Sequential Motor Dynamic Acceleration and Re-acceleration Simulations: Comparison of ETAP® and EMTP-RV® Software

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Abstract--The induction motor sequential dynamic acceleration and re-acceleration after a 3-phase short circuit fault were simulated using the Electrical Transient Analyzer Program (ETAP), and the Electromagnetic Transient Program – Restructured Version (EMTP-RV). The results of the two software programs were compared to see how close their outputs were to one another. The comparison includes generator's active power, mechanical power, exciter voltage, terminal voltage, speed, and induction motor slip. Also, the voltage stability *i.e.* voltage dip and rise during the process was investigated.

***Keywords*: ETAP, EMTP-RV, Induction Motor, Dynamic Acceleration, Re-acceleration.**

I. Introduction

The use of computer software program in performing electrical power system simulations is indeed a core tool of today's generation. There are varieties of software products available in the market featuring different functionalities and user interfaces. However, the software programs should generate accurate results based on the accepted principles, theories, and standards. In this endeavor, we used two of the leading commercial power system programs in the market today, the ETAP Enterprise Solution and EMTP-RV to simulate the (1) sequential dynamic acceleration of induction motors, and (2) motor re-acceleration after a 3-phase short circuit fault.

The ETAP Enterprise Solution was developed by Operation Technology, Inc., USA. It has been in the market since 1986 and has earned respect from worldwide users for being a very powerful design and analysis tool and having an extremely user-friendly interface. It has many calculation capabilities and one of these is the Transient Stability analysis. EMTP-RV was released in 2003 by the EMTP Development Coordination Group under the technical leadership of Hydro-Quebec. It is used by many researchers for its sophisticated program and vast modeling capabilities for the simulation of electromagnetic, electromechanical and control systems in multiphase electric power systems.

II. System Modeling

The system is an island with no power grid support [1]. It includes a generator, a group of six induction motors, and a constant impedance load as shown in Fig. 1 and Fig. 2. The diesel unit generator is rated at 1.87 MW, 0.85 Pf. The generator sub-transient model is shown in Fig. 3. Its Exciter/AVR and Engine/Governor controller block models are shown in Fig. 4 and Fig. 5 respectively. The induction motor ratings range from 225 HP to 400 HP with load mechanical torque expressed in "$A\omega^2$". The motor's dynamic circuit and load model are shown in Fig. 6 and Fig. 7 respectively. Table I summarizes the techniques available in the software programs used in modeling the system.

TABLE I
MODELING TECHNIQUE

	ETAP	EMTP-RV
Generator Unit	Machine's User-Interface	Machine's User-Interface
Exciter/AVR	Built-in Standard Library Model	Built-in Standard Library Model
Engine/ Governor	UDM: User-Defined Dynamic Model	Control library
Induction Motor Dynamic Model	Library User-Interface	Machine's User-Interface
Mechanical Load	Library User-Interface	Control library

ETAP has several built-in models of controller for Generator Exciter/AVR and Engine(Turbine)/Governor control systems based from IEEE standard and common manufacturer models available in the market. It has also a User-Defined Dynamic (UDM) interface that is used to create control systems of the like via third party software, Matlab Simulink©. In case of the load dynamic model, ETAP associates such to the motor through library interface by polynomial equation or point by point curve definition.

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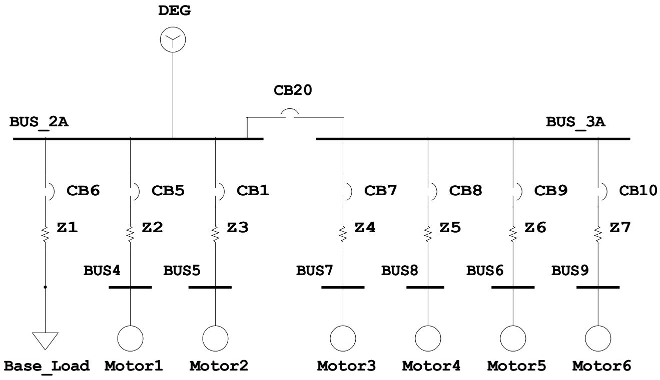


