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Effect of Damping Constant and Rotor Inertia Constant On One-Dimensional Ring Power System Electromechanical Wave Propagation

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Abstract:

This paper completes the previous work that introduced the analysis of the electromechanical wave propagation that follow a disturbance occurring at any machine in the one-dimensional ring power system model. The analysis is performed for the varying of damping constant (D) and rotor inertia constant (M) of the system machines. The continuum principle, which considered for the power system leads to a set of nonlinear partial differential equations (PDE). So, the discretization concept was applied in this paper. MATLAB package is used to carry out the simulation. From which, some of the wave propagation parameters are calculated. Simulation results in different situations are presented and discussed. These results present and show the important effect of damping constant and rotor inertia constant on one-dimensional ring power system electromechanical wave propagation.

Key Words:

Electromechanical wave propagation, damping constant, rotor inertia constant, one-dimensional system and continuum system

I. INTRODUCTION

Successful operation of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to the loads. Ideally, the loads must be fed from constant voltage and frequency sources at all times. This means that both voltage and frequency must be held within tolerances so that the loads may operate satisfactorily [1].

Faults and other random events set the rotors of large electric generators in motion with respect to their synchronous reference frame. The study of this phenomenon is of great interest in electric power engineering, as instabilities of this motion frequently impose operational limits on the power network. The phenomenon of electromechanical oscillations of rotors for all the machines causes the propagation of a wave, named electromechanical wave propagation.

The normal technique for studying electromechanical transients in power systems is to set up a large detailed model of the entire system comprising of nonlinear differential and algebraic equations (Swing equations at the internal generator nodes and power-flow equations at the external nodes) and then integrate the resulting nonlinear ordinary differential equations numerically [2].

It is only in recent years that simultaneous measurement of rotor angles, through synchronized phasor measurements units (PMU's), has been made possible with the help of the global positioning system (GPS). Several preliminary observations over long distances have confirmed the existence of electromechanical wave propagation with speed less than that of light.

Power systems are equipped with suitable control and protection devices to oppose the oscillations; else, the disturbance will propagate overall the system. Hence, the synchronous generators connected to the system start to go out of step and the system trends to the black out status. Different issues were illustrated before [3-5].

In this paper, the effect of damping constant (D) and rotor inertia constant (M) is considered. From the presented results, it will be clear that the important effects of these factors on the electromechanical wave propagation.

II. MATHEMATICAL MODEL

The simple derivation of the power transmission equation (PTE) proceeds with considering a generator that supplies a variable current at constant voltage producing variable power. The difference between the electrical and mechanical power of a generator (P_e and P_m) is the power that accelerates the generator rotor. The rotor acceleration in angle δ is described by the swing equation:

$$M\ddot{\delta} + D\dot{\delta} = P_m - P_e = P_a \qquad (1)$$

With referring Eq.1 to a system base power the swing equation becomes:

$$\frac{2H}{w}\ddot{\delta} + wD\dot{\delta} = P_m - P_e \qquad (2)$$

Where, P_m .. the input mechanical power, P_e .. the output electrical power, P_a .. the accelerating power is the difference between P_m and P_e, H .. the rotor inertia constant, the damping constant (D), the rotor inertia constant (M) is the product of (ω) and (J), where, (ω) is the angular frequency and (J) is the moment of inertia of the rotor, and the rotor angle is (δ).

To illustrate the traveling wave phenomenon, a ring system of 44 generators was constructed using MATLAB as mentioned in [6]. The continuum power systems concept has been studied before [7-8]. The relatively large number (44) makes the comparison with the PDE more obvious. Identical transmission lines connected the generators. So that, the swing equations are in the form:

$$\begin{aligned}\ddot{\delta}_k + 0.01\dot{\delta}_k &= P_k - [2 - \cos(\delta_k - \delta_{k-1}) - \cos(\delta_k - \delta_{k-1})] \\ &\quad - 6\,[\sin(\delta_k - \delta_{k-1}) + \sin(\delta_k - \delta_{k-1})]\end{aligned} \tag{3}$$

for k=2,…,N-1

$$\begin{aligned}\ddot{\delta}_1 + 0.01\dot{\delta}_1 &= P_1 - [2 - \cos(\delta_1 - \delta_N) - \cos(\delta_1 - \delta_2)] \\ &\quad - 6\,[\sin(\delta_1 - \delta_N) + \sin(\delta_1 - \delta_2)]\end{aligned} \tag{4}$$

$$\begin{aligned}\ddot{\delta}_N + 0.01\dot{\delta}_N &= P_N - [2 - \cos(\delta_N - \delta_{N-1}) - \cos(\delta_N - \delta_1)] \\ &\quad - 6\,[\sin(\delta_N - \delta_{N-1}) + \sin(\delta_N - \delta_1))]\end{aligned} \tag{5}$$

The powers (P_k) are computed from the equilibrium angles.

