# Reduce frequency oscillation using energy storage system and Phasor Measurement Units technology

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*Abstract:* - 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 generating plants connected by relatively weak tie lines. The frequency oscillation is the major problem for interconnected power systems; hence, the stability of these oscillations is an important condition. The inter-area oscillation, equipment such as Static Var Compensator and various Flexible AC Transmission System devices, are being increasingly used. Although Power System Stabilizers exist on many generators, there effect is only on the local area and do not effectively damp out inter-area oscillations. The injection of a stable electrical energy into disturbed power system decreases the oscillations; in our research we proposed the use of an electric energy storage system to reduce the frequency oscillations by using phasor measurement unit. This technique is applied in the Algerian interconnection power.

*Key-Words:* - Oscillation damping; PMU; ESS; Power System; Inter-area Oscillation

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## 1 Introduction

The interconnection power system consists of many generators connected between them by long line transmission. the flow of electric power transmission between two interconnected zones is bidirectional, if one of the generators is disconnected, the power supply of this area is provided by other generators.

Frequency is one of the most important operating parameters of the electrical system [1], [2]. System frequency has a very important impact on the safety and stability of the operation of the power system. operation of the electrical system. The fast variation of the load on a large scale generates the imbalance between the energy produced and the overall load which induces the frequency variation, this phenomenon in an interconnected power system causes a blackout in the absence of a suitable control system and can lead to stability, safety, and power quality problems.

Our problem is to stabilize the wide interconnection power system, the control techniques for local interconnections power system do not resolve the wide inter-area oscillations.

The development of electrical energy storage system (EESS) techniques allows to storage a significant amount of electrical energy [3], in our research we will use this energy for the primary control of the frequency. on the other hand, for rapid control and measurement continuity, we will also use PMU technology for data acquisition and transmission between the measurement points and the control platform.

Energy storage systems use several technologies like batteries, Thermal, Mechanical Storage, Hydrogen and Pumped Hydropower.

The proposed solution will be applied on the Algerian 400KV interconnected power grid, we validated the results by the simulation with the software simulink / matlab.

## 2 Problem Formulation

### 2.1 Oscillation problem

Several incidents have occurred on the interconnection lines linking power plants or different countries, these events cause technical and economic damages. Inter-area oscillations result from system events coupled with a poorly damped power system. Undamped inter-area oscillations may cause severe problems in power systems including large-scale blackouts. Oscillations are observed in the large system with groups of power plants connected by relatively weak tie lines. These oscillations are undesirable because they result in sub-optimal power flows and inefficient operation

of the grid. The stability of these oscillations is a critical concern.
the extension of the Algerian interconnected electrical network linking several power plants and also with neighboring countries, requires techniques to have a network with less oscillation
In order to minimize these oscillations, a damping method must be integrated, there are several techniques that have been used to dampen oscillations, such as Flexible Alternating Current Transmission System (FACTS) and Power system stabilizers (PSS). On the other hand, due to the development of electrical energy storage systems (ESS), which give a very stable energy, we will use these systems to dampen the oscillations on the interconnection lines.

## 2.2 Description of Algerian power system (400KV)

The Algerian interconnected power system of 400KV is composed of four areas [4], as shown in Fig.1

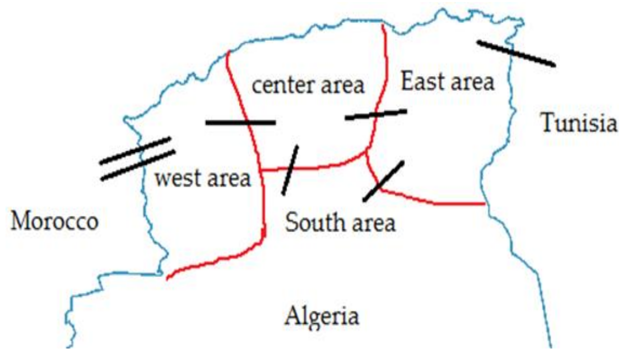


Fig.1 Algerian interconnection areas (400kv).

• The west area is supplied by the SKT power plant with a power of 3X412MW.
• The center area is supplied by the SKH power plant with a power of 3X412MW.
• The Est area is supplied by two power plants, SKS power plant with a power of 2X412MW and SKD power plant with a power of 3x412.
• The south area is supplied by three power plants, TILGHEMT power plant with 3X197MW, HMN power plat with 3X220MW, and OUMECHE power plant with 2X228MW.

With neighboring countries, the Algerian network is connected with double 400KV lines with Morocco and a 400KV line with Tunisia.

