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doi:10.15199/48.2023.12.04

Design of a computer code to evaluate the influence of the harmonics in the transient stability studies of electrical networks

***Abstract**. This paper aims to present the design of a computer code: Transient Stability Code (TRANS_STAB_CODE) for the Transient Stability studies of electrical power systems under the influence of harmonics, using the GUI in MATLAB. The program was run for the loads are linear and nonlinear (Static Var Compensator (SVC), Thyristor controlled Reactor (TCR), and Unified Power Flow Controller ((UPFC)), After describing the program was run for five networks IEEE: 6 Nodes 3 Machines, 09 Nodes 03 Machines, 10 Nodes 02 Machines, 13 Nodes 04 Machines and 14 Nodes 05 Machines. The Transient Stability studies by the methods of: RungeKutta, Euler, and Heun. The results were almost consistent and show the influence of higher harmonics on Transient Stability in electrical networks.*

***Streszczenie.** Artykuł ma na celu przedstawienie projektu komputerowego kodu: Transient Stability Code (TRANS_STAB_CODE) do badań stabilności przejściowej systemów elektroenergetycznych pod wpływem harmonicznych, z wykorzystaniem GUI w MATLAB-ie. Program został uruchomiony dla obciążeń liniowych i nieliniowych (Static Var Compensator (SVC), Tyrystorowy Reaktor (TCR) oraz Unified Power Flow Controller ((UPFC)), Po opisaniu program został uruchomiony dla pięciu sieci IEEE: 6 węzłów 3 Machines, 09 Nodes 03 Machines, 10 Nodes 02 Machines, 13 Nodes 04 Machines i 14 Nodes 05 Machines. Badania stabilności przejściowej metodami RungeKutty, Eulera i Heuna. Wyniki były prawie zgodne i pokazują wpływ wyższych harmoniczne dotyczące stabilności przejściowej w sieciach elektrycznych. (**Projekt kodu komputerowego do oceny wpływu harmonicznych w badaniach stabilności nieustalonej sieci elektrycznych**)*

Keywords: Transient Stability, Harmonics, Electrical networks, Graphic User Interface, MATLAB.
Słowa kluczowe: Stabilność przejściowa, harmoniczne, sieci elektryczne, graficzny interfejs użytkownika, MATLAB.

1. Introduction

Transient stability analysis plays an important role for maintaining security of power system operation [1]. The analysis is mainly performed through numerical simulations, where numerical integration is carried out step by step from an initial value to obtain dynamic response to disturbances. In general, such a numerical simulation method is effective since it can easily take into account various dynamic models for complex power systems as well as various time sequences of events.

Furthermore, the method is useful in analyzing various kinds of complex nonlinear phenomena such as in [2]. However, the numerical simulation is usually time consuming, and therefore, it is not necessarily suited for real time stability assessment.

An alternative approach, called transient energy function methods [3], assesses system stability based on the transient energy. Those methods provide fast and efficient stability assessment for a number of disturbances. Although they are practically useful, a common disadvantage is concerned with the accuracy of stability judgment. A major limitation is that they cannot deal with detailed models for power systems since the transient energy functions are available only for limited types of power system models [4]. Another problem is that the most of the methods require the evaluation of critical energy, which affects considerably the accuracy of stability assessment.

In this work we describe the transient stability: how to improve transient stability by FACTS devices, introduce the basics of transient stability, then we describe the developed program (TRANS_STAB_CODE)), and finally we analyze and study the transient stability of two network systems: 6 node network and 14 node network with and without the harmonics, and finally we provide interpretations of the results obtained.

2. Enhancement Of Transient Stability By Shunt Facts Devices

Equal-area criterion is commonly used for the assessment of transient stability of power system where power system representation is usually simplified as single machine infinite bus (SMIB) system [5]. For the sake of analysis, let us consider a lossless SMIB system with a shunt FACTS device as shown in Fig. 1(a) and (b), where *E'* and *V* represent the machine internal voltage and infinite bus voltage. The dynamics of the machine, in classical model, can be represented by the following differential equations [6].

