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# European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

Technical Report TA User Project

## Improved droop regulation for minimum power losses operation in islanded microgrids

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**Abbreviations**

<i>DER</i>	Distributed Energy Resource
<i>TA</i>	Trans-national Access
<i>IDR</i>	Improved droop regulation for minimum power losses operation in islanded microgrids

## **Executive Summary**

In this work, the experimental tests about an improved primary regulation for inverter interfaced units in islanded microgrids are described. The considered approach employs an on-line minimum losses Optimal Power Flow, OPF, to devise the set points composing the primary regulation curve. The experimental tests is implemented for a 4-bus test system with two generation buses and two loads. At the end of this work, the parametric analysis is proposed to show the effectiveness of proposed method as well as the improved reliability of the system.

## 1 General Information of the User Project

User Project acronym: IDR

User Project title : Improved droop regulation for minimum power losses operation in islanded microgrids

Host research infrastructures: PRISMES Hardware-in-the-loop simulator and multi microgrid test platform

Access duration (in weeks): 5 weeks

User group members: Prof. Eleonora Riva Sanseverino, University of Palermo, Italy

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## 2 Research Motivation

### 2.1 Objectives

Research propose an improved primary regulation, a novel non-linear droop control where not only considering the power sharing issue but also constraining by frequency limits. And then, find a new feasible and optimized operation points which minimizes production power losses for an islanded microgrid during 24 hours of operation by OPF process. The droop coefficients in the f-P plane in islanded MGs during transients, also the lowest value of the energy losses in the microgrid, both during a load variation and in steady-state is necessary.

### 2.2 Scope

- Integrating proposed droop control loop combined with the limiters of droop coefficients  $K_G$  and frequency,
- Testing the stability of the new droop regulation when the load varies,
- Collecting data and conducting data analyses.



### 3 State-of-the-Art/State-of-Technology

Droop control is a popular method for power sharing and stability support in microgrids. In the literature, linear, nonlinear and dynamic droop methods have been explored. Linear droop control (also known as conventional droop control) is carried out at the so called 'grid forming' DG units for primary regulation of frequency and voltage in microgrids and to rate power sharing between DG generators in the system [1-6]. The work [7] presents a scheme for parallel connected inverters control based on linear droop in a stand-alone AC system. The features can be measured at local level at the inverter premises, so that the system does not need control signals exchange between inverters. A new linear droop control technique for parallel connected inverters operating in an islanded grid or connected to an infinite bus is described in [8], without any communication between inverters.

Differently from linear droop control in which constant droop coefficients are considered, nonlinear droop control is implemented with frequency and voltage droop relations whose parameters change as a function of the optimized output power for power sharing among the different sources. This method is described in details in the study presented in [9]. This research implements an optimized power sharing among different DGs, finding a solution that minimizes the operating cost. An experimental study was also carried out to prove the effectiveness of nonlinear droop control.

Dynamic droop control is implemented when on line adjustments of droop parameters are carried out. In some papers, the no load voltage and no load frequency are used as dynamic signals to control the output power of each DG. In [10], an improved droop control method with automatic master to correct the voltage regulation is shown. A robust control scheme is provided in this case to keep a good stability and dynamic response. This issue is also considered in [11]-[12]. The work in [13] mentions a cost optimization based on a dynamic power sharing method. In this case, a linear unit commitment, based on a frequency droop scheme, is resolved to find out the amount of power that each generator should inject into the bus. To prove the results, some experimental tests are carried out. However, results are just concentrated on the power sharing issue, without considering frequency conditions.

## 4 Executed Tests and Experiments

### 4.1 Test Plan

The experimental study aimed to test operating characteristics of the system when the droop coefficients change to adapt with load changing conditions in 24 hours.