III. SYSTEM SIMULATION AND ANALYSIS

To simulate the proposed system, a 44-generator system simulation was constructed using the MATLAB package. As stated before in [6]. The generators internal impedances are considered approximately zero and one per unit internal voltage.

The transmission lines are supposed to be a pure reactance with a value of 0.1 per unit. Each shunt load has a magnitude of one per unit and with a 0.8 lagging power factor. The initial perturbation is proposed at the 22nd node (generator terminals) with an impulse shape has a peak value of one per unit and occurs at zero time. The figures shown below show the effects of damping constant and rotor inertia on the electromechanical oscillation through the entire power system.

First consider the effect of damping constant with rotor inertia equal one per unit. From Figure (1), with zero damping, it is noticed clearly the propagation of the electromechanical wave through the entire network and its severity which may cause any of the generators or all of them to go out of step.

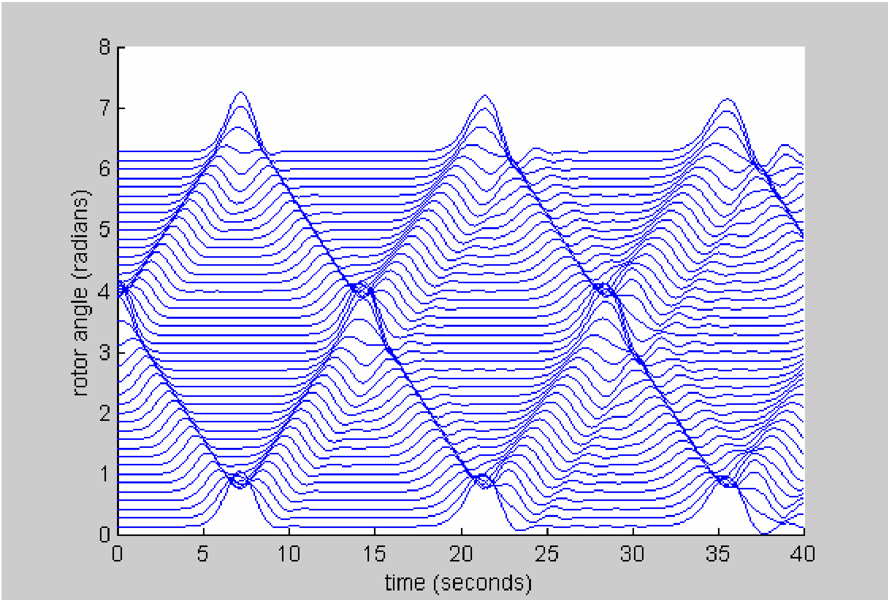

Figure (1): torque angle wave-propagation (M=1, D=0.0)

To show the idea very well, a three dimensions graph is presented in figure (2), in which the electromechanical wave is drawn with time and location of the generators along the ring system model.

