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Inter-Area Oscillation Monitoring in Maghrebian Power Grid Using Phasor Measurement Unit

M. Tsebia, H. Bentarzi

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***Abstract*—**In the inter-connected power systems, a phenomenon called inter-area oscillation may be caused by several defects. In this paper, a study of the Maghreb countries inter-area power networks oscillation has been investigated. The inter-area oscillation monitoring can be enhanced by integrating Phasor Measurement Unit (PMU) technology installed in different places. The data provided by PMU and recorded by PDC will be used for the monitoring, analysis, and control purposes. The proposed approach has been validated by simulation using MATLAB/Simulink.

***Keywords*—**Inter-area oscillation, Maghrebian power system, Simulink, PMU.

I. INTRODUCTION

THE constitution of the Euro-Mediterranean market of the electric power was defined in Barcelona in 1995 [1] for the objective of the establishment of an integrated and inter-connected energy market.

Currently, the interconnected network 400 kV connects Algeria (Chefia)/Tunisia (Jendouba), Algeria (HassiAmeur)/ Morocco (Bourdim), and also Morocco (Melloussa)/Spain (Puerto of the Cruz) as shown in Fig. 1 [2], [3].

The extension of the interconnected networks leads to a difficulty to monitor and control the oscillations produced in various parts of the power system, which have an anxious effect on the system stability and the security operation.

The low frequency modes (0.1 to 0.8 Hz) [4], [5] are found to involve groups of generators or power generation plants in one side of the tie oscillating against groups of generators in the other side. These oscillations are undesirable as they result in suboptimal power flows and inefficient operation of the power grid. The study of these oscillations is of vital concern.

In order to improve the monitoring of the stability of interconnected power grids, a PMU based system of measurement in real time may be used.

II. MEDITERRANEAN POWER GRID INTERCONNECTION

The Maghrebian and European networks are inter-connected and must operate in synchronization. There are several inter-connected levels of voltage, but in this study, only the inter-connected networks rated at 400 kV between Algeria-Tunisia, Algeria-Morocco will be taken into consideration. The interconnected network 400 kV generates a phenomenon called inter-area oscillation, which is often caused by the opening of the interconnection switches among Maghreb countries. Some examples may be quoted as follows [6].

The incident of January 24th, 2006 in the Western network and Centers at 18 h 41 min, which occurred at full point evening, caused the separation of four sub-networks in Algerian power system.

The incident appeared on May 17th, 2008 with the shutdown of the three groups of the power generation station of Jijel, Algeria (a loss of 500 MW), which caused the opening of the interconnection between Algeria and Morocco.

The incident of July 15th, 2009 with the shutdown of the three groups of SKH, Algeria (a loss of 1100 MW) caused the opening of the interconnections Algeria - Morocco and Algeria -Tunisia followed by a significant decrease in the frequency.

The incident of August 11th, 2011 at 19:00 relating to the separation of the networks Western and Eastern of Morocco occurred following the release of the power lines 400 kV and 220 kV connecting these two networks and it caused the opening of the power lines of interconnection 200 kV between Algeria and Morocco as well as all power lines of interconnection with Tunisia.

Almost all of these incidents are caused by the oscillations in the interconnected networks. The quoted incidents have negative influences on the economy as well as the installed equipment. In order to ensure the synchronization between different areas and for the best monitoring, the installation of PMU may be strongly recommended.

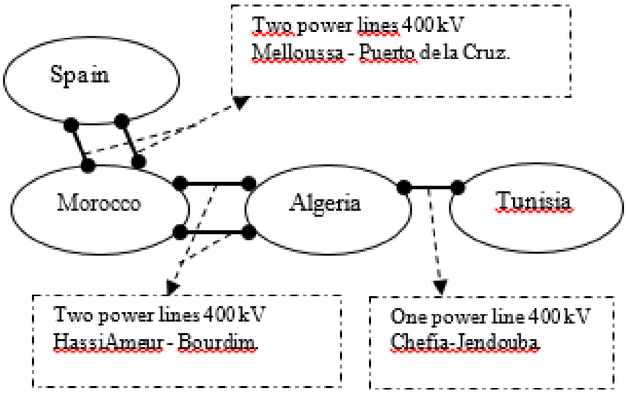

Fig. 1 The Mediterranean power system interconnection

III. PMU TECHNOLOGY

PMU gives phasors information (magnitude and phase angle) about current and voltage in real time [7]-[9]. PMUs are