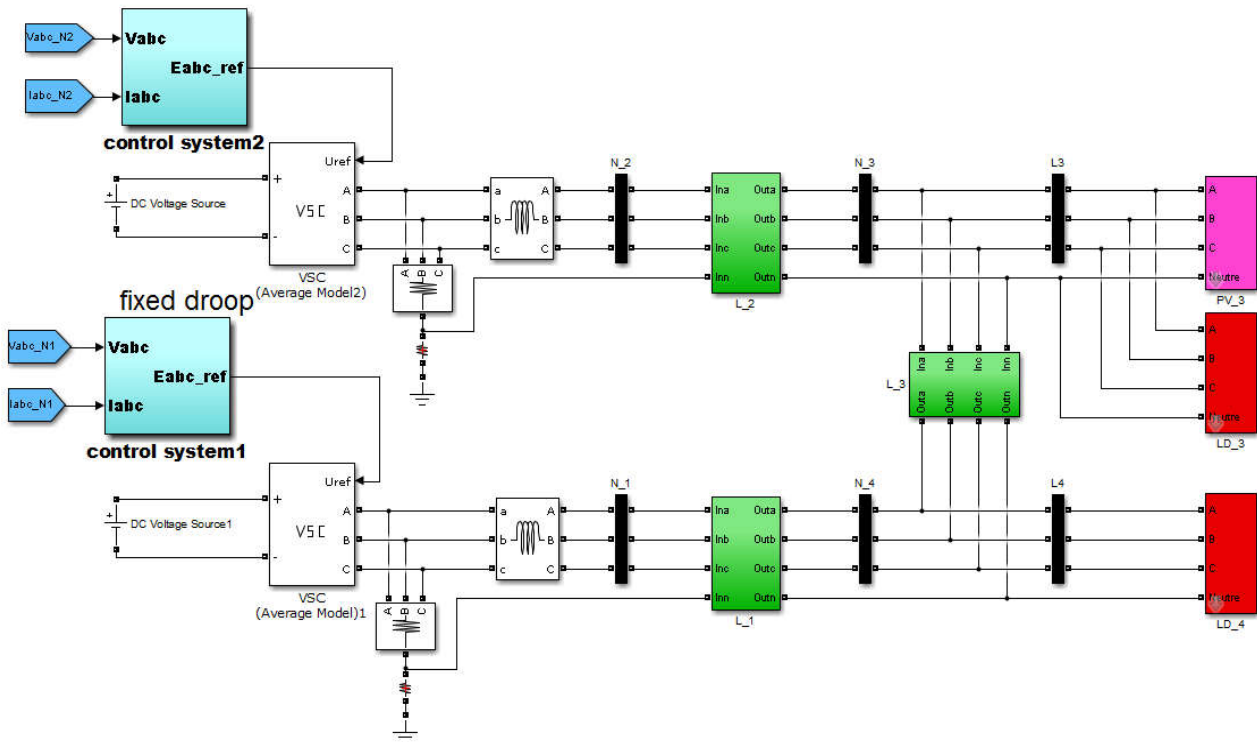
- Phase 1: The model of system was first implemented in the RT-lab simulator to check operating parameters
  - + An experiment is implemented with fix droop coefficients for both generators
  - + An experiment is implemented with fix droop coefficient at DG1 and changing droop coefficient at DG2
- Phase 2: The model of system was testing in hardware in the loop simulation with participation of real PV systems to check operating parameters
  - + An experiment is implemented with fix droop coefficients for both generators
  - + An experiment is implemented with fix droop coefficient at DG1 and changing droop coefficient at DG2

### 4.2 Standards

- Voltage:  $360V \leq V \leq 440V$
- Frequency:  $49 \text{ Hz} \leq f \leq 50\text{Hz}$

### 4.3 Test Set-up(s)

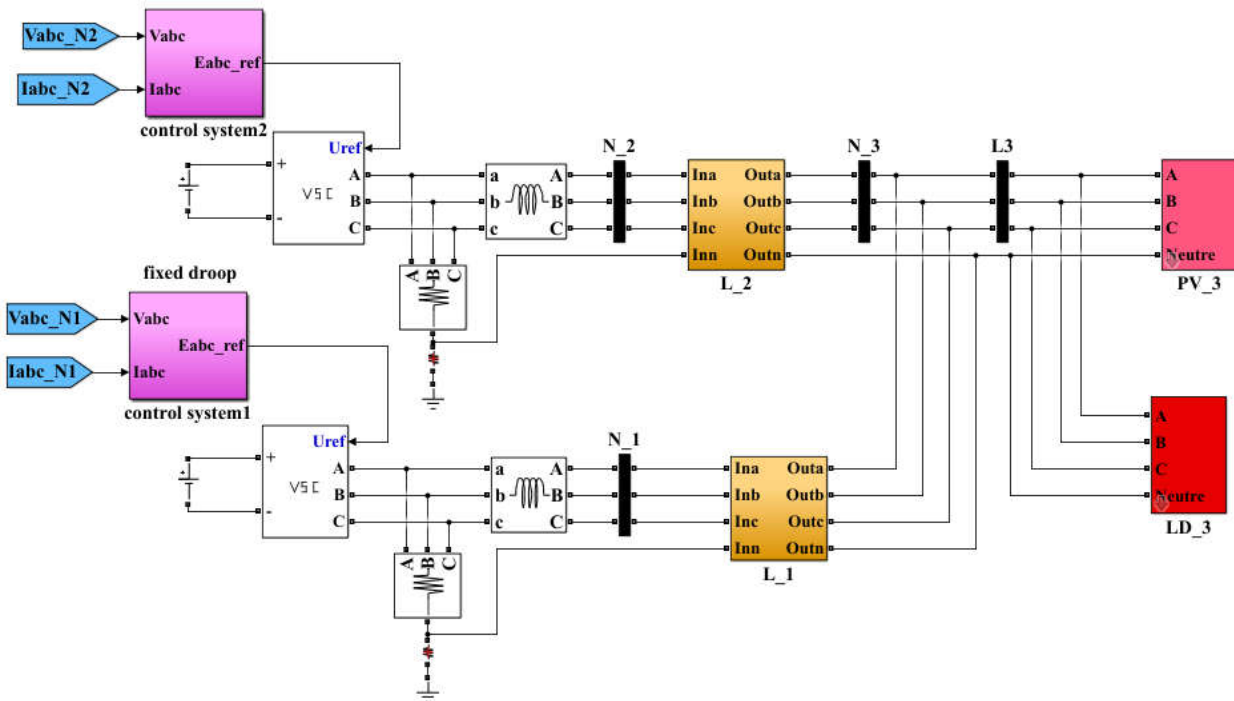
**Phase 1:** The model of system was first implemented in the RT-lab simulator shown in Figure 1. A simple two generators test system connected to two loads The energy demand data set at node 3 will be simulated as a set of peak loads for hours 1 to 24 in a day. A real PV system is connected with node 3



