SAU Fen Bilimleri Enstitüsü Dergisi
7.Cilt, 1.Sayı (Mart 2003)

EFFECTS OF SHORT DURATION VOLTAGE SAGS ON INDUCTION MOTORS

A.Serdar Yılmaz, Ertan Yanıkoğlu, Turker F. Çavuş

Özet- **Kısa süreli gerilim düşümleri, duyarlı tüketicilerde yanlış çalışma veya devre dışı kalma ile sonuçlanan ani gerilim azalmaları olarak tanımlanmaktadırlar. Kısa süreli gerilim düşümleri, genlik ve süreç gibi iki büyüklük ile karakterize edilirler. Gerilim düşümünün genliği arıza yeri ile tüketici arasındaki elektriksel mesafe ile belirlenir. Gerilim düşümü süresi ise koruma cihazlarının arıza temizleme zamanı tarafından belirlenir. Gerilim düşümleri endüstriyel tüketicileri ciddi biçimde ilgilendirmektedirler. Bu tür gerilim düşümleri hassas yükler ile özellikle bilgisayar, ayarlanabilir hız sürücüleri gibi elektronik cihazların ve proses kontrol sistemlerinin düzgün çalışmasına engel olabilmektedir. Bunun1a birlikte asenkron motorlar da bu düşümlerden etkilenmektedir. Gerilim düşümü sırasında asenkron motorlar hız kaybederek yavaşlamakta ve momentinde azalma meydana gelmektedir. Bu makalede, bir sanayi tesisinde bulunan ve farklı yük-moment karakteristiğine sahip, büyük ve küçük güçlü asenkron motorların kısa süreli gerilim düşümleri sırasındaki davranışları incelenmiştir.**

Anahtar Kelimeler- **Kısa süreli gerilim düşümleri. Enerji kalitesi**

Abstract **- Voltage sags are described momentary drops in voltage that may cause misoperations or outages in the utility customers' sensitive load. Voltage sags are characterized by a magnitude and duration. The electrical distance between the fault and the customer determines the magnitude of the voltage sag. The duration of the voltage sag is determined by the fault clearing. Voltage sags are becoming a very serious concern to many industrial customers. These sags can disrupt the operation of sensitive load, especially electronic equipment like computers, adjustable speed drives and the process control systems. However, these sags affect induction motors. An induction motor will slow down and its torque will decrease during voltage sag. In this paper, behaviors of large and small induction motors that have different load-torque characteristics are investigated during a short duration voltage sag in an industrial plant.**

Keywords- **Short duration voltage sags. Power quality.**

I.INTRODUCTION

Short duration voltage sags can be defined as decr in rms voltage between 10% and 90%at fundame frequency. They can last from half cycle to one min A typically voltage sag waveform (15% sag, 3 cyc is shown in Fig.1. [1,2]. Starting of large induc motors and remote faults are most important cause voltage sags. Voltage sags due to remote short circ are more effective and frequently occurrence voltage sags due to motor starting. Voltage sag ca some problems in sensitive loads like mis-opera and outage [3].

Waveform of voltage sags in the distribution syst without any induction motors are rectangular form there are any induction motor in the distribu systems, voltage waveform losses rectangular fo Induction motor slows down on occurrence of volt sag. This loss of speed and torque lasts until fault be cleared. After fault clearing, induction mo accelerates its load again and reaches its nominal sp and torque. However, this re-acceleration does occur just as fault is cleared. After fault clear voltage reaches its old value smoothly and slowly. T delay is originating form the induction motors. T phenomenon is called post fault voltage sag. The p fault voltage sag can last up to several seconds and voltage will be between 60% and 90%. Sensitive lo can be outage during the post voltage sags. Longer duration is an important factor for the outage. Beca of induction motors draw high reactive current fr the network during and after voltage sags, induct motors prolong the voltage sags [4,5].

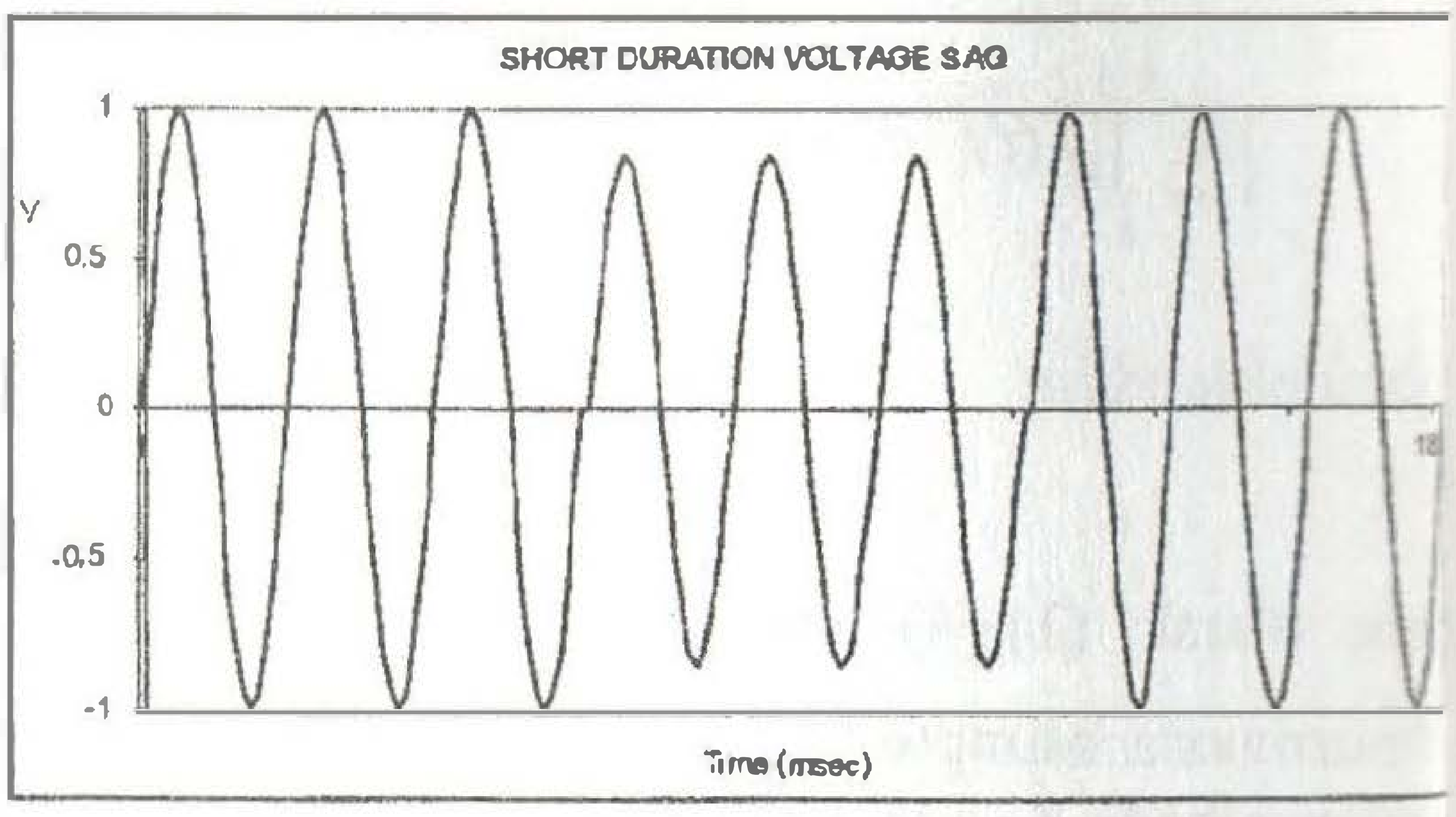

Fig.1 A typically voltage sag waveform

A.S.Yılmaz, K.Maraş Sütçü İmam University, Dept of Electrical and Electronics Eng., Karacasu Campus, K.Maraş/Turkiye, asyilmaz@ksu.edu.tr
E.Yanıkoğlu and T.F.Çavuş, Sakarya University, Dept of Electrical and Electronics Eng., Esentepe Campus Sakarya /Turkiye, yanik@sakarya.edu.tr, tfcavus@sakarya.edu.tr

II. CALCULATION OF SHORT DURATION VOLTAGE SAGS

quantify sag magnitude in radial system, a plified radial distribution network model, shown in g.2, is considered. For following network, sag gnitude at point of common coupling (PCC) bus is lculated by equation (1), when a short circuit occurs bus F.

