INJECTION OF GREEN ELECTRICITY INTO THE CONVENTIONAL ELECTRICITY NETWORK

Antonio JAOMIARY[1], Edouard Ravalison ANDRIANARISON[2]

[1] Associate Professor, CERESA Laboratory, Doctoral School in Engineering and Innovation Sciences and Techniques, University of Antananarivo, Madagascar.
[2] Full Professor, CERESA Laboratory, Doctoral School in Engineering and Innovation Sciences and Techniques, University of Antananarivo, Madagascar.

ABSTRACT

This article proposes an approach for injecting electricity from renewable energy sources into a conventional power grid. The energy transition is a process that requires the analysis and operation of existing infrastructures (conventional networks) by connecting them with new and renewable energy production systems. This involves mastering the modalities of the energy mix. This is currently dominated by petroleum products.
In order to help improve this situation, it is important to propose methods and models for developing and using these sources to develop the electricity mix. The latter requires a good command of the various techniques for hybridising an electrical energy network.

Keyword: *Control, Green electricity, Hybrid systems, Energy transition, Electro-energy systems*

1. INTRODUCTION

Our research involves injecting green electricity into a high-voltage A power network (formerly known as the "medium-voltage network"). We are proposing a hybridisation approach and applying it to a typical network designed to supply electricity to a town with more than 140,000 inhabitants. One of the criteria for choosing this city is its high potential for renewable energy. We therefore collected technical and meteorological data for an application city in order to assess the qualities of our hybridisation model. This model will take account of the requirements for injecting green energy into the network under study [2]. Numerical tools are used to validate our results.

1.1 Technical data on electrical network

We will use data concerning the conventional electricity network and the renewable energy systems to be connected to this network. we have:

Table -1 Technical data on electrical network

Type of power plant	Installed capacity [MW]	Available capacity [MW]
Diesel thermal power plant	12,72	10,18
Photovoltaic solar power plant	2,5	2,3

1.2 Solar potential in the town of application

For the purposes of our study, the brightest period of the year gives solar radiation of 7,1 kWh/m2. The maximum irradiation is 7,5 kWh/m2. During the darkest time of the year, incident short-wave solar radiation is less than 5,7 kWh/m2. The figure below shows this trend [1]:

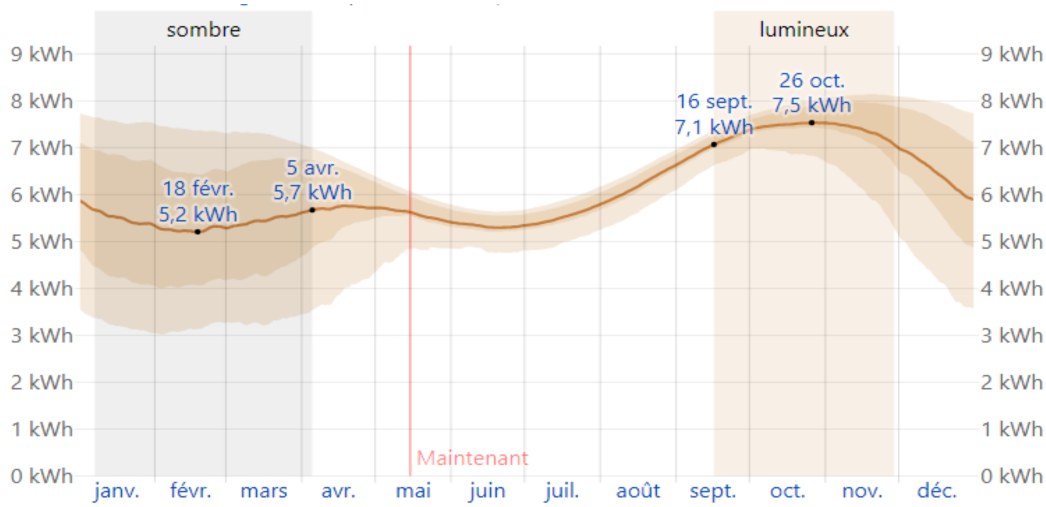

Fig -1 Average solar radiation in the city of application

2. METHODOLOGY

The photovoltaic solar energy production system connected to a conventional grid is a way of achieving the objectives of the energy decentralisation process, through the use of clean or green energy. In fact, it makes it possible to provide the population with local electro-energy systems[3].

What's more, it is always possible to use these systems to provide back-up power when the conventional grid fails [5].