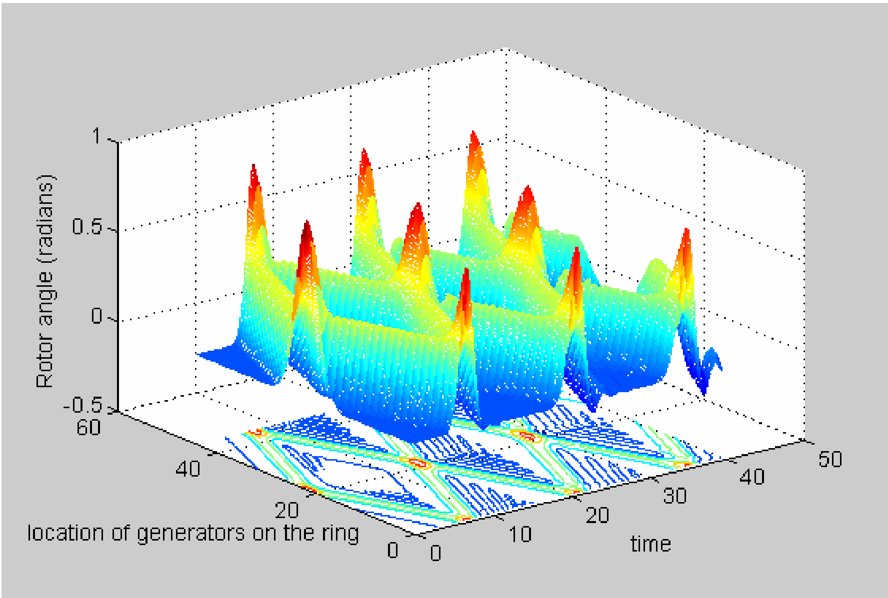

Figure (2): torque angle wave-propagation w.r.t time and generator location (M=1, D=0.0)

And this is also presented for the all cases to explain the idea of the effect of damping constant and rotor inertia constant on the electromechanical wave propagation. If the damping is increased to a value of 0.1 per unit, the wave propagation in the 44-generator system will be as shown in figure (3) and figure (4), which shows that the amplitude of the propagating disturbance decrease until it vanishes after few seconds.

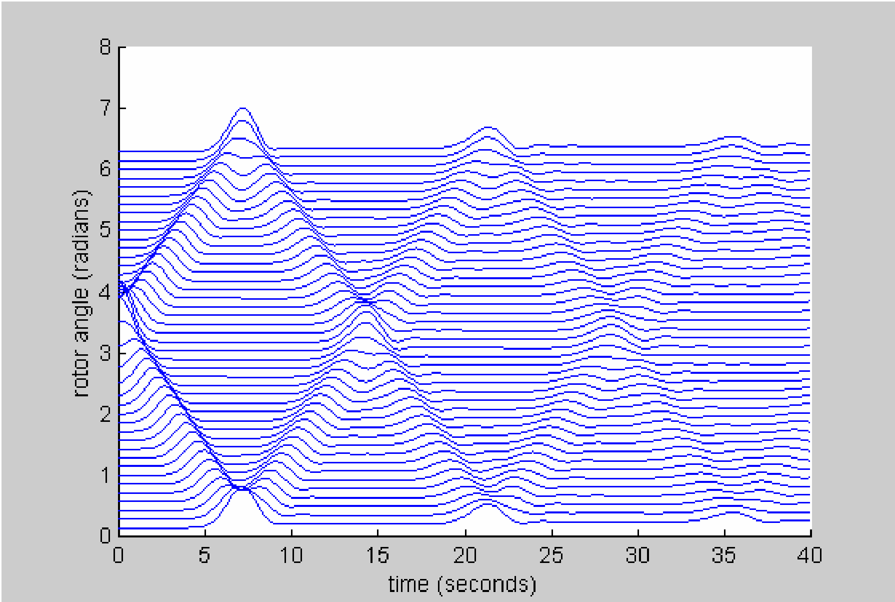

Figure (3): torque angle wave-propagation (M=1,D=0.1)