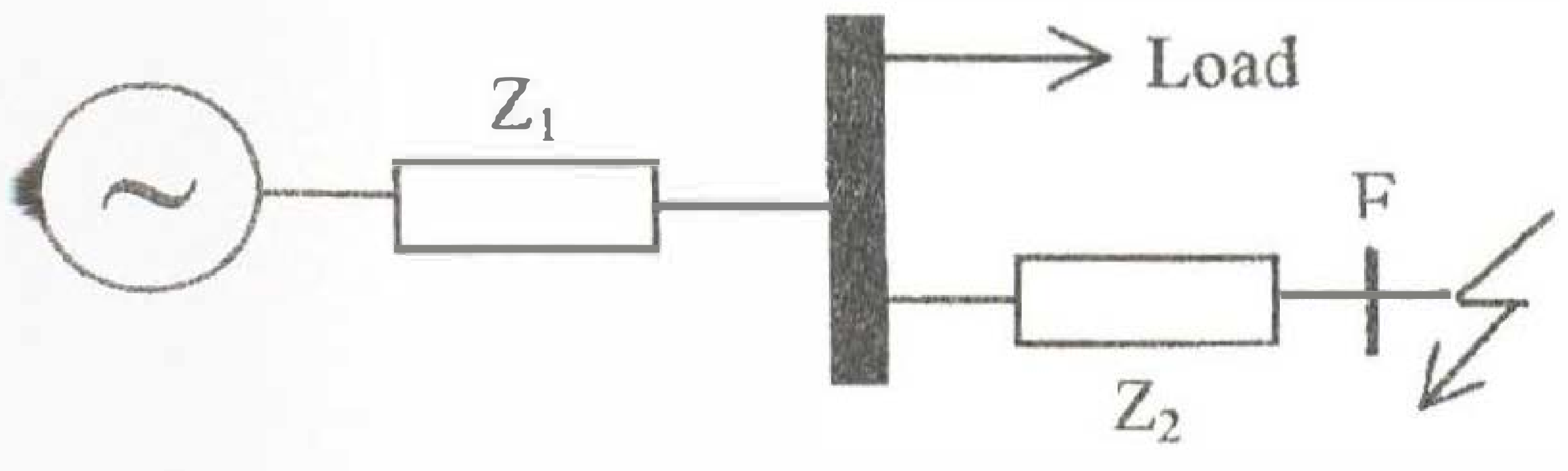

Fig.2 Simplified radial distribution networks

$$V_{sag} = \frac{Z_2}{Z_1 + Z_2} \qquad (1)$$

ecause of pre-fault voltage is assumed 1.0 pu (100%), alculated voltage drop are in per unit. Sag magnitude elates to nominal voltage and fault location. In Fig.3, his relation is shown for different voltage levels. For he calculation, a 165 mm² overhead line is used and ault levels of 100 MVA [4,6].

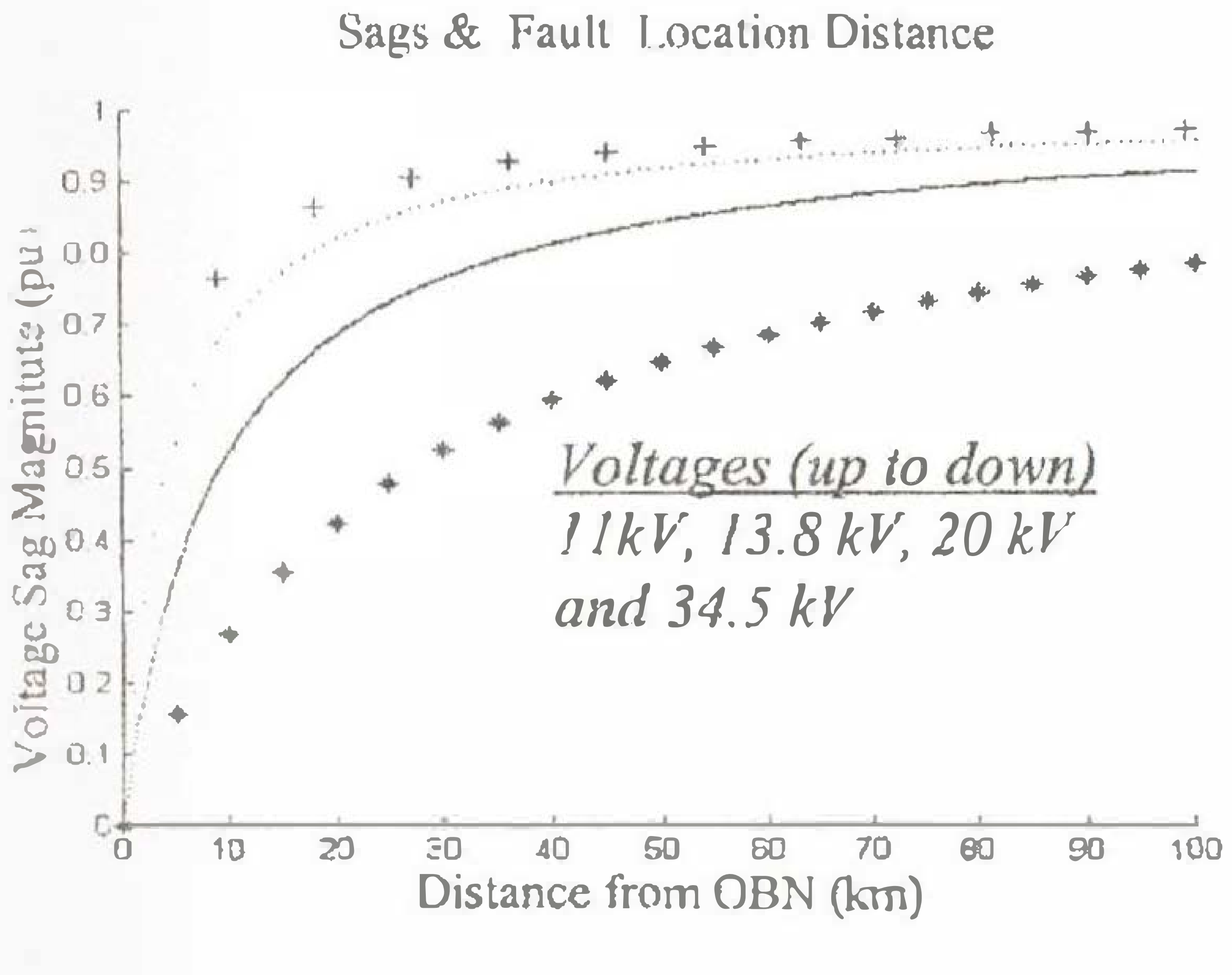

Fig.3 Sag magnituede versus distance

III. STEADY STATE AND TRANSIENT MODELS OF INDUCTION MOTOR

Induction motors have a large usage area (70%-80%) in the industrial power systems. They can be represented as a constant power load and have dynamic characteristics during the transient phenomena. Therefore, it is required a transient model for transient conditions. Transient motor model is shown in Fig.5 [7]. In steady state operation conditions, induction motors are represented by equivalent diagram in Fig.4.

In this diagram, motor is modeled by the resistance and reactance belong to stator, rotor and air gap magnetic reactance.

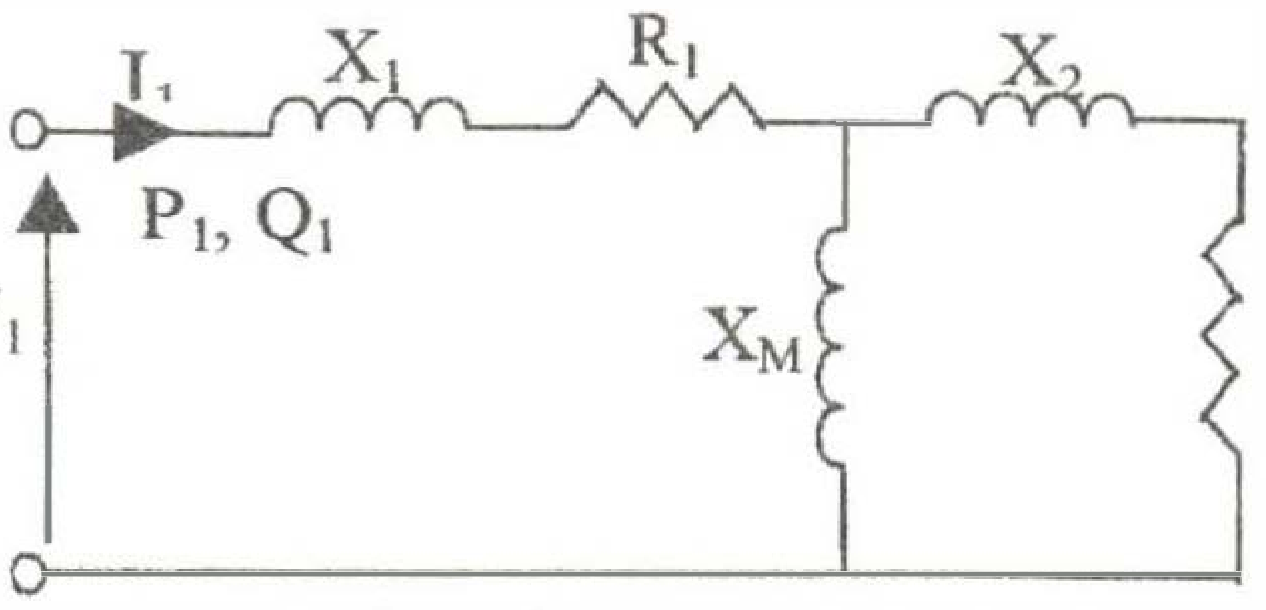

Fig.4 Equivalent diagram of induction motor

Equations of real and reactive power, measured from motor terminals, are given in (2) and (3). Also, electromagnetic torque can be calculated by using equation (4).