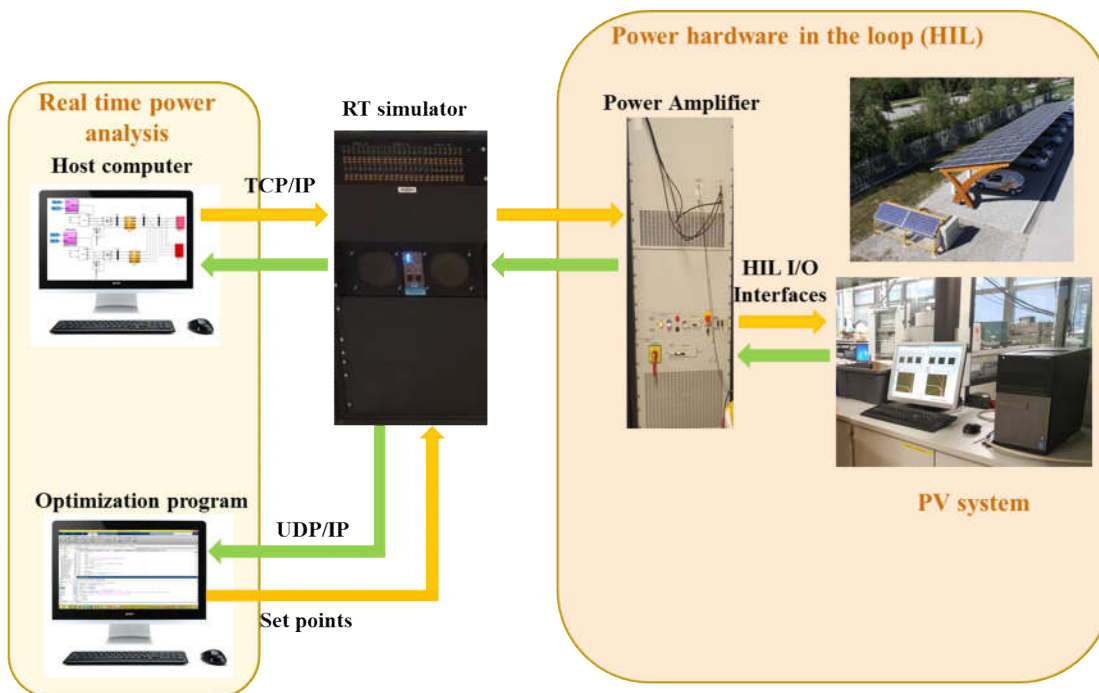
*Fig. 1. The model of 4-bus test system in RT-lab simulator*

**Phase 2:**

The model of 3-bus system was implemented shown in Figure 2. There are only 2 generators connected with one load and a PV system. The configuration of Hardware in the loop system is expressed in the figure 3.



*Fig. 2. Model of 3-bus test system in RT-lab*



*Fig. 3. RT-LAB Simulator with target system and HIL*

### 4.4 Data Management and Processing

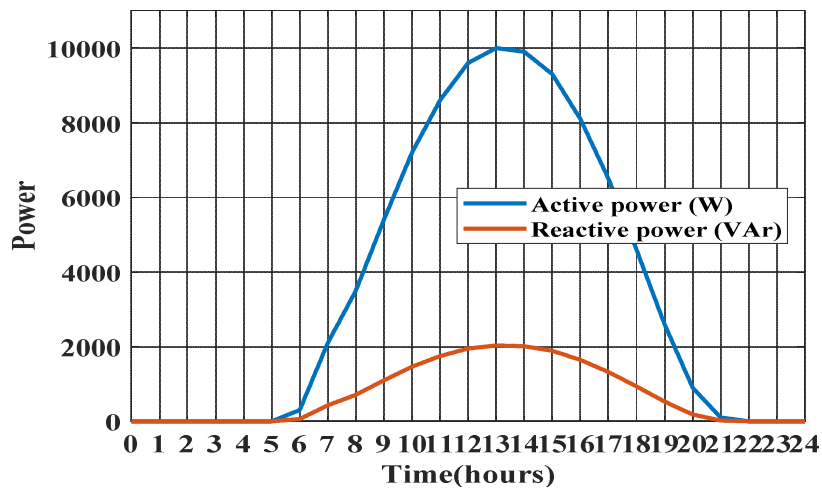
#### Phase 1:

The electric features of transmission lines in the 4-bus system are shown in the following Table 1:

**Table 1** Electric features of 4-bus system

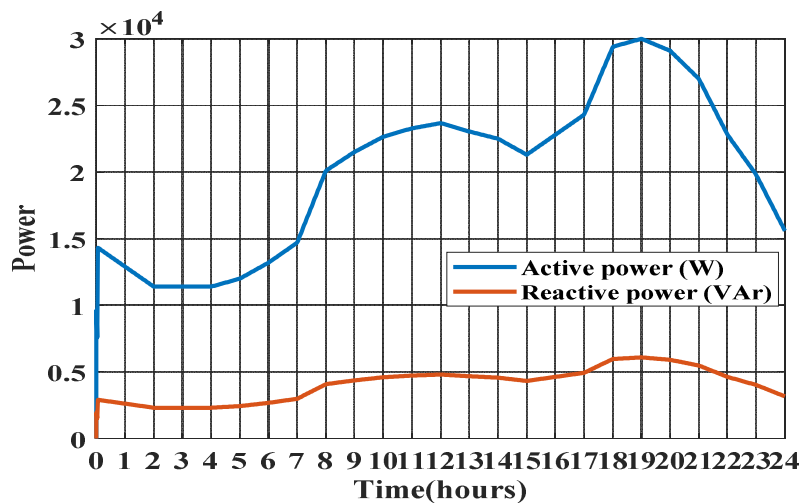
From	To	R (Ohm/km)	X(Ohm/km)	L(km)
1	4	0.43	0.14444	0.5
2	3	0.43	0.14444	2.5
3	4	0.43	0.14444	0.5

The energy profile of PV system in 24 hours is shown in the figure 4



**Fig. 4.** Power profile of PV system

Figure 5 instead shows the assumptions made for the load consumption at bus 3. While figure 6 shows real and reactive power consumptions at bus 4, which is a purely consuming node.



**Fig. 5.** Energy demand at load 3 in 24 hours

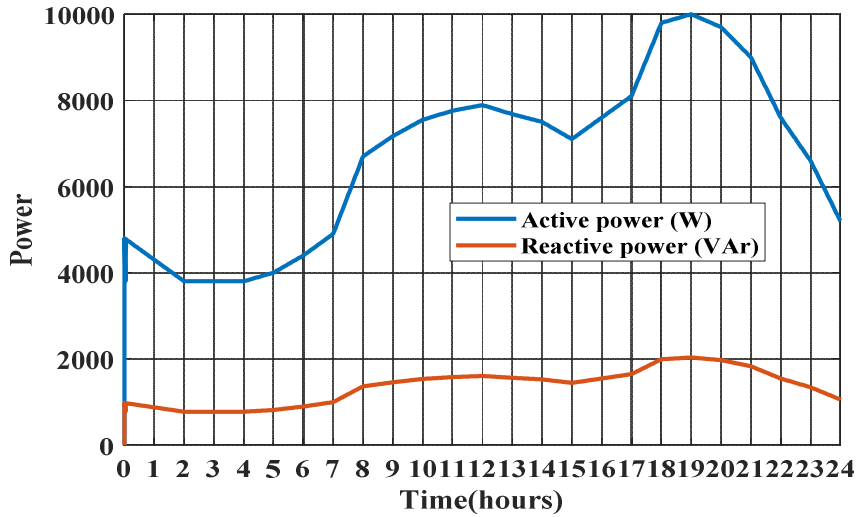


Fig. 6. Energy demand at load 4 in 24 hours

**Phase 2:**

The electric features of transmission lines in the 4-bus system are shown in the following Table 2:

**Table 2** Electric features of 4-bus system

From	To	R (Ohm/km)	X(Ohm/km)	L(km)
1	3	0.43	0.14444	1
2	3	0.43	0.14444	2.5

As it appears from figure 4, bus 3 is also connected to a PV generation system, whose measured production curve in a generic day is reported in figure 7.

