Influence of the Load Models in the Dynamic Voltage Stability of an Electric Power System

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Abstract. Voltage stability plays a very important role during the planning and design stages of an electric power network as well as during the system operation. In the last years in various countries worldwide, several power network collapses (blackouts) caused by voltage problems have been reported. This can be produced by a lack of sufficient reactive power reserve during heavy load or by the occurrence of severe contingencies. In this paper it is studied and analysed the influence of the load models in the dynamic voltage stability assessment of an electric power system. It was used the BPA test power network. A severe contingency situation was simulated to perform the study. The automatic voltage regulators of the generating units and the turbine speed governors were modelled as well as the transformer taps. The simulation results were obtained using the commercial transient software package EUROSTAG. Finally some conclusions that provide a better understanding of the voltage collapse phenomena are pointed out.

Key words

Electric Power System, Voltage Stability, Voltage Collapse, Load Models

1. Introduction

Most power systems are nowadays operated very near to their operating limits due to increase in consumption, while economic and environmental constraints have limited construction of new generation facilities and lines [1]. On the other hand, the change in the power system industry, with competition and liberalization of the energy market, increased the pressure on system operation, demanding new procedures and tools for online voltage stability assessment and identification of preventive control actions [2].

Voltage stability has become of the most important power system research areas. A lot of effort has been focused upon the cause and mechanism of voltage instability, and corresponding counter-measures [3]. Voltage stability is essentially a dynamic phenomenon and is affected by voltage control and load characteristics under voltage fluctuations [4].

This paper is devoted to the study and analysis of the influence of the load models in the dynamic voltage stability assessment of an electric power system. In the simulations it was used the BPA (Bonneville Power Administration) test power network, considering a severe contingency situation [5]. The automatic voltage regulators of the generating units and the turbine speed governors were taken into account as well as the transformer taps. The simulation solution were obtained using the commercial transient software package EUROSTAG developed by Electricité de France and Tractebel Energy Engineering.

2. Applied software

The simulations were carried out using the professional grade time-domain simulation software package EUROSTAG. The main feature of these computer programs is to propose a unique solution to various issues with a high degree of performance [6]. This single integrated program is able to simulate the full range of electrical phenomena, from transient to long term stability and gives continuous display for fast and slow events.

The numerical integration scheme is performed using a mixed Adams–BDF implicit integration method with automatic variable step size [7]. The differential and algebraic equations are solved simultaneously and the truncation error is evaluated in every step for determining the best step size. In practice, it automatically drops to values far bellow the smallest time constant, and when they diminish out, it gradually increases up to values larger than the smallest time constant of the whole system.

3. Load models

A. Static loads

Static loads are generally represented by an exponential model in which the active and reactive power depend on voltage and frequency.

$$P = P_o \left(\frac{U}{U_o} \right)^{\alpha} \left(\frac{\omega}{\omega_o} \right)^{\delta} \quad (1)$$

$$Q = Q_o \left(\frac{U}{U_o} \right)^{\beta} \left(\frac{\omega}{\omega_o} \right)^{\gamma} \quad (2)$$

P_o and Q_o are respectively the active and reactive loads supplied by the load flow program. U denotes the busbar voltage [8], [9] and U_o the busbar voltage at the initial conditions; ω is the angular velocity and ω_o is the synchronous speed.

In this study δ and γ load model exponents are assumed equal to zero, since the power system frequency was considered constant. Table I present the different load models in accordance with the α and β model parameters.

TABLE I. - Static load models

Load Model	α	β
Constant power	0	0
Constant current	1	1
Constant impedance	2	2

B. Dynamic loads

In this study it was only considered the double squirrel cage induction motors. The applied software assumes a balanced situation and the torque speed curve is approximated by a piece-wise linear function [10]. In figure 1 it is present a schematic representation of the induction motor.

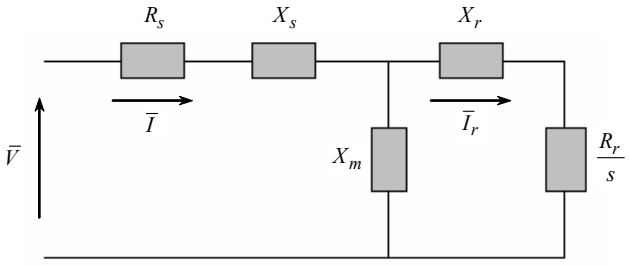

Fig. 1. Schematic representation of the induction motor

Table II shows the induction motor parameters used in this study. This dynamic load was connected to the busbar 8 of the test power network.