# 3 Problem Solution

## 3.1 Installation of PMUs in the 400kv interconnected power

Since the appearance of PMU technology, it has made it easier to read the parameters of the electrical network in real time [5]. In our case, in order to better measure the power system parameters, we will install two PMUs at the end of each interconnection line, as shown in Fig. 2.
Synchronized phasor measurement provides synchronized voltage and current phasors with high accuracy against a common time reference. This is achieved by synchronizing the sampling of the signals using the Global Positioning System (GPS) [5].
Measurements provided by Phasor Measurement Units (PMUs) are typically collected by a local computer and transmitted at high speed over a local communication network to a host computer known as a Phasor Data Concentrator (PDC), [6]. The information received by the different PMUs will be used for monitoring and control.

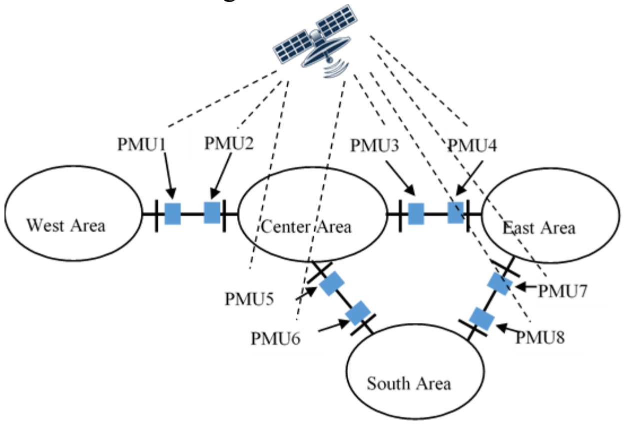


Fig.2 Position of PMU in the Algerian interconnection power system (400kv).

Each PMU measures the angle of the line voltage and current signal, the measured values will be transmitted to a local platform in the area for local control and monitoring, and also to the global PDC platform for the control of the interconnection lines.
Synchrophasor data is currently used in different areas for the following applications in power system operation in real time:
• Appearance of generator triggering by observing the frequency drop, the df/dt increase, the change of angular separation and decrease in voltage amplitude.
• Improve real-time situational awareness frequency monitoring, df/dt, angular separation.
• Monitoring of the power system in real time.

### 3.2 PMU formulation

PMUs measure current and voltage by amplitude and phase of the line transmission. High-precision time synchronization (via GPS) makes it possible to compare measured values of different locations far from each other.

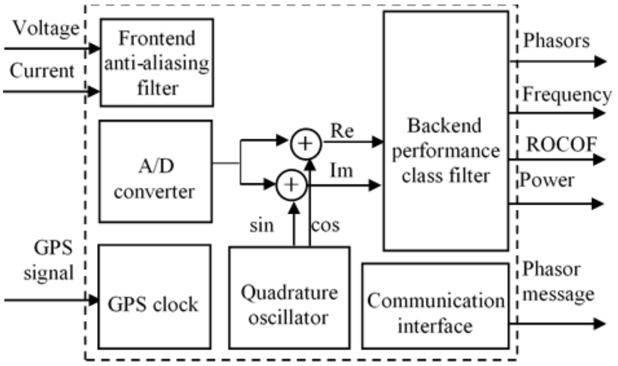


Fig.3 Proposed communication system between PMUs and PDC.

The information sent from the PMU to a PDC are in continuous and they are provided with time stamps, so it is possible to compare the synchronization between the other PMUs [6], [7], [8].
The synchrophasor definition [7], [9] is shown in (1):

$$X(t) = X_m \cos(\omega t + \varphi) \quad (1)$$
$$X = \frac{X_m}{\sqrt{2}} e^{j\varphi} \quad (2)$$

Where $X = \frac{X_m}{\sqrt{2}}$ is the RMS value of the signal X(t) and φ is the instantaneous phase angle.
Then
$$X = X_m \cos(\omega_0 + \varphi) = X_m \cos(2\pi f_0 + \varphi) \quad (3)$$
Where $f_0$ represents the nominal angular system frequency (50 Hz)
The difference between the actual and nominal frequencies is represented in (4).
$$g = f - f_0 \quad (4)$$
Where g represents the difference between the actual and nominal frequencies.
Equation (4) can be written as:
$$X(t) = X_m\, cos(2\pi \int f dt + \varphi)$$
$$X(t) = X_m\, cos(2\pi \int (f_0 + g) dt + \varphi)$$
$$X(t) = X_m\, cos(2\pi f_0 t + (2\pi \int g dt + \varphi \quad (5)$$
The new synchrophasor representation of this sinusoidal waveform, is shown in (6)
$$X(t) = \frac{X_m}{\sqrt{2}} \quad (6)$$
Frequency is defined as shown in (7):
$$f(t) = \frac{1}{2\pi} \frac{d\varphi(t)}{dt} \quad (7)$$