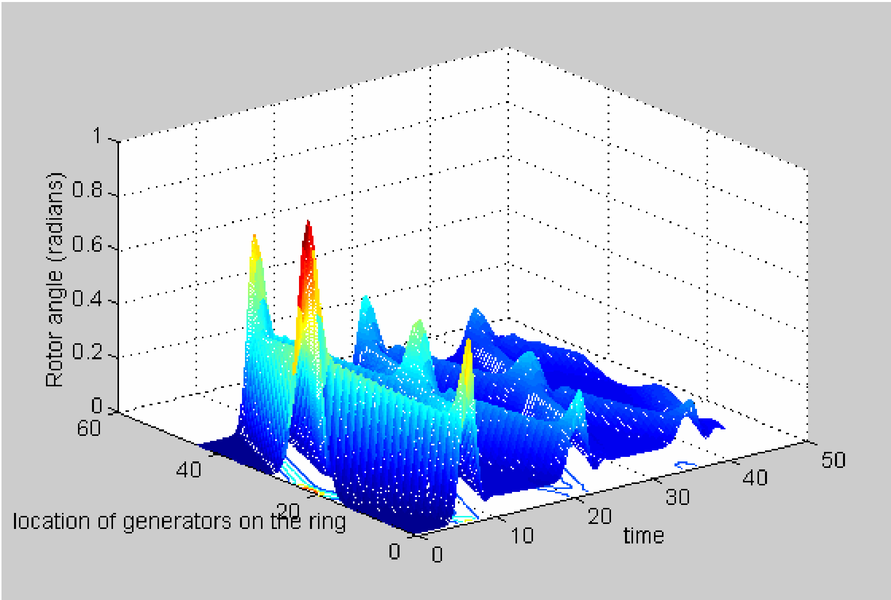

Figure (4): torque angle wave-propagation w.r.t time and generator location (M=1, D=0.1)

With the damping equal one per unit the torque angle wave is shown in figure (5) and figure (6), from which it is shown that the high damping constant suppress the disturbance wave from the beginning of its propagation. It is clear that the higher oscillatory wave vanishes with the increase of damping constant.

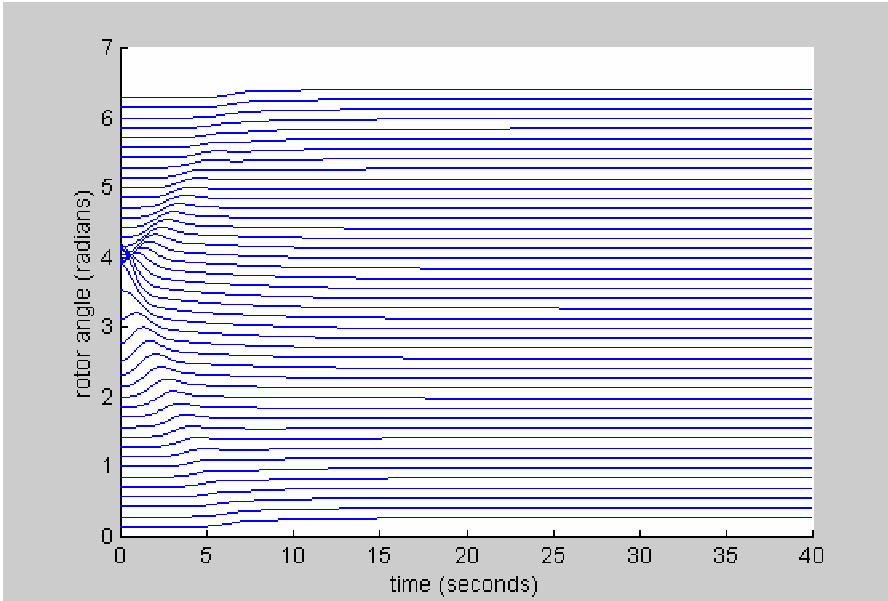

Figure (5): torque angle wave-propagation (M=1, D=1.0)

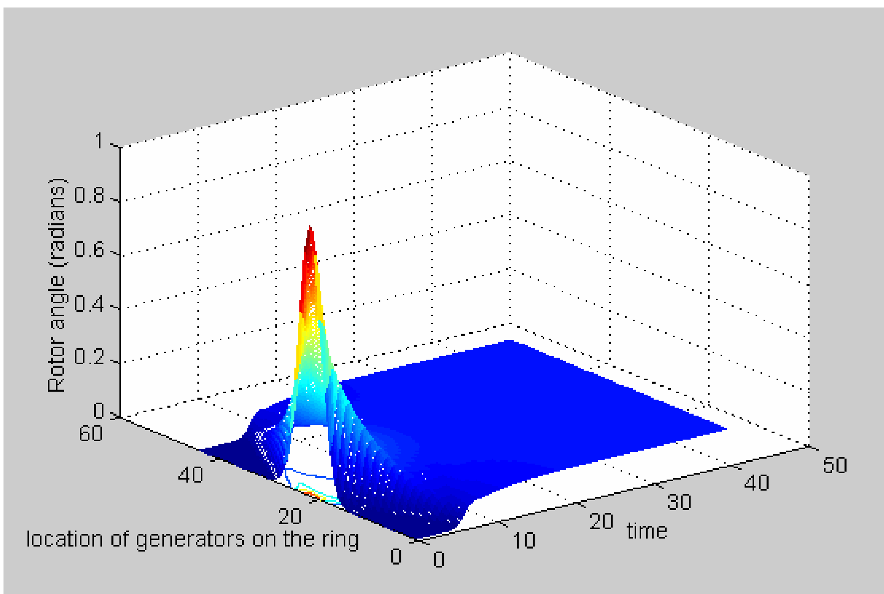

Figure (6): torque angle wave-propagation w.r.t time and generator location (M=1, D=1)