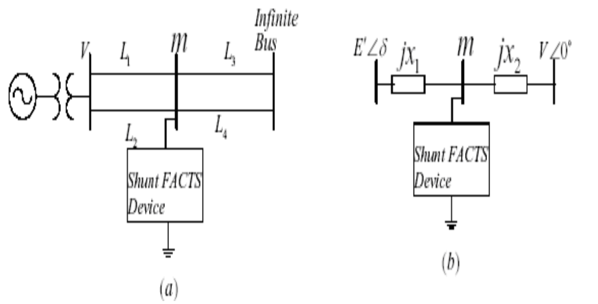

Fig.1. A SMIB with a shunt FACTS device, a) single line diagram. b) equivalent circuit.

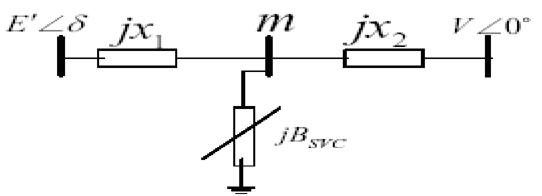

Fig.2. A SMIB system with SVC

(1) $$\frac{d\delta}{dt} = \omega$$

(2) $$\frac{d\delta}{dt} = \frac{1}{M}\left(P_m - P_e - D \right)$$

Here δ, ω, M, D, P_m and P_e are angle, speed, moment of inertia, damping coefficient, input mechanical power and output electrical power, respectively, of the machine. The electric al output power without FACTS devices P_{e0} of the machine can be written as:

(3) $$P_{e0} = \frac{E'}{(X_1 + X_2)} \sin\delta + P_{\max}\sin\delta$$

3. Fundamentals of transient stability

Transient stability concerns with the matter of maintaining synchronism among all generators when the power system is suddenly subjected to severe disturbances such as faults or short circuits caused by lightning strikes, the sudden removal from the transmission system of a generator and/or a line, and any severe shock to the system due to a switching operation.

Because of the severity and suddenness of the disturbance, the analysis of transient stability is focused on the first few seconds, or even the first few cycles, following the fault occurrence or switching operation.

First swing analysis is another name that is applied to transient stability studies, since during the brief period following a severe disturbance the generator undergoes its first transient overshoot, or swing. If the generator(s) can get through it without losing synchronism, it is said to be transient stable [7]. On the other hand, if the generator(s) loses its synchronism and cannot get through the first swing, it is said to be (transient) unstable. There is a critical angle within which the fault must be cleared if the system is to remain stable.

The equal-area criter is needed and can be used to understand the power system stability.

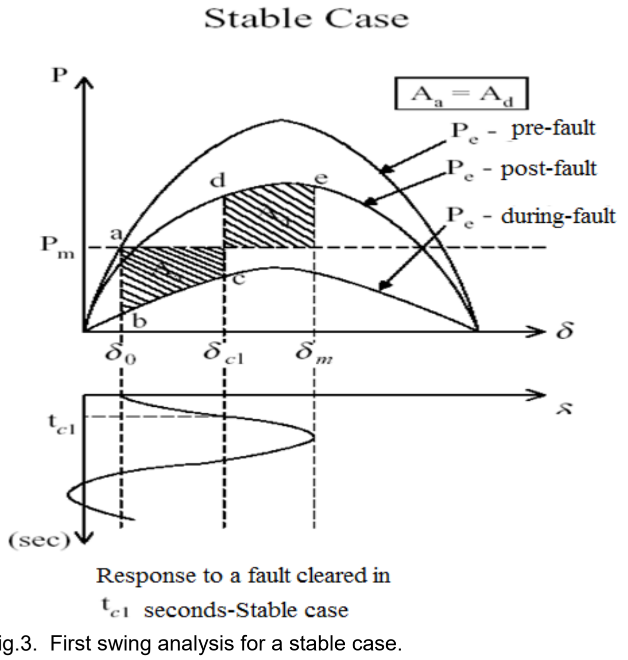

Fig.3. First swing analysis for a stable case.