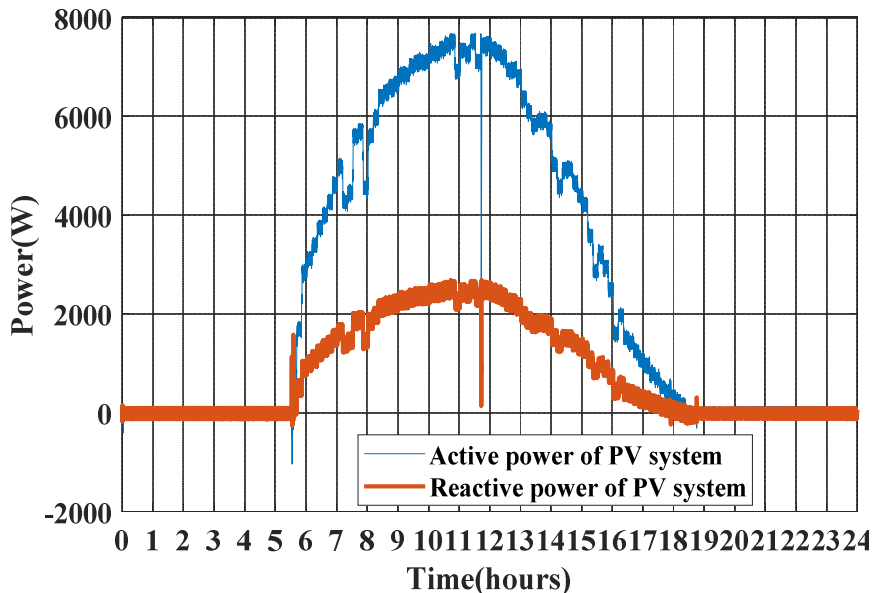


Fig. 7. Power profile of PV system

The energy demand data set at node 3 is shown in the figure 8

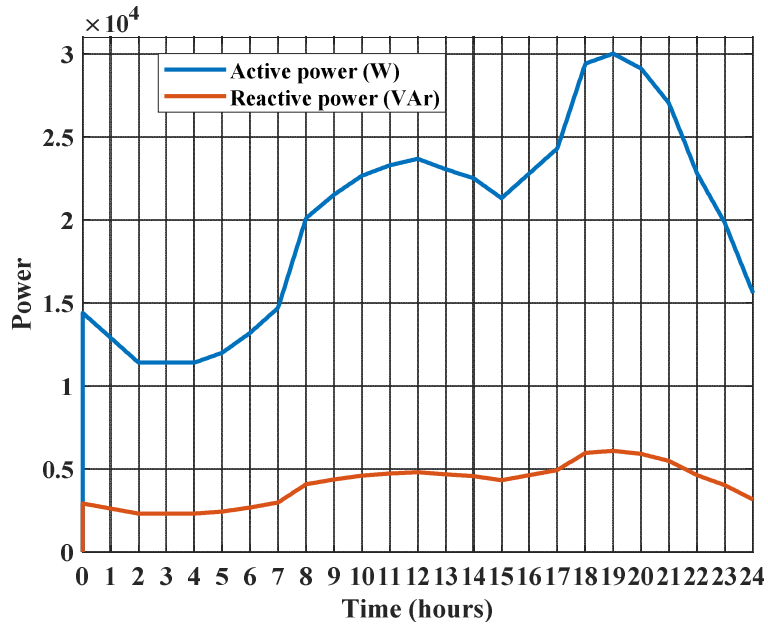


Fig. 8. The load profile at node 3 in 24h hours

## 5 Results and Conclusions

### Phase 1:

Figure 9 show a comparison in the 24 hours of the generated power at the inverted interfaced unit where the optimized droop curve is set.

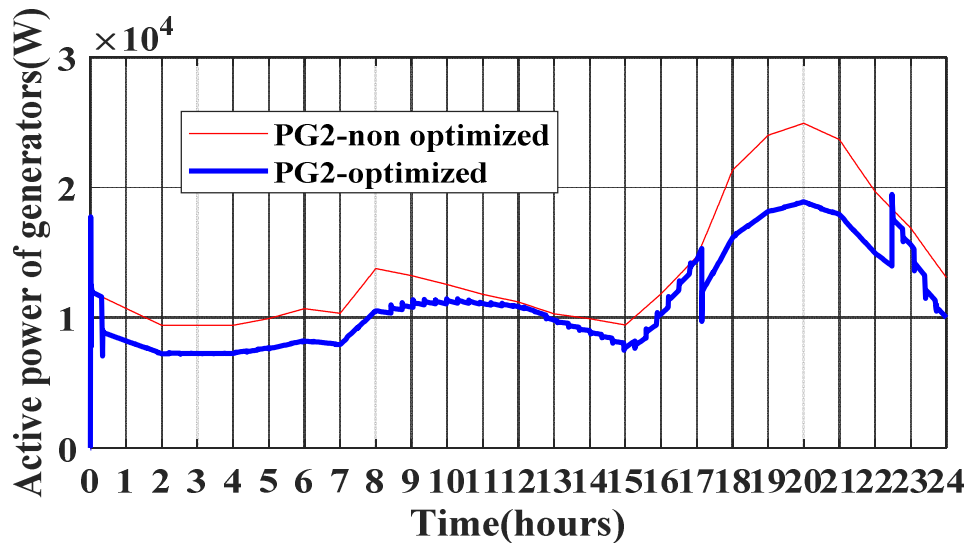


Fig. 9. Active power of generator DG2 with and without optimized droop regulation

Figure 10 shows a comparison along the 24 hours of the power losses in the system considering the new droop technique and the standard droop.