TABLE II. - Induction motor parameters

Bus	H [s]	R_s [p.u.]	X_s [p.u.]	X_m [p.u.]	R_r [p.u.]	X_r [p.u.]
8	0.600	0.010	0.145	3.300	0.008	0.145

In figure 1 and in table II s is the motor slip; H is the inertia constant; R_s is the stator resistance; X_s is the stator leakage reactance; X_m is the rotor-stator mutual reactance; R_r is the rotor resistance and X_r is the rotor leakage reactance.

4. Test power network

In figure 2 it is shown the BPA test power network that was used in this study. The simulations were carried out considering the network data presented in [5], [11]. It was simulated the tripping of one of the five 500 kV overhead transmission lines between busbars 6 and 7 at the time equal to 20 s. The operating point assumed in this study corresponds to a 6855 MW and 1046 MVAr load level. Four scenarios were analysed as it is shown in table III. In all situations the load was always assumed as constant impedance in busbar 11.

TABLE III. - Analysed scenarios

Scenarios	Load models in busbar 8
Case I	Constant impedance
Case II	Constant current
Case III	Constant power
Case IV	Induction motor

In all situations the ULTC regulation effect of the transformer connected between busbars 10 and 11 was taken into account. In every scenario it was analysed the overall system voltage stability. Generator G_1 is considered as an infinite busbar, G_2 and G_3 are modelled in detail. The automatic voltage regulators of the generating units and the turbine speed governors were considered.

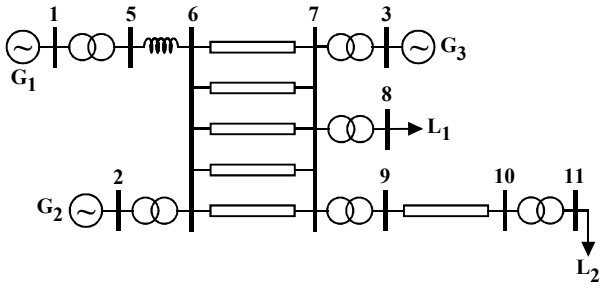

Fig. 2. BPA test power network single line diagram

5. Results

Figure 3 shows the voltage, the active and reactive load variation in busbar 8 (case I). Figure 4 presents the voltage variation in busbars 11, ULTC position and the field current of the synchronous generators (case I).