Secondly, consider the effect of rotor inertia on the wave propagation with zero damping. For the rotor inertia (M) equal 0.5 per unit, figure (7) and figure (8), show the torque angle wave.

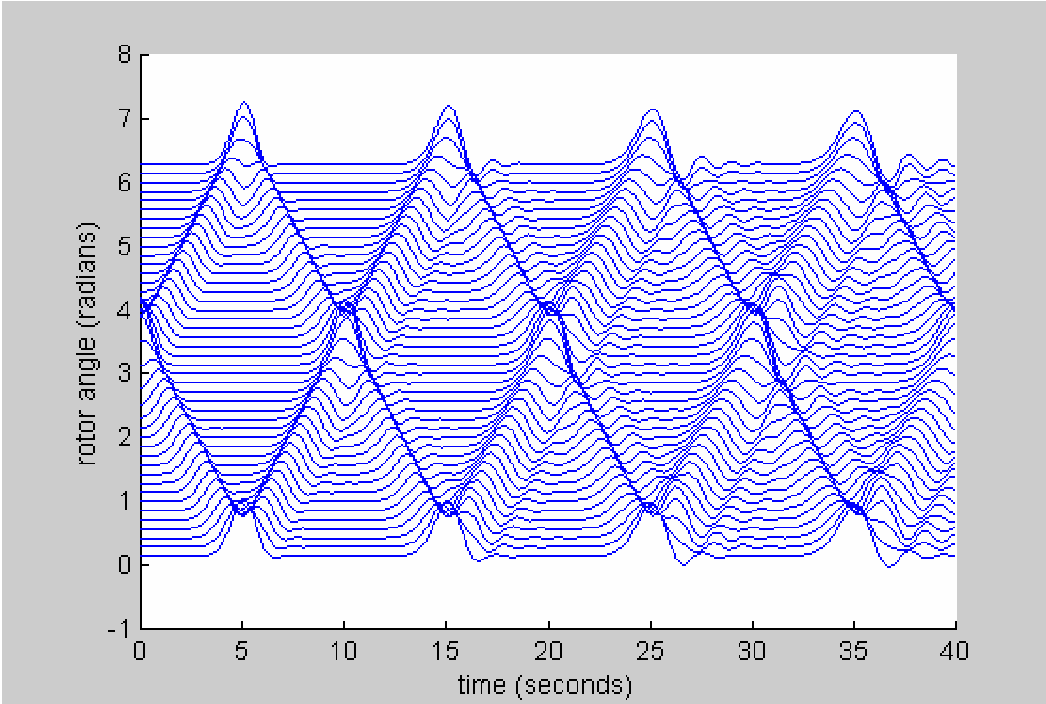

Figure (7): torque angle wave-propagation (D=0.0, M=0.5)