3.1 Swing Equation

The moment of inertia and the accelerating torque of a synchronous machine ca PRZEGLĄD ELEKTROTECHNICZNY, ISSN 0033-2097, R. 99 NR 12/2023n be related as follow

(4) $$J\frac{d^2\delta_m}{dt^2} = T_a$$

where

J the moment of inertia, δ_m mechanical angle, and $T_a = T_m - T_e$ The accelerating torque, the difference between the mechanical torque and the electromagnetic torque. In steady-state conditions,

(5) $$T_m = T_e, \quad T_a = 0$$

The relationship between the mechanical angle and the electrical angle (rotor angle) can be expressed as

(6) $$\delta = \frac{P}{2}\delta_m$$

Where P is the number of poles of the machine. Then, the equation of the accelerating torque can be re-written as

(7) $$J \cdot \frac{2}{P} \cdot \frac{d^2\delta}{dt^2} = T_a$$

It is reasonable to assume that the machine speed deviates very little from the synchronous speed ω_s therefore,

(8) $$\omega_s J \cdot \frac{2}{P} \cdot \frac{d^2\delta}{dt^2} = \omega_s T_a = P_a$$

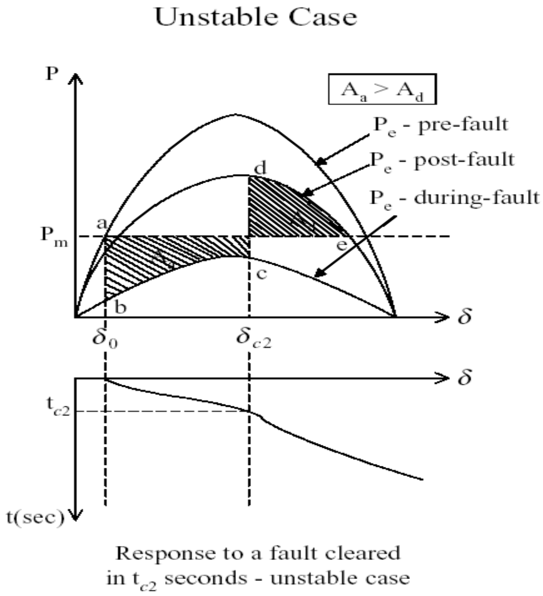

Fig.4. First swing analysis for an unstable case

A commonly used constant, inertia constant H , is defined as the ratio between the stored energy in watt-seconds and VA rating of the machine, namely,

(9) $$H = \frac{\frac{1}{2}J\omega_s}{S}$$

It can be re-arranged as

(10) $$J\omega_s = \frac{2HS}{\omega_s}$$

One can relate this equation to the equation for the accelerating power P_a ,

(11) $$\frac{2HS}{\omega_s} \cdot \frac{2}{P} \cdot \frac{d^2\delta}{dt^2} = P_a$$

If one defines

(12) $$\omega_0 = \frac{P}{2}\omega_s$$

Then, the above equation can be expressed as

$$\frac{2H}{\omega_0}\cdot\frac{d^2\delta}{dt^2}=\frac{P_a}{S} \qquad (13)$$

Where all quantities are in their actual values. Finally, the swing equation with the accelerating power in per unit value can be obtained as follows

$$\frac{2H}{\omega_0}\cdot\frac{d^2\delta}{dt^2}=P_a \qquad (14)$$

Or

$$M\cdot\frac{d^2\delta}{dt^2}=P_a \qquad (15)$$

Where M is the angular momentum, and:

$$M=\frac{2H}{\omega_0}=\frac{H}{60\pi} \qquad (16)$$

4. Structure of TRANS_STAB_CODE

Our program is called TRANS_STAB_CODE was developed to studies of transient stability of electrical networks [8]. TRANS_STAB_CODE can analyze and studies of transient stability of electrical networks in two cases: Trans_Stab_Linear_Loads where the loads are linear and Trans_Stab_Harmonic_Loads where there are non-linear loads (SVC, TCR, and UPFC) [9].

