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Reduction in the use of fossil fuels by improving the interconnection power system oscillation

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ABSTRACT

Many international organizations have called for reducing usage of renewable energy as a means to reduce carbon dioxide emissions, this paper studies the case of electricity production based to fossil fuels. Currently existing solutions is to shift from fossil fuels to clean renewable energy. Electrical interconnections are used between large-scale areas; these interconnections have a major problem that is the phenomenon of oscillations. The amount of fossil energy used by power plants depends on the electrical load required. with these conditions it is not possible to reduce the amount of energy required to satisfy the electrical load required. The solution proposed in this paper is the improvement of interarea oscillation using phasor measurement unit technology for real-time monitoring and accuracy of measurements. We tested the proposed solution for the north African power system. The results show the importance of improving interconnection networks to reduce fossil fuels use.

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1. INTRODUCTION

The demand for electrical energy consumption is still increasing over time. The producers of electric energy use mainly fossil sources in order to ensure the availability and satisfaction of the demand for electric energy consumption. Fossil energies have a major disadvantage that is the release of carbon dioxide (CO_2) emissions which is harmful to the environment. About two-thirds of carbon dioxide emissions come from the transportation, production and consumption of fossil energy [1]. Today, the power generation sector produces nearly 530 g of CO_2 per Kilowatt-hour on a global average [2]. The reduce of energy use on carbon dioxide emissions is an active area of research.

The use of fossil energies is responsible for environmental problems such as and air pollution and global warming, which cause health problems [3]. The reduction of fossil fuels is the concern of every country [4], [5]. On the other hand, most of the neighboring countries are connected to each other with electric lines, which are called interarea connection lines [6]. Among the consequences of the oscillations is the disconnection of the electric lines connecting two areas or more, so each area must increase the production of electric energy in order to balance between production and consumption of electric energy which also increases the carbon dioxide emissions. The objective of our research is to improve the interconnections between regions in order to increase the availability of electrical energy across several areas and to reduce the operation of the power plants of electrical energy production thus reducing the consumption of fossil energies.

In order to improve the interconnection oscillations, we proposed the use of phasor measurement unit PMU technology for synchronization and taking real-time measurements [7], and an interconnection control system for the closure of interconnection lines in the case of increased demand to energy consumption, with this solution we avoid the rate of operation of power plants so the use of fossil energy is also reduced by improving interarea oscillation.

2. THE PROPOSED METHOD

In this paper, we first study the architecture of the North African interconnection network, then a statistical situation of the energy exchange between the three countries (Algeria, Tunisia and Morocco) is made. To demonstrate the role of interconnection we will compare the interconnection energy curve with the energy curve without interconnection. To simulate our proposal; we start with the mathematical development of the PMU then we apply this technology for the North African electrical power system. Using MATLAB software, we simulate the power system under different condition or E1, E2, E3 The energies produced by area 1, area 2 and area 3 respectively. D1, D2, D3 the demands in electrical energy needs by area 1, area 2 and area 3 respectively. So, we can write the following relations [8]:

E1=D1+E11
E2=D2+E21
E3=D3+E31

Knowing that E11, E21, E31 is the excess energy for area 1, area 2 and area 3 respectively, as shown in the Figure 1. Our proposal is to improve the interconnections between areas in order to accumulate excess energy that will then be used across all areas in the case of an increase in the demand for electrical energy, as show in Figure 2. With this technique we avoid starting up additional power plants, which means reducing the use of fossil fuels.

