Contribution to the Transformation of the Distribution Network of the City of Douala into a Smart Grid using OpenDSS and OMNet++: Reduction of Technical Losses and Improvement of Voltage Profile

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***Abstract*— This paper presents a contribution to the transformation of a conventional network into a smartgrid for the improvement of voltage profile and the reduction of technical losses. The co-simulation framework is SGsim, it allows to simulate different applications in the context of smartgrid and for studying the impacts of photovoltaic systems on distribution networks. The use of PV panels improves the voltage stability and reduce power losses in the network. The framework is composed of a simulator interfaced with the phasor simulator, OpenDSS and the communication network simulator, OMNet++. An interface protocol is implemented for the exchange of data between OpenDSS and OMNet++ using a component object model server. The paper discussed the need for such a tool in the power systems simulation field. The paper also explored different features and advantages of the framework and its applications. The co-simulation framework is tested using a real Douala-based reduced network in Cameroon.**

Keywords*— Smartgrid, Technical Losses, Voltage Profile, OpenDSS, OMNet++

I. INTRODUCTION

An electrical network is composed of equipment intended to produce, transport and supply energy to consumers who are the last links in the chain [1]. Between the amount of energy produced and the one which is used, there is a gap which represents losses, and can be classified into two categories namely non-technical losses and technical losses [1], [2]. Non-technical losses are due to theft of energy, the quality of the measuring devices or quite simply counting errors [2], [3]. The technical losses that will be the subject of our study are due to network equipment [3]. During power transit, the cables through their resistance consume active energy by joule effect and skin effect and through their reactance they consume reactive energy which produce the voltage drop at the end of the line. The first objective of any energy distribution company is to minimize these losses [4]. The solution of non-technical losses will take place with the advent of smartgrids which do not have a standard definition [5] but that can be presented as the network of the future, bringing together the electrical, communication and IT network. The introduction of distributed generation (DG) in modern distribution systems causes bidirectional power flow that could create potential challenges and impacts. Such to reduce the technical losses in the electrical network [6]. As the photovoltaic (PV) systems penetration increases in the distribution side, a lot of concerns arise regarding the potential impacts that could appear. These potential impacts affect the power quality [5], [6] (harmonic injection, voltage fluctuation, flicker, etc.), voltage regulation. Power system simulation is essential for understanding the behavior of the system under different conditions. However, there are a lot of computational constraints and difficulties due to limitations of computational resources. These constraints become more problematic especially when the network models become more complex. Different mathematical techniques, engineering tools and software have been developed to address the complexities of power system modeling and simulation [7]. Electromagnetic transient (EMT) tools offer the best accuracy; however, the high accuracy of EMT tools is accompanied by various constraints such as the size of the modeled system and the time-step size of simulation. There is an inverse relation between the EMT simulation time-step and the total simulation time [8].

This paper will discuss the development of a co-simulation framework using OpenDSS and OMNet++ that is focused on performing PV impact on the voltage profile and the reduction of technical losses. The framework supports real time simulation. Therefore it is possible to evaluate time-critical applications such as real time monitoring and control. The paper will explore the features of the framework and its various applications. The reason for developing such a tool is to overcome some of the simulation constraints (simulation time-step, simulation execution time, size of the simulated network) when studying high PV penetration impacts in large distribution networks. The interface is designated for the exchange of necessary data through a COM interface. This allows the user to perform Electromagnetic transient and communication simulation of distribution networks with interconnected PV systems simultaneously.

This paper is organized as follow: first, we will talk about the smart grid, the co-simulation and the need for co-simulation in PV impact studies for reduction of technical losses. Second we will present the Douala-based reduced

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network, the tools and methods used in this paper. Third we will present the simulation results and analysis.