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M. Tsebia and H. Bentarzi are with the Research Laboratory of Signal and Systems, Institute of Electrical Engineering and Electronics, UMBB University, Boumerdes, Algeria (phone: +213 772288608, fax: +213 24818333, e-mail: lss@ univ-boumerdes.dz).

the most accurate and advanced synchronized phasor measurement instrument. Fig. 2 shows a functional block diagram of a typical PMU. The GPS receiver provides the 1 pulse-per-second (pps) signal, and a time tag consisting of the year, day, hour, minute, and second [8].

Effective utilization of this technology is very useful for mitigating blackouts and monitoring the real time behavior of the power system. With the advancement of the technology, the microprocessor based instruments such as protective Relays and Disturbance Fault Recorders (DFRs) may incorporate the PMU module along with other existing functionalities as an extended feature.

The synchronized PMU is comparatively new technology, so many researchers are dynamically developing applications using this PMU. It seems clearly that many of these applications can be conveniently grouped as follows [10]-[12]:

- Power System Real Time Monitoring,
- Advanced network protection,
- Advanced control schemes.

A. PMU Principle

A pure sinusoidal waveform can be represented by a unique complex number known as a phasor. Consider a sinusoidal signal [8], [10],

$$x(t) = X_m \cos(\omega t + \varphi) \quad (1)$$

where X_m: the peak value of the sinusoidal voltage,ω=2πf : the frequency of the voltage in radians per second, f: the frequency in Hz,φ: Phase angle in radians with respect to the reference.

The phasor representation of this sinusoidal signal is given by:

$$x(t) = \frac{X_m}{\sqrt{2}} e^{j\phi} = \frac{X_m}{\sqrt{2}} (\cos\phi + j \sin\phi \quad (2)$$

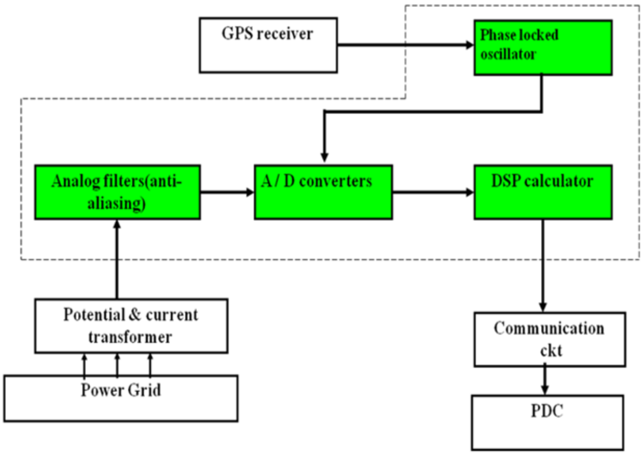

Fig. 2 Functional Block Diagram of the PMU

It can be noted that the signal frequency '$\emptyset$' is not explicitly stated in the phasor representation. The magnitude of the phasor is in terms of and its $\frac{X_m}{\sqrt{2}}$ phase angle is$^{\varphi}$, given in (1). The sinusoidal signal and its phasor representation given by (1) and (2) are illustrated in Fig. 3 [8], [10].

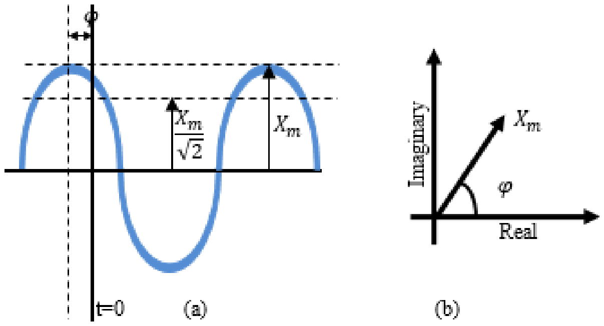

Fig. 3 (a) Sinusoidal signal (b) phasor representation

B. PMU Applied to Power Grid

Inter-area oscillations result from system events coupled with a poorly damped electric power system. The oscillations are observed in the large system with groups of generators or power generation plants connected by relatively weak tie lines [5]. The low frequency modes (0.1 to 0.8 Hz) [4], [5] are found to involve groups of generators or generation plants,on one side of the tie oscillating against groups of generators on the other side. These oscillations are undesirable as they result in suboptimal power flows and inefficient operation of the grid.