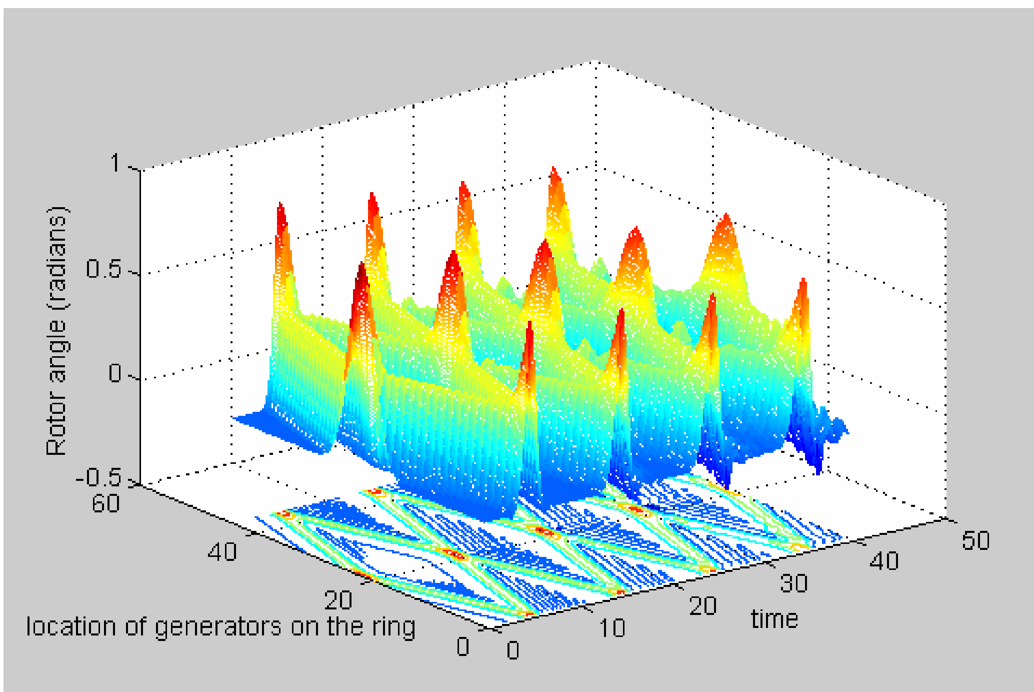

Figure (8): torque angle wave-propagation w.r.t time and generator location (D=0.0, M=0.5)

For M equal one per unit, its effect is shown in figures (9) and (10), for torque angle. To emphasis our ideas we take M equal two per unit to show its effect in figures (11) and figure (12).

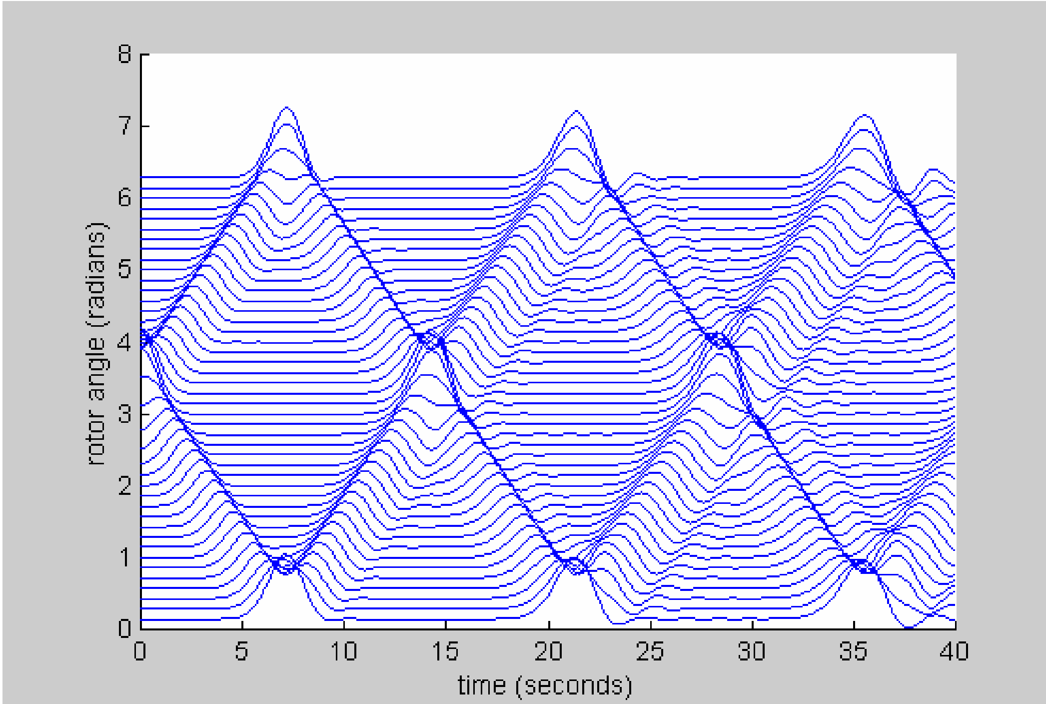

Figure (9): torque angle wave-propagation (D=0.0, M=1)