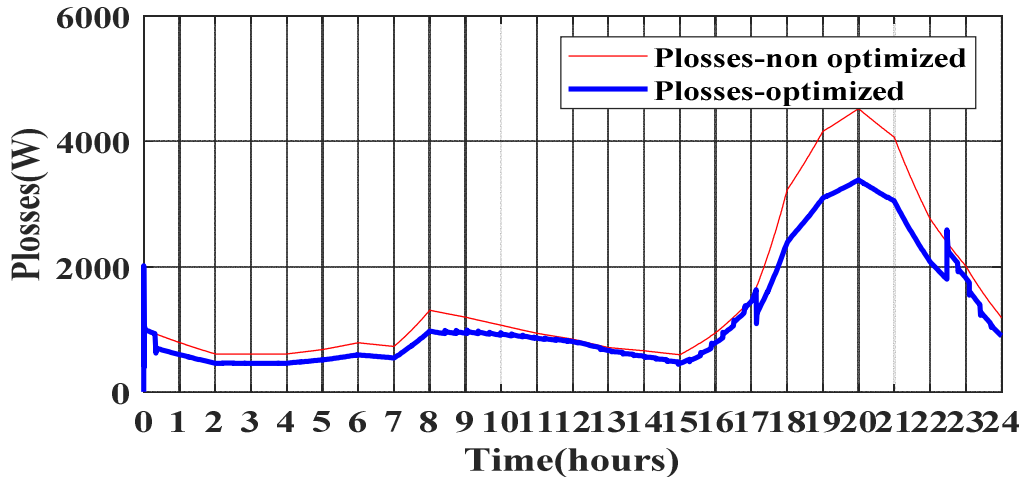


Fig. 10. Power losses of system with and without optimized droop regulation

Figure 11 shows a comparison along the 24 hours of the frequency in the system considering the optimized droop technique and the standard droop.

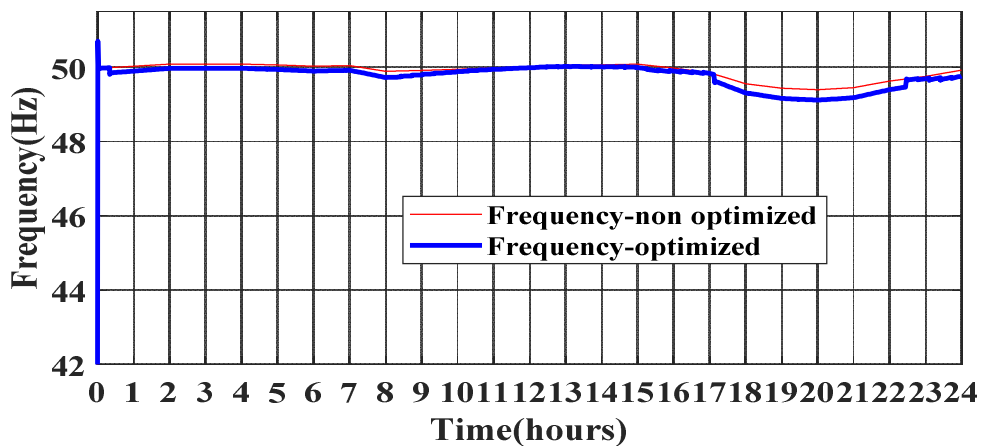


Fig. 11. Frequency of system with and without optimized droop regulation

Figure 12 shows the bus voltages along the 24 hours operation considering the new droop technique.