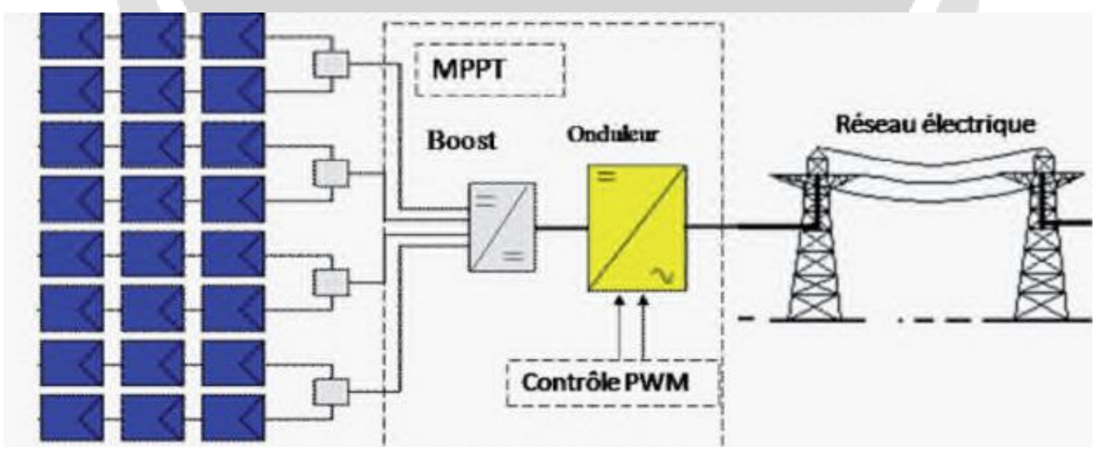

Fig -2 Grid-connected photovoltaic solar system

In our case, we are studying the system of photovoltaic panels connected to the existing electricity grid in the town of application. The grid-connected PV system consists of the photovoltaic fields, the Boost Chopper, the DC/AC converter or central inverter, i.e. a single inverter is used for all the fields, MPPT regulation and PWM control for the inverter.

2.1 Modelling a grid-connected photovoltaic system

For the modelling of a photovoltaic generator, there are several cell models which differ from each other in the number of parameters involved in the calculation of the output voltage and current, such as :

- The ideal model;
- The model with one diode;
- The model with one diode with shunt resistance;
- The model with two diodes;
- The model with two diodes with shunt resistance.

In our case, we choose the one-diode model with shunt resistance. This is the most classic model, using current to model the incident luminous flux, a diode for the physical phenomena of polarisation and two resistors in series and parallel.

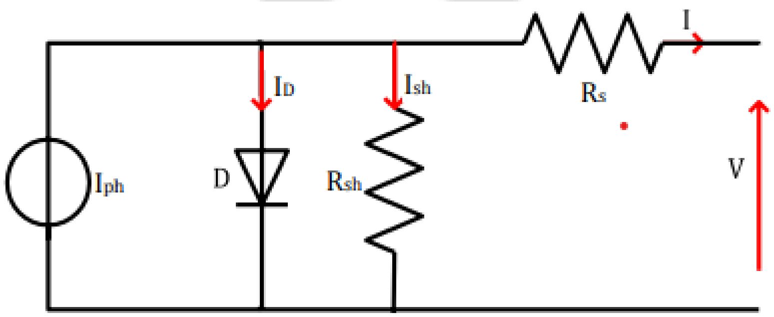

Fig -3 Equivalent model of a photovoltaic cell

These resistors will have a certain influence on the current-voltage characteristic of the solar cell: The series resistance is the cell's internal resistance and mainly represents the resistance of the semiconductor used.
The shunt resistance is due to a leakage current at the junction, and depends on the way the junction has been made.
The diode current is given by:

$$I_D = I_0.[e^{\frac{q.(V+R_S.I)}{A.K.T}} - 1] \qquad (1)$$

$$I = I_{Ph} - I_0 - I_{Sh} \qquad (2)$$

$$I = I_{Ph} - I_0\left[e^{\frac{q.(V+R_S.I)}{A.K.T}} - 1\right] - \frac{(V+R_S.I)}{R_{Sh}} \qquad (3)$$

2.2 Chopper model

The chopper is used to regulate the transfer of energy from a source to the load with high efficiency under certain conditions. It can return energy from the supply, lower or raise the voltage under certain conditions.
In our case, we use the boost converter known as a DC-DC converter. The input source is direct current (inductor in series with a voltage source) and the output load is direct voltage (capacitor in parallel with the resistive load) [8].