$$P_1 = \frac{R_1 + R_e}{(R_1 + R_e)^2 + (X_1 + X_e)^2} V_1^2 \qquad (2)$$

$$P_1 = \frac{R_1 + R_e}{(R_1 + R_e)^2 + (X_1 + X_e)^2} V_1^2 \qquad (3)$$

$$M_E = M_T.(1-s)^m = I_2{}^2 . \frac{R_2}{2.\pi.f.s} \qquad (4)$$

where, stator parameters are illustrated by 1, rotor parameters are illustrated by 2. Other variables are given in appendix-A.

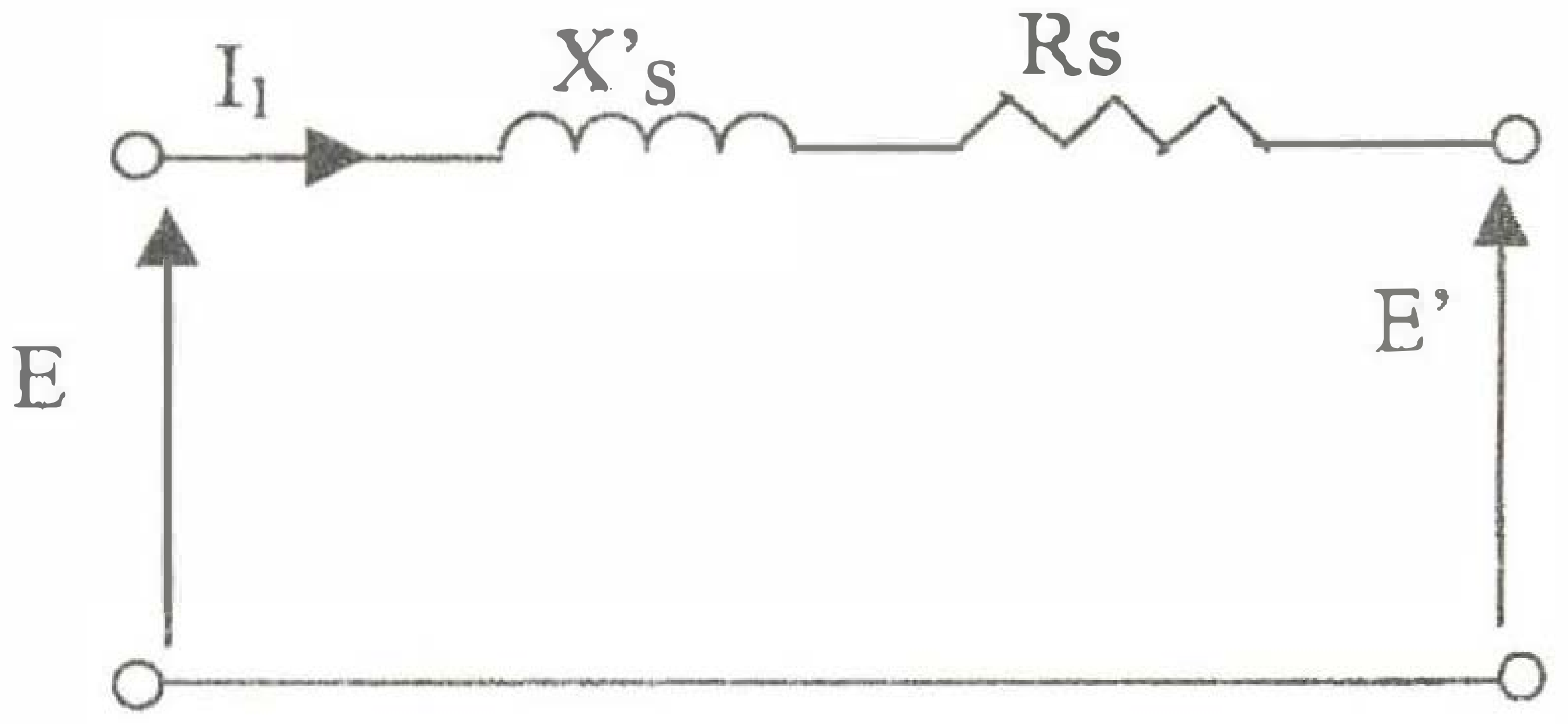

Fig.5. Transient equivalent diagram of induction moto

In this circuit, E is stator terminal voltage and E' is voltage behind transient impedance. Induction motor is modeled by equation (5) and (6) in transient conditions [7,8,9].

$$\frac{dE'_d}{dt} = -\frac{1}{T'_0}[E'_d + (X_0 - X'_S).I_{1q}] + n_s.s.E'_q \qquad (5)$$

$$\frac{dE'_q}{dt} = -\frac{1}{T'_0}[E'_q - (X_0 - X'_S).I_{1d}] + n_s.s.E'_d \qquad (6)$$

where, T'_0 is open circuit time constant and n_s is synchronous speed. Other parameters are given in appendix-A. Both of these equations are represent the rotor dynamics. Acceleration of rotor is defined by equation (7).

$$\frac{ds}{dt} = \frac{1}{2Hm}[Pm - Pe] \qquad (7)$$

IV. SAMPLE SYSTEM AND COMPUTER SIMULATIONS

A typically distribution system and an industrial plant supplied from 34.5 kV transformer substation are illustrated in Fig.6. They're a lot of low and medium voltage induction motors in the industrial plants such as sample system shown in Fig.6. In this paper, numbers of motors aredecreased and simplified system is simulated in SIMPOW [10] package. Sample system data are given in appendix-B. Rated voltages of B154, B35, ISLETME, OGY, OGM, AGM and AGY buses are 154 kV, 34.5 kV, 34.5 kV, 34.5 kV, 3.45 kV, 0,4 kV and 0,4 kV respectively. There are seven motors at bus OGM. Rated power of each motor is 1,5 MVA and all motors are considered in load flow analysis. Number of 400 V low voltage (LV) Motors in bus AGM are eight and rated power of each motor is 100 kW. Two of them are loaded 80% and the others are loaded 70%. Static load at bus AGY is $2.1+j1.8$ MVA. This load has constant power characteristics. Mechanical torques of all LV motors are constant. But mechanical torque of all medium voltage (MV) motors change with square of (1-s).

In the simulations, behavior of induction motors and all system are observed during the 3 phase symmetrical fault at bus AGY. Fault clearing time is 0.3 sec. Because of all motors are identical, only simulation results belonging to one motor are given.