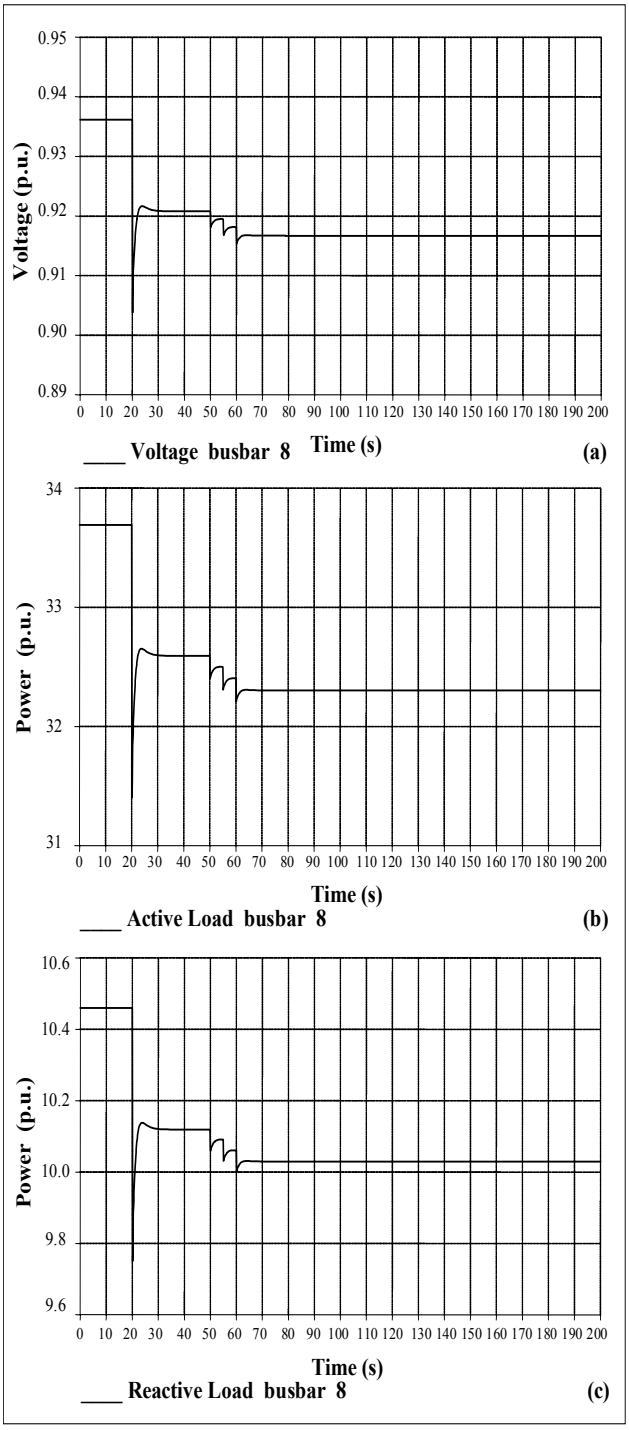

Fig. 3. (a) Voltage variation in busbar 8
(b) Active load in busbar 8
(c) Reactive load in busbar 8

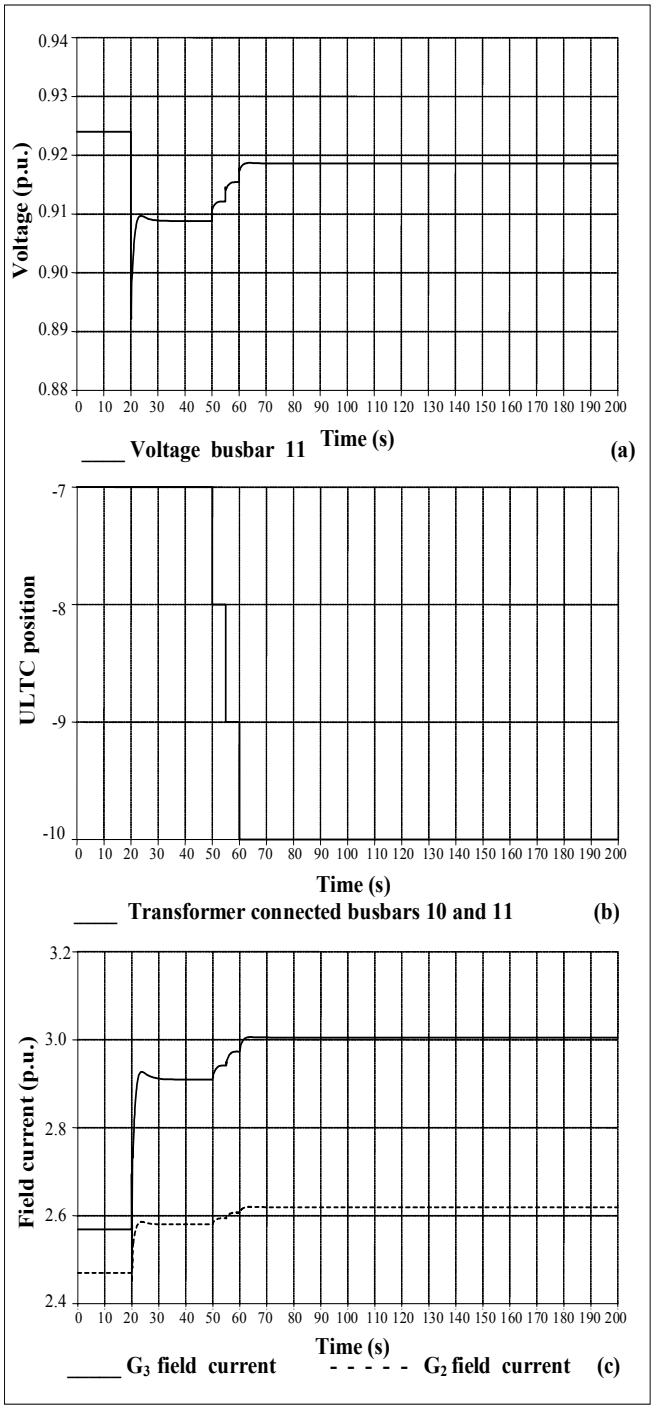

Fig. 4. (a) Voltage variation in busbar 11
(b) ULTC position
(c) G_2 and G_3 field currents

