution networks. Impact analysis on losses demonstrated that an adequate amount of PV generation (30% PV) decreased the daily total losses in the system, while an inappropriate amount of PV (100%) generation increased the losses. Vita, Alimardan, & Ekonomou (2015) assessed the impact of DG of a distribution network on the voltage profile and energy losses. The results obtained in this paper show that an adequate location and size of DG are essential for reducing the power losses and improve voltage profile.

2. EXPERIMENT

In this study, a real distribution network in Ecuador is analyzed. Firstly, load and PV profiles are created.

2.1. Load profiles scenarios

To assess the impacts of DG in the distribution system, a QSTS power flow was carried out. This provides a better criterion for analyzing the network in the worse scenario (e.g., max generation min demand). The transformer demand profile, the storage system profile, the PV profiles and the load consumption profiles used in this study have a resolution of 10 minutes and were provided by the local

Electric Distribution Utility CENTROSUR (Zambrano & Molina, 2015). Unitary load profiles, solar radiation and load consumption profiles of each customer are depicted in the Figures 1 and 2.

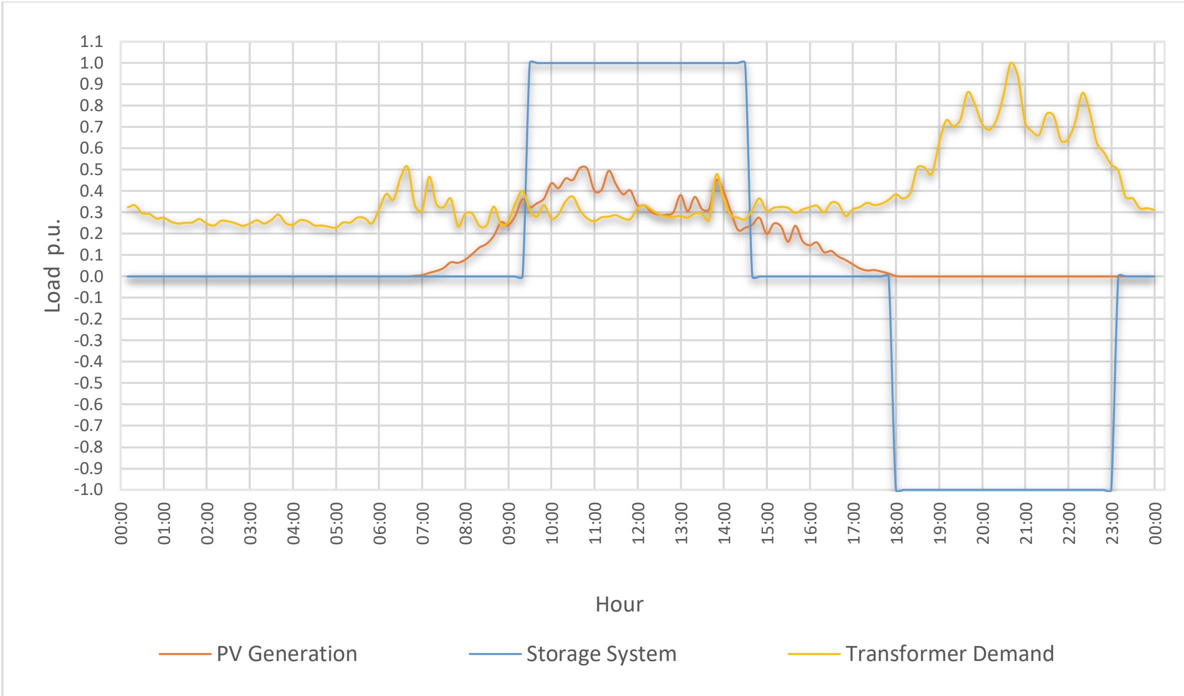
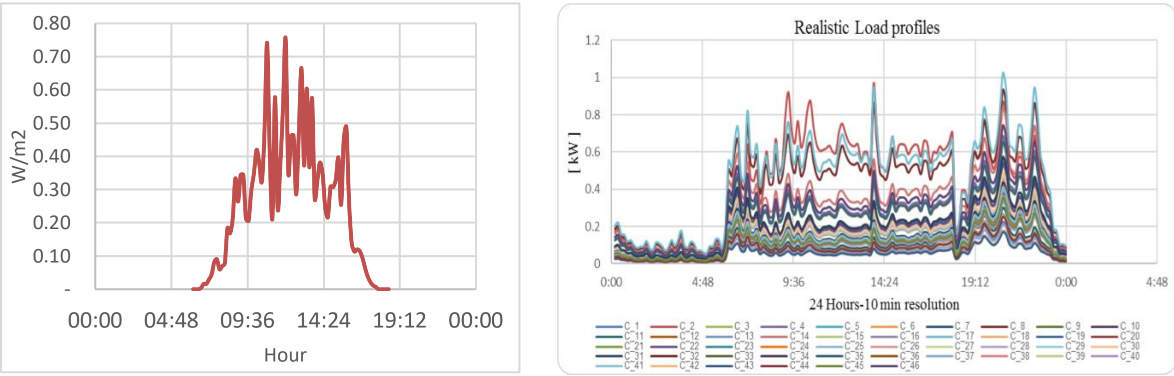