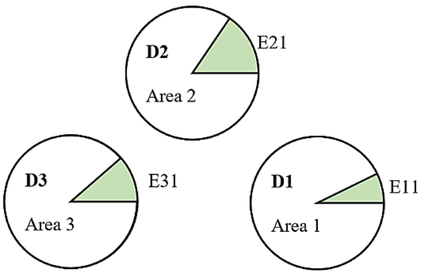

Figure 1. Distribution of electrical energy for areas without interconnection

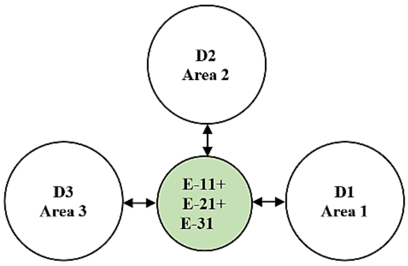

Figure 2. Distribution of electrical energy for regions with interarea connection

3. RESEARCH METHOD

3.1. North African interconnection grids

The north Africa regional interconnection, as shown in Figure 3, which includes Morocco, Algeria, and Tunisia, which was initiated since 1950s and evolved into multiple transmission interconnections between the three countries. Then, Spain was connected to Morocco in the late 1990s [9].

These interconnections among the three countries reinforce the traditional links that already exist. Morocco is linked with Algeria by three electrical tie buses (two uses 220 kV and one in 400 kV). Tunisia is linked with Algeria by five electrical tie buses (two in 90 kV, one in 150 kV, one in 220 kV and one in 400 kV) [10], [11].

3.2. North African electricity production statistics

Each country has built interconnections with the power grids of neighboring countries, and each country import and export electrical energy, as shown in Table 1 and Table 2 [12]. There are several types of power plants, the main production techniques are based on [13]–[16]: i) fossil fuels energy, ii) wind energy, ii) solar energy, and iv) hydro energy

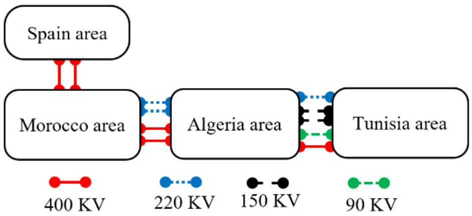

Figure 3. North African interconnection structure

The analysis of the annual electricity production statistics shows that the large percentage of production is based on fossil energy, as shown in Table 3, which means the carbon dioxide emissions rate is important, and it has a negative impact for the environment. In order to reduce the carbon dioxide emissions, it is necessary to reduce the production of electrical energy based on fossil energy in one hand. But, in the other hand it is necessary to maintain the satisfaction of the demand for electricity [17].

The electricity demand, as shown in Figure 4, during peak periods the demand for electrical energy is high, so power plants must increase production in order to meet the demand, furthermore as production increases the amount of fossil energy increases and the pollution rate also increases [18].

Table 1. Energy importation (Gwh)

Year	Algeria- Morocco	Algeria- Tunisia
2017	124.60	412.20
2018	160.60	345.30
2019	194.98	336.34

Table 2. Energy exportation (Gwh)

Year	Algeria- Morocco	Algeria- Tunisia
2017	430.00	449.50
2018	225.00	371.60
2019	201.52	471.81

Table 3. Net annual generation electrical power (Twh) [12]

Country	Annual Generation	Fossil fuels	Wind	solar	Hydro
Algeria	2019	72.87	/	0.47	0.15
	2018	68.35	/	0.46	0.12
	2017	68.23	/	0.37	0.06
Morocco	2019	/	/	/	/
	2018	27.65	3.86	0.42	2.00
	2017	26.62	3.06	0.95	1.56
Tunisia	2019	19.51	0.50	/	0.07
	2018	18.62	0.45	/	0.02
	2017	18.51	0.45	/	0.02

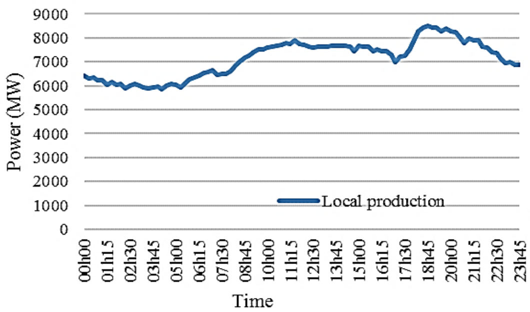

Figure 4. Electricity production of Algeria grid (November 2020) [19]

3.3. The role of interconnection power system on the environment

Each area should have in place electricity lines that allow the electricity production by its power plants to be transferred across its borders to neighboring countries. This interconnection system ensures the availability of electrical energy across any country included in the interarea grid. The produced energy covers sudden energy demand without increasing the production of power plants. As shown in Figure 5, the peak of the electricity demand starts from 5:30 p.m. until 9:00 p.m. during this period; it is the electrical energy available on the interconnection power system that will supply consumers.

Interconnected power system has a major role in large-scale energy transmission, however the extent of this power grid across several countries generates oscillations. In the case of these oscillations are significant, the interconnection links open automatically. The main problem of oscillation detection is the difficulty of measuring the parameters of the interconnected power system in real time and the synchronization between several areas [20]. Another difficulty is the monitoring of such a large-scale power system [21]. The solution proposed in our research; it is the integration of PMU into the interconnected power networks in order to improve the management and supervision of the interconnection system.

3.4. PMU technology

Phasor measurement technology is considered one of the most important new measurement technologies for electrical systems because of its ability to sample analogue voltage and current waveforms data in synchronism using a GPS clock and calculating, in different locations of the power system, the corresponding phasor component (50/60 Hz) [22]. This synchronized sampling technique provides the same reference for the phase calculations.

PMU technology provides phasor values (magnitude and phase angle) about current and voltage in real-time [23]. Phasor measurement units are the most advanced and accurate synchronized phasor measurement instrument. A functional block diagram of a PMU, as shown in Figure 6. The GPS receiver provides the one pulse-per-second (PPS) signal, and a time tag including the date (year, month and day) and time (hour, minute and second).

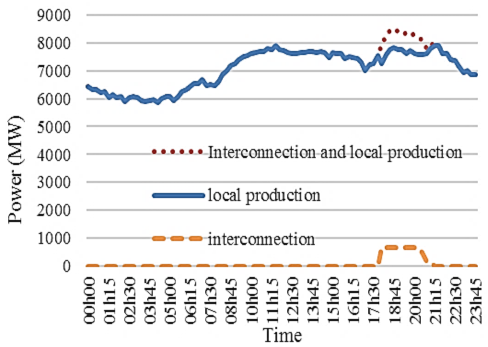

Figure 5. Interconnection and local production electricity

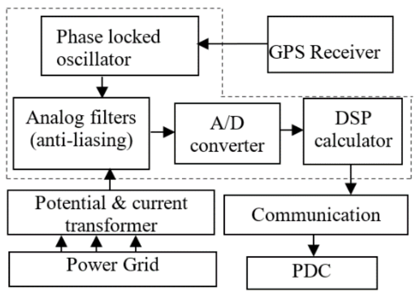

Figure 6. Functional block diagram of the PMU

The use of this technology is very effective in mitigating outages and monitoring the real-time behaviour of the electrical system. With the advancement of instrumentation technology, the microprocessor-based instruments such as disturbance recorders (DFRs) and protective relays can incorporate the PMU module with other existing features such as an extended function.

Synchronized phasor measurement technology is relatively new, and as a result, many researchers around the world are developing applications and solutions for power systems using this technology. It seems that the application areas can be grouped as follows [22], [23]:
- Power system real time monitoring,
- Advanced network protection,
- Advanced control schemes

A pure sinusoidal waveform can be represented by a unique complex number known as a phasor. Consider a sinusoidal signal [24],

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

Where:
X_m: The peak value of the sinusoidal voltage.
$\omega=2\pi f$: 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 (2).

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

The simulation block consists of three current sensors and three voltage sensors; which will be considered as inputs to the 'positive zero sequence' block. The Discrete Fourier Transform (DFT) technique is used for phasor estimation. If x(t) is sampled “M” times per cycle of the 50 Hz signal, then the sample set “Xm” is produced as given in the (3) [23].

$$X_m = \sqrt{2}\sin(\frac{2\pi m}{M} + \varphi) \tag{3}$$

Then DFT of sinusoid x(t) in time domain mentioned above in (3), can be calculated using the (4) [24].

$$X(k) = \frac{1}{M}\sum_{m=0}^{M-1} x(m)e^{-j2\pi\frac{k}{M}} \tag{4}$$

The following equations give the amplitude MagX and phase angle PhaseX

$$Mag(k) = \sqrt{\left(ReX(k)\right)^2 + (ImX(k))^2} \tag{5}$$

$$Phase = tan^{-1}\frac{ImX(k)}{ReX(k)} \tag{6}$$

3.5. Improve inter-area oscillation monitoring

The monitoring system may contain functionalities for detecting inter-area oscillation, and taking appropriate actions, either in the forms of alarms, or by means of direct control system. In order to ensure the synchronization between different areas and for the best monitoring, the installation of PMU is strongly recommended. To overcome the inter-area oscillation, equipment such as static var compensator (SVC) [25], and various Flexible AC transmission system (FACTS) [26] devices are increasingly used voltage source converters (VSC) [27]. These techniques have been widely used due to the recent advancement in the power electronic technology.

In order to simulate the integration of the PMU into the north African interconnection power system, we have developed a model of the north African interconnection power system, as shown in Figure 7, it consists of three areas, the area one (Tunisia), the area two (Algeria) and area three (Morocco). The area one and two are connected by a single 400KV interconnection line, and the area two and three are connected by two 400KV interconnection lines [10], [28].

Each PMU is linked with a GPS synchronization system in order to measure various parameters in real time. The measured parameters are transmitted to the PDC platform via the industrial communication protocols such as IEC 61850 and IEEE C37.118 [29], [30]. The management of data transmitted by the PDC platform will be used for monitoring [31] and for the detection of oscillations in real time [32], [33], in order to maintain the proper functionality of the interconnection system [34], as shown in Figure 8.

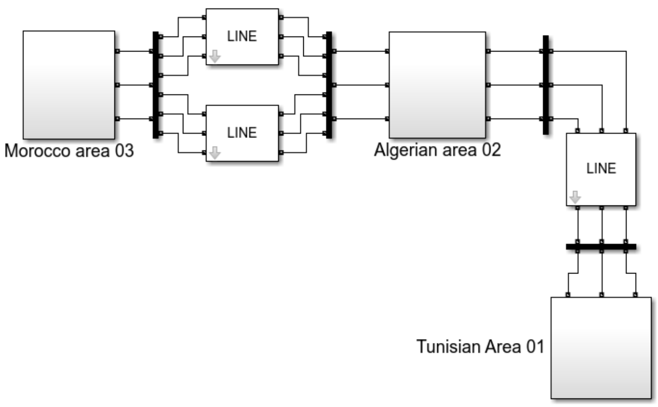

Figure 7. North African simulation model

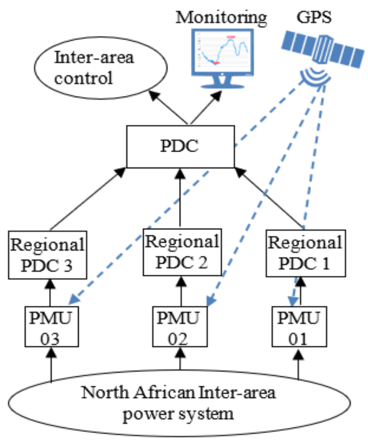

Figure 8. Monitoring and control of interconnection power system

4. SIMULATION RESULTS AND DISCUSSION

The objective of the simulation is to validate our proposed solution. We will simulate different situation of interconnections between adjacent areas. The loads used for each zone have fixed values. For the analysis of the curves measured by the PMUs we will just choose the power curves and frequency curves.

The first case is the operation of each area without closing the interconnection line. The second case is the operation of the power system with closing the interconnection lines. The third case is the simulation an overload in area one without closing the interconnection line between areas. The fourth case is the simulation an overload in area one with closing the interconnections lines. in the latter case; is to simulate the system with an electrical fault on the interconnection line to see the performance of our supervision system in the event of an electrical fault.

4.1. Operation of the interconnection power system without closing of interconnection lines

In this case, we simulate the model of power system under normal condition, and each area supply their loads without interconnected with other areas. Figure 9 shows the power values for each area, in the case where there is no interconnection line closure, we notice that each area produces a different power than the others in order to satisfy the requested electrical load. In order to reach the objective of reducing the use of fossil energies we have proposed the solution of using interconnections between areas, but to do so we need a real time measurement system to facilitate the synchronization, and precise to avoid the problem of disconnection or blackout phenomenon. In the next simulation we will interconnect the three areas in order to compare the values of the power available on the network.

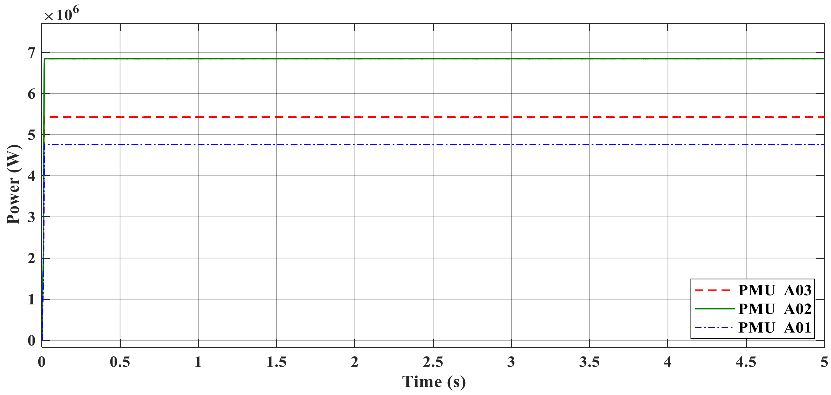

Figure 9. Power measurement by PMUs

4.2. Operation of the interconnection power system with closing of interconnection lines

In the second case, we will simulate the system with the connection of the interconnection line between areas. We keep the same values of the first case, the power values are shown in Figure 10. The PMUs measure the power of each area, we notice that all PMUs give almost the same power values. In the case of closing the interconnection lines we notice that the power distribution is almost the same on the three areas.

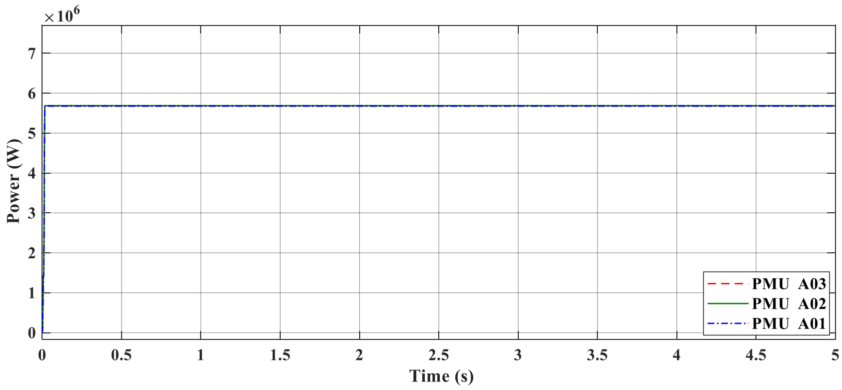

Figure 10. Power measurement by PMUs

4.3. Simulation of load increasing without closing of interconnection lines

In the third case, we keep the interconnections open so each area is independent of the others, we simulate an increase in the electrical load in area one in the time interval 1 to 3 seconds, Figure 11 shows the power curves measured by the PMUs. The variation of the power in the interval 1 to 3 seconds, in this period the production of energy is also increased in order to satisfy the electrical load, thus an increase of the quantity of fossil energy consumed to produce the necessary energy. On the other hand, in the same period, other areas produce an excess of energy compared to the power required for consumption. Our solution to reduce the consumption of fossil energy is to use this excess energy to cover the electrical load required by area one to reach this solution with performance and stability it is necessary the electric system has a reliable system of measurement and control and less oscillation.

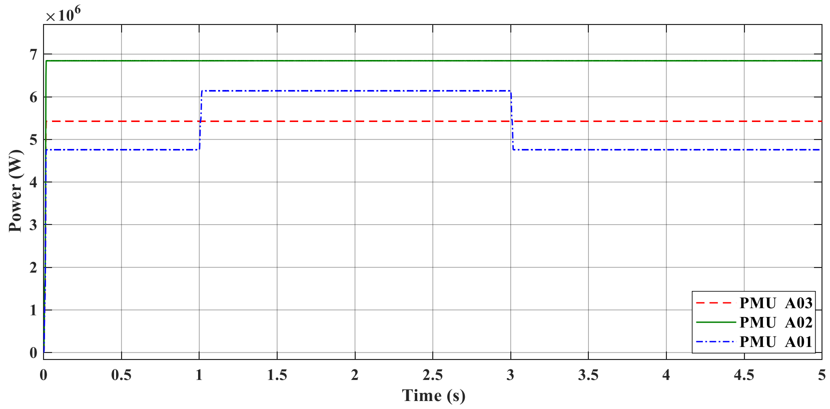

Figure 11. Power measurement by PMUs

4.4. Simulation of load increasing with closing of interconnection lines

The increase of the same load as the third case, in the case of closing the interconnection lines, we notice that a slight increase of the energy production to cover the requested electrical load in comparison with the third case, as show in Figure 12. The reduction of the energy produced means the reduction of the use of fossil energy.

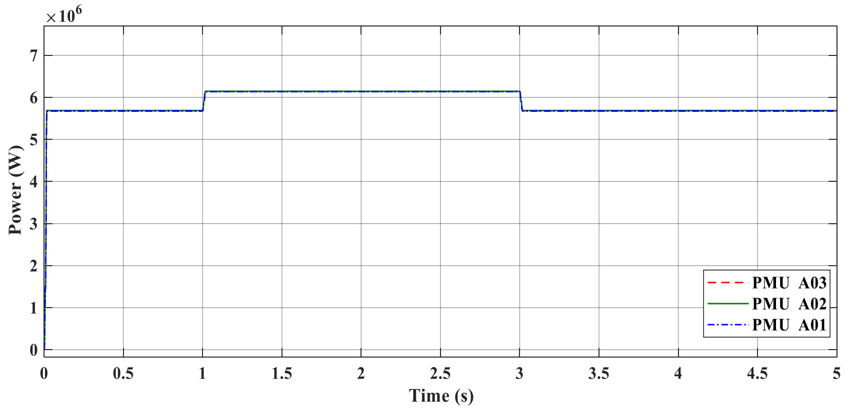

Figure 12. Power measurement by PMUs

4.5. Simulation of an electrical fault

We will simulate a fault on the interconnection line between area 1 area 2 et time of 2 second, and the disconnection of the same line at time of 3 second, the objective of this simulation is to show the advantage of the integration of the PMU technology in the interconnection power system for the monitoring and analyze the power system state. Figure 13 shows interconnecting power curves lines under fault and disconnection between area one and area two. In the case of an electrical fault, the proposed system detects a sudden variation of the power and important oscillations, as shown on Figure 14, the presence of these oscillations on the interconnection lines generally causes blackouts therefore a robust monitoring and control system is needed to avoid minimizing the interarea oscillations.

From the shape of the power curve, as show in Figure 13, we can easily estimate the amount of fossil energy used to produce the necessary power; in the case of disconnection of an interconnection line we notice the same power on area 2 and 3, on the contrary for area 1 the power decreases. The action of opening an interconnection line generates a weak oscillation, as shown in the Figure 14.

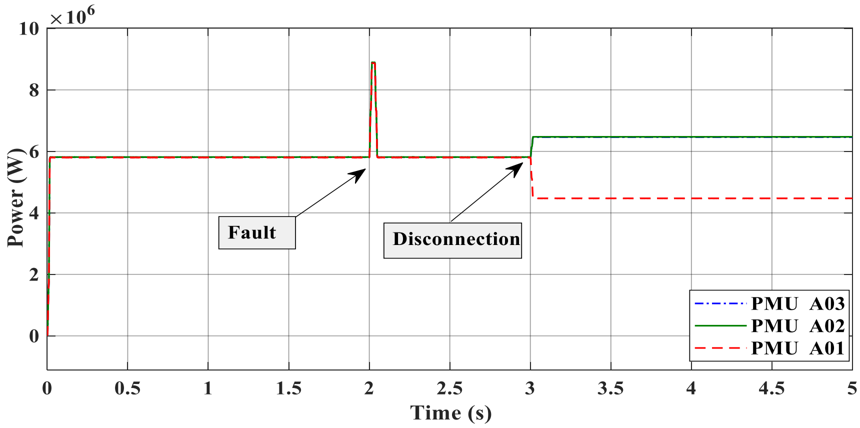

Figure 13. Power measurement under fault and disconnection case

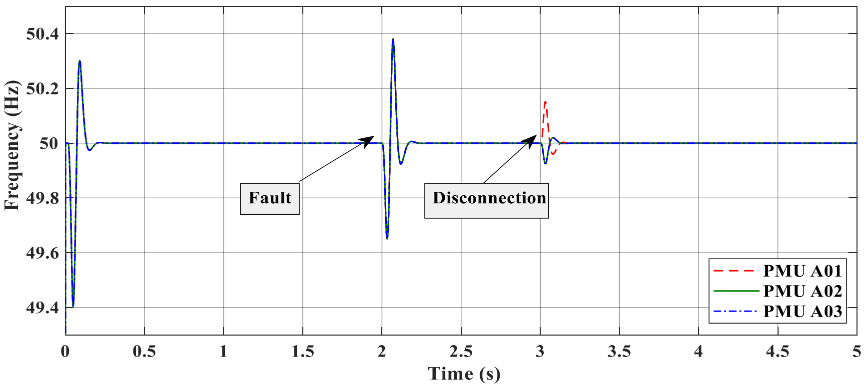

Figure 14. Frequency measurement under fault and disconnection case

5. CONCLUSION

In this research work, we have proposed a technical solution to reduce the use of fossil fuels and increase the availability of electrical energy by improvement of interarea oscillation. In the first part, the exchanges of electrical energy on the North African interconnection power system are studied; and in order to reduce the use of fossil energy that may be used to produce electricity, we have proposed the solution of strengthening and improving the interconnection power system by integrating new technologies for the monitoring and management of the interconnected power system in order to increase and ensure the availability of electrical energy. The simulation of the interconnection system with the use of the PMU for monitoring and detection of oscillations shows the advantage of this solution to increase the availability of electrical energy on the interconnection power system among several countries.

The inter-area oscillation has been simulated, these oscillations caused by faults events. The obtained results show that the advantage of a new approach by integrating the PMUs in the monitoring of the inter-area oscillation and control system. The obtained simulation results are also satisfactory for suggesting this approach as a method to be used for detecting this inter-area oscillation and mitigating its effects and for the monitoring system. The improvement of the interconnection system helps to reduce the production of electric energy at the level of power plants and increase the availability of electric energy to the network on a large scale, thus the use of fossil fuels for the production of electricity also reduces.

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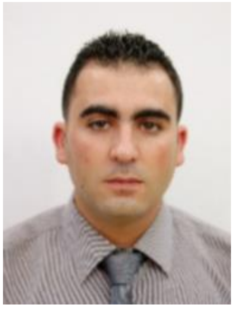

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