II. SMART GRID

Fig. 1 shows the structure of a smart grid. Smartgrid is a network that put together the electrical network, the communication network and the computer network. They have the following structure:

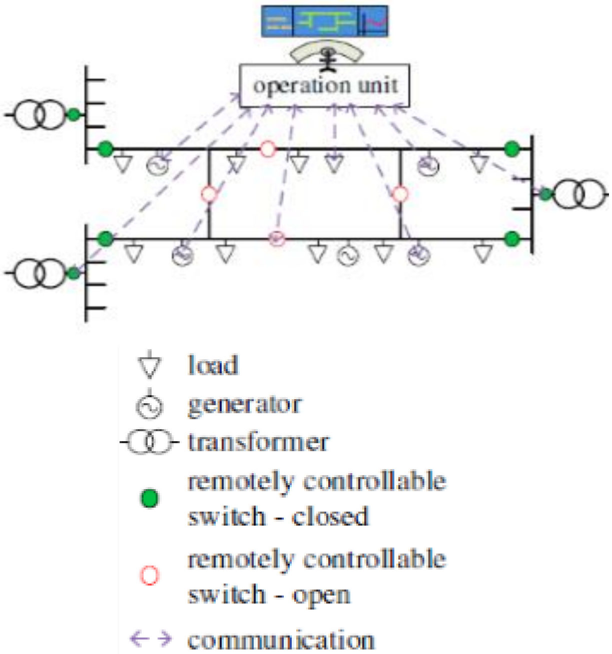

Fig. 1. Structure of Smartgrid [9]

III. REVIEW OF CO-SIMULATION METHODS

Co-simulation is a simulation technique that involves the integration of two different types of simulation engines. The concept of digital co-simulation was practically introduced during the 1980s [10]. The earlier versions of co-simulators were used in modeling high voltage direct current systems [11]. New applications for co-simulation were developed with the introduction of flexible AC transmission system and static VAR compensator devices [12], [13]. Literature review suggests that most developed co-simulation software involved the interface of a mature transient stability analysis tool with another mature Electromagnetic transient tool [13]. Co-simulation will be very useful in PV system integration studies that require multi-rate time-steps since using small time-step with Electromagnetic transient simulation for the entire system is inefficient. This will facilitate the analysis of large systems with PV plants since it will be time consuming and computationally expensive to simulate and solve the entire system in Electromagnetic transient simulator. The potential impacts of PV system on distribution networks include, but not limited to, voltage fluctuations, technical losses, resonance, etc. These impacts cannot be studied using a power flow simulation tool. However, a co-simulation tool combining Electromagnetic transient simulator and communication data using OpenDSS and OMNet++ for power flow techniques will offer better benefit of studying most of these impacts.

IV. CO-SIMULATION FRAMEWORK

The SGsim consists mainly of two main simulators, OpenDSS and OMNet++. It uses the open source power simulator OpenDSS which is an electric power Distribution System Simulator (DSS) for supporting distributed resource integration and grid modernization efforts. To simulate the communication part of the smart grid, the open source discrete event simulator OMNeT++ is used. The framework is composed of different parts as shown in Fig. 2:

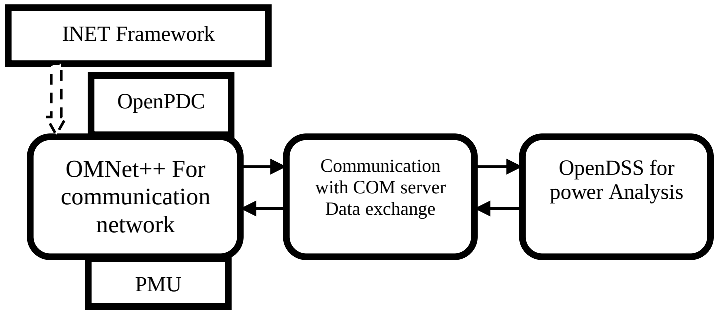

Fig. 2. Parts of Co-simulation Framework

A. *OMNet++*

OMNeT++ is an open source discrete event simulator and is free for academic use. OMNeT++ It is an object-oriented component-based discrete event network simulation framework which is gaining wide acceptance in the scientific community for building and simulating communication systems [14]. Inside OMNeT++ we have built some smart grid components such as Phasor Measurement Units (PMU) and a Phasor Data Concentrator (PDC) interface that can communicate with a real PDC such as openPDC [14], [15]. The openPDC administered by the Grid Protection Alliance (GPA) is a complete Phasor Data Concentrator software system designed to process streaming time-series data in real-time. The openPDC implements a number of standard phasor protocols, which can be used to receive data from devices. The supported protocols are IEEE C37.118 , IEEE 1344, BPA PDCstream, FNET, SEL Fast Message, and Macrodyne [15]. The IEEE 1344 standard for synchrophasors was completed in 1995 and reaffirmed in 2001. In 2005, it was replaced by IEEE C37.118-2005 [16], which was a complete revision and dealt with issues concerning use of PMUs in electric power systems. A typical simulation model consists of modules that communicate through message passing. The simple modules are written in C++ and can be grouped into compound modules and so forth. OMNeT++ models are often referred to as networks and are described in OMNeT++'s NED (NetworkDescription) language. The initial value of the parameters can be assigned either in the NED files or in the configuration file (omnetpp.ini). The INET framework contains detailed implementations for several protocols in the different network layers. For example, it has implementations for TCP, UDP, IPv4 and IPv6. It provides implementations for link-layer models like PPP, Ethernet and 802.11 [17].

Fig. 3 shows the PMU unit, which also uses UDP in the transport layer.

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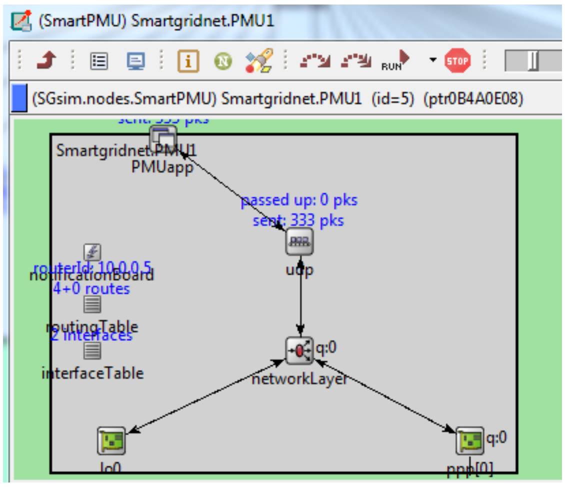

Fig. 3. PMU Unit

Fig. 4 shows the PDC unit, which uses UDP in the transport layer.