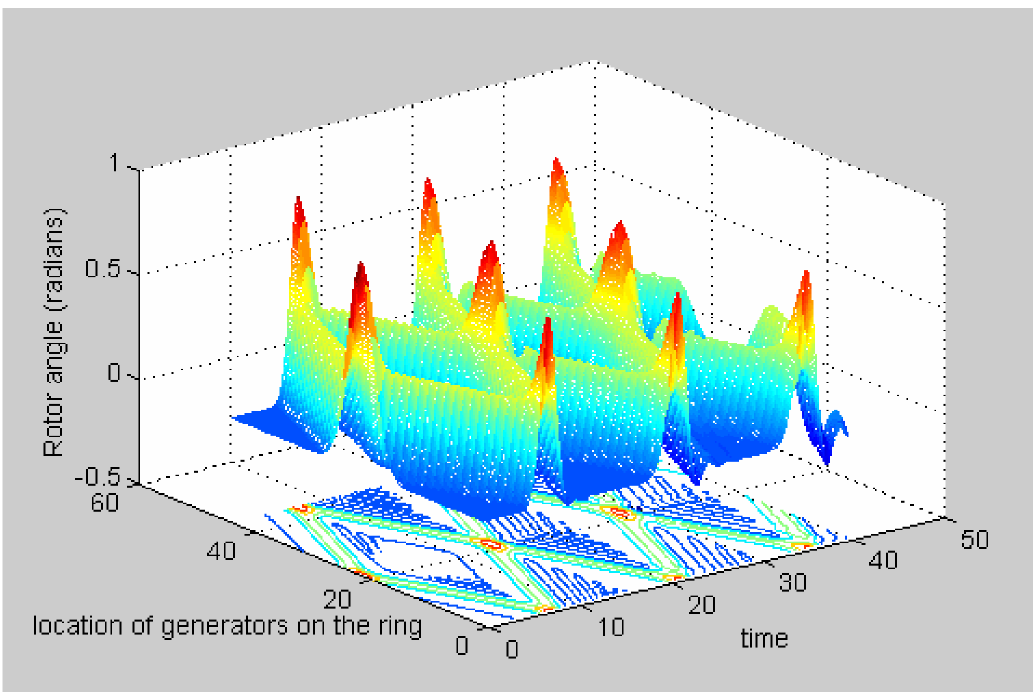

Figure (10): torque angle wave-propagation w.r.t time and generator location (D=0.0, M=1)