TRANS_STAB_CODE is a computer code produced in MATLAB, and allows you to run multiple applications and functions (MATLAB files).

TRANS_STAB_CODE structure is based on graphical interfaces [10] performed by MATLAB (GUI).

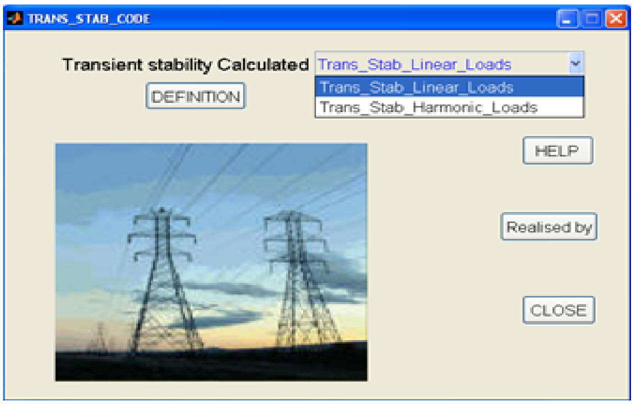

Fig.5. Principal Window of TRANS_STAB_CODE Program

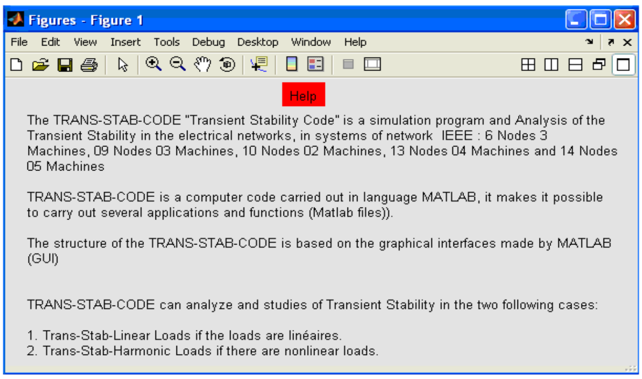

Fig.6. Help window of TRANS_STAB_CODE Program

The graphical interface TRANS_STAB_CODE program contains a title which signifies the objective of this program "Transient Stability Calculated", and two functions: Trans_Stab_Linear_Loads, and Trans_Stab_Harmonic _Loads with four push buttons:

- The first button Definition: the definition of transient stability of power systems.
- The second button Help: gives an overview of the program.
- The third button Realised by: the author of this program.
- The fourth button close: You can quit the program TRANS_STAB_CODE.

If we click on Trans_Stab_Linear_Loads, another window pops up and we can choose to study the electrical network systems:

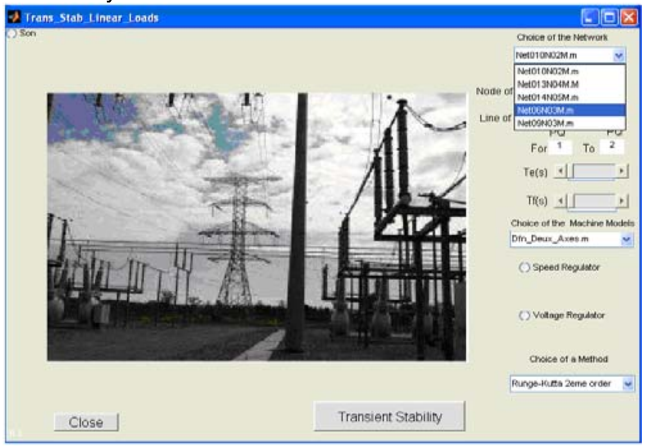

Fig.7. Electrical network system selection for studies of transient stability with linear loads

If we press the button "Net06N03M, the block diagram of the network appears as follows:

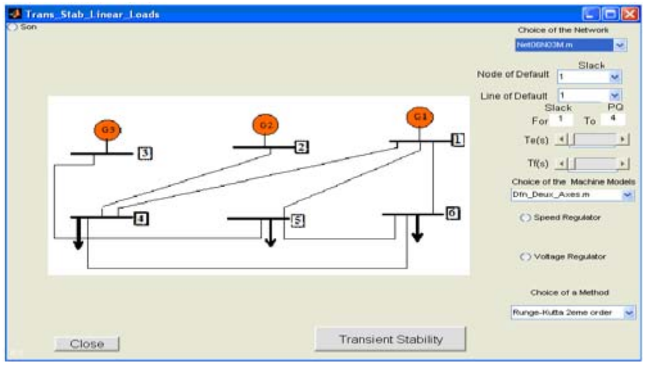

Fig.8. Synoptic diagram of network system 03machines 6 nodes

The execution of the program by a click on Transient Stability, allow us to see the difference of the angles of the generators (Fig.9).

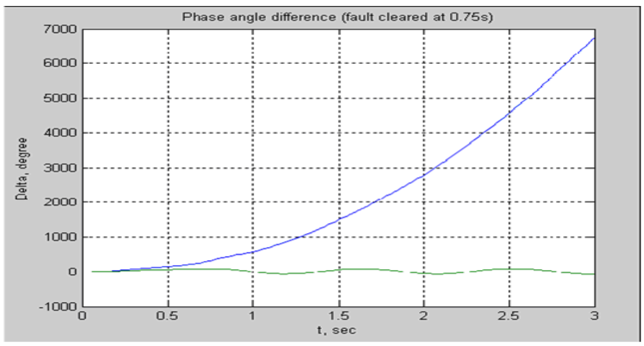

Fig.9. Difference of the angles of generators

If we press the button "Net14N05M, the block diagram of the network appears as follows:

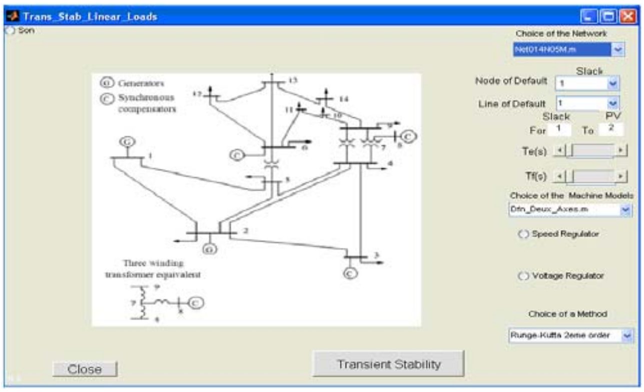

Fig.10. Synoptic diagram of network system 05machines 14 nodes

The execution of the program by a click on Transient Stability, allow us to see the difference of the angles (Fig.11) in Case normal (without SVC).

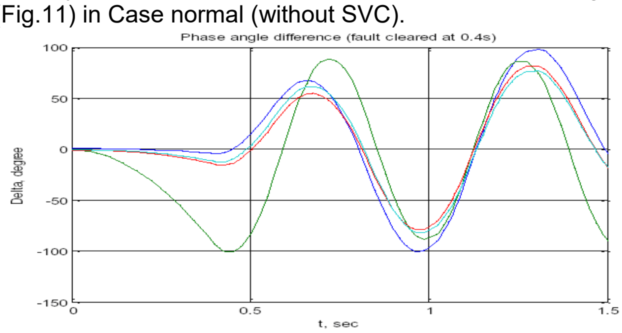

Fig.11. Plots of angle differences for machines 2, 3, 4 & 5 when fault on bus 2 cleared at 0.4sec

If we click on Trans_Stab_Harmonic_Loads, another window pops up and we can choose to study the electrical network systems (fig.12)