To overcome the inter-area oscillation, equipment such as Static Var Compensator (SVC) and various Flexible AC Transmission System (FACTS) devices is increasingly used [10]. These techniques have been widely used due to the recent advancement in the power electronic technology. The involvement of SVC and FACTS in the transmission network is through the so-called Variable Series Compensation (VSC). Besides, the FACTS devices, the application of Super-Conducting Magnetic Storage (SMES) to enhance the inter-area oscillation damping can also be used.

Power System Stabilizers that exist in many generation plants affect only the local area and do not effectively damp out inter-area oscillations. It has been shown that the inter-area oscillations can be detected through the analysis of PMUs located at different buses of the power system.

Oscillations in power system are classified by the system components that they will affect [8]:

- Intra plant mode oscillations: Machines on the same power generation site oscillate against each other at 2.0 to 3.0 Hz,
- Local plant mode oscillations: In local mode, one generator swings against the remaining of the system at 1.0 to 2.0 Hz,
- Inter area mode oscillations: This phenomenon is observed over a large part of the network. It involves two coherent groups of generators swinging against each other at 1 Hz or less.

Instability in power system may be manifested in many different ways. Generally, the stability problem is related to a maintaining synchronous operation. Instability may also be encountered without a loss of synchronism.

Since power systems rely on synchronous machines for generation of electrical power, a necessary condition for satisfactory system operation is that all synchronous machines must remain in the synchronism state. In this research work, this advanced technology (PMU) has been implemented with the help of MATLAB environment. The developed PMU Simulink model has been tested in the three areas power system. Such application can be used for the monitoring system as well as the protection and control system [11], [12].

TABLE I
ALGORITHM OF SELECTION OF CONTROL METHOD [8]

Frequency	Deviation	Actions
50 Hz	0	Nominal frequency
49.98 Hz/50.02 Hz	±20 mHz	Primary control
49.95 Hz/50.05 Hz	±50 mHz	disturbed operation
49.8 Hz/50.2 Hz	±200 mHz	maximum deviation of the frequency of the almost stable state
49.2 Hz/50.8 Hz	±800 mHz	minimal frequency instantaneous
49 Hz/51 Hz	>1000 mHz	criterion of the frequency of unbalancing of load