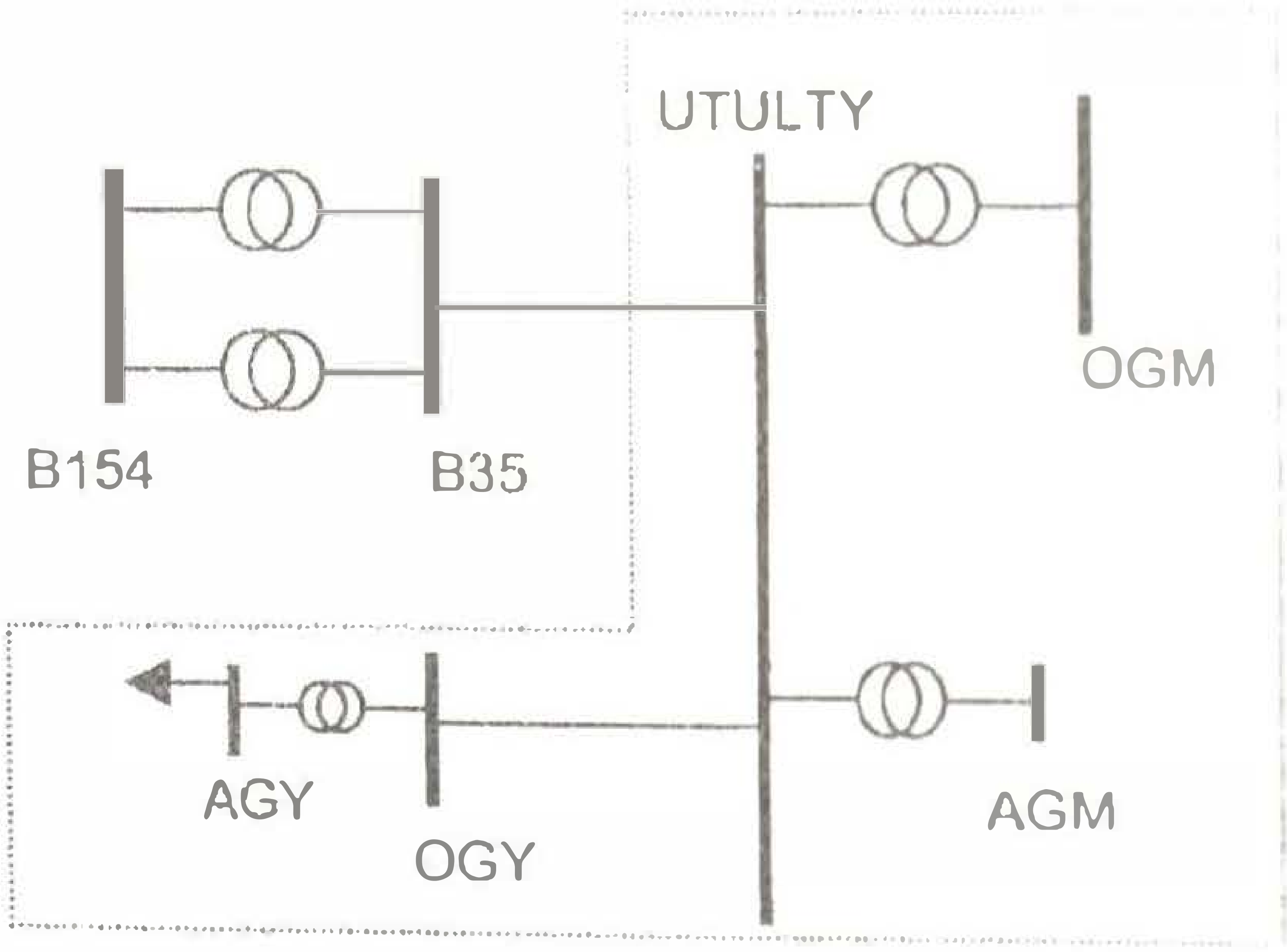

Fig.6 Sample distribution system

IV.1 LOW VOLTAGE MOTOR AT BUS AGM

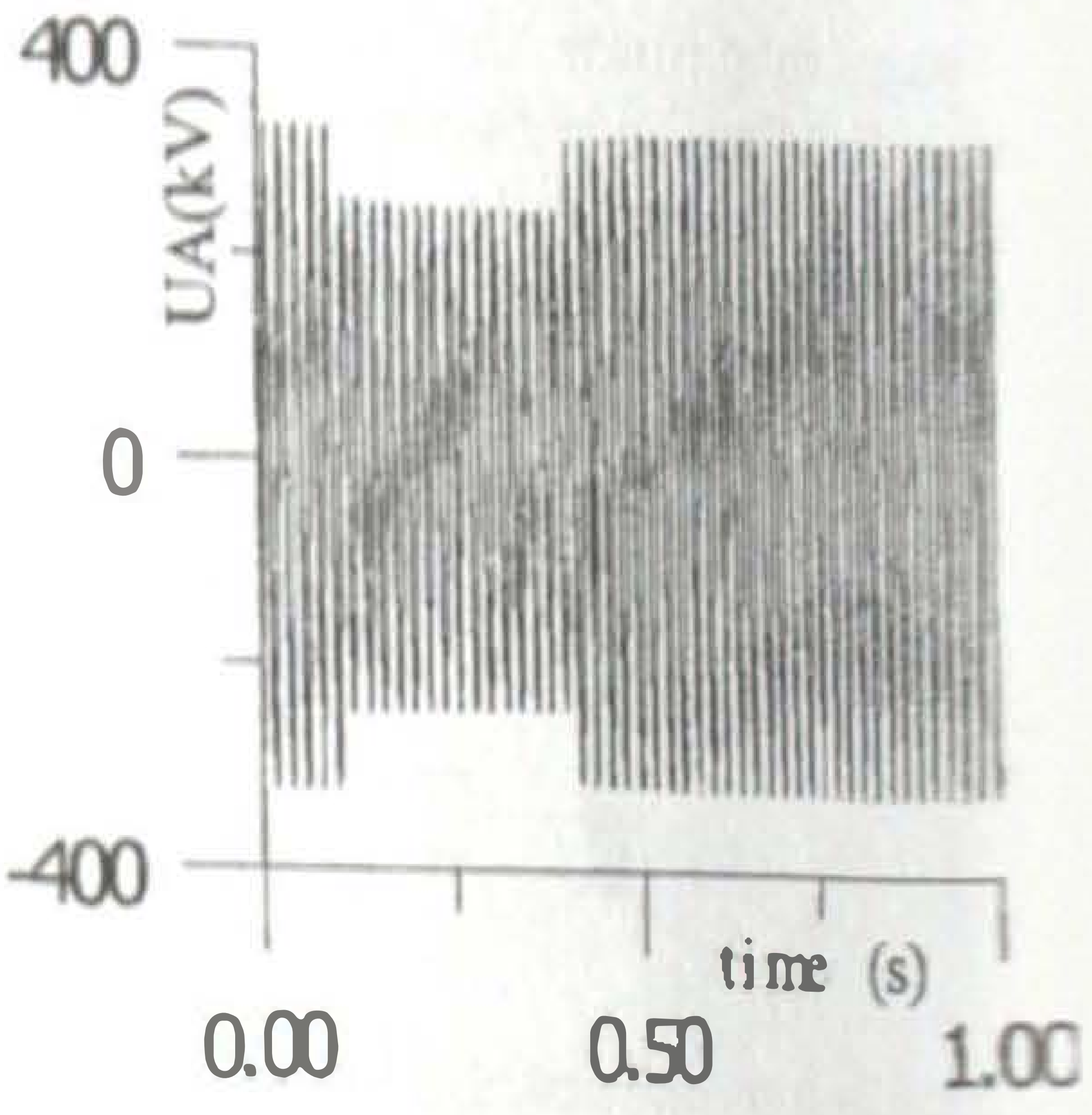

Fig.7 Phase A voltage waveform (Phase to Ground)

