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Measured harmonics modelling and study of their impact on the transient stability of electrical networks using MATLAB software platform

***Abstract**. The herein-described work aims to study and analyze the impact of harmonics on the transient stability of electrical networks. To do this, we measured harmonics in an Algerian industrial installation for different load power values namely (P = 2MW, P = 4MW, P = 6 MW and P = 10 MW). Using harmonic measurements obtained through this industrial facility, a harmonic model was created using MATLAB/SIMULINK software. Subsequently, this model was introduced in a standard IEEE 9 bus electrical network model to carry out study and analysis simulations of the transient stability of this network system with fault (line opening fault) to observe the impact of these harmonics on the transient stability of the being studied network. The contribution in this work is the creation of a harmonic model under MATLAB/SIMULINK. Through harmonic measurement tests in an industrial electrical installation for different load power values, this created model can be used with any electrical network to study the effect of harmonics on the object to be studied.*

***Streszczenie.** Opisana praca ma na celu badanie i analizę wpływu harmonicznych na stan przejściowy sieci elektrycznych. W tym celu zmierzyliśmy harmoniczne w algierskiej instalacji przemysłowej dla różnych wartości mocy obciążenia, mianowicie (P = 2 MW, P = 4 MW, P = 6 MW i P = 10 MW). Wykorzystując pomiary harmoniczne uzyskane w tym zakładzie przemysłowym, stworzono model harmoniczny przy użyciu oprogramowania MATLAB/SIMULINK. Następnie model ten wprowadzono do standardowego modelu sieci elektrycznej magistrali IEEE 9 w celu przeprowadzenia symulacji badania i analizy przejściowej stabilności tego systemu sieciowego z uszkodzeniem (błąd otwarcia linii) w celu obserwacji wpływu tych harmonicznych na przejściową stabilność sieci badana sieć. Wkładem w tę pracę jest utworzenie modelu harmonicznego w środowisku MATLAB/SIMULINK. Dzięki testom pomiarów harmonicznych w przemysłowej instalacji elektrycznej dla różnych wartości mocy obciążenia, stworzony model można wykorzystać w dowolnej sieci elektrycznej w celu zbadania wpływu harmonicznych na badany obiekt. (**Modelowanie harmonicznych pomiarowych i badanie ich wpływu na stabilność przejściową sieci elektrycznych przy użyciu platformy programowej MATLAB**)*

Keywords: Harmonics, transients, stability, electrical network.
Słowa kluczowe: Harmoniczne, stany nieustalone, stabilność, sieć elektryczna.

1. Introduction

An electrical energy network is said to be in a transient stability regime, if following a major disturbance, which may result from a sudden loss of a generator, a line, or more frequently a short circuit, it returns to a permanent state of synchronous operation. Generally, transient stability studies focus on the most probable and most restrictive faults like short circuit, tripping of large generation units, load transfer, loss of interconnection lines, etc [1,2].

The study of the stability of an electrical network is of paramount importance because it allows us to evaluate the capacity of the network to return to a normal or synchronous operating state after fault elimination. It also makes it possible to determine the time delay to be displayed at protections level [3].

For an electrical network in stable operation, the mechanical power of the turbine driving a generator and the electrical power supplied by the latter are balanced (neglecting losses) for any machine[4]. When the network undergoes a significant disturbance (three-phase short-circuit in a transmission line, significant pressure drops, loss of a high-power generator, opening of a heavily loaded line, … etc.), the difference between the mechanical and electrical powers induces an acceleration or a deceleration which can lead to the loss of synchronism of one or more generators [5]. In this case, the rotor angles start oscillating. The intervention of voltage and speed regulation systems can help to restore synchronous operation and possibly drive the network to a new stable operating state [6,7].

The work described in this paper begins with the measurement of harmonics from an industrial installation as a function of the electrical power of the load in this installation. The powers considered for this purpose are: (P =2MW, P =4MW, and P=6MW and P=10MW). The obtained measurements were used to create a model of the included harmonics using MATLAB/SIMULINK software. Subsequently, this model can be introduced into any model of an electrical network to observe and study the effects of these harmonics on the transient stability of the considered network [8,9].

2. Transient stability of a multi-machine system

During the transitional period, the dynamics of an electrical network can be described using a system of differential equations of the following general form [10]:

$$\frac{dx}{dt} = f(x,u) \tag{1}$$

where : x : System state variables vector; u : System control parameters vector.

Transient stability concerns the study of the network dynamics described by the set of differential equations (1). This study provides information related to the time variations of internal angles, rotor speeds, voltages, current and power of the production units as well as the variations of voltages, currents and powers transmitted in the branches of the forward transport lines, during and after the disturbance. In one hand, this analysis allows us to judge whether the system is in stable operation or not and on the other hand to size the protections supposed to eliminate the fault before reaching the critical time [11,12].