Figure 1. Unitary load profiles.



a) 24 hours 10-min resolution b) 24 hours 10-min resolution

Figure 2. Solar radiation and load consumption profiles of each customer.

2.2. Real distribution network

The case network was tested in secondary circuits that are part of the LV system CENTROSUR. This LV network is in the parish of Totoracocha, Cuenca, Ecuador and belongs to feeder 0325. This network feeds a three-phase transformer of 50 kVA, number 63991. This transformer supplies 44 residential and 2 commercial customers and 26 lights. The network was modeled considering GIS data, consumer location and configuration conductor characteristics. The network was represented in OpenDSS, a software used in scientific literature to analyze the impact of DG in electrical power distribution systems (Electric Power Research Institute, 2014). After the load profile and PV profile are defined, the solution mode ‘daily’, which is a simulation of 24 hours, was used to solve the QSTS power flow in OpenDSS. Each PV profile was modeled as a single-phase negative load with a power factor equal to 0.98. The network topology of the case study is shown in Figure 3. The maximum length of this real system from transformer to the last customer is 262 meters. Blue lines represent aerial lines while green lines represent underground lines.

Figure 3. Network topology.

After the network is modeled the base scenario is presented to carry out comparison with different solar PV penetration. Five scenarios are presented in Table 1.

Table 1. Simulation scenarios.

Scenario	Total customers with PV	% of total customers with PV
1	2	4%
2	5	11%
3	9	20%
4	23	50%
5	46	100%

In each scenario presented in the table, a percentage of the total of 46 customers is considered, including PV generation. For example, in scenario 1 it is considered that 4% of 46 customers add PV generation. For each scenario, it is assumed that each customer adds 2 kW of PV generation. The base case is the scenario that does not include PV generation. Finally, the impacts on the losses and on voltages profiles are analyzed and compared with the base case.

3. RESULTS AND DISCUSSION

3.1. Case 1: Impact of PV generation on LV distribution network

Reversed power flow

Simulation results show that there are no problems for the first three scenarios. On the other hand, results show a reversal of active power flow from the customer back to the transformer with 50% accumulated PV connection during a day, as shown in Figure 4.