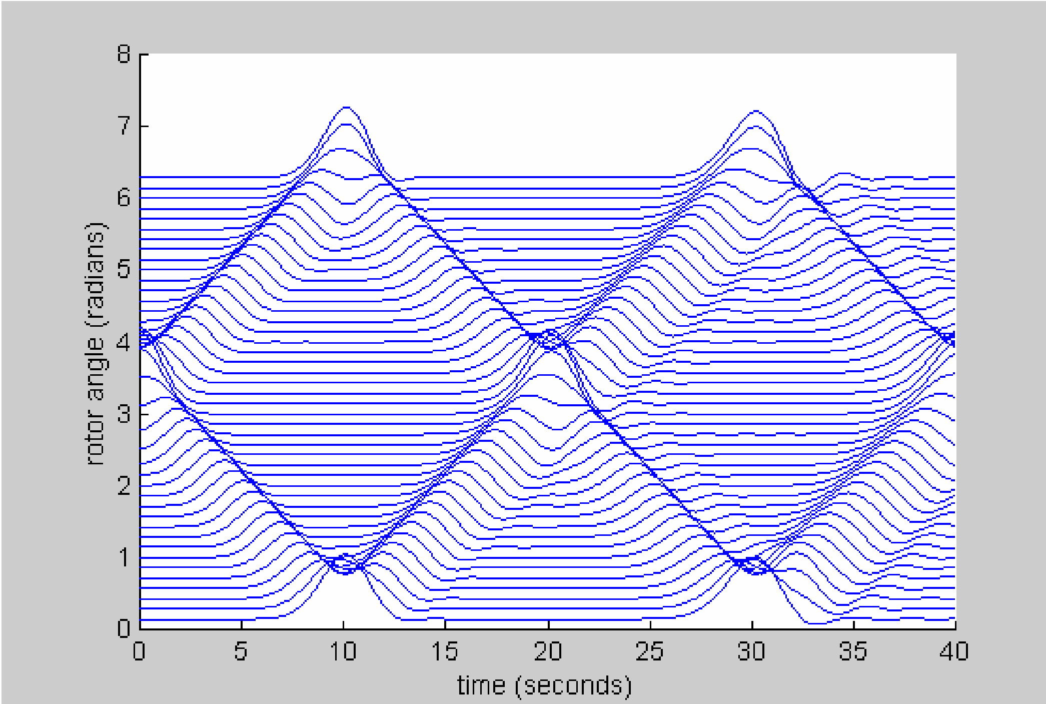

Figure (11): torque angle wave-propagation (D=0.0, M=2)

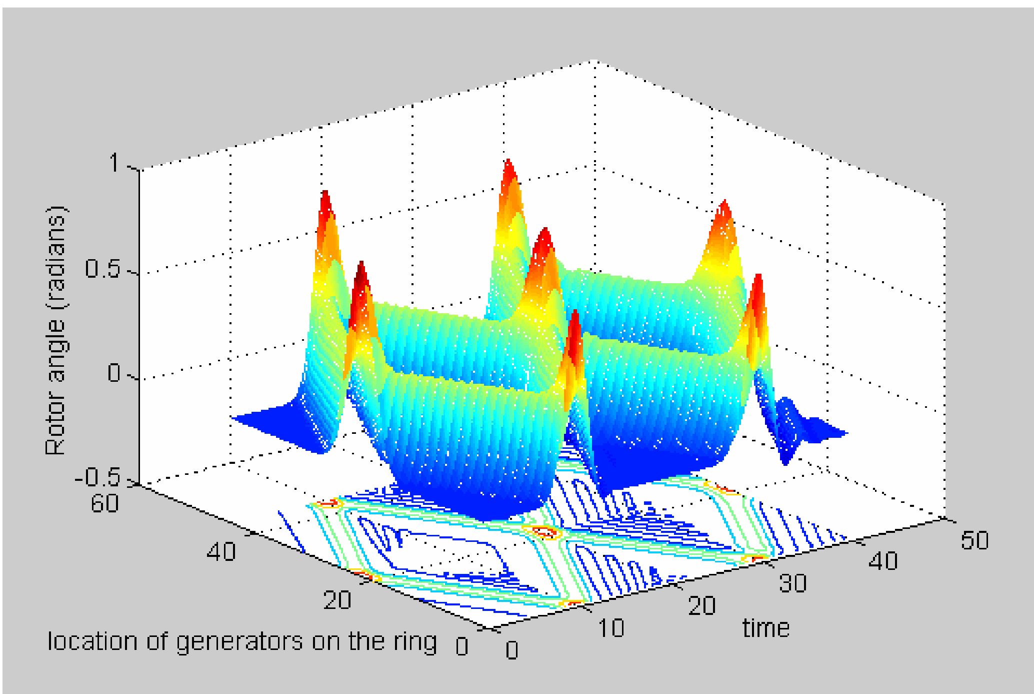

Figure (12): torque angle Wave-propagation w.r.t time and generator location (D=0.0, M=2)

From the above figures for changing the rotor inertia, it can be said that with increase of rotor inertia the electromechanical wave propagation velocity decrease. This coincides with the equation mentioned in [2] in which the phase speed of the wave:

$$\upsilon = \sqrt{\frac{wV^2 \sin\theta}{2H|Z|}} \qquad (6)$$

Where υ is the electromechanical wave propagation speed, V is the terminal voltage, Z is the transmission line impedance, and θ is the transmission line impedance angle. It is clear from equation (1) that $M = 2H / w$ and this mean that with increase of rotor inertia the electromechanical wave propagation velocity decrease.

IV. CONCLUSION

This paper presents the effect of damping constant and rotor inertia constant of the machines on the behavior of electromechanical wave propagation in a one-dimensional ring power system. The analyzed system is continuum, and it is discretized for simplicity of analysis. From the simulation results, it is clear that the higher oscillatory wave vanishes with the increase of damping constant and it suppresses the disturbance wave from its propagation through the entire network. Also, the increase of rotor inertia constant leads to the electromechanical wave propagation velocity decrease.

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