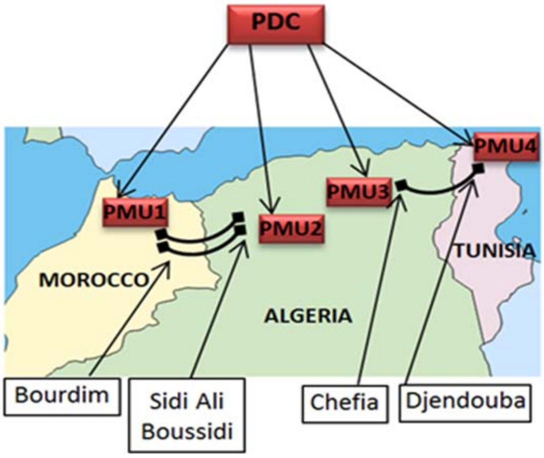

Fig. 4 PMUs location in the Maghrebian power system

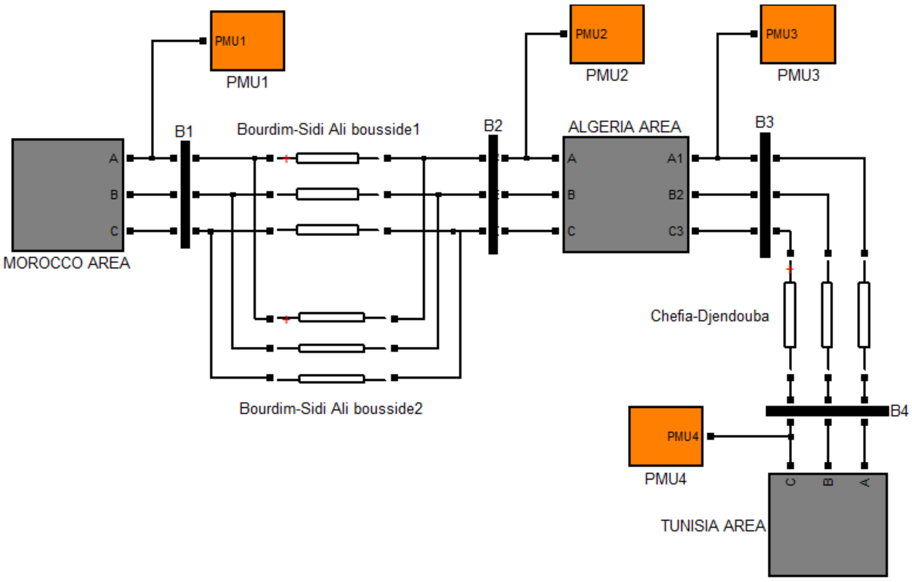

Fig. 5 Simulink model of Maghrebian power system

IV. SIMULATION RESULTS AND DISCUSSION

In this case study, the power system 400 kV interconnected between Algeria-Tunisia and Algeria-Morocco has been simulated by integrating four PMUs, one in each transmission substation, in the other words, two PMUs at each tie bus. The first transmission line is between Sidi Ali Boussidi power transmission substation (Algeria) and Bourdim (Morocco); the second transmission line is between Chefiapower transmission substation (Algeria) and Djendouba (Tunisia) as shown in Fig. 4. A Phasor Data Concentrator (PDC) may be used for recording data of PMUs in the network. The Simulink model of this power system is illustrated in Fig. 5. Thus, the Meghrebian power system consists of three areas, which are Morocco, Algeria, and Tunisia area as shown in Fig. 4.

A. Case I

The first case study is to simulate a fault between Algeria area and Morocco area. The PMUs recordings of voltages, currents, and powers are shown in Figs. 6-8, respectively. The Fault is applied at 2 and cleared at 2+1/50 s.

In this case, the obtained simulation results show that the oscillation is significant in the power line Algeria-Morocco and weak between Algeria and Tunisia.

B. Case II

The second case studies the fault between Algeria and Tunisia area. The simulation recordings of PMUs are shown in Figs. 9-11. In this case, the obtained simulation results show that the oscillation is important on the line Algeria/Tunisia and weak between Algeria and Morocco.