Figure 5 shows the voltage, the active and reactive load trajectory in busbar 8 (case II). Figure 6 presents the voltage variation in busbars 11, ULTC position and the field current of the synchronous generators (case II).

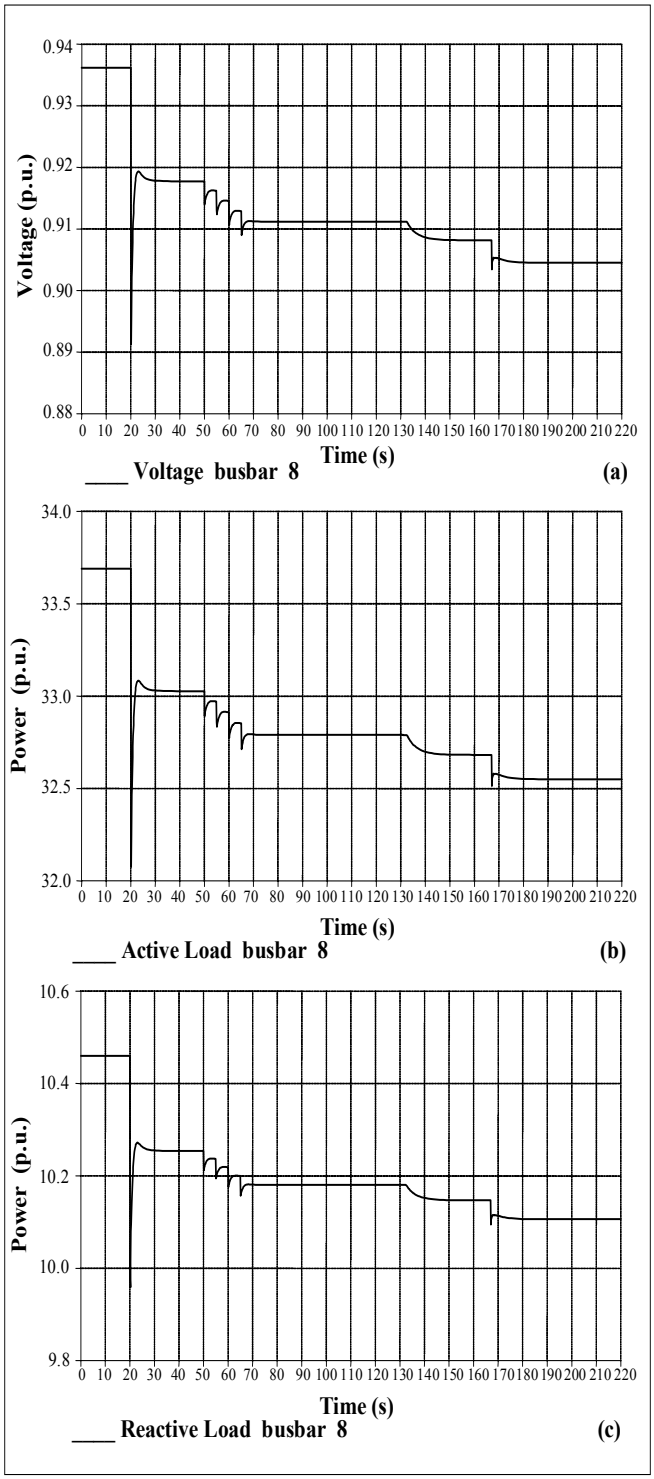

Fig.5. (a) Voltage variation in busbar 8
(b) Active load in busbar 8
(c) Reactive load in busbar 8