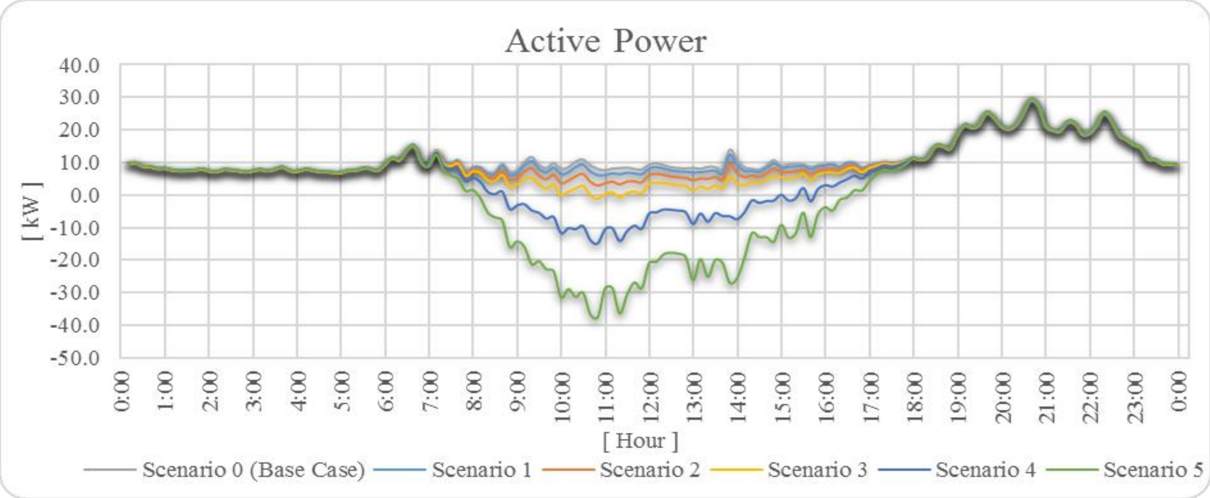


Figure 4. Active Power flow [kW] for different DG penetration scenarios.

System losses

The effect on systems losses was also studied when PV generation is included. Figure 5 depicts the daily system losses. High losses take place due to the reversed power flow when the radiation levels are high, and the demand is low. The maximum loss value is 1156.35 W and it occurs in scenario 5 at 10:40 am.

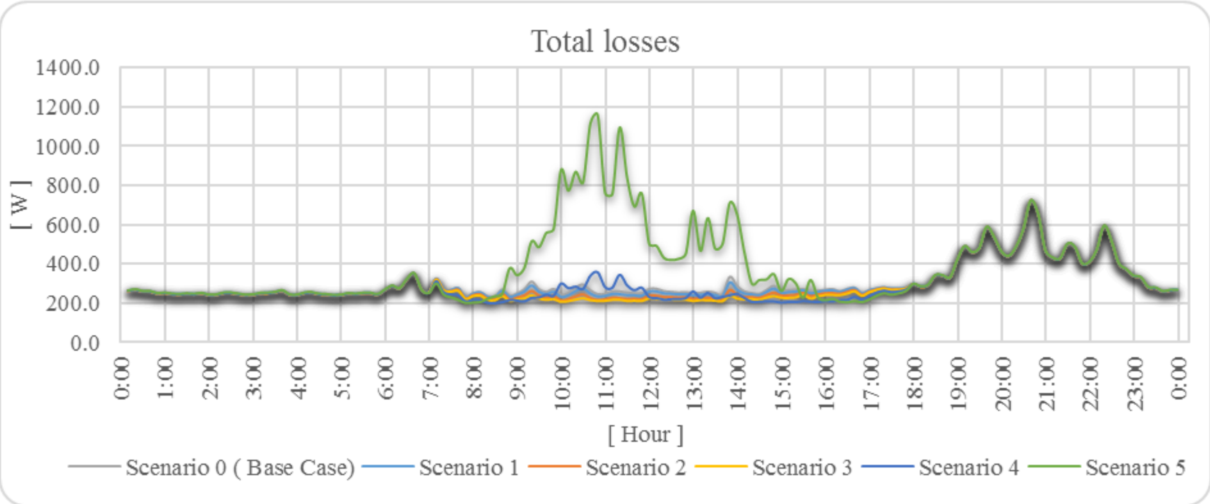


Figure 5. Total system losses [W] for different DG penetration scenarios.