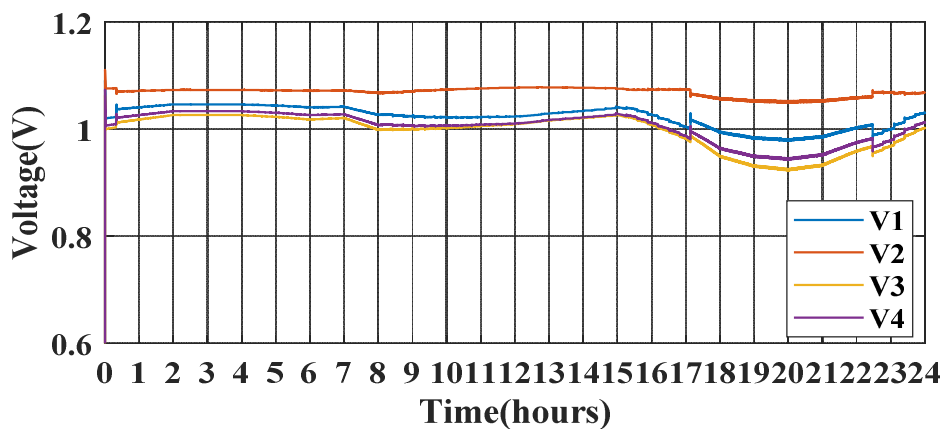


Fig. 12. Voltage at 4 buses with optimized droop regulation

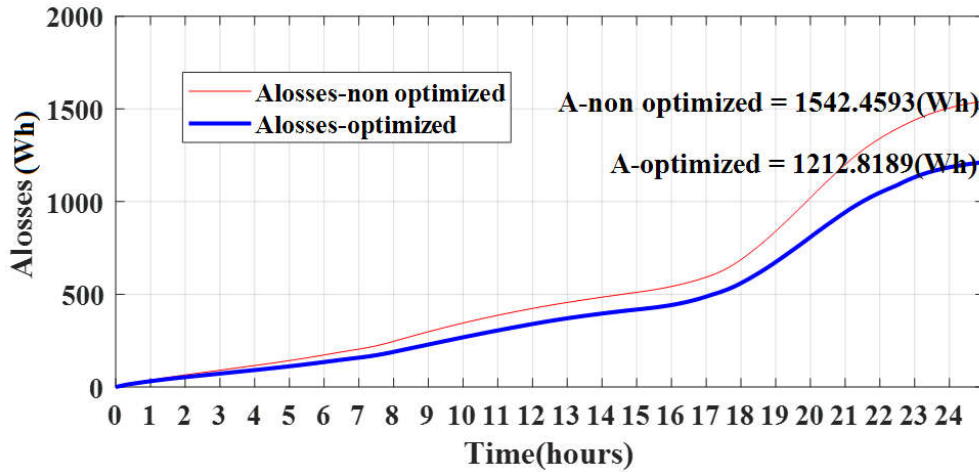


Fig. 13. Improvement of power losses with and without optimized droop regulation

**Phase 2:**

Results for the experimental HIL tests are illustrated in Fig. 14 to 18. Again, active power in the system turns to be reduced and frequency is kept within the limitations, as confirmed by figures 14 and 15.