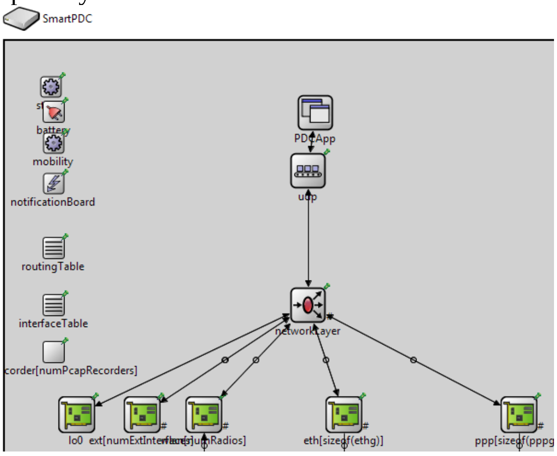

Fig. 4. PDC Unit

Fig. 5 shows the router unit

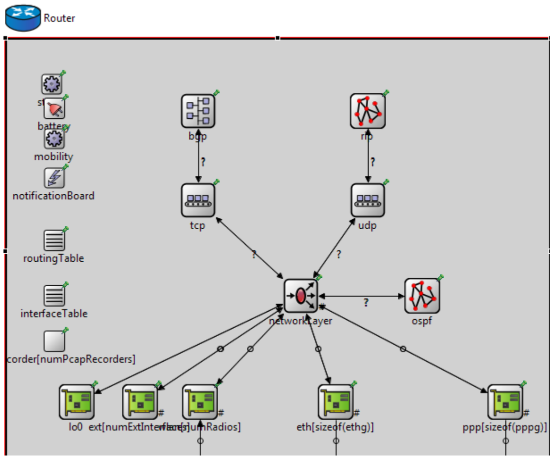

Fig. 5. Router Unit

B. *OpenDSS*

The Open Distribution System Simulator (OpenDSS, or simply, DSS) is a comprehensive electrical system simulation tool for electric utility distribution systems. OpenDSS refers to the open source implementation of the DSS. It is implemented as both a standalone executable program and an in process COM server DLL designed to be driven from a variety of existing software platforms [18]. The executable version has a basic text based user interface for the solution engine to assist users in developing scripts and viewing solutions. The program supports nearly all rms steady state (i.e., frequency domain) analyses commonly performed for utility distribution system planning and analysis [19]. In addition, it supports many new types of analyses that are designed to meet future needs, many of which are being dictated by the deregulation of utilities worldwide and the advent of smart grid [20]. OpenDSS can be used for different purposes such as distribution planning and analysis, solar and wind plants simulations and storage modeling. The program has several built in solution modes such as snap shot power flow and harmonics. Analyzing power systems using OpenDSS requires writing a script that describes the power system. OpenDSS supports a Component Object Model (COM) interface which makes it possible to design and execute custom solution modes and features from an external program and perform the functions of the simulator, including definition of the model data [21].

Since the developed software is intended to be open-source, OpenDSS is chosen for the modeling of the distribution network. OpenDSS is an open-source distribution system simulator. It is structured like a transient stability program and it solves the frequency domain equations of the system. Like most harmonic solvers, OpenDSS is linear, multi-frequency and multi-phase phasor solver. It builds and solves the nodal admittance matrix at each frequency and solves it directly. OpenDSS is not an Electromagnetic transient solver [22].

Therefore, it cannot support studies that require switching models of inverter-based Distributed Generation. So the dynamic modeling features of OpenDSS are still limited, and some work is being done in this area to improve the dynamic functionalities of OpenDSS. However, it is a very good tool for running power flow. It can handle large-size distribution networks and has fast simulation time. OpenDSS also has a COM interface server which allows it to be operated from external software. All those features made OpenDSS a very good candidate for modeling and solving the distribution network and interact with the Electromagnetic transient part of the Co-simulation tool [21], [22].

V. PRESENTATION OF REAL DOUALA-BASED REDUCED NETWORK IN CAMEROON

Fig. 6 shows the network used in this work. It is the network of the city of Douala in Cameroon.

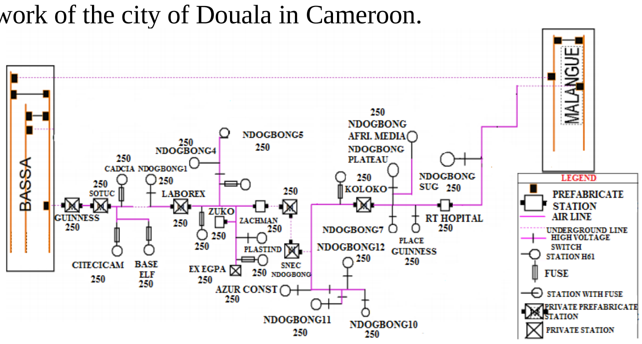

Fig. 6. The real Douala-based reduced network

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Fig. 7 shows our proposition of smart grid