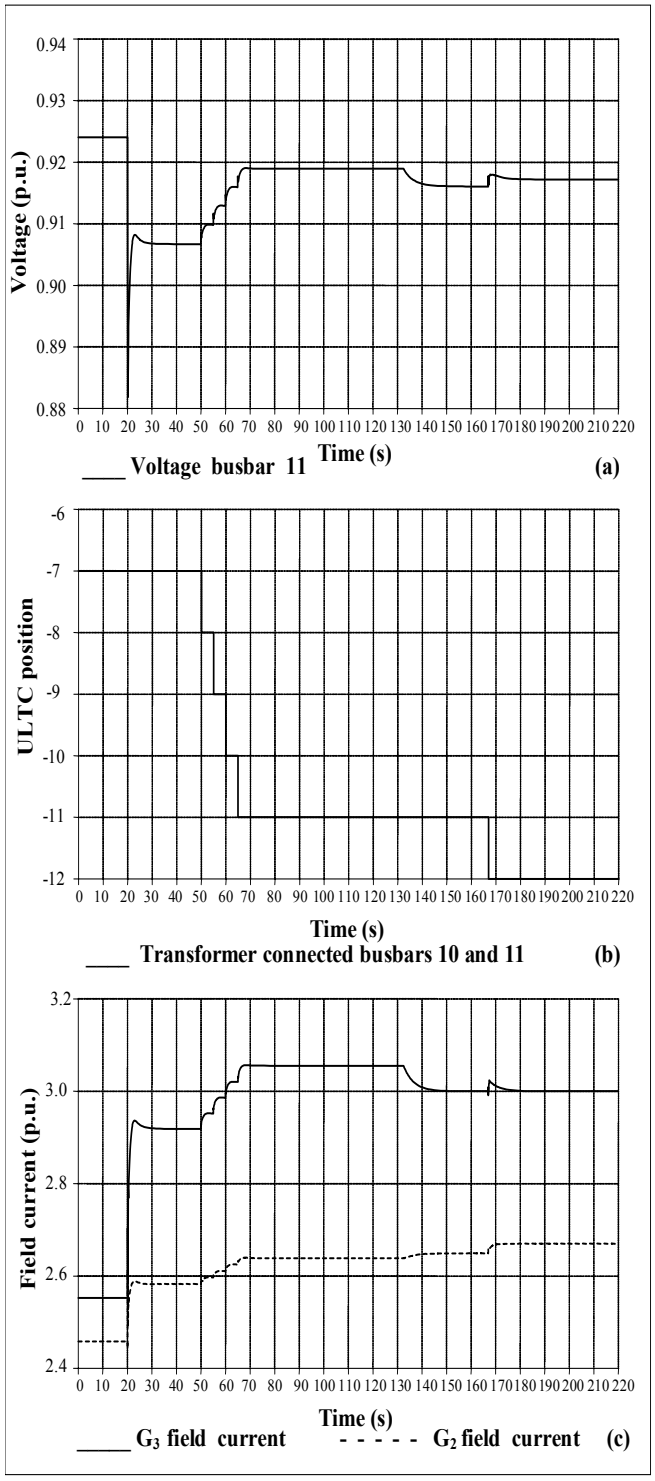

Fig.6. (a) Voltage variation in busbar 11
(b) ULTC position
(c) G_2 and G_3 field currents

Figure 7 shows the voltage, the active and reactive load variation in busbar 8 (case III). Figure 8 presents the voltage variation in busbars 11, ULTC position and the field current of the synchronous generators (case III).