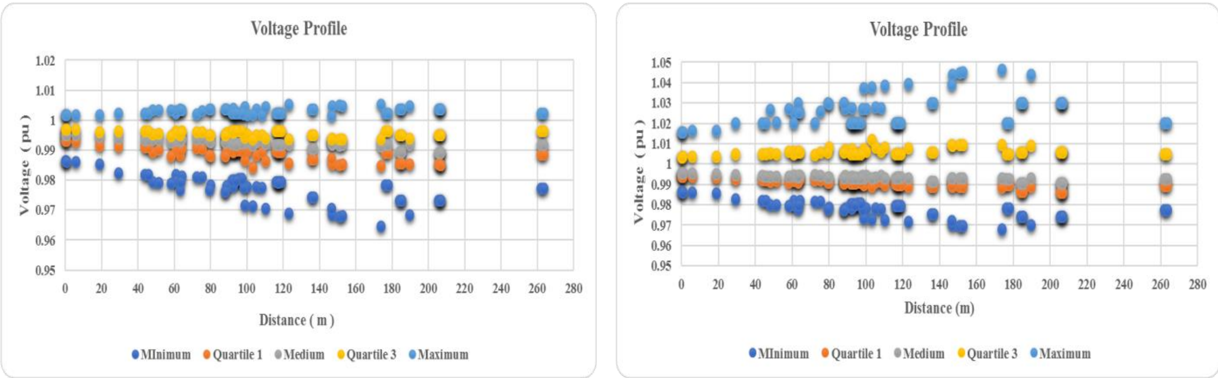
Table 2 summarizes the daily system losses. In this table are presented the maximum losses for each scenario. For scenario 0 to scenario 4 the maximum losses are the same. Nevertheless, for scenario 5 when 100% of PV generation is considered, there are extra losses equal to 434.32 W.

Table 2. Daily Total System losses (case 1).

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Losses (W)	722.028	722.028	722.028	722.028	722.028	1156.35
Difference (W)	-	-	-	-	-	434.322

Voltage profiles

Voltage profiles are also evaluated for each scenario. The voltage profile across the whole system for scenarios 0 and scenario 5 are shown in Figure 6 (a) and (b) respectively. The voltage values represent the voltage along the feeder. Both these figures reveal that for scenario 0 the voltage drop is 0.965 p.u. and it occurs in bus bta_656101 which is located 174 meters from the power transformer. In scenario 5, the voltage increase is 1.0466 p.u. According to IEEE standard 1547-7 the voltage allowed should be between 0.95 and 1.05 p.u. In this study, no voltage violation occurs when these scenarios are considered in the system. Once analyzed the system with PV generation, storage system is also included to analyze possible effects on the technical parameters.



a) Scenario 0 b) Scenario 5

Figure 6. Voltage profile for scenario 0 and 5 (case 1).

3.2. Case 2: Impact of PV generation with storage systems (BESS) on LV distribution network

Reversed power flow

Nowadays battery storage systems are being used to help the integration of PV generation into the grid. In this study, the storage system was modeled as a curve load which is charged from 09:30 am for a time of 5 hours and is discharged from 6 pm when there is no solar radiation (according to Fig. 1). For this case, it was considered that in all scenarios each customer adds the same 2 kW of PV generation and a power of 200 W of storage. If scenario 5 is compared in case 1 and 2 (Figs. 4 and 7, respectively), it can be noted that when storage systems are integrated with PVs, a reduction of reverse power flow of 39 kW to 29 kW is obtained. It can be also appreciated that the load peak at 21:00 is reduced in all scenarios due to the storage systems being added.