Fig. 1. ETAP One-Line Diagram Model

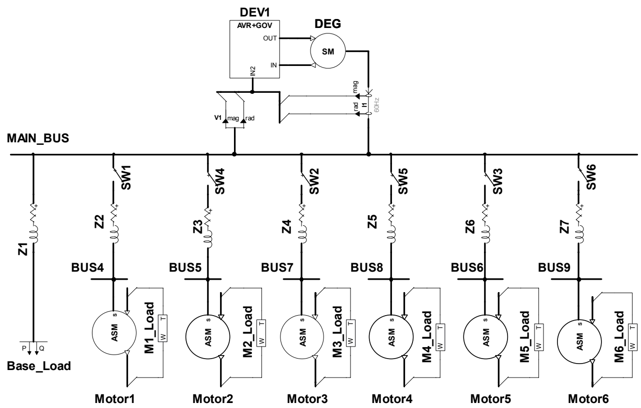


Fig. 2. EMTP-RV One-Line Diagram Model

A. Generator Model

The ETAP generator model complies with the IEEE Standard 1110-2002 [2]. The generator model used is a sub-transient model and it is represented by two equivalent rotor windings (the field winding and a damper winding) on the direct axis and two equivalent rotor damper windings on the quadrature axis. The circuits are shown in Fig. 3 and the parameters are given in Appendix A.

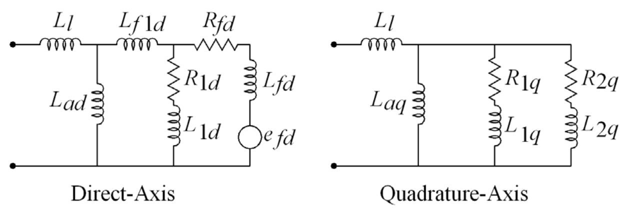


Fig. 3. Generator Model (field circuit plus one damper circuit on Direct-Axis and two damper circuits on Quadrature-Axis)

B. Exciter/AVR Model

The Exciter/AVR model is IEEE standard ST2 model [3]. The model utilizes both generator terminal current and voltage to comprise the power source. The rectifier loading and commutation effects are accounted for by the characteristics determined by the equations $F_{EX.}$ The transfer block diagram is shown in Fig. 4 and the parameters are given in Appendix B.

ETAP and EMTP-RV both provide built-in standard library models for this type of Exciter/AVR.

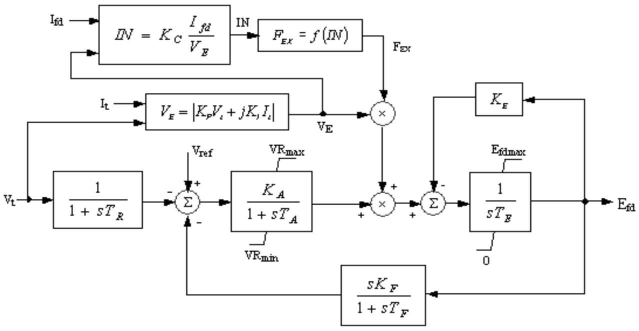


Fig. 4. IEEE ST2 Exciter/AVR Transfer Block Diagram Model

C. Engine/Governor Model

The Engine/Governor is of Woodward Diesel type. The model essentially includes three parts, i.e. Electric Control Box, Actuator and Engine. The transfer function block diagram is given in Fig. 5 and the parameters are given in Appendix C.

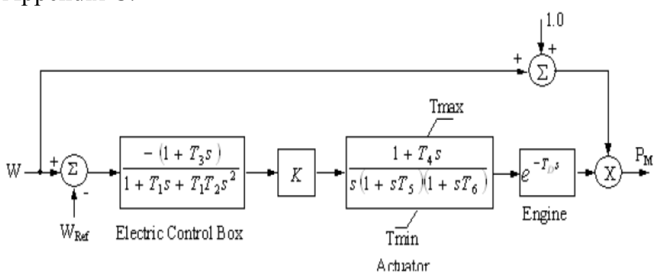


Fig. 5. Woodward Diesel Engine Transfer Block Diagram Model

D. Induction Motor Circuit and Load Model

The Induction Motor Model is a double squirrel cage with independent bars and its equivalent circuit is shown in Fig. 6. The load mechanical torque curve profile is shown in Fig. 7. The motors' nameplate data and load parameters are given in Appendix D.