The ROCOF (Rate of Change of Frequency) is defined shown in (8):

$$ROCOF(t) = \frac{df(t)}{dt} \quad (8)$$

### 3.3 Integration of energy storage systems in the power system

Energy storage systems are among key factors for future smart grids. The ESSs are evaluated and considered for the frequency regulation [10].
The solution proposed in your research is installed ESS for each interconnection line [11], in the case of exceeding the frequency variation the ESS will be injected into the network in order to reduce the overshoot and eliminate oscillations.
Energy storage devices can be categorized as mechanical, electrochemical, chemical, electrical, or thermal devices, depending on the storage technology used [12]. The performance of energy storage devices can be defined by their output and energy density.

Frequency regulation is the constant second-by-second adjustment of power to maintain system frequency at the nominal value [13], [14]. If demand exceeds supply, the system frequency falls, and brownouts and blackouts are likely. If utilities generate more power than consumers demand, the system frequency increases, possibly damaging all connected electrical devices. energy storage can provide regulating power with subsecond response times [15], [16].

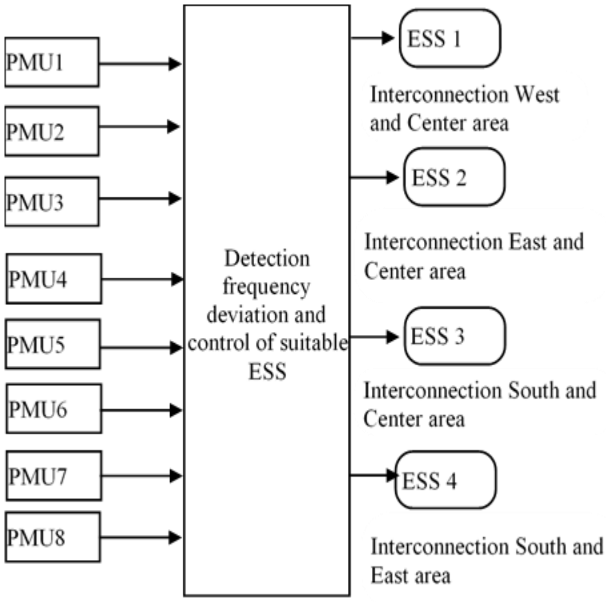


Fig.4 Control system based on ESS and PMU

The control system receives the information from the PMUs, among the information received the most important for the control is the ROCOF.
In case of a frequency deviation, the control system sends a signal to activate the injection of ESS into the network closest to the measurement point [17], [18].
If the deviation is still exceeded, another command sends to activate the injection of ESS downstream and upstream until stability is obtained, [19].

### 3.4 Simulation and discussion

The simulation model is composed of four areas with four interconnection lines, and PMUs. To eliminate the oscillations, we will use four ESS, one for each interconnection line, for the first step we simulate the system with a dynamic load and without ESS integration, In the second step we integrate the ESS system. we visualize the ROCOF and the phase curves for analysis of the results. We use Simulink/Matlab for results validation.