At first, we must solve the equations of the initial power flow and determine the amplitude of the initial voltage of each node and its corresponding phase angle [13,14].

The machine's currents before the disturbance are calculated from:

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*} \quad i = 1,2,\dots m \tag{2}$$

(3) $$P_i = \sum_{j=1}^{n} V_i V_j \left|Y_{ij}\right| \cos\left(\theta_{ij} + \delta_j - \delta_i\right)$$

(4) $$Q_i = \sum_{j=1}^{n} V_i V_j \left|Y_{ij}\right| \sin\left(\theta_{ij} + \delta_j - \delta_i\right)$$

where : m is the number of generators; V_i is the terminal voltage of the i^{th} generator; P_i and Q_i are the generator real and reactive powers, and S^* is the conjugate of the complex power.

The electrical and mechanical powers of the machine in the stable state before the disturbances are the same and given by:

(5) $$P_{ei} = P_{mi} = \operatorname{Re}\left\{E_i', I_i\right\} = \sum_{j=1}^{m} \left|E_i'\right|\left|E_j'\right|\left|Y_{ij}\right| \cos\left(\theta_{ij} - \delta_i + \delta_j\right)$$

The oscillations equation of the multi-machine system is expressed by:

(6) $$\frac{H_i}{\pi f_0}\frac{\partial^2 \delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m} \left|E_i'\right|\left|E_j'\right|\left|Y_{ij}\right| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) = P_{mi} - P_{ei}$$

where: Y_{ij} are the elements of the reduced failing admittance matrix.

H_i : Is the inertia constant of the i^{th} machine expressed on a common basis.

For the transient stability analysis [15,16], we have to solve the two state equations: equation (7) and equation (8).

(7) $$\frac{d\delta_i}{dt} = \Delta\omega_i \quad i = 1, \ldots, n$$

(8) $$\frac{d\omega_i}{dt} = \frac{\pi f_0}{H_i}\left(P_{mi} - P_{ei}\right)$$

Where:

δ is the rotor angular position,

ω is the rotor speed.

3. Experimental tests

Experimental tests to measure harmonics, in an Algerian industrial installation, were carried out using the Power Quality Analyzer: Chauvin Arnoux CA 8332B, see figure 1.

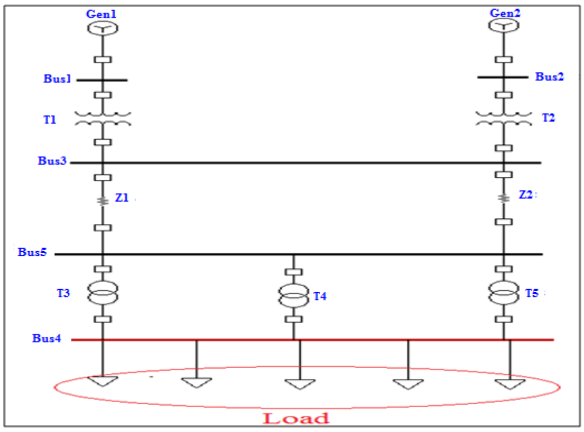

Fig. 1. Electricity network of an Algerian industrial facility

The histogram of the harmonics obtained through the measurements carried out using the Power Quality Analyzer C.A 8332B, as a function of the load power, is shown in the following figure:

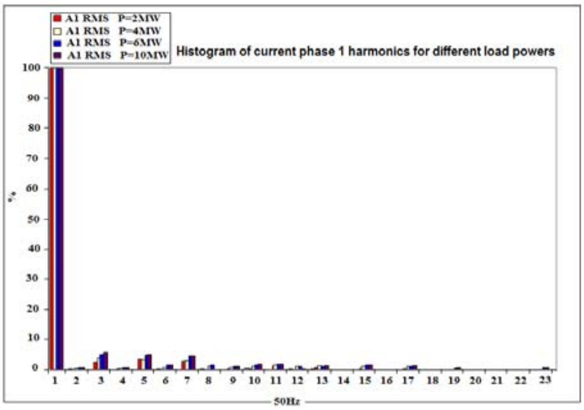

Fig. 2. Comparison of the histogram of the harmonics of the currents for different load powers

Through the measurements previously carried out at the level of the installation of our electrical network, to create our harmonic model, assuming that for x >> r sources, the impedance of each source (the three-phase RLC tap block) is calculated as follows [17]:

(9) $$S = \frac{U^2}{Z} \Rightarrow Z = \frac{U^2}{S}$$

(10) $$Z = L \times 2\pi f \Rightarrow$$

(11) $$L = \frac{U^2}{S \times 2\pi f}$$

Through this harmonic model that we created, this model was introduced into the MATLAB/SIMULINK software to do study and analysis tests of the transient stability for a polluted IEEE 9-node network system: we therefore presented the harmonic models created on MATLAB/SIMULINK for the powers (P =2MW and P=6MW), in the same way we obtain the harmonic models for the powers P = 4MW, and P = 10MW.