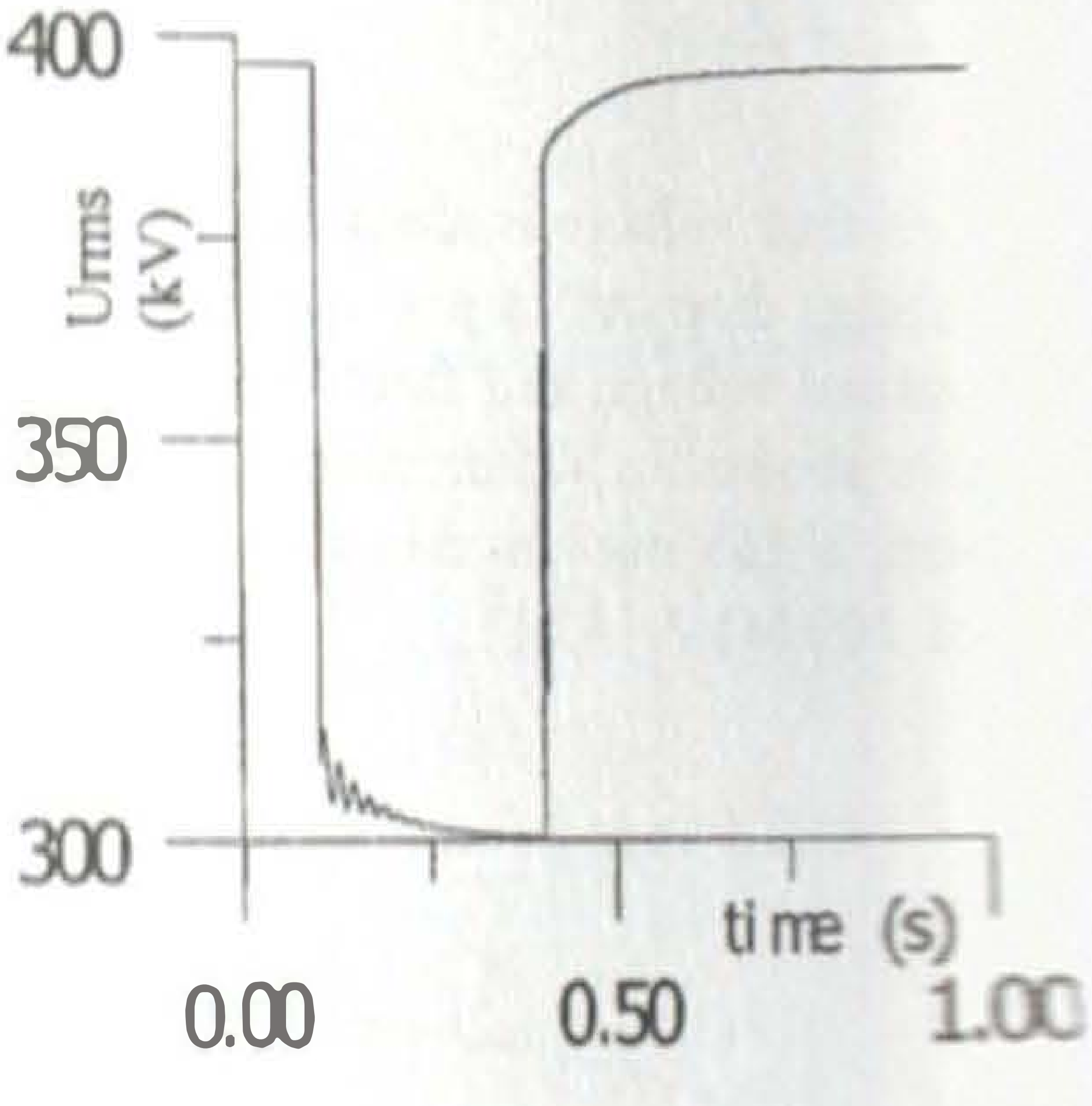

Fig.8 Urms (Phase to Phase)