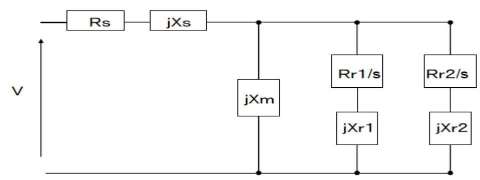


Fig. 6. Induction Motor Equivalent Circuit Model (typical to all motors)

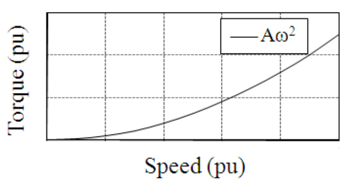


Fig. 7. Load Mechanical Torque Curve (typical to all motors)

III. STUDY CASES

Three study cases were simulated: (1) Sequential Motor starting, (2) 3-Phase Short Circuit Fault and Removal of Fault at Main Bus, and (3) 3-Phase Short Circuit Fault and Removal of Fault at the terminal of Motor 1.

A. Case 1

The system was initially loaded with a constant impedance load. The motors were sequentially started beginning at time = 3 sec. and at 5 sec. subsequent interval. The starting sequence was Motor 1, Motor 3, Motor 5, Motor 2, Motor 4 and finally Motor 6.

The results of the simulation are shown in Fig. 8 to Fig. 13.

In the stability point of view, the system was stable with +37～-30% voltage fluctuation (Fig. 8), 2.8% maximum generator speed variation (Fig. 12) and the motors accelerated successfully (Fig. 13). ETAP and EMTP-RV demonstrated very close results in all of the plots.