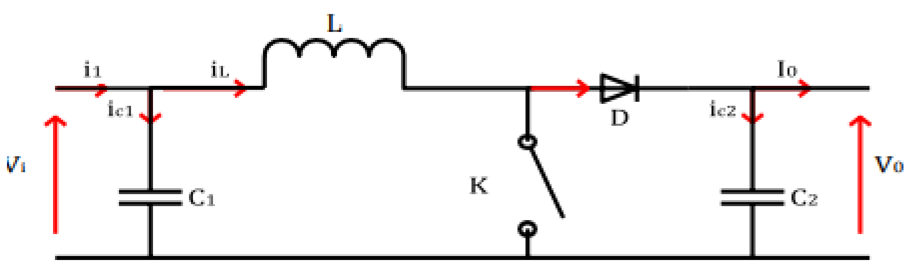

Fig -4 Chopper model

When switch K is closed, the current in the inductance iL increases progressively and it stores energy during the positive half-wave. Then, if switch K opens, the inductance opposes the decrease in inductance current and generates a voltage which is added to the source voltage applied to the load across the diode.

- If K is closed:

$$i_{c1}(t) = C1\frac{dV_i(t)}{dt} = i_i(t) - i_L(t) \qquad (4)$$

$$i_{c2}(t) = C2\frac{dV_0(t)}{dt} = -i_0(t) \qquad (5)$$

$$V_L(t) = L\frac{di(t)}{dt} = -V_i(t) \qquad (6)$$

- If K is open:

$$i_{c1}(t) = C1\frac{dV_i(t)}{dt} = i_i(t) - i_L(t) \qquad (7)$$

$$i_{c2}(t) = C2\frac{dV_0(t)}{dt} = i_L(t) - i_0(t) \qquad (8)$$

$$V_L(t) = L\frac{di(t)}{dt} = V_i(t) - V_0(t) \qquad (9)$$

2.3 Inverter model

The inverter is a power electronic device used to transform direct currents and voltages into single-phase or three-phase alternating current. The voltage output by the inverter must be closer to a sinusoid. In our case, we are using a three-phase inverter [4].

The three-phase inverter consists of three arms. Each arm consists of two switches. The switches selected form a switching cell. Their operation must be complementary so as never to short-circuit the DC source. The switches must therefore be bidirectional in current and consist either of a thyristor and a diode in antiparallel or a transistor with a diode in antiparallel [8].

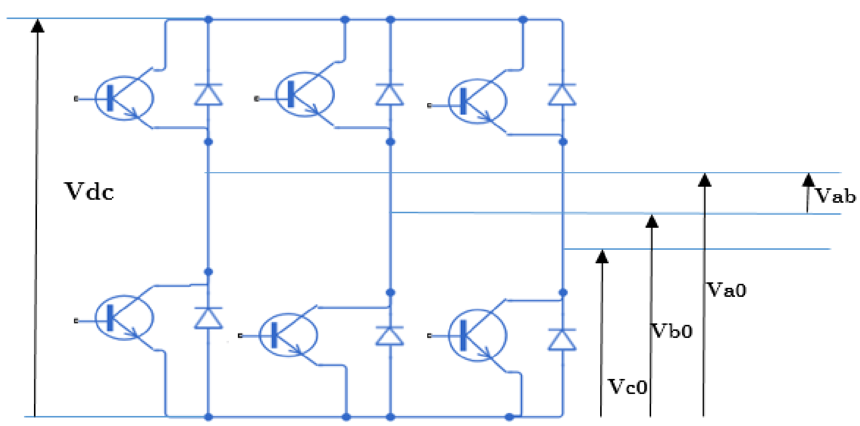

Fig -5 Inverter model

The voltages $V_{ab}, V_{bc}\ et\ V_{ca}$ are the compound voltages are obtained from these relations:

$$\begin{cases} V_{ab} = V_{a0} + V_{0b} = V_{a0} - V_{b0} \\ V_{bc} = V_{b0} + V_{0c} = V_{b0} - V_{c0} \\ V_{ca} = V_{c0} + V_{0a} = V_{c0} - V_{a0} \end{cases} \quad (10)$$