#### 3.4.1 Simulation of dynamic load without ESS integration

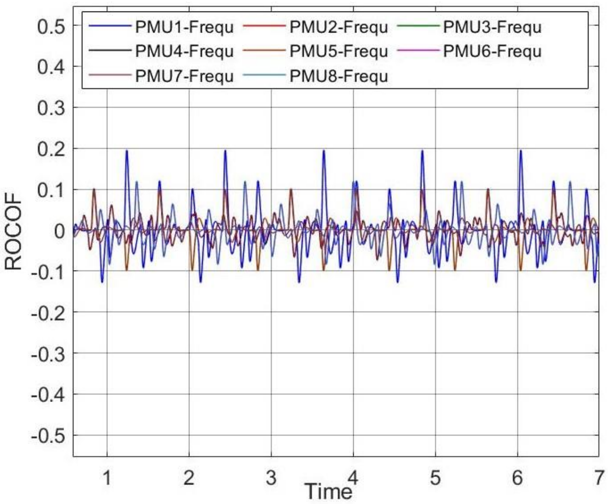


Fig.5 Frequency deviation without control

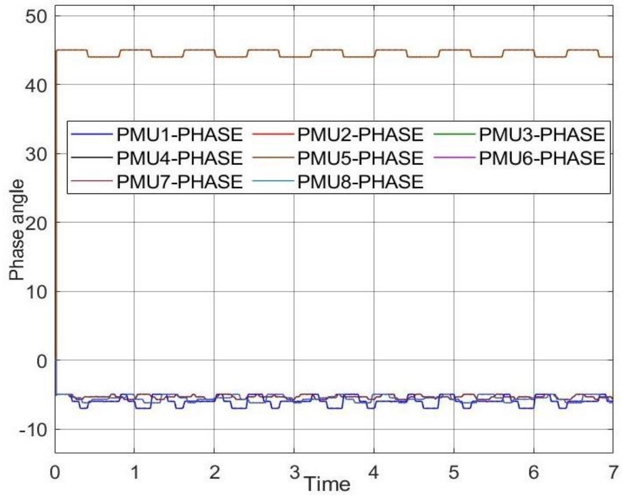


Fig.6 Phases measured by PMUs

In this case of a dynamic load and without frequency control; the PMUs measure the frequency curve in real time. we notice that the frequency oscillations are important and continuous over time, this kind of phenomenon influences the energy quality and the stability of the system

#### 3.4.1 Simulation of dynamic load without ESS integration

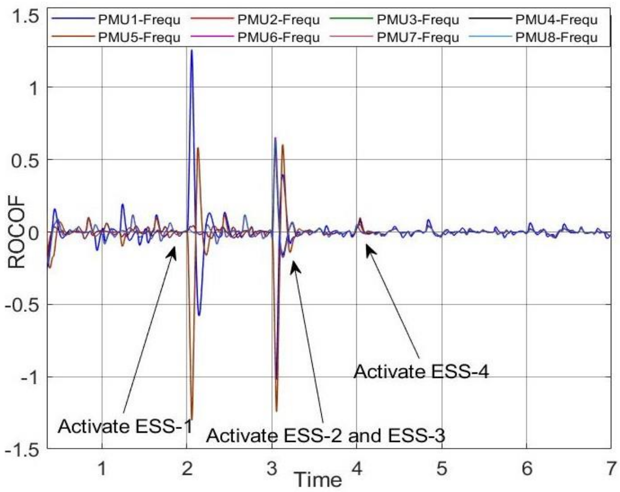


Fig.7 Phases measured by PMUs with activate ESS

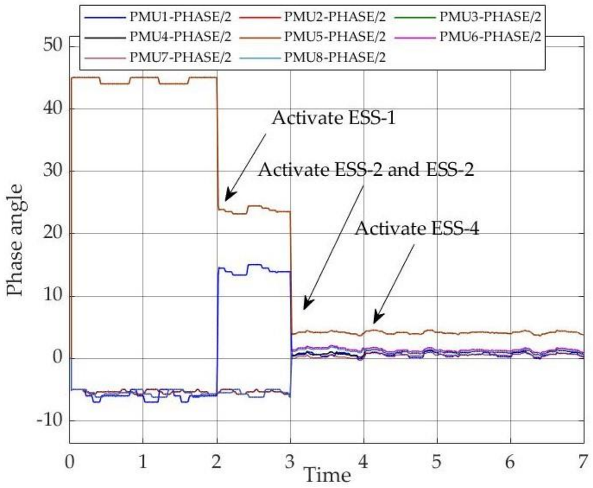


Fig.8 Phase measured by PMUs

In this part of the simulation we will use ESS to reduce the oscillation of the frequency, as fig.7, following the detection of a deviation by the PMUs, a control signal is sent to activate the injection of ESS-1 in the interconnection line, we notice a slight reduction in oscillation but the stability of the system is insufficient, so the control system activates ESS-2 and ESS-3 at the same time, for the second phase a better stabilized frequency is obtained, fig.8.
with the activation of EES-4 the system we notice that the frequencies measured by different PMU are in synchronization

# 4 Conclusion

This research is contributing to the reduction of oscillations on interconnected power system. We based on the frequency parameter to analyse the behaviour of power system stability, to get the values of the frequency in real time and in continuity we used the PMU technology, from the measurements obtained we have exploited the parameter of the frequency to get the variation of deviation frequency.
The first result obtained is the best visualization of the variation of frequency using PMU, then we proposed the integration of ESS in the system to control the frequency oscillations.
According to the simulation results, the reduction of the oscillations of the interconnection system is obtained with the integration of ESS on the interconnection lines connecting the different zones. Moreover, as the number of ESS increases, we will obtain better stability of the power system.
Another advantage of this solution is the possibility of integrating renewable energies into the energy storage system.

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## Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Mohammed TSEBIA, simulation and writing
Hamid BENTARZI, verification and validation of results.