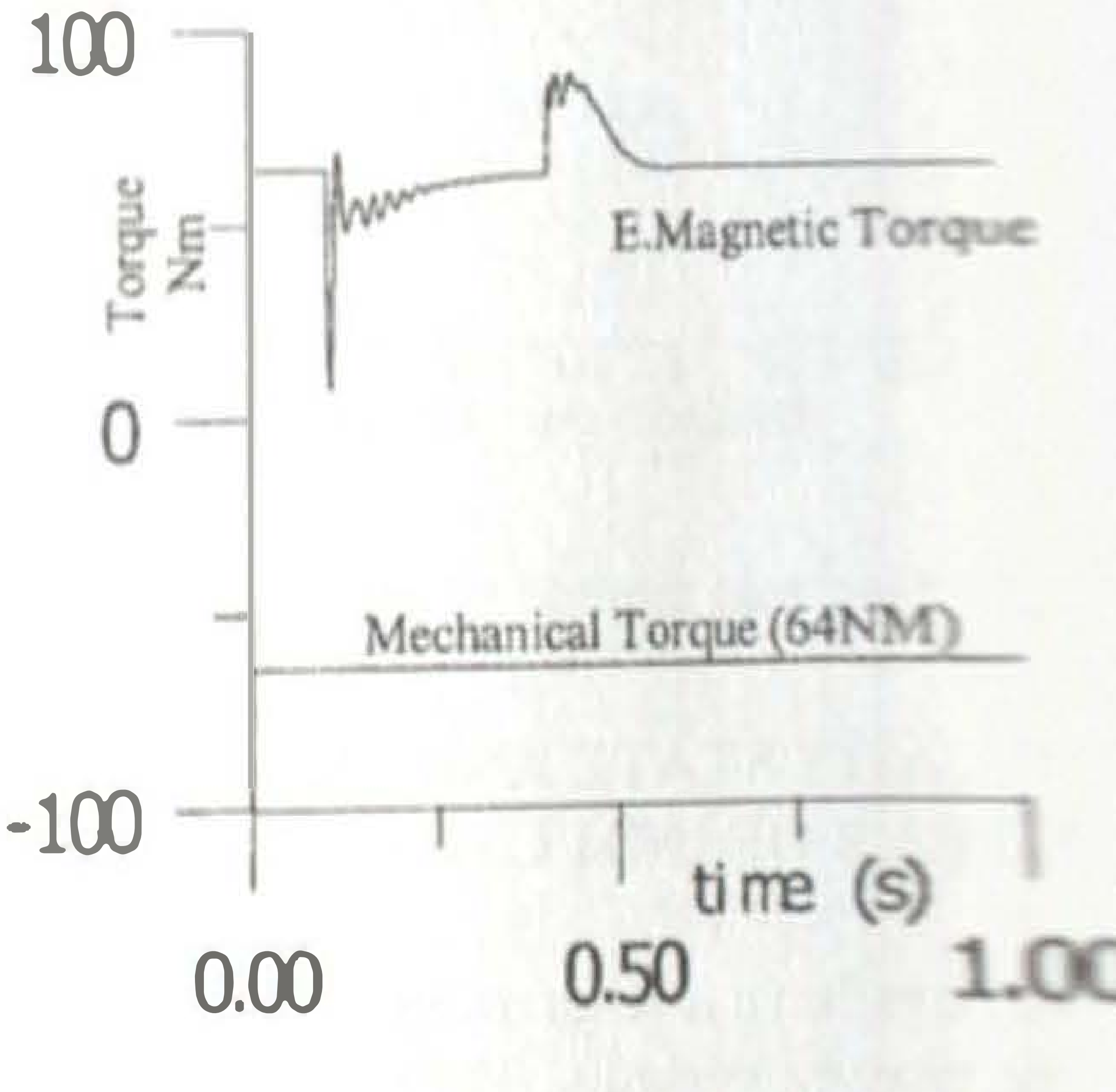

Fig.9 Torque

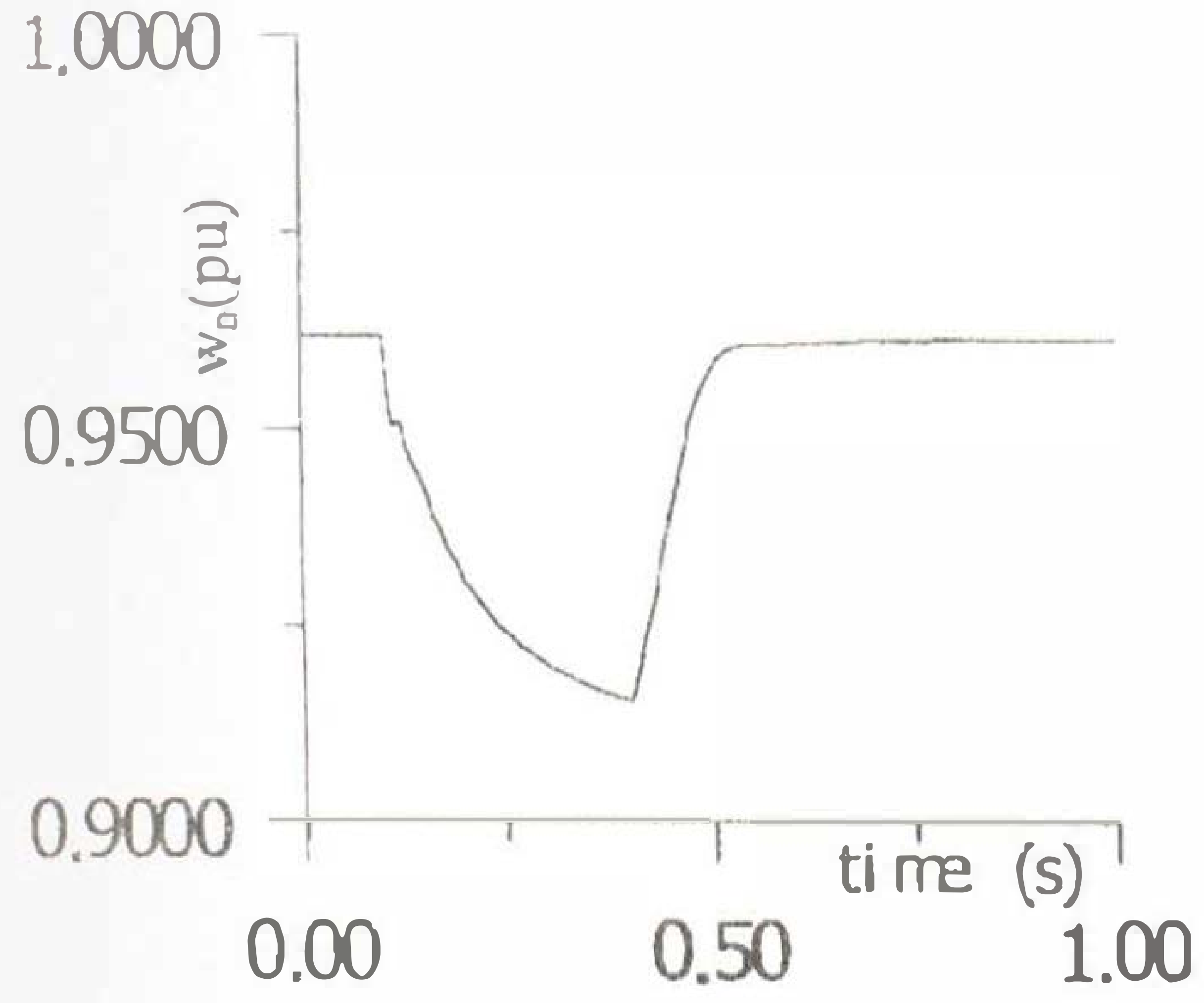

Fig.10 Asynchronous speed

IV.2 MEDIUM VOLTAGE MOTOR AT BUS OGM

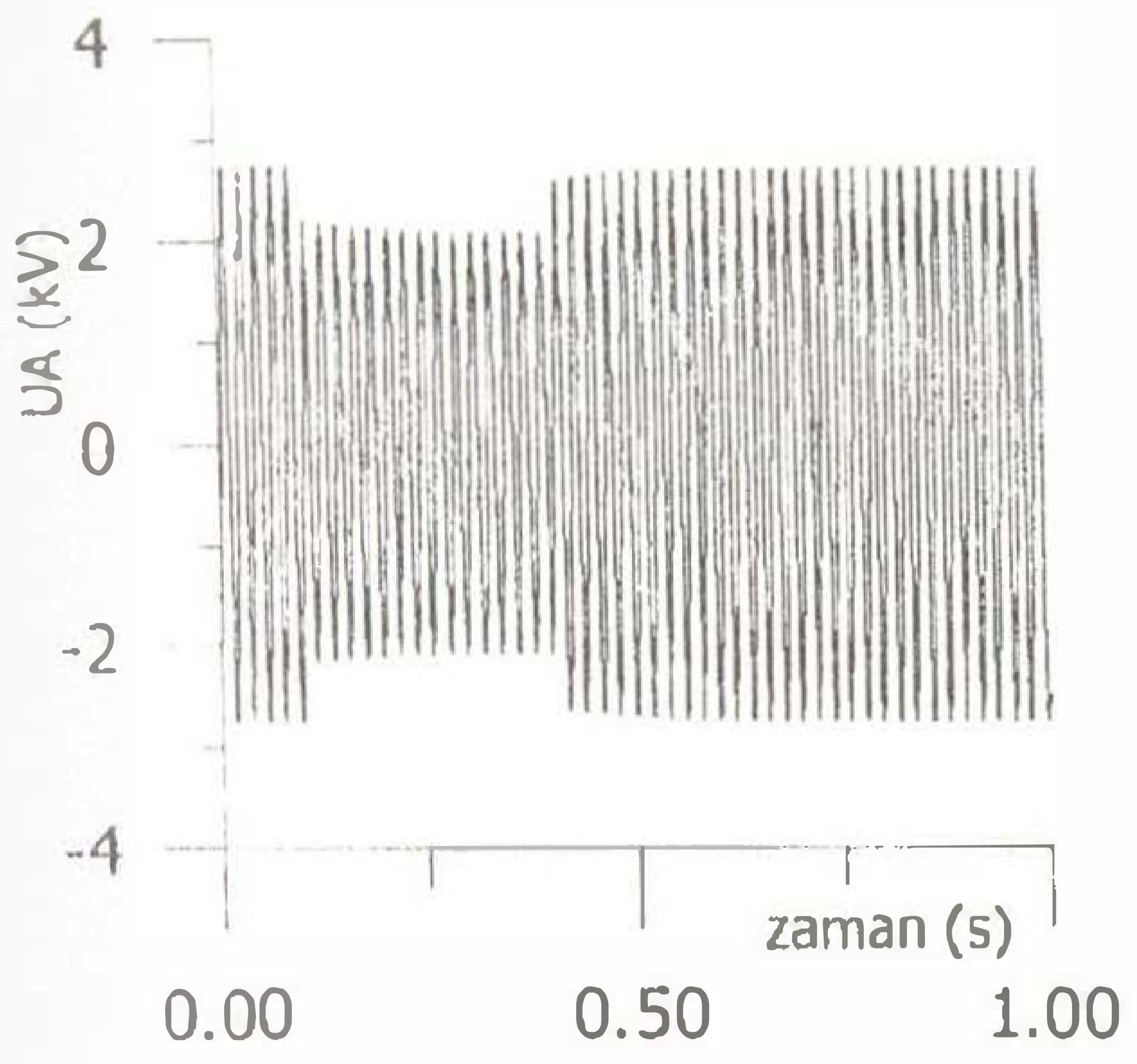

Fig.11 Phase A voltage waveform (phase to ground)

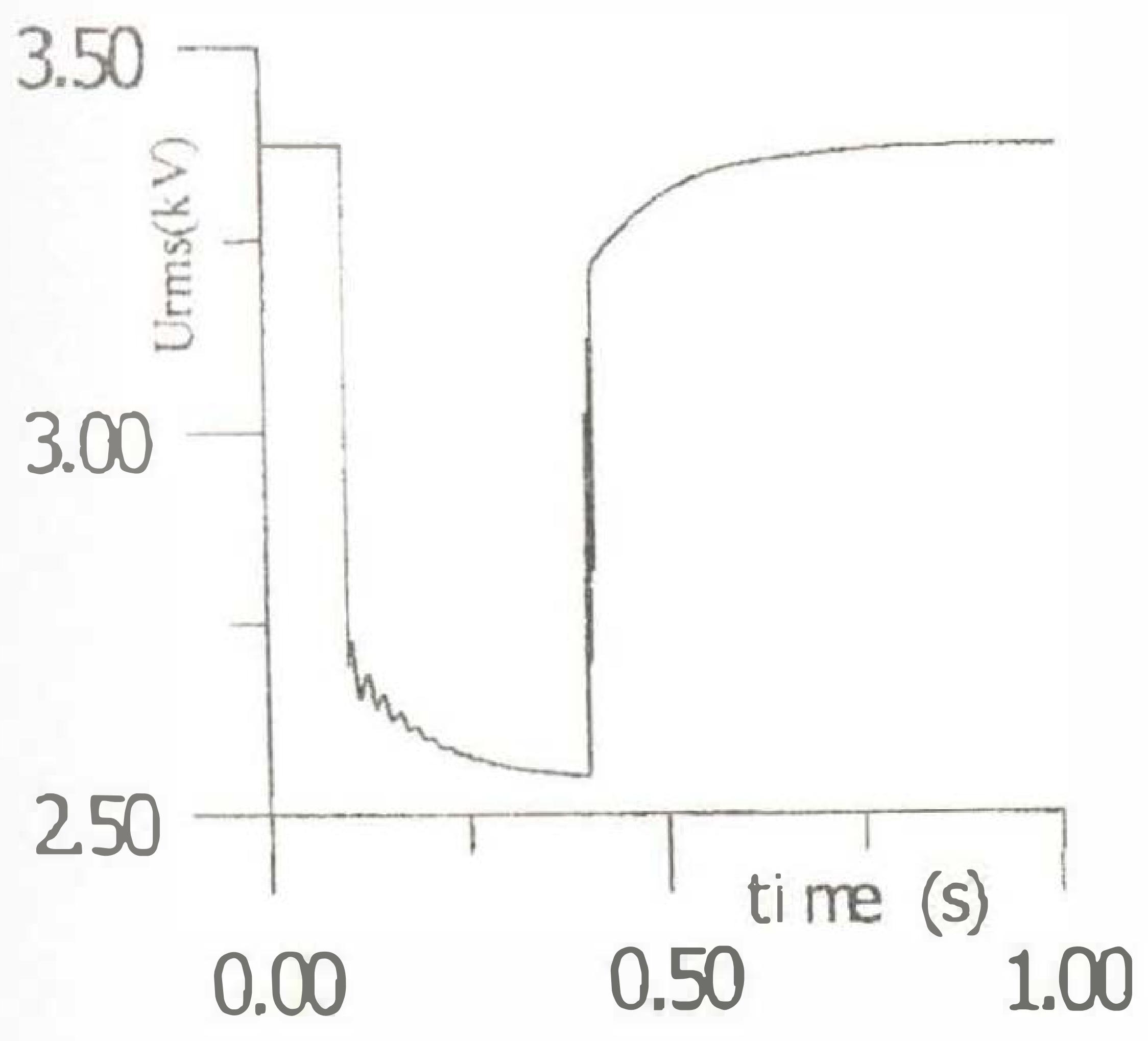

Fig.12 U_{rms} (phase to phase)