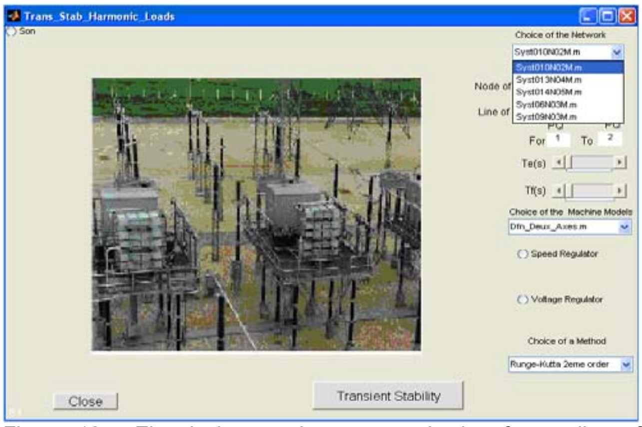

Figure 12. Electrical network system selection for studies of transient stability with non linear loads

If we press the button "Syst06N03M, the block diagram of the network appears as follows:

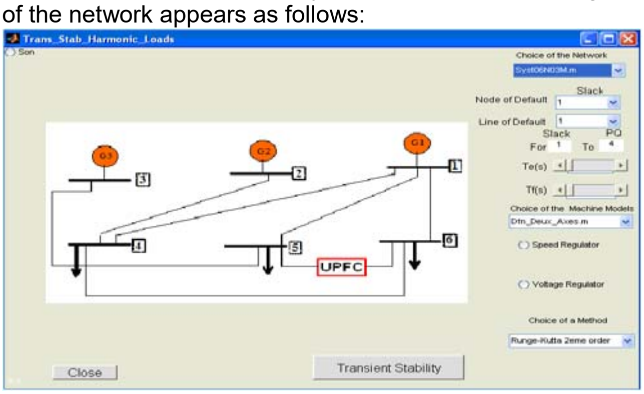

Fig.13. Synoptic diagram of network system 03machines 6 nodes with UPFC

The execution of the program by a click on Transient Stability, allow us to see the difference of the angles with UPFC [11], appears as the Fig.14.

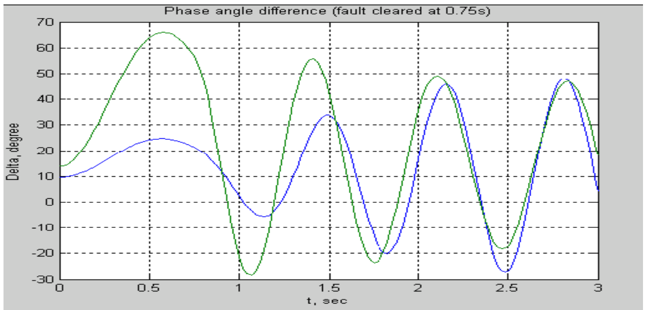

Fig.14. Speed of the generators of network system 03 machines 9 nodes

If we press the button "Net14N05M, the block diagram of the network with SVC appears as follows:

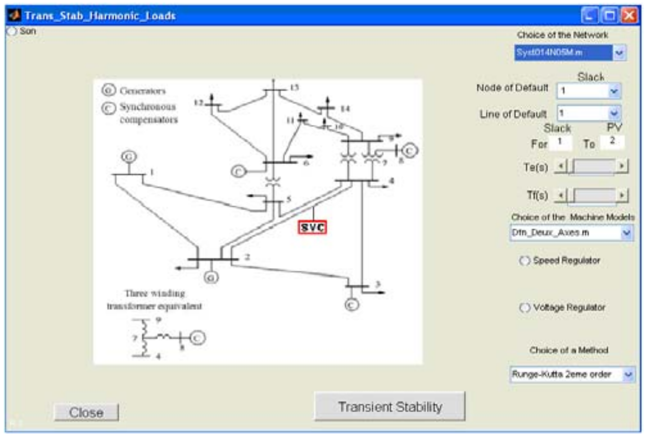

Fig.15. Synoptic diagram of network system 05 machines 14 nodes, with SVC

The execution of the program by a click on Transient Stability, allow us to see the difference of the angles with SVC [12], appears as the Fig.16.