Where: V_{a0}, V_{b0} et V_{c0} are the inverter input voltages (DC). The "O" point has been taken as the reference for these voltages. The three DC input voltages are given by the following relationships [6]:

$$\begin{cases} V_{a0} = V_{an} + V_{n0} \\ V_{b0} = V_{bn} + V_{n0} \\ V_{c0} = V_{cn} + V_{n0} \end{cases} \quad (11)$$

Where V_{an}, V_{bn} et V_{cn} are the phase voltages and the voltage $Vn0$ is the reference voltage at neutral with respect to point O. Assuming the load is balanced, we have the following relationship [9]:

$$V_{an} + V_{bn} + V_{cn} = 0 \quad (12)$$

$$V_{n0} = \frac{1}{3}(V_{a0} + V_{b0} + V_{c0}) \quad (13)$$

The voltage expression becomes :

$$\begin{cases} V_{an} = \frac{1}{3}(2V_{a0} - V_{b0} - V_{c0}) \\ V_{bn} = \frac{1}{3}(2V_{b0} - V_{a0} - V_{c0}) \\ V_{cn} = \frac{1}{3}(2V_{c0} - V_{a0} - V_{b0}) \end{cases} \quad (14)$$

2.4 Simulation tool

Using the above models, we get the following simulink block:

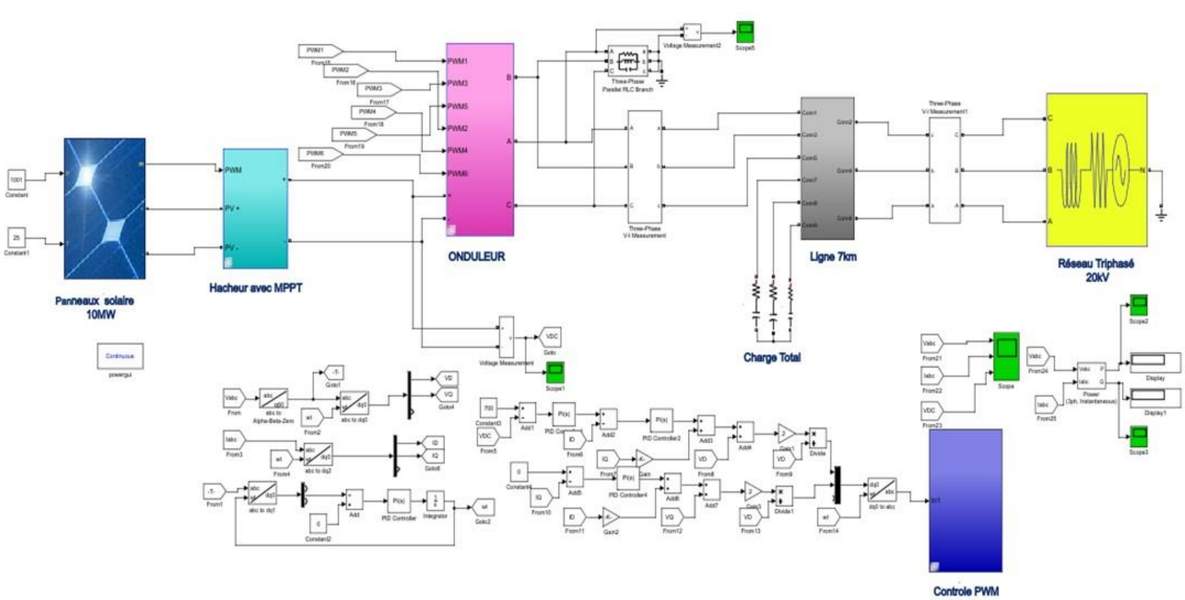

Fig -6 Similink injection block

3. RESULTS AND DISCUSSION

This section will highlight the output voltage of the solar photovoltaic system, the output voltage of the chopper, the voltage at the inverter output and the active and reactive power involved. We will analyse the following curves:

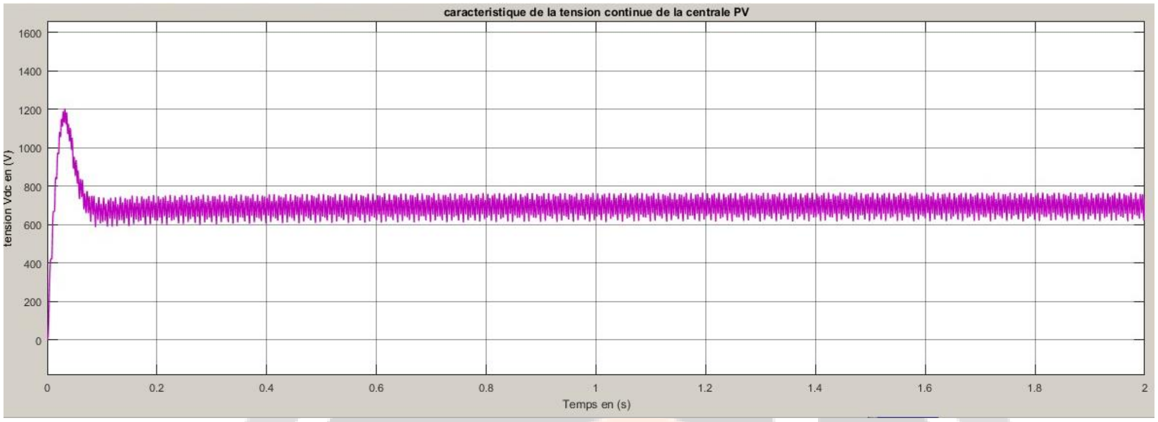

Chart -1 Chopper output voltage

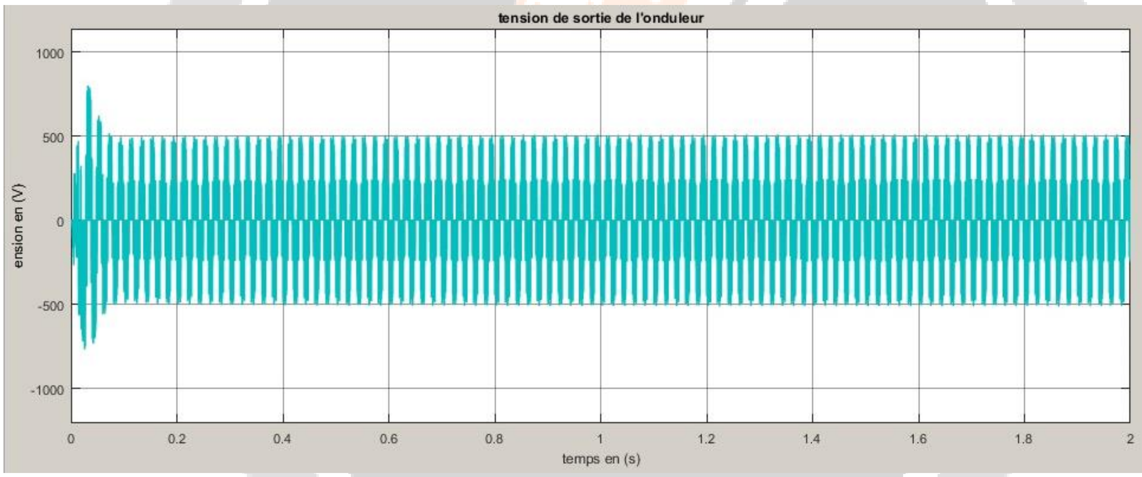

Chart -2 Inverter output voltage

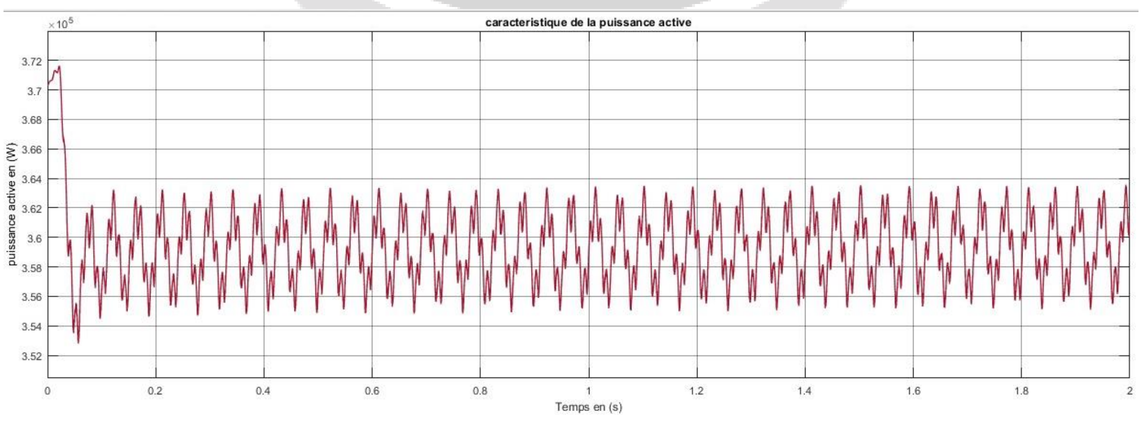

Chart –3 Active grid power

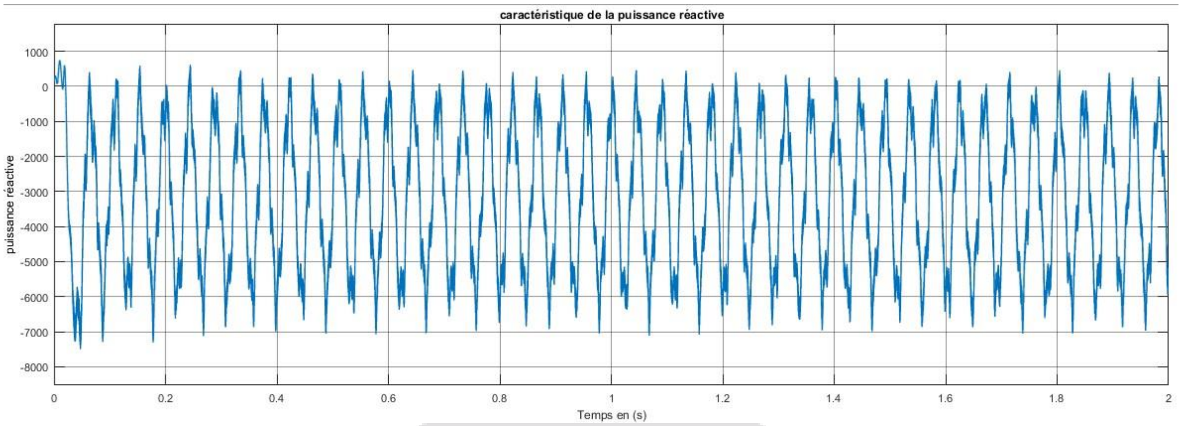

Chart –4 Network reactive power

By superimposing the current and voltage, we have:

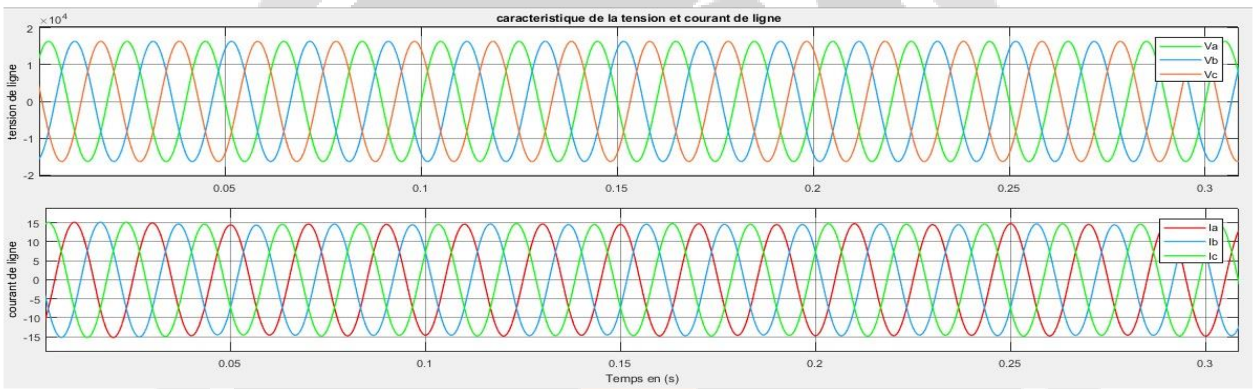

Chart –5 Line voltage and line current

We can see that when the power plant starts up, there is no load, the voltage is very high, up to 1200 V, and after a few seconds, where the loads are connected, the voltage varies from 585 to 745 V. We can also say that theoretically, we have seen that the DC voltage curve is linear but in practice, we have seen that there is an oscillation and the voltage is not perfectly linear but we only take the average value.

The DC voltage coming from the inverter is almost sinusoidal, there is a moment when the voltage is zero, i.e. during the change from positive to negative alternation, there is a small moment when the voltage remains zero. What's more, the voltage is high when the power plant is starting up, at 800 V.