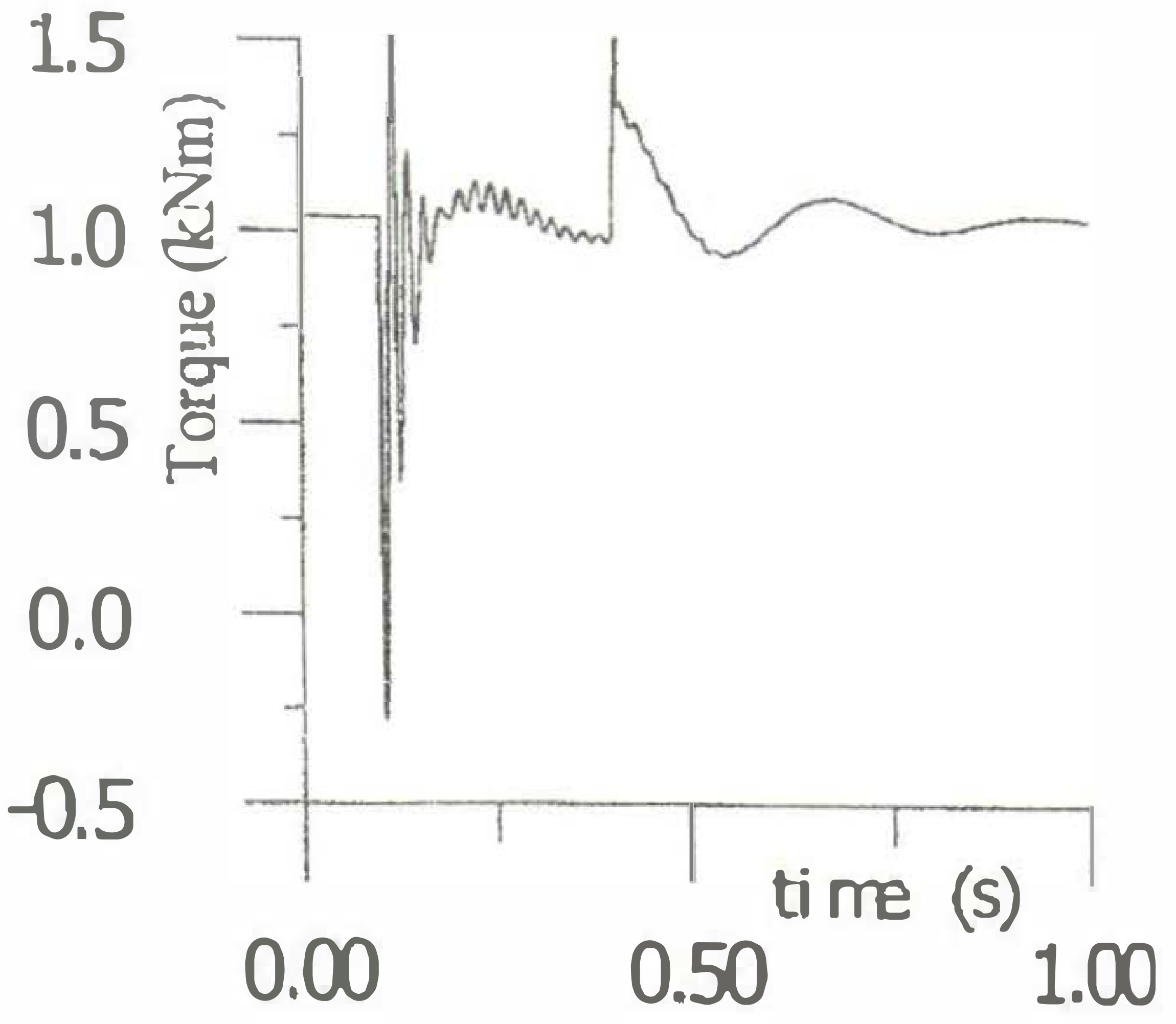

Fig.13 Electromagnetic torque

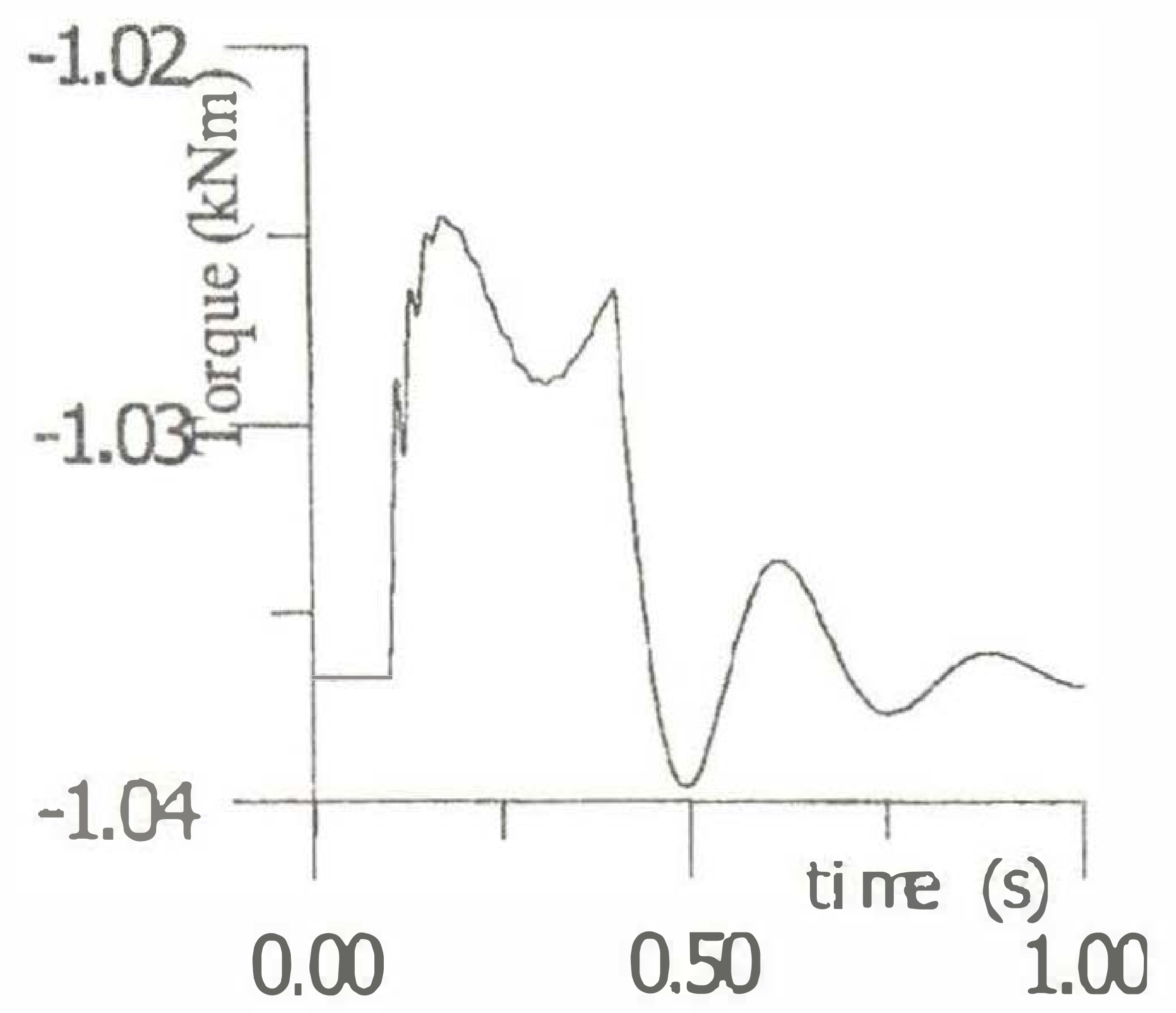

Fig.14 Mechanical torque

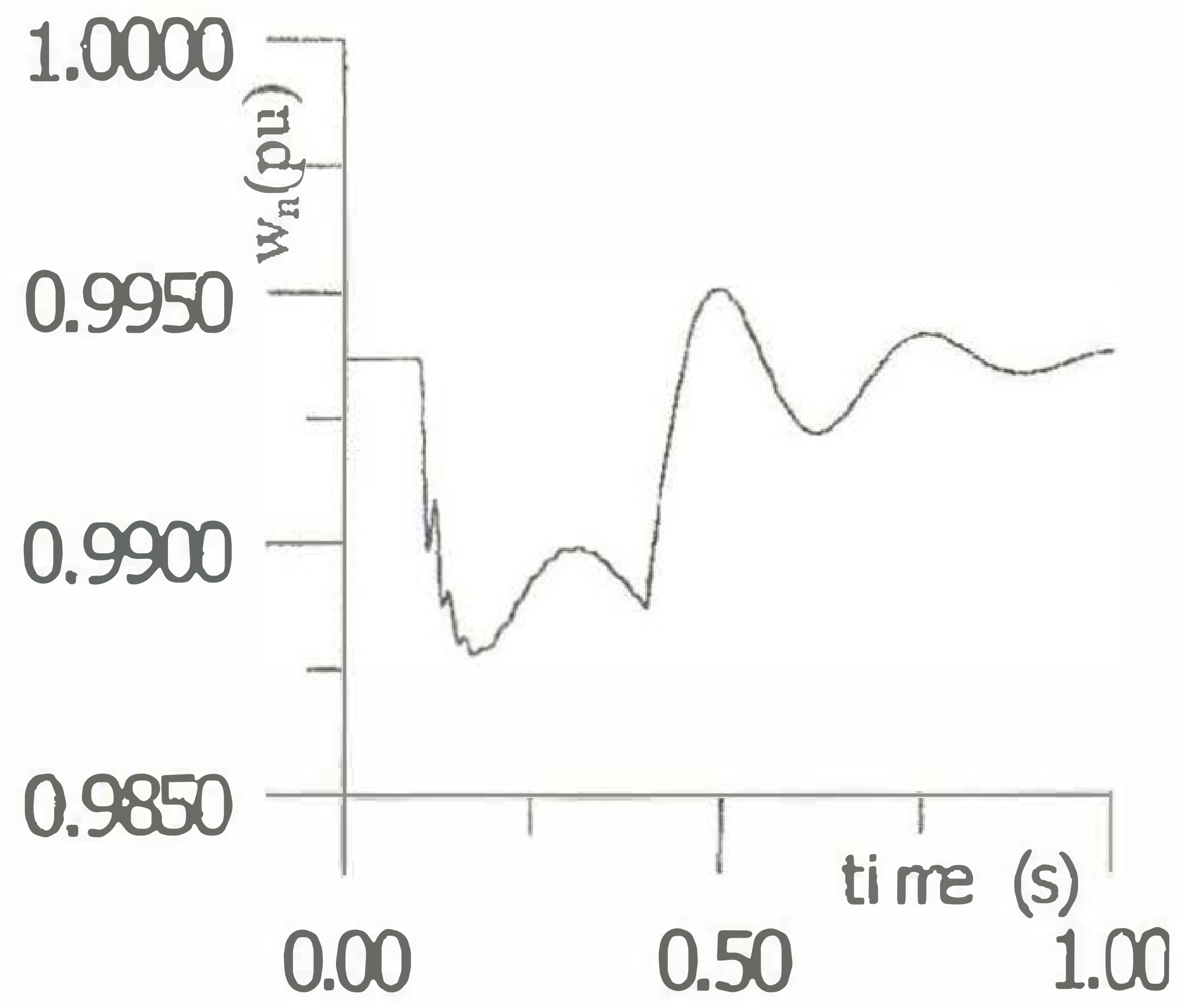

Fig.15 Asynchronous speed

V.CONCLUSIONS

It is observed a large decrease in both torque and voltages. Sag magnitude is about 25% level. While terminal voltages of LV motors decrease to 300 V, MV terminal voltages of MV motors decrease to 2,6 kV (25%) too. This is a so dangerous condition. Setting and coordination of protection devices should provide for high-level protection. Thus, motors are prevented against damage. Also, induction motors draw high-level reactive current during the voltage sag, because of constant power characteristics. So there will occur heating problems.

However, it can be shown that there are some changes in both mechanical and electromagnetic torque in Fig.9, 13 and 14. Mechanical torque of LV motors doesn't change, because they have constant mechanical torque. But it is observed that the decreases, shown in Fig.9, in electromagnetic torque of LV motors during the voltage sag. Also, it is observed a momentary increase in electromagnetic torque after fault is cleared from same figure too. Similarly, there are some changes in both electromagnetic and mechanical torque of MV motors. Because of mechanical torque of these motors change with square of (1-s), mechanical torque change during the voltage sags. Speed changes of MV motors are oscillatory. Changes in LV motors more smoothly and linear than MV motors. It can be shown in Fig.10.

It can be shown that all induction motors slow down during the voltage sag as defined in first section. This does not limit relation between induction motors and voltage sags. It is not expected that voltages of motors reach to old value. Induction motors encourage the voltage sags. They draw high reactive current for a short time from the supply after fault clearing. Because of this current flow through impedance between electrical supply and motors, voltage drop is not prevented. During the post fault voltage sag, voltage magnitude is between 60% and 90% of nominal value for several seconds. This situation can be shown in Fig 8 and 12 from 0.4 sec. They can be shown in the results of simulations, As a results of the all simulations, it can be induction motors have a feature increased to voltage sags. They behave as a generator when the first time of the fault and supply short-circuit. And than they draw high reactive current after fault is cleared. So they lead to additional voltage sag. This is so dangerously for power quality. It should be provided that sensitive loads and induction motors cannot be supplied from it or neighbor feeders. Impedance between PCC and loads should be large.