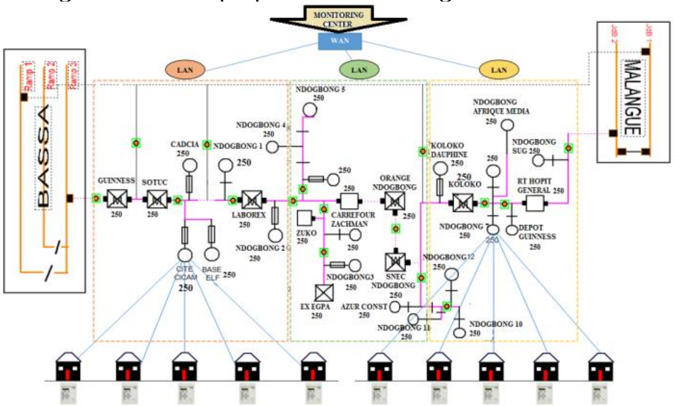

Fig. 7. The intelligent structure of Douala-based reduced network

We have proposed an intelligent structure which includes a telecommunication network organized around LANs and a WAN network which integrates intelligent devices such as PMUs, routers, servers, smart meters and intelligent electronic gear.

VI. RESULTS OF CO-SIMULATION

A. Loadshape

Fig. 8 shows the load shape for our real electrical network.

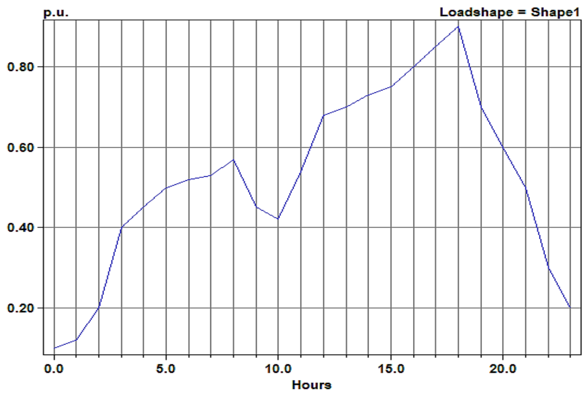

Fig. 8. Loadshape

B. Voltage profile without PV panels

Fig. 9 shows the voltage profile of the electrical network without PV system.

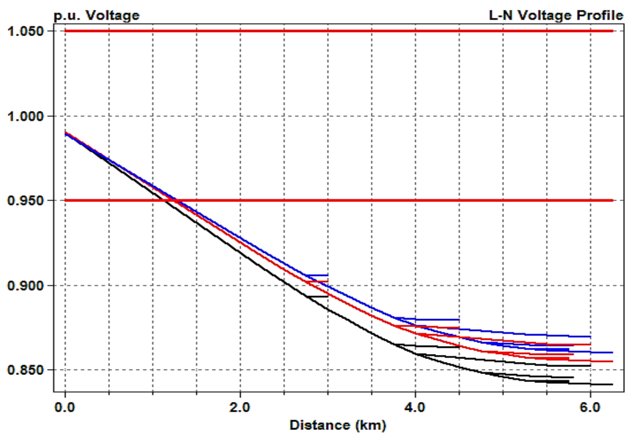

Fig. 9. Voltage profile without PV panels

Fig. 10 shows the voltage profile on the bus 1.

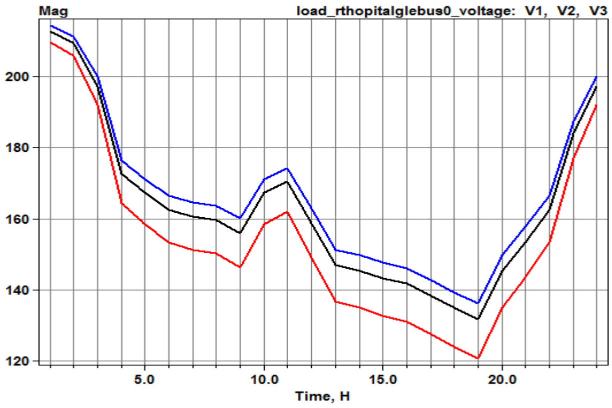

Fig. 10. Voltage profile on bus 1 without PV panels

C. Active and reactive Losses on network without PV panels

Fig. 11 shows losses on the real Douala-based reduced network. The active losses are 58 kW on line 1. The reactive losses are 50 kvar on line 1. All the network have total losses around 16.74 %.