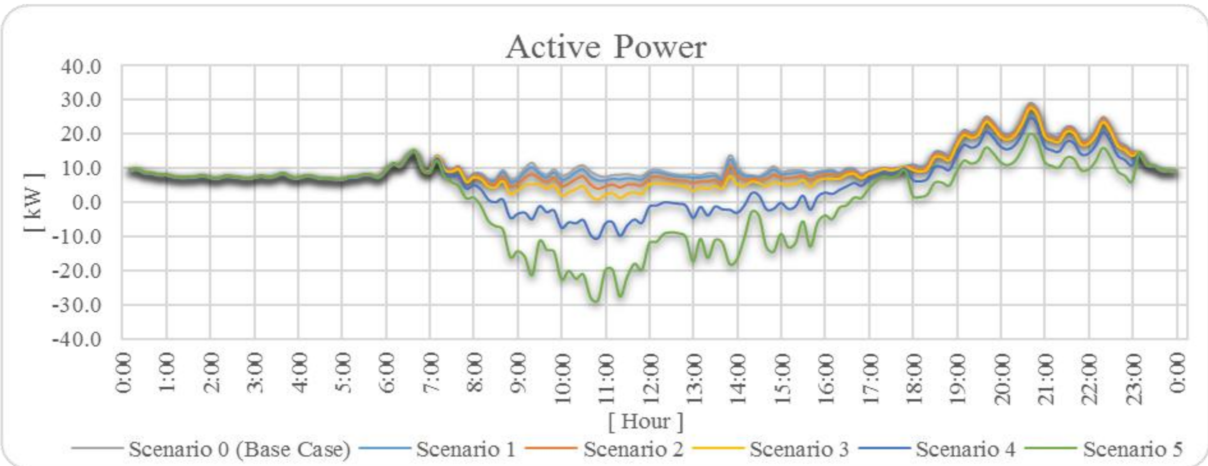


Figure 7. Active power flow (kW) for different DG penetration scenarios and with storage system.

System losses

When BESS is added to the network, system losses are reduced. The maximum losses value take place in scenario 5 at 10:40 am and it is 761.7 W, as shown in Figure 8.

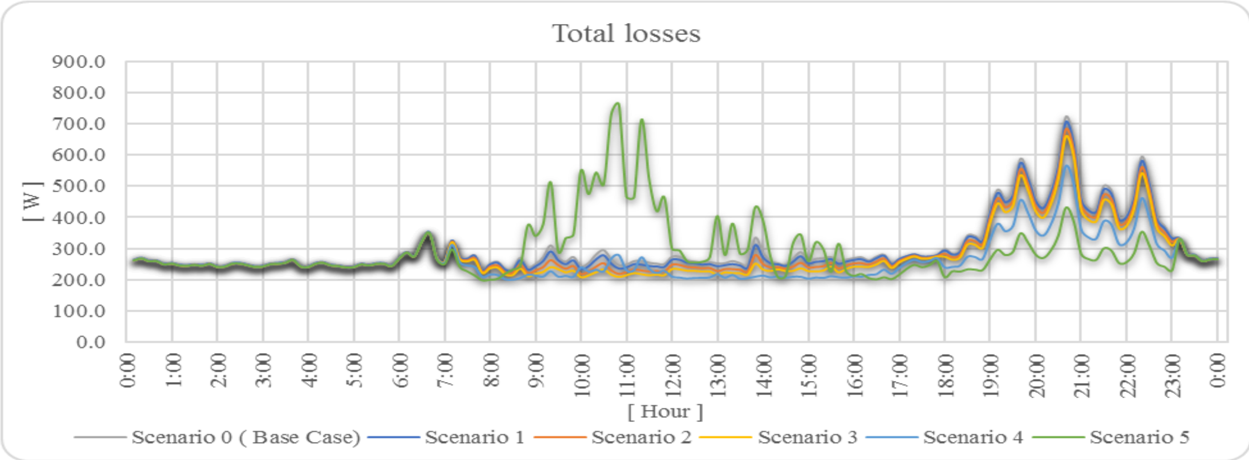


Figure 8. Total system losses [W] for different DG penetration scenarios and with storage system.