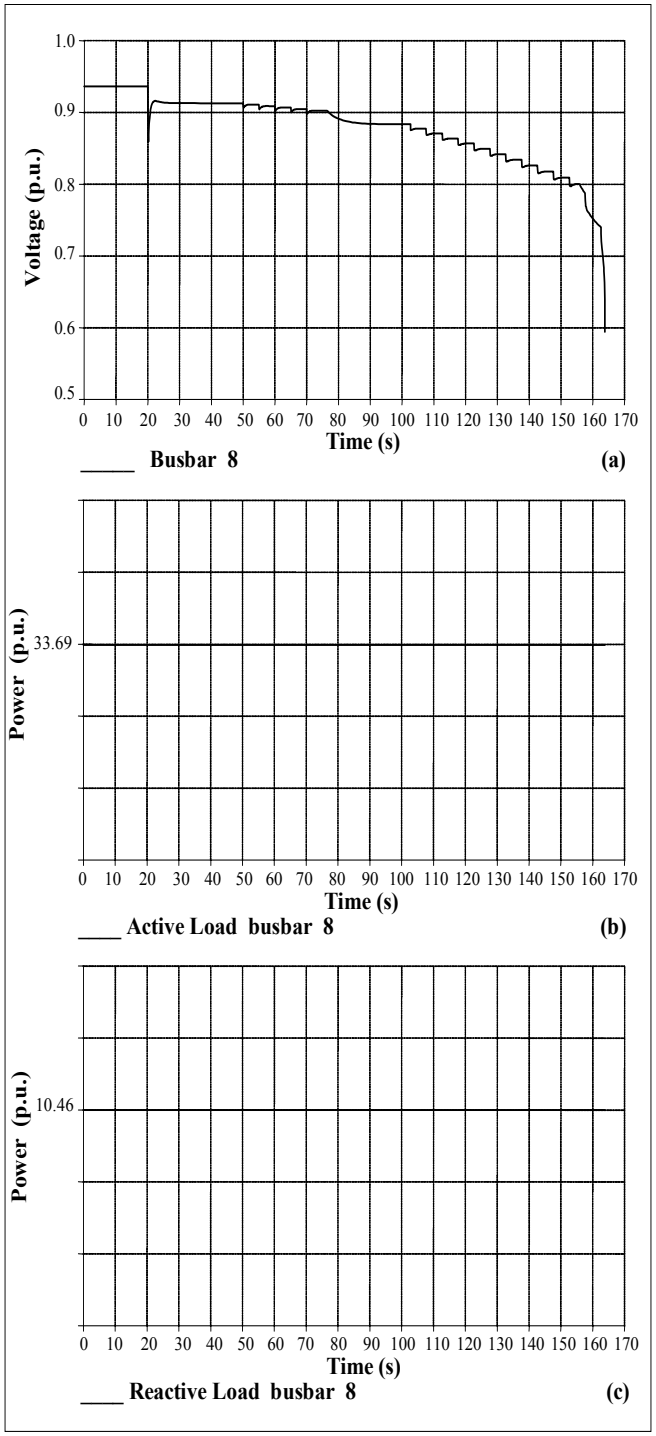

Fig.7. (a) Voltage variation in busbar 8
(b) Active load in busbar 8
(c) Reactive load in busbar 8