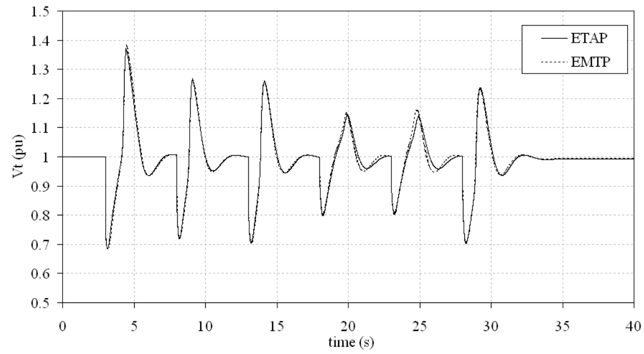


Fig. 8. Case 1 – Generator Terminal Voltage

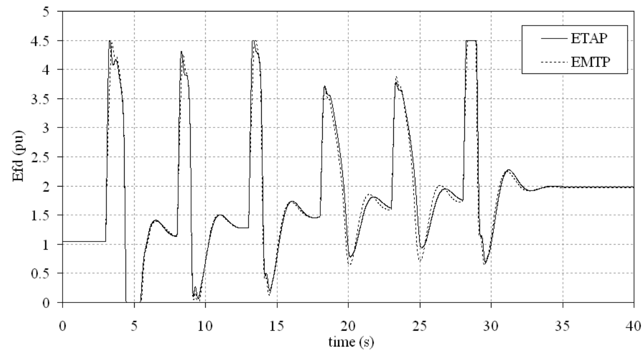


Fig. 9. Case 1 – Generator Exciter Voltage

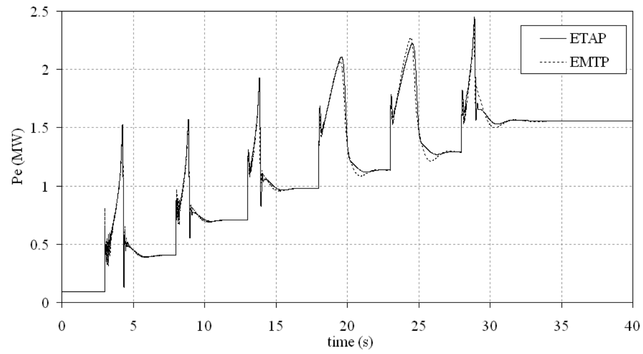


Fig. 10. Case 1 – Generator Active Power

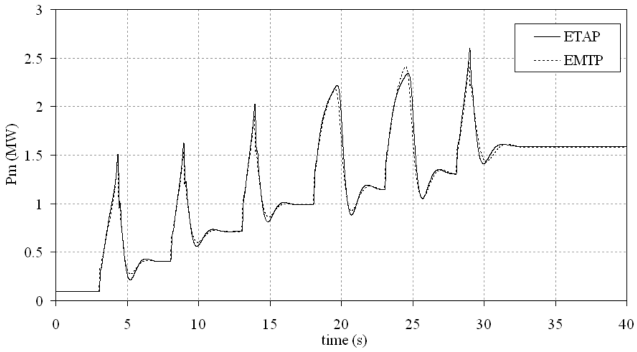


Fig. 11. Case 1 – Generator Mechanical Power

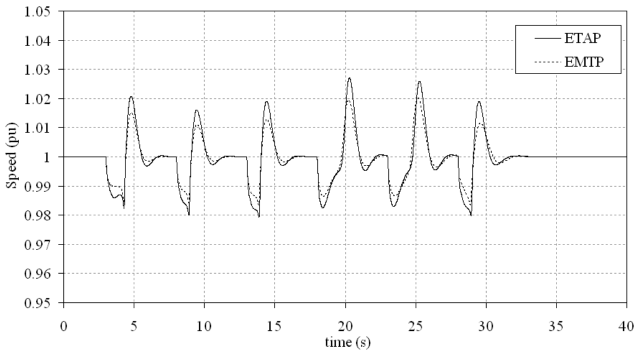


Fig. 12. Case 1 – Generator Speed

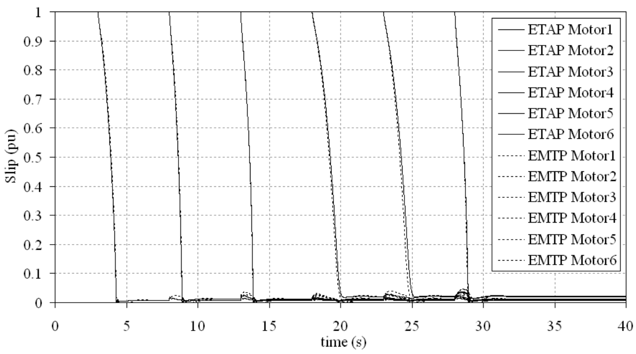


Fig. 13. Case 1 – Motors Slip

B. Case 2

The system was initially at steady state with all the loads in service. 3-Phase short circuit fault occurred at the main bus at 1 sec. and was cleared after 0.2 sec.

The results of the simulation are shown in Fig. 14 to Fig. 19. As can be seen in Fig. 14, the voltage recovery immediately after the removal of the short circuit fault was approximately 0.4 pu (per unit) only. This magnitude was low to re-accelerate the motors quickly. Apparently, the motor slips further increased and drew more reactive power making it hard for the generator to recover the voltage since its exciter field voltage reached the ceiling. It took approximately 3 sec. for the voltage to rise at a stiff rate and eventually settled in 6 sec. The results were critical and the under voltage condition sustained for 3 sec. which would have put the system protective device mechanism into operation to protect the equipment. Hence, to avoid such occurrence, the fault clearing time should be made faster.

From the view point of comparison of ETAP and EMTP-RV, the results were very close in all of the plots.

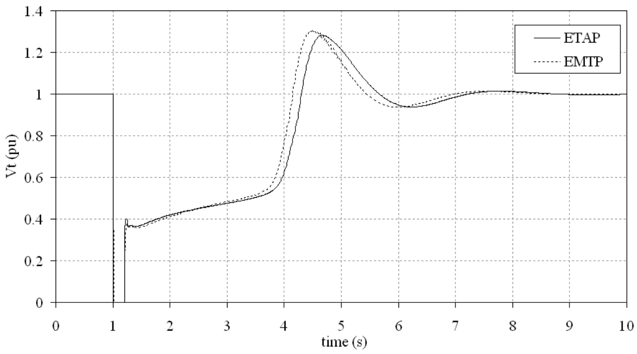


Fig. 14. Case 2 – Generator Terminal Voltage

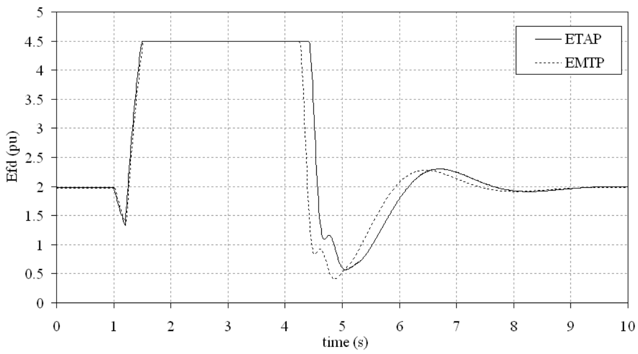


Fig. 15. Case 2 – Generator Exciter Voltage