In Table 3 a summary of the maximum daily system losses is presented for each scenario. From scenario 1 to scenario 4 losses are lower than in the scenario 0. However, for scenario 5 there are extra losses equal to 39.64 W. It can be concluded that the percentage appropriate of PV penetration is 50% (scenario 4), in which a reduction of 155.42 W with respect to the base case is obtained.

Table 3. Daily Total System losses (case 2).

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Losses (W)	722.02	708.64	692.16	660.33	566.6	761.66
Difference (W)	-	-13.38	-29.86	-61.69	-155.42	39.64

Voltage profiles

Figure 9 illustrates the simulation results for voltage profile when PV and storage are considered together. According to the figure, the maximum voltage value is 1.037 p.u., which means a voltage improvement when compared with case 1, where only PV was considered.

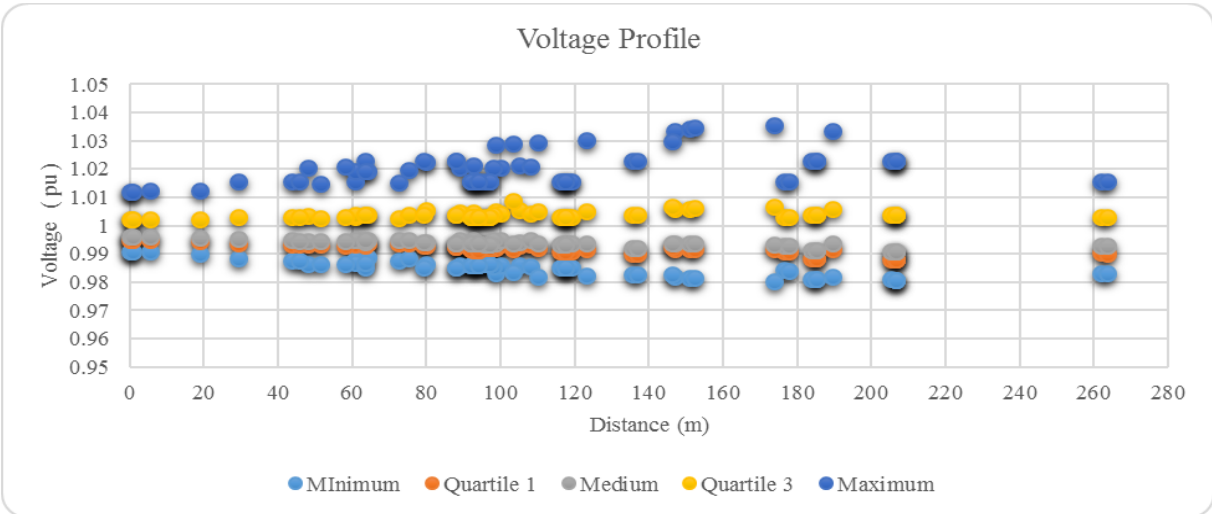


Figure 9. Voltage profile for scenario 5 (case 2).

4. CONCLUSIONS

This study underlines the importance of analyzing the impact of PV generation and storage systems on a real distribution network. As illustrated, problems such as the reversal of active power flow can be produced when PV generation is connected. However, this problem can be reduced by adding storage units. System losses and the voltage profile improved when BESS was added. Results also showed that the power range of DG should be between 0 and 2 kW, when only PV is considered. Above this limit, there would be violations on the voltage levels. Too reduce problems of reverse power flow and power losses, the storage power should not exceed 200 W.

ACKNOWLEDGMENTS

The first author thanks SENESCYT, the University of Cuenca and IPL for offering the opportunity to study with the support of the scholarship program. The authors are grateful to the electrical company Empresa Eléctrica Regional Centro Sur C.A. (CENTROSUR) for the provision of the technical information about the electrical network of one sector of Cuenca needed for this work.

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