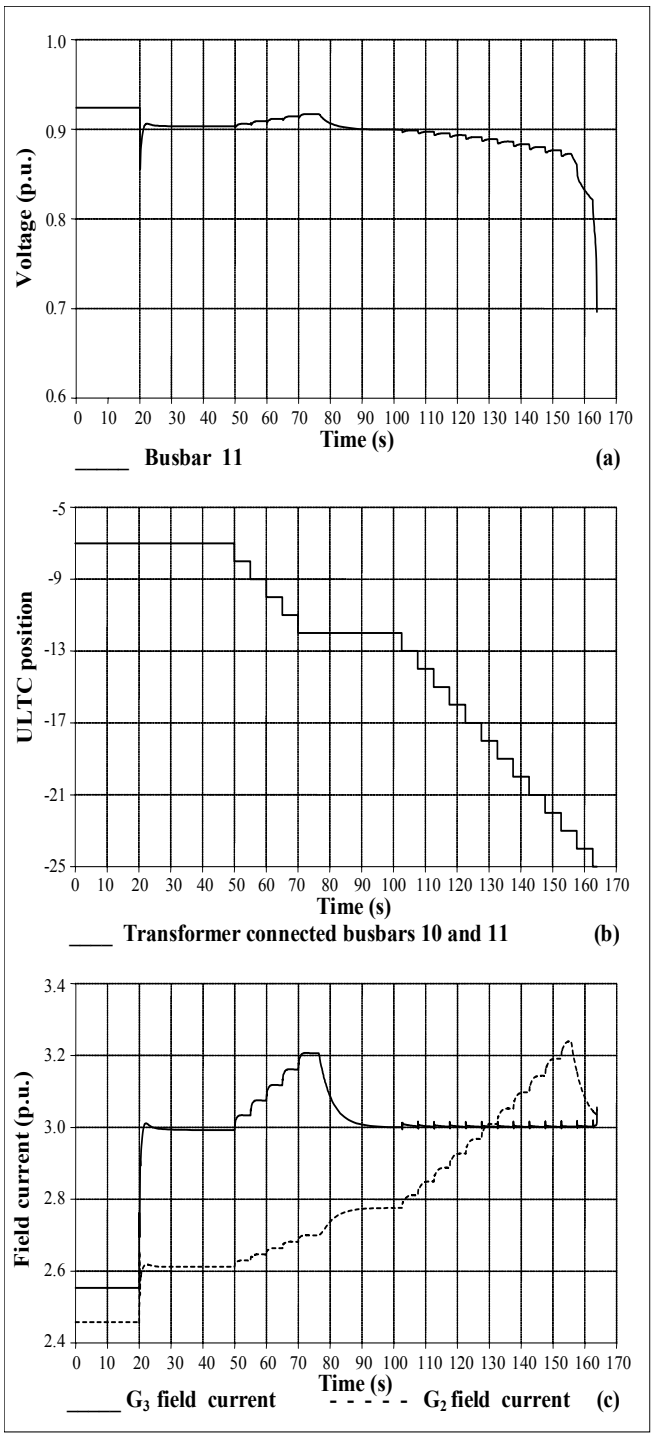

Fig. 8. (a) Voltage variation in busbar 11
(b) ULTC position
(c) G_2 and G_3 field currents

Figure 9 shows the voltage, the active and reactive load variation in busbar 8 (case IV). Figure 10 presents the voltage variation in busbars 11, ULTC position and the field current of the synchronous generators (case IV).

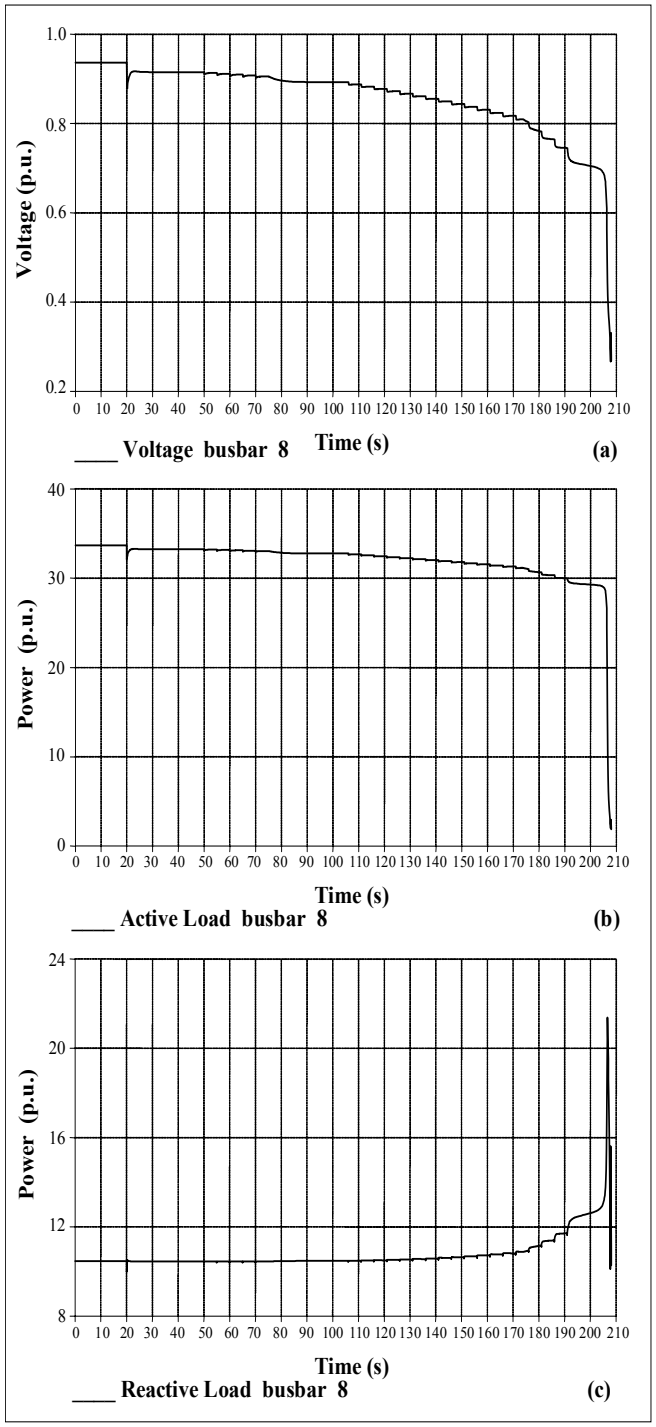

Fig. 9 (a) Voltage variation in busbar 8
(b) Active load in busbar 8
(c) Reactive load in busbar 8