REFERENCES

[1] IEEE Voltage Sag WG Report, Proposed chapter 9 for predicting voltage sags (dips) in revision to IEEE std 493, IEEE Trans. on Industry Applications, Vol.3 pp.805-821, 1994.

[2] Bollen, M.H.J., Fast assessment methods f voltage sags in distribution systems, IEEE Trans. o Industry Applications, Vol.32, No.6, pp.1414-142 Nov/Dec 1996.

[3] Dugan, R.C. and et al, Electrical Power Syste Quality, Mc Graw Hill, 1996.

[4] Lamoree, J. and et al, Voltage sag analysis ca studies, IEEE Trans. on Industry Applications, Vol.3 No.4, pp.1083-1089, July/Aug 1994.

[5] Das, J.C., Effects of momentary voltage dips the operation of induction and synchronous motor IEEE Trans. on Industry Applications, Vol.26, No. pp.711-717, July/Aug 1990.

[6] Yılmaz, A.S., Short duration voltage sags, the report (in Turkish), SAU FBE June 2000.

[7] Kundur, P., Power system stability and contr (Ch.7), Mc Graw Hill, 1994.

[8] Brereton, D.S., and et al, Representation induction motor loads during power system stabil studies, AIEE Trans. PA&S, pp.451-461, Aug 1957.

[9] Machowski, J, and et al, Power system dynami and stability, John Wiley & Sons, 1997.

[10] SIMPOW User Manual Release 10, ABB Pow Systems, Power System Analysis Dept., Väster Sweden.

APPENDICES

A. MOTOR EQUATIONS

$$s = \frac{n_s - n}{n_s} \quad ; \quad \text{slip} \qquad \text{(A-}$$

$$R_R = R_2/s \qquad \text{(A-}$$

$$Re = \frac{R_R . X_M^2}{R_R^2 + (X_2 + X_M)^2} \; ; \qquad \text{(A-}$$

steady state equivalent resistance

$$Xe = \frac{R_R . X_M^2 + X_2 . X_M . (X_2 + X_M)}{R_R^2 + (X_2 + X_M)^2} \; ; \qquad \text{(A-}$$

steady state equivalent reactance

$$X_0 = ns.(Ls + Lm) \; ; \qquad \text{(A-}$$

transient stator reactance

$$X'_S = ns.\left[(Ls + Lm) - \frac{L^2 m}{Lr + Lm} \right] \; ; \qquad \text{(A-}$$

motor transient reactance

Ls: Self inductance of stator windings
Lr : Self inductance of rotor windings
Lm : Rotor, stator mutual inductance
n_s : Synchronous speed

n: Rotor speed

. SAMPLE SYSTEM DATA

$_{BAZ}$=100 MVA (Base power)

ransformers :

Tr1 and Tr2) (B154-B35)
5 MVA, 154/34.5 kV, x=%10, Y,Δ
r3 (B35-ISLETME)
.5 MVA, 34.5/11 kV, x=%7.5, Y,Y
r4 (ISLETME-AGM)
MVA, 34.5/0.4 kV, x=%5.5, Y,Y
r5 (OGY-AGY)
MVA, 34.5/0.4 kV, x=%5.5, Y,Y

ines

ine 1 (B35-ISLETME)
=0.0001 pu, X=0.01 pu
ine 2 (ISLETME-OGY)
=0.0005 pu, X=0.003 pu

nduction Motors & Loads

IV Motor : S_N=1.5 MVA, U_N=3.3 kV, H=0.85 pu
$_1$=0.0105 pu X_1=0.152 pu X_2=0.0924 pu X_M=5.416
u R_M=0 pu
V Motor : S_N=0.1 MVA, U_N=0.4kV, H=0.25 pu
$_1$=0.038 pu X_1=0.139 pu X_2=0.119 pu X_M=3.14 pu
$_M$=0 pu

tatic Load: at bus AGY (380 V, S=2.1+j1.8 MVA)