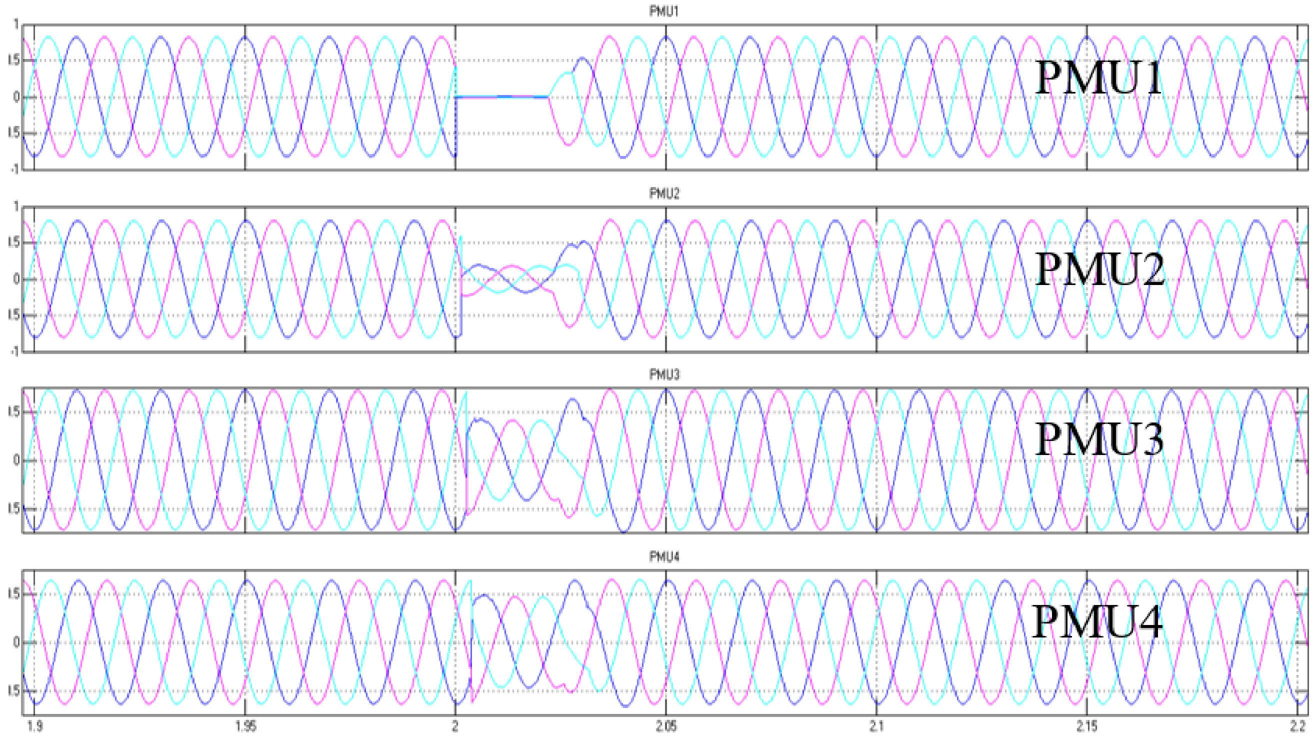

Fig. 6 Voltage results

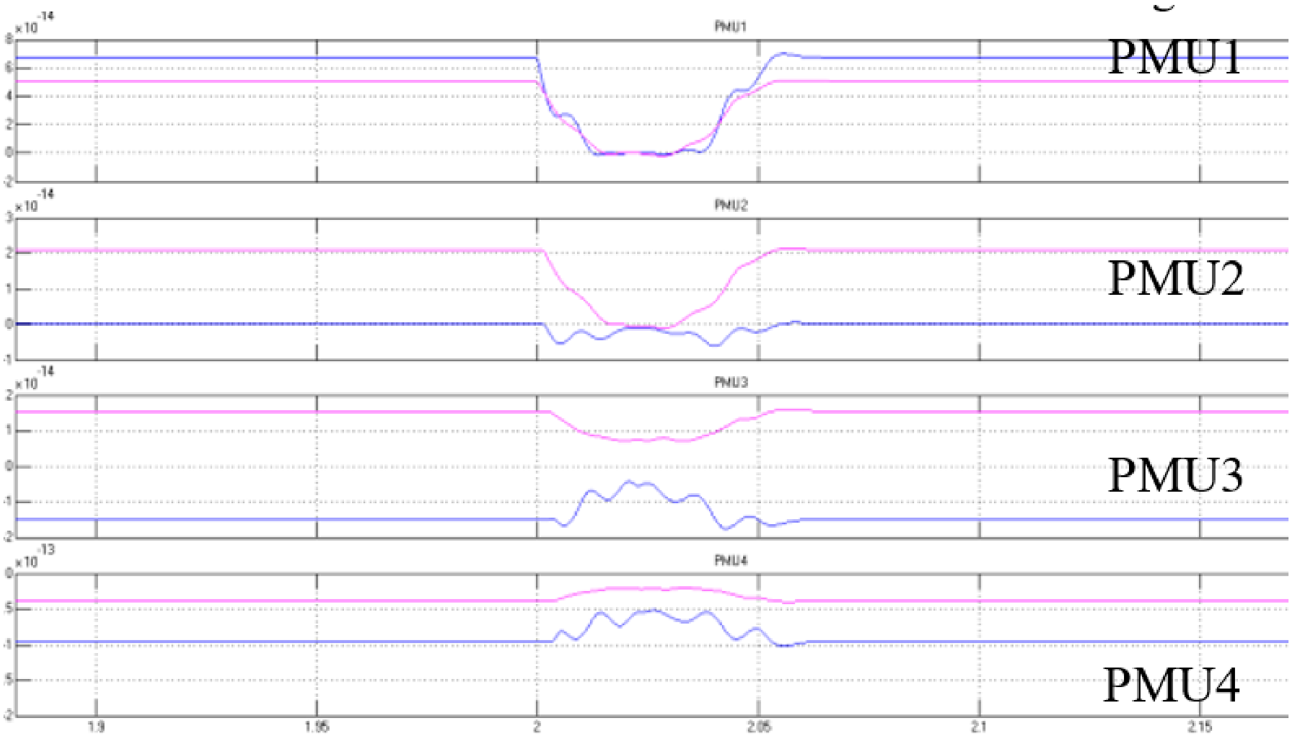

Fig. 7 Current records

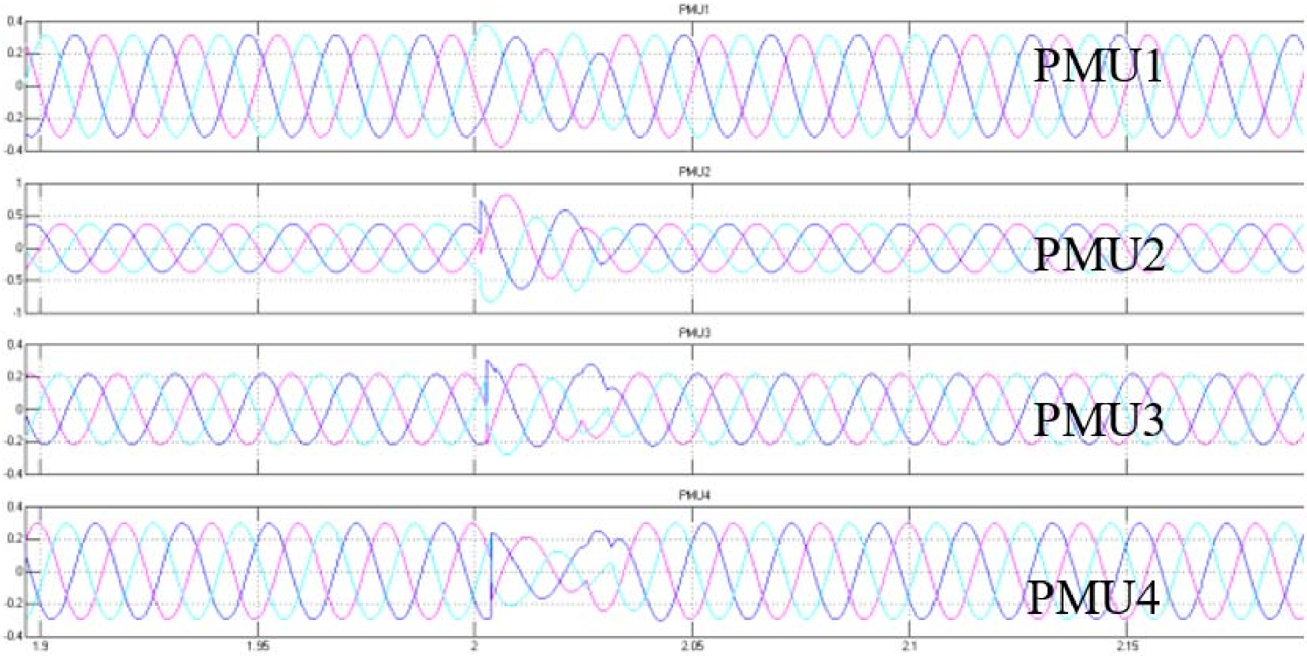

Fig. 8 Power records

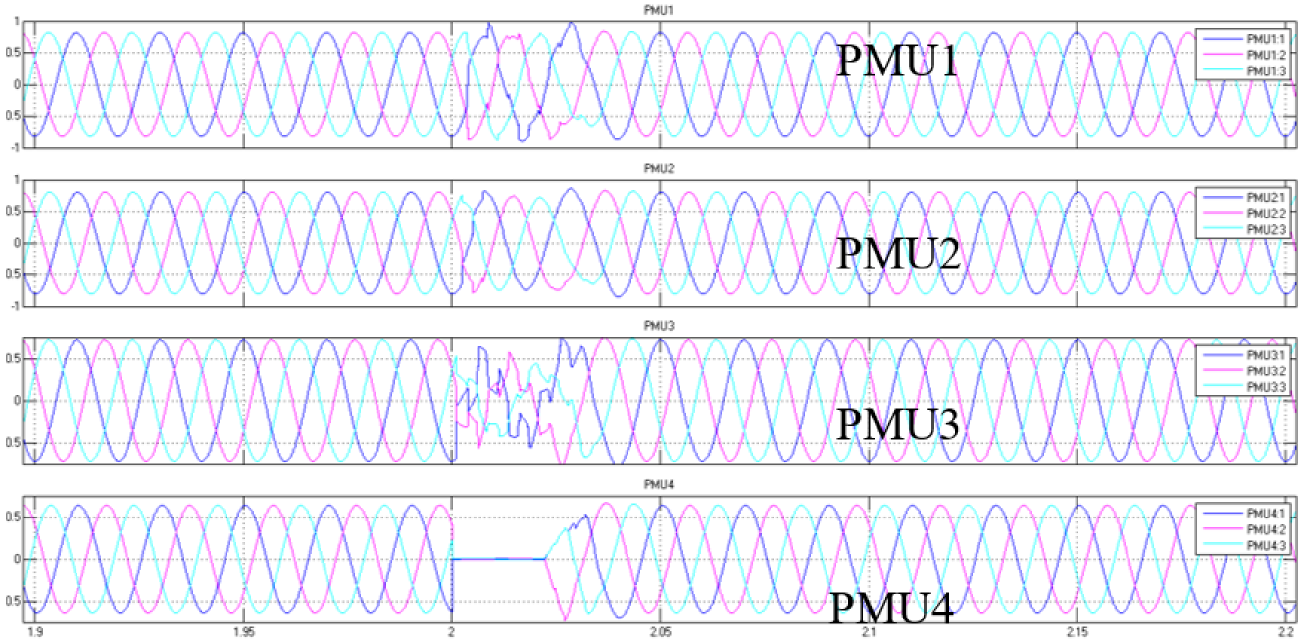

Fig. 9 Voltage results

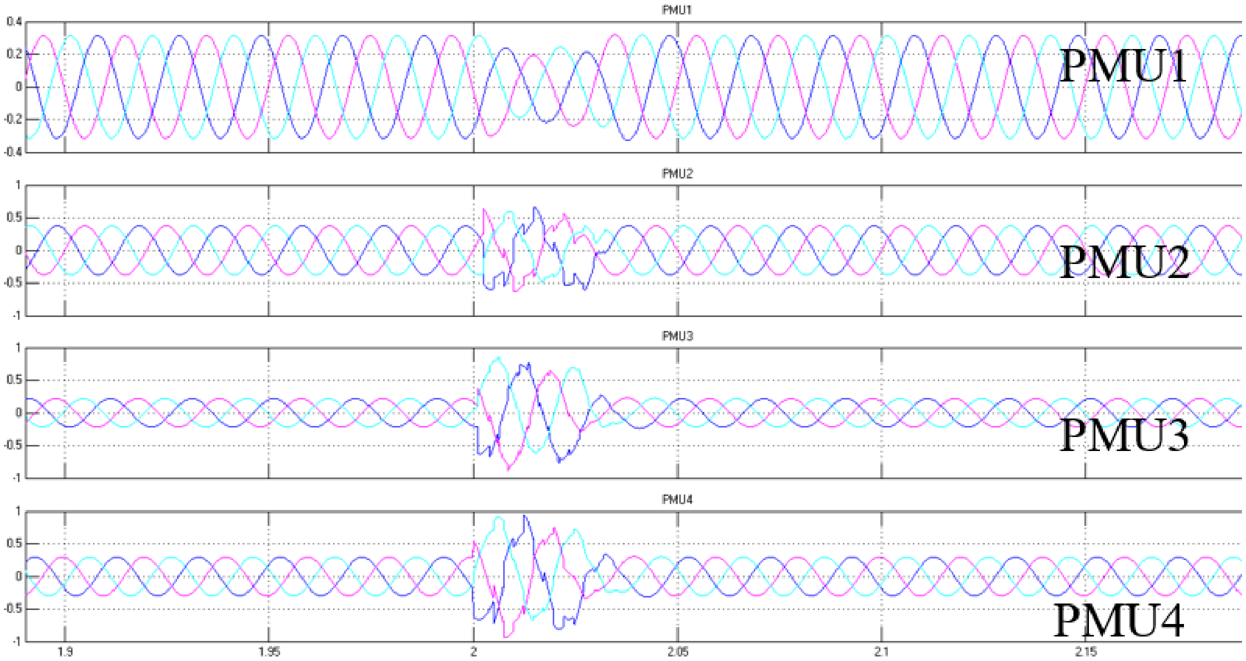

Fig. 10 Current results

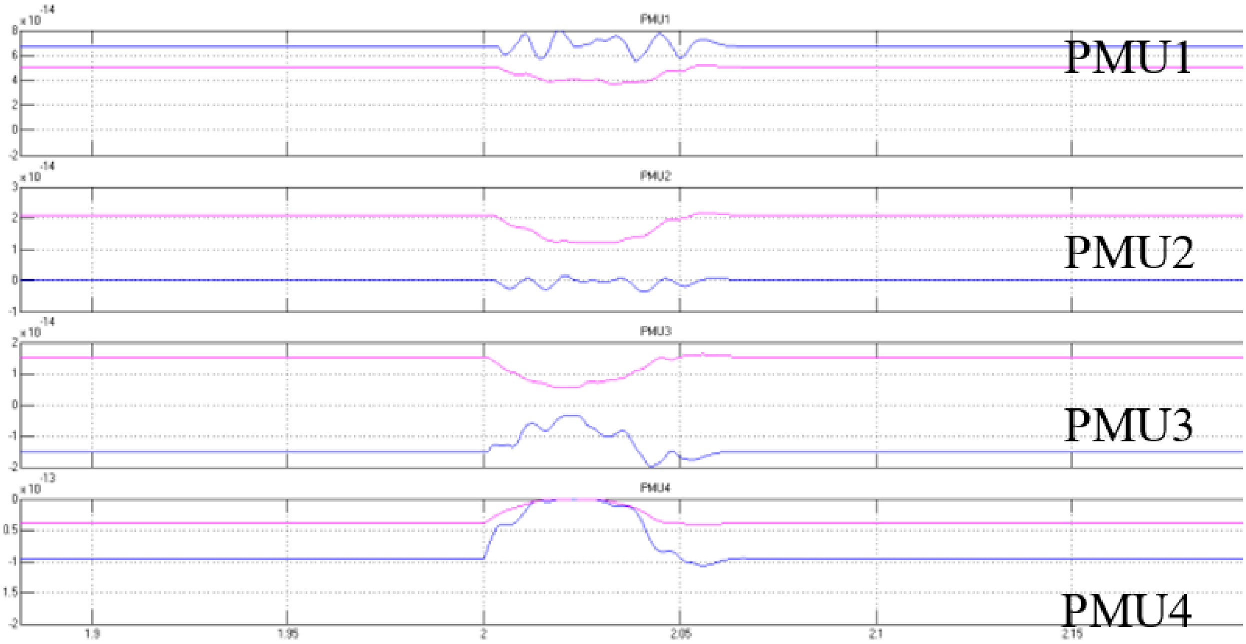

Fig. 11 Power records

V. CONCLUSION

In this paper, the interconnected electrical network of the Maghreb countries (Algeria, Tunisia and Morocco) has been studied. The identification of the oscillation caused by the interconnection switches opening due to the faults or the shutdown of some groups of generators has been presented. The proposed approach which integrates the PMUs for measurement associated with PDC has been simulated using MATLAB/Simulink. The inter-area network has been simulated under the different conditions that may cause the oscillation such as two fault locations and disconnection case of one area. The obtained simulation results show that the advantage of using the PMUs in monitoring and control system for detecting the inter-area oscillation.

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H. Bentarzi(M'17) received his Ingniorat and Magister degrees from Institut National d'Electricit et Electronique (INELEC), Boumerdes, in 1989 and 1992 respectively. Both are in applied Electronics. However, he achieved his PhD degree at the EcoleNationalePolytechnique, Algiers, in Micro-Electronic, in 2004.

From 1993 to 1998, he was lecturer at INELEC, Boumerdes. From 1998 to 2011, he was a member of the Engineering Science faculty at the University of Boumerdes, with activities centered upon control and protection systems. Since 2012, he has been full professor at the Institute of Electrical Engineering and Electronics, UMBB University, Boumerdes, Algeria.

His current research interests include power systems protection and wide area measurement systems improvement using the recent developed technologies of communication. He has been author and co-author in more than hundred technical papers.

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