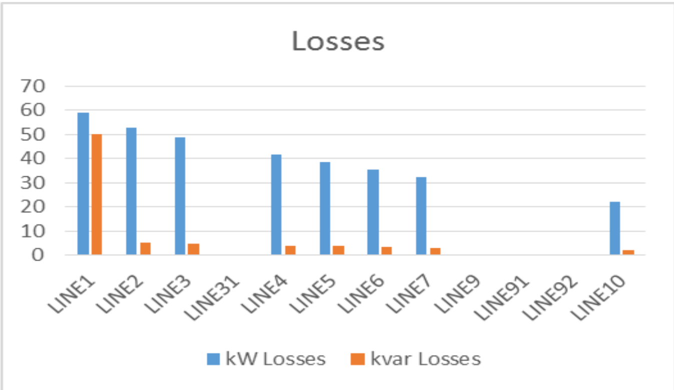

Fig. 11. Active and reactive losses without PV panels

D. Voltage profile with PV panels

Fig. 12 shows the voltage profile with PV panels. We can see and improvement of voltage profile.

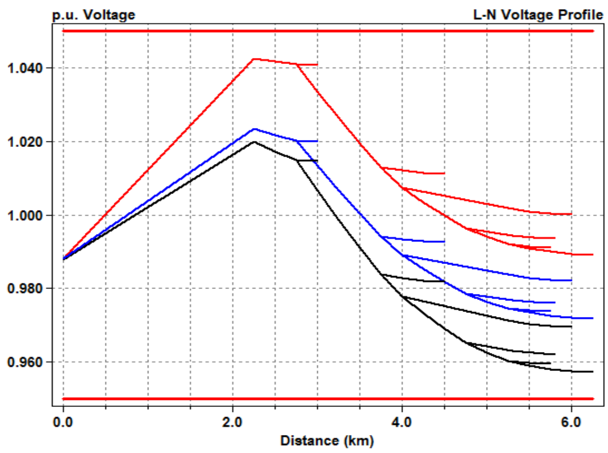

Fig. 12. Voltage profile with PV panels

Fig. 13 shows the voltage profile on bus 1 with PV panel. There is an improvement of voltage on that bus.

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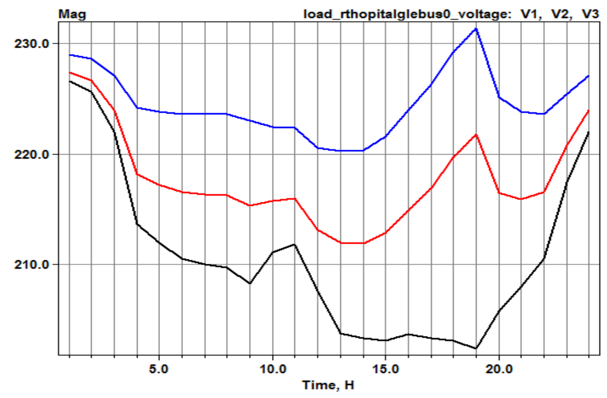

Fig. 13. Voltage profile on bus 1 with PV panels

E. Active and reactive losses with PV panels

Fig. 14 shows the active and reactive losses on the network with PV panels.