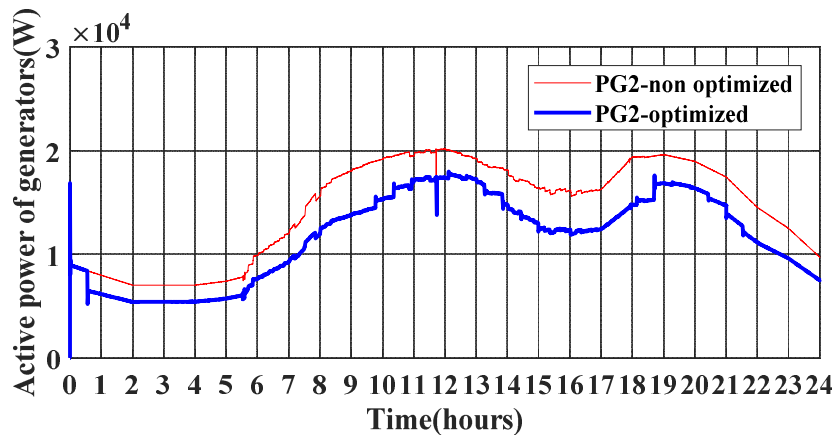


Fig. 14. Active output power of DGs in 24 hours

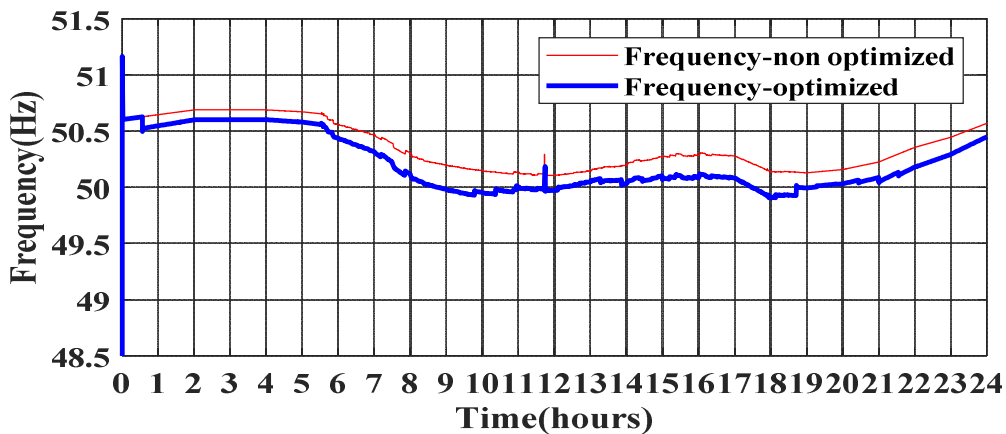


Fig. 15. Frequency of system in 24 hours



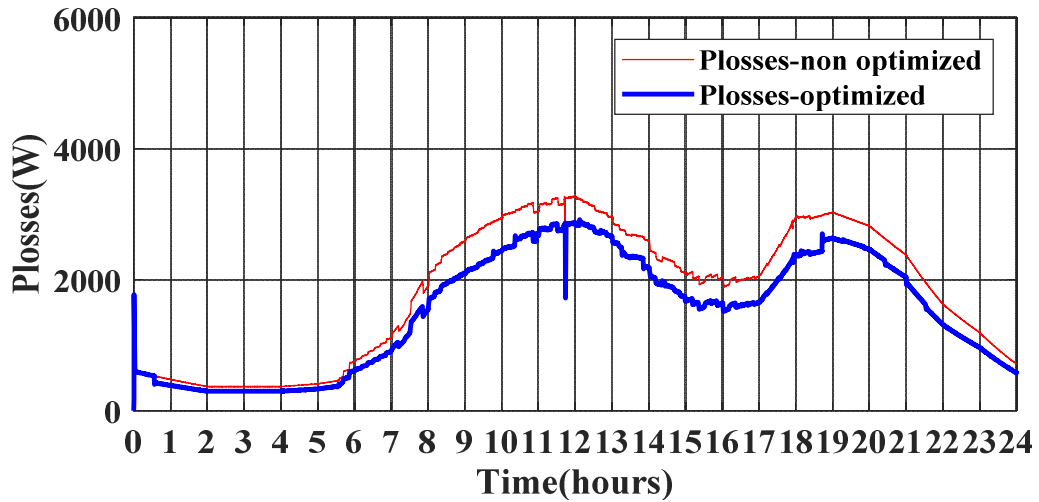


Fig.16. The power loss of system in 24 hours

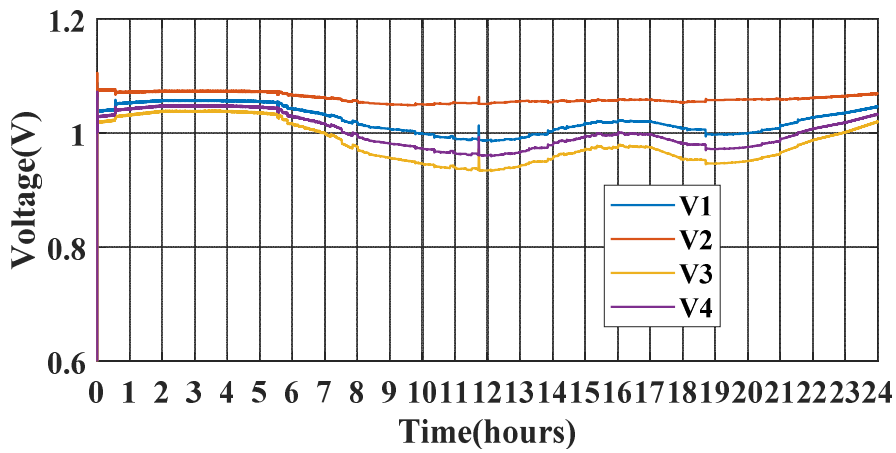


Fig. 17. Voltage profile of DGs in 24 hours

The following figure 18 shows the improvement in terms of energy losses with an overall improvement as compared to conventional drop of 16,15%.

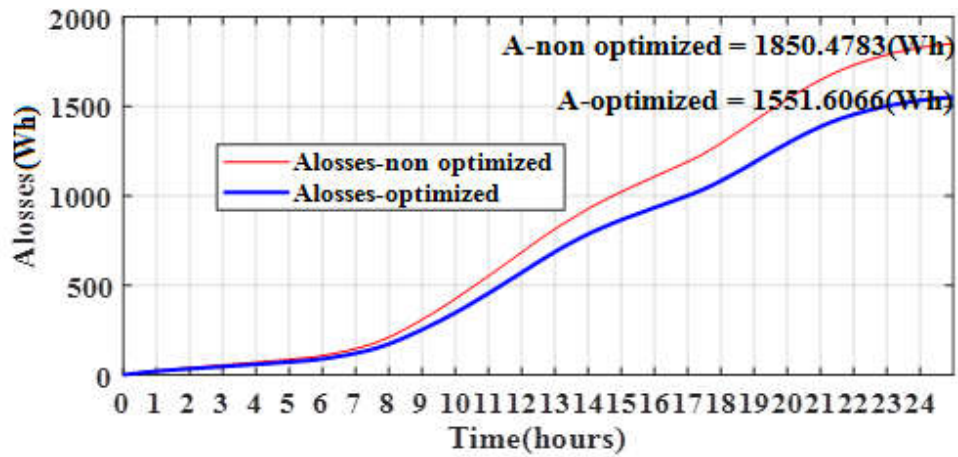


Fig. 18. The energy loss of system in 24 hours

System frequency fluctuates within the limitation, as shown in figure 25, from 49.9 Hz to 50.7 Hz. The frequency response in Fig. 25 shows that the response of frequency is smooth. The DG2 is adjusted to inject enough power in the system in a way that minimizes power losses for the system. The power loss illustrated in Fig. 26 shows that the new regulation method gives smaller losses operation as compared to conventional regulation method of about 16,15%. It is expected that larger systems and LV systems may provide even larger absolute values of power loss reduction. From the proportion of power sharing and the obtained values of frequency, it can be observed that the new regulation demonstrates its powerful efficiency compared to conventional droop method, the system operates in a more effective way at every changing load step.

In this paper, a new droop regulation method is proposed for inverter-interfaced units in islanded microgrids. The results have been compared with conventional droop control to prove the effectiveness of the new droop control curve. The results are also simulated using RT lab simulator and to test operating characteristics of the system with hardware in the loop simulation..

## **6 Open Issues and Suggestions for Improvements**

Further works will produce similar droop regulation curves in larger systems, also optimizing other operating features as fuel cost or operating cost. The proposed on-line procedure ensures a robust optimized operation, since no 24-hours scheduling or rolling horizon approaches are needed for tertiary regulation. In future works, as already outlined in the conclusions of part I of this paper, the consideration of storage units will provide even more flexibility and possibility to improve the operational features even more. Other works, will also consider optimized voltage adjustment in droop control.

## **7 Dissemination Planning**

Submit paper to IEEE Transactions on Smart Grid or Sustainable Energy, Grids and Networks - Journal - Elsevier

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## 9 Annex

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