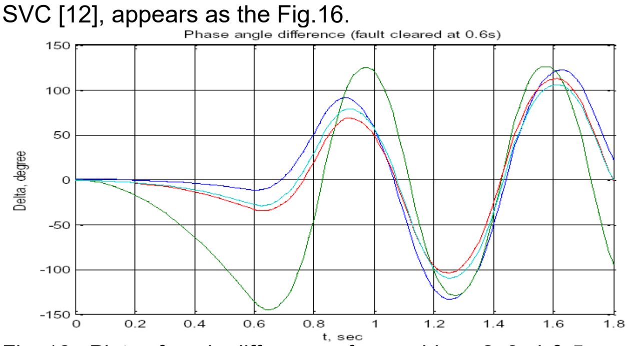

Fig. 16. Plots of angle differences for machines 2, 3, 4 & 5 when Fault on bus 2 cleared at 0.6 sec

5. Results and analysis

For the network system IEEE 6-bus, where there is a fault at bus 6 and for a cleared time of 0.75 sec, we note that in the normal case (no UPFC), the rotor angles curve of machines 2 and 3 shown in figure.9 shows the transient instability of the network system (δ_2 diverged), and consequently therefore the network system is not stable even after cleared the fault.

By cons in the same network system IEEE 6-bus, and for the same fault, if one set a UPFC in the line (5-6) as presented in the block diagram of Figure 13, the curve of the rotor angles machines2 and 3 shown in Figure 14, shows the transient stability of the network system just at the beginning of cleared time of the fault 0.75sec.

Through these results one can say that the transient stability enhancement is achievable with UPFC, As well as the UPFC is extremely effective by handling disturbances of dynamic system.

For the network system IEEE 14-bus, the study is performed with the intention of analyzing the effect of fault location in conjunction with the fault clearing time. A three-phase fault at bus 2 near generating station on line 2-4 is shown with a learing time of 0.4 sec. It is observed in fig. 11. That generator 2 is severely disturbed [13]. The results of the angle differences of the machines in the system, when fault occurred on line 2-4 and the fault is cleared in 0.5 sec are shown in fig.11.

The swing curves for all five generators represented by classical models are shown in Figure 16, when SVC is placed in line 2-4 to determine clearing time. Figure 16 shows the results of the angle differences of the machines in the system, when three-phase fault is occurred on line 2-4 after SVC is placed [14]. The clearing time of fault that is 0.6 sec, is increased when SVC is placed.

6. Conclusion

The TRANS_STAB_CODE program is called « Transient Stability CODE ", developed in MATLAB environment has been tested on several nonlinear loads such as: SVC, TCR, UPFC, and gave entire satisfaction for the simulations performed confirming the relevance of this code. The results were almost consistent and show the influence of higher harmonics on transient stability in electrical networks. And we have confirmed the possibility to analyze other nonlinear loads generating harmonics in power systems with this computer code TRANS_STAB_CODE.

On the basis of different nonlinear loads simulated on a number of different networks, which we consider fairly representative to validate our computer code, we can conclude that the computer code TRANS_STAB_CODE gives better results and can admit the improved graphical interface of this code, reducing the number of windows that are modifying it to simplify its use.

The developed program is tested for several cases and major conclusions are the transient stability is improved by decreasing first swing with FACTS devices. FACTS devices help in improving transient stability by improving critical clearing time. The fault that is closer to the generating station must be cleared rapidly than the fault on the line far from the generation station.

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FACTS device must be placed in the main power transfer of the critical machine. The effectiveness of the proposed method has been shown with IEEE 14-bus system and compared the critical clearing angle and critical clearing angle without and with SVC device. From the result it has been observed that there is a improvement in critical clearing time and critical clearing angle with the help of the SVC device.

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