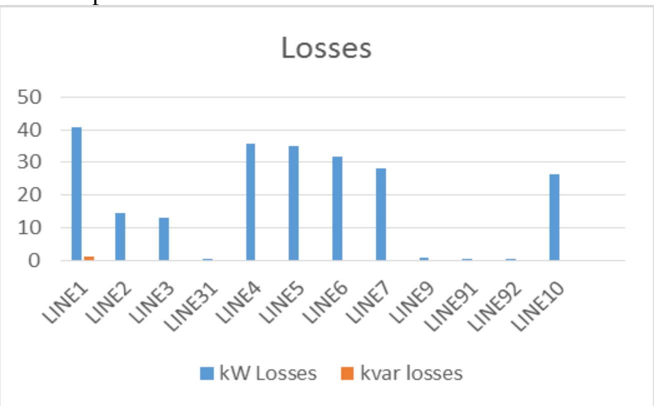

Fig. 14. Active and reactive losses with PV panels

The active losses have been reduce to 40 kW. The total losses are now 9.68 %.

F. Comparison of voltage of two systems

Fig. 15 shows the comparison of voltage of two systems.

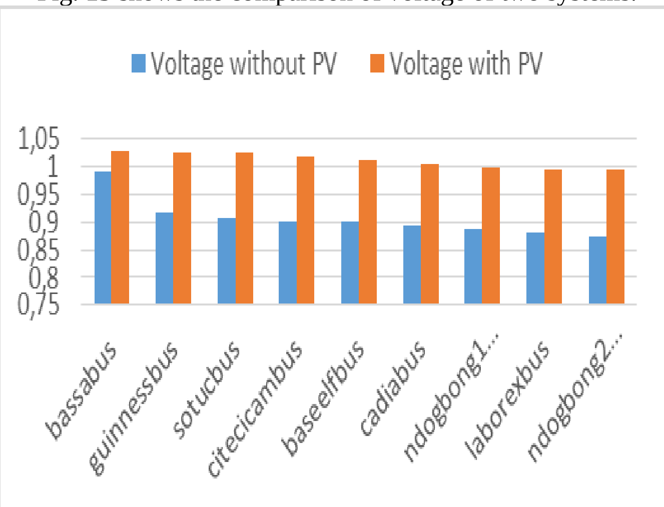

Fig. 15. Comparison of voltage of two systems

G. Comparison of losses of two systems

Fig. 16 shows comparison of losses of two systems.

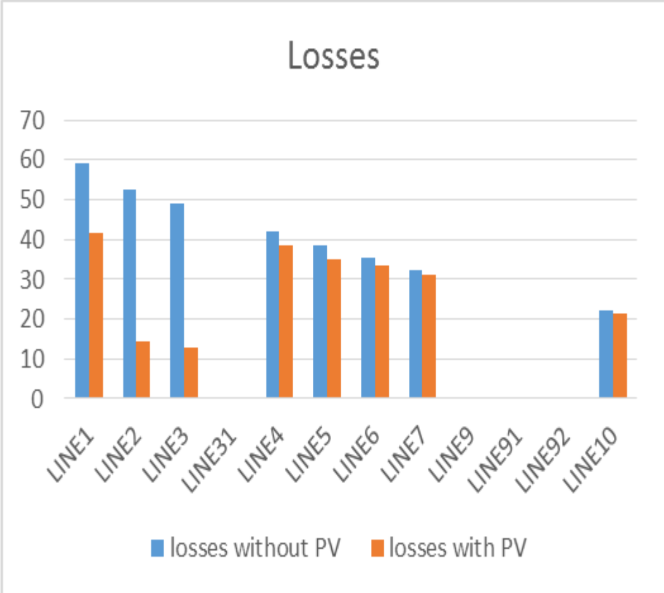

Fig. 16. Comparison of losses of two systems

VII. CONCLUSION

This work allowed us to improve the voltage profile and reduce technical losses on real electrical network, which could result in an important monthly energy gain. We move from 16.74 % losses to 9.68 % losses after integrating PV system. This result can be improved if we carry out a study on the optimal placement of distributed generation including solar power plants and wind power plants with the aim of reducing losses in the network.

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