The inverter voltage is almost constant between -500 and 500V.

the active power varies between 3.4 and 3.57 MW during load interception or city needs. the reactive power is almost negative.

The line voltage is 20kV and the three voltages are almost sinusoidal, the line currents are also sinusoidal.

4. CONCLUSIONS

The simulation results show that the injection of green electricity or the connection of renewable energy sources requires the implementation of several devices to stabilise the energy flow. In our case, we have considered photovoltaic solar energy as a source of green electricity. Satisfactory results were obtained in relation to the targets set. We have not defined exact penetration rates for solar photovoltaic electricity, but we have been able to quantify a significant proportion of energy that can be injected into the network without the network losing its synchronisation. In fact, the injection of solar energy increases the voltage on the network. The study of the simulation provides insights into the voltage and power characteristics. Another part of our work, which we will be publishing in a separate article, concerns conventional grid-wind hybridisation.

5. ACKNOWLEDGEMENT

I would like to express my sincere thanks to Professor Edouard Ravalison ANDRIANARISON, the scientific guarantor of my HDR.

6. REFERENCES

[1] J. Zaninetti, Vector modeling of global illumination in ray tracing, Ecole Nationale Supérieure des Mines de Saint-Etienne, 2013, p. 190.
[2] Iweh, Chu & Gyamfi, Samuel & Tanyi, Emmanuel & Effah-Donyina, Eric. (2021). Distributed Generation and Renewable Energy Integration into the Grid: Prerequisites, Push Factors, Practical Options, Issues and Merits. Energies. 14. 1-34. 10.3390/en14175375.
[3] Pellegrino, S., Lanzini, A., & Leone, P. (2017). Greening the gas network–The need for modelling the distributed injection of alternative fuels. Renewable and Sustainable Energy Reviews, 70, 266-286.
[4] Terfa, H., Baghli, L., & Bhandari, R. (2022). Impact of renewable energy micro-power plants on power grids over Africa. Energy, 238, 121702.
[5] Rehmani, M. H., Reisslein, M., Rachedi, A., Erol-Kantarci, M., & Radenkovic, M. (2018). Integrating renewable energy resources into the smart grid: Recent developments in information and communication technologies. IEEE Transactions on Industrial Informatics, 14(7), 2814-2825.
[6] Pastore, L. M., Basso, G. L., Quarta, M. N., & de Santoli, L. (2022). Power-to-gas as an option for improving energy self-consumption in renewable energy communities. International journal of hydrogen energy, 47(69), 29604-29621.
[7] Azeroual, M., El Makrini, A., El Moussaoui, H., & El Markhi, H. (2018). Renewable Energy Potential and Available Capacity for Wind and Solar Power in Morocco Towards 2030. Journal of Engineering Science & Technology Review, 11(1).
[8] Pouresmaeil, E., Gomis-Bellmunt, O., Montesinos-Miracle, D., & Bergas-Jané, J. (2011). Multilevel converters control for renewable energy integration to the power grid. Energy, 36(2), 950-963.
[9] Singh, M., Khadkikar, V., Chandra, A., & Varma, R. K. (2010). Grid interconnection of renewable energy sources at the distribution level with power-quality improvement features. IEEE transactions on power delivery, 26(1), 307-315.
[10] Yousef, A. M., Ebeed, M., Abo-Elyousr, F. K., Elnozohy, A., Mohamed, M., & Abdelwahab, S. M. (2020). Optimization of PID controller for hybrid renewable energy system using adaptive sine cosine algorithm. International Journal of Renewable Energy Research-IJRER, 670-677.
[11] Keyhani, A., Marwali, M. N., & Dai, M. (2009). Integration of green and renewable energy in electric power systems. John Wiley & Sons.
[12] Hörsch, J., Schäfer, M., Becker, S., Schramm, S., & Greiner, M. (2018). Flow tracing as a tool set for the analysis of networked large-scale renewable electricity systems. International Journal of Electrical Power & Energy Systems, 96, 390-397.

BIOGRAPHIE

	Antonio JAOMIARY, Associate Professor at the University of Antsiranana, Director of the Higher School for Technical Education Academic background: Doctorate in Electrical Engineering, Engineer in Advanced Maintenance Techniques and CAPEN in Electrical Engineering. Professional experience (convincing): Teacher-Researcher, DL Trainer/Consultant, Project Manager for the PADEVE-Antsiranana City program, PDPU Project Management Advisor.