The next block shows the harmonic model (H-2MW) in MATLAB/SIMULINK software environment [18, 19].

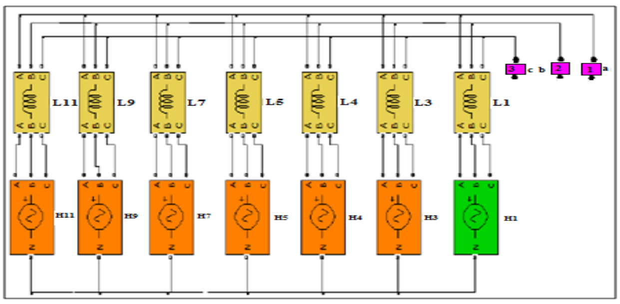

Fig. 3. Harmonic model data (H-2MW) in MATLAB/SIMULINK

4. Simulation and results

4.1. Failure due to an open a line

During this new step, we performed a simulation of line opening (7-5) at the instant: t = 0.2sec (see figure 4), for different load power values. The harmonic model is connected to node 6 of the considered network. This will allow us to study the transient stability of this electrical network using MATLAB/SIMULINK software.

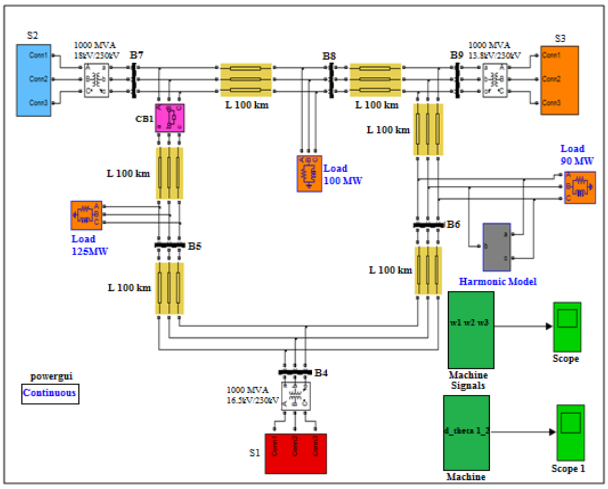

Fig. 4.Schematic of an opening diagram of a line in a 9-node IEEE network system under MATLAB/ SIMULINK.

The transient stability curves without harmonics and with harmonics as a function of the load power values (P = 4MW and P = 6MW) of generator 2 are shown below.