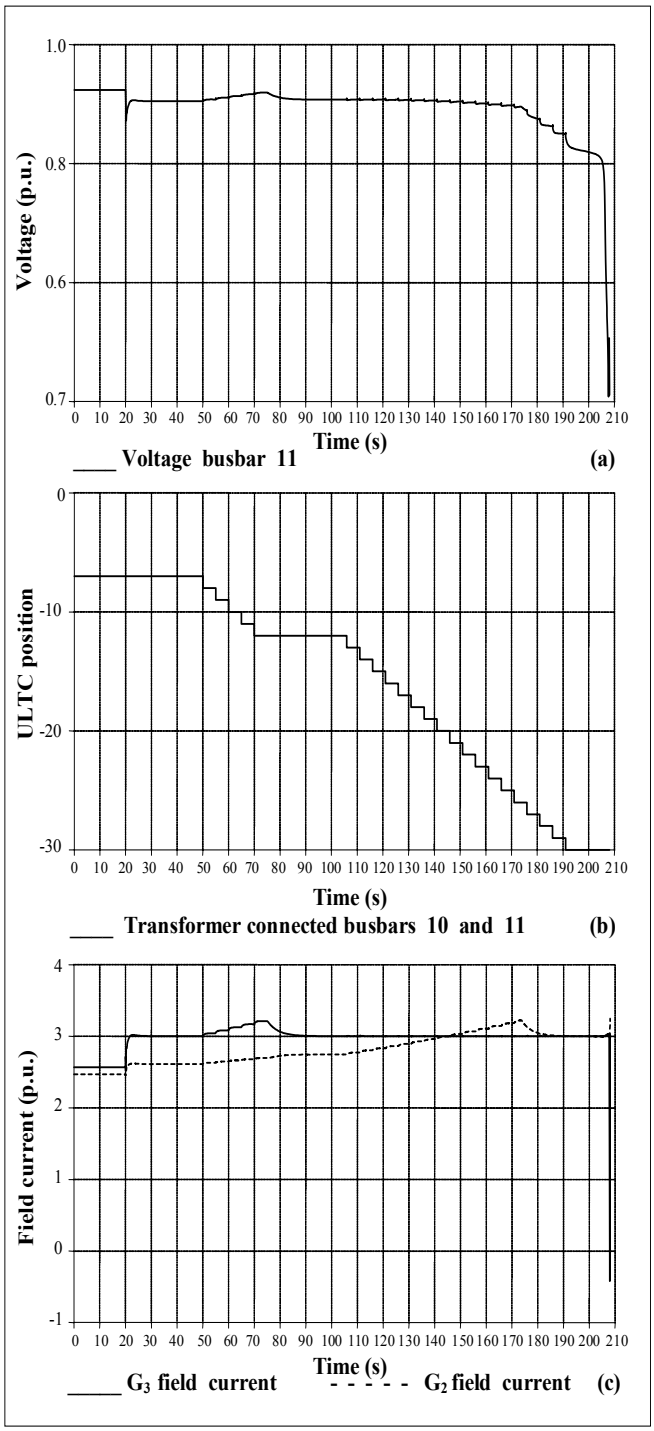

Fig.10. (a) Voltage variation in busbar 11
(b) ULTC position
(c) G_2 and G_3 field currents

6. Conclusions

In this paper it was studied and analysed the influence of the load models in the dynamic voltage stability assessment of an electric power system. For the tripping simulation of one of the five 500 kV overhead transmission lines between busbars 6 and 7 a voltage collapse arises in the cases III and IV. Case II presents more transients than case I, although both situations are stable. If a voltage dip arises in an induction motor then a small decrease of the active power occurs while the reactive power increases drastically. From the above results it is pointed out that accurate load models play a very important role in the dynamic voltage stability analysis in order to specify control actions.

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