a. Rotor angles of generator 2

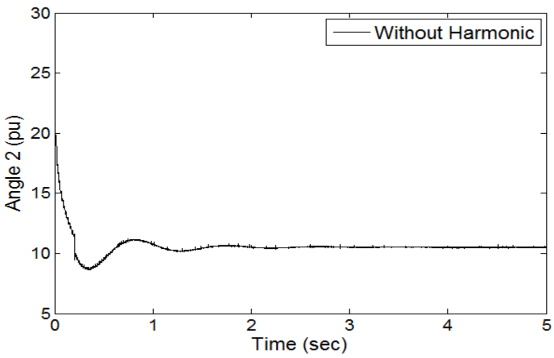

Fig.5. Rotor angle curve of the of generator 2

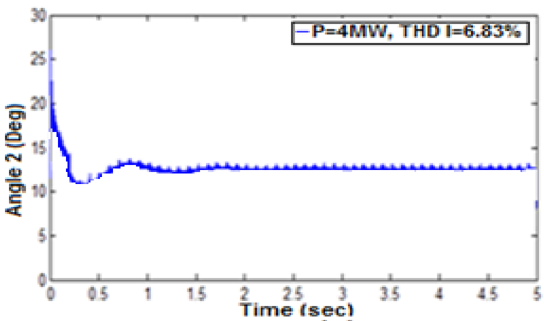

Fig.6. Rotor angle curve of the of generator 2

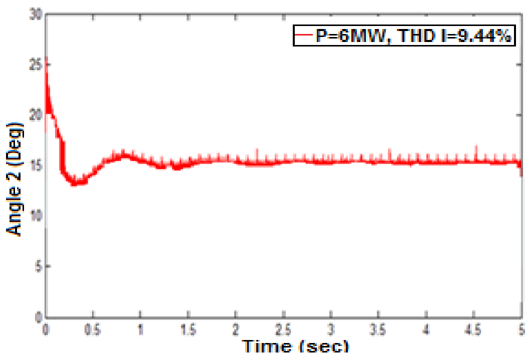

Fig. 7. Rotor angle curve of the of generator 2

b. Speed of Generator 2

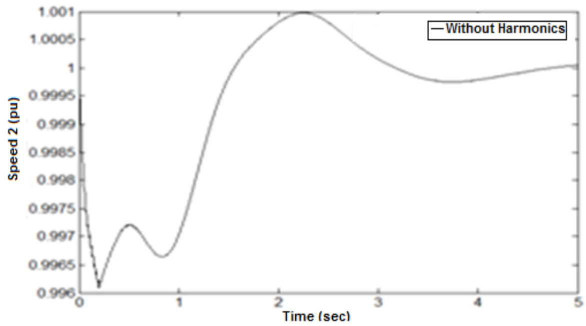

Fig.8. Speed curve of generator 2

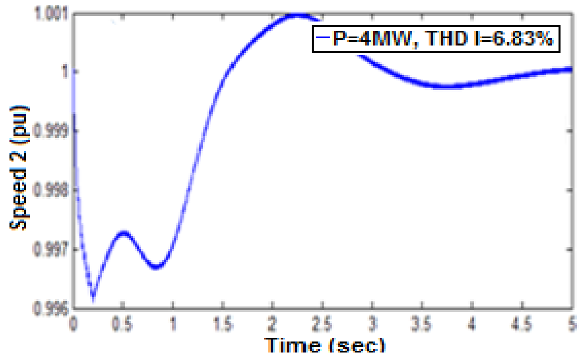

Fig.9. Speed curve of generator 2

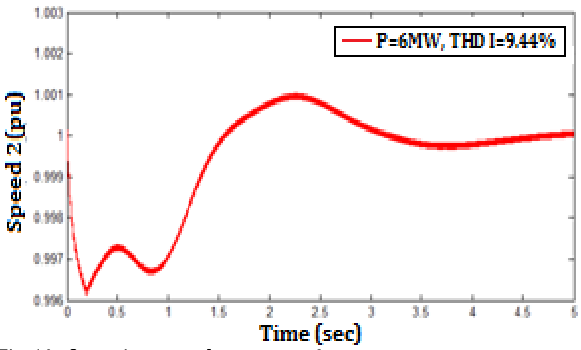

Fig.10. Speed curve of generator 2

c. Results Interpretation

In the absence of harmonics and according to rotor curve of generator 2 (δ_2) shown in figure (5), it is noted that the speed of the machine loses its sinusoidal shape because of the fault introduced but after the elimination of the default the speed returns to its initial form.

As for the figure (6), and for a load power (P=4MW), one easily notices the impact of the opening line defect on the curve of the rotor angle of the considered generator 2 (δ_2). In addition, it is noted that there is an increase in the fluctuations on the curve of the angle of the rotor compared to the previous case following the increase in the current THD, the inertia and the damping of the system. The latter always retains its transient stability.

In figure (7), and when the load power reaches 6MW, we also notice that the angle of the rotor curve of generator 2 (δ_2) is visibly influenced by the fault as in the previous case. But the fluctuations of the curve of the rotor angle increase more than the previous case, this is due to the increase of the current THD. After the fault interval, the system still retains its transient stability.

Also, and as illustrated in figure (8), in the absence of harmonics, the speed of the generator_2 (ω_2), oscillates around its initial value with a small fluctuations until the end of the cycle.

Referring to the curve in figure (9) corresponding to (load capacity = 4 MW and THD I = 6.83%) as in the previous curves, we note the effect of error on the velocity curve (ω2) with a significant increase in fluctuations mainly due to the increase in THD stream.

Finally, for figure (10), for (load power = 6MW, THD I = 9.44%), we notice that the speed curve of generator 2 (ω2) is influenced by the fault in the same way as for the previous cases but the fluctuations have increased much more because of the increase in THD current.

Conclusion

During the first stage of this work, harmonics were measured in an Algerian industrial installation for load power levels of: 2MW, 4MW, 6MW and 10MW respectively. Subsequently, we used the results of these measurements to create a harmonic model using the MATLAB/SIMULINK software. The model thus created was inserted into a standard electrical network system: IEEE 9 nodes to see the impact of these harmonics on the transient stability of the electrical network system under study.

In a second step, we used the system described above to study the transient stability of the network system in the case where the harmonics model is connected to node 6 of the considered network. To this end, several faults have been introduced into the system, namely: the fault of line opening (line (5-7)) with different values of current THD for different load power values: P = 4 MW, P = 6 MW.

Through the simulation obtained results, it was noticed that there was a significant effect of harmonics on the transient stability of electrical networks and that the harmonic rate THD increases with the increase in load power. Through these same simulations, we also confirmed the effect of the harmonics of a model connected to an electrical network on the transient stability. In fact, these effects increase as the power of the load and the maximum THD of the current increase (the shape of the rotor angles and the speeds of the generators are influenced proportionally by the harmonic ratio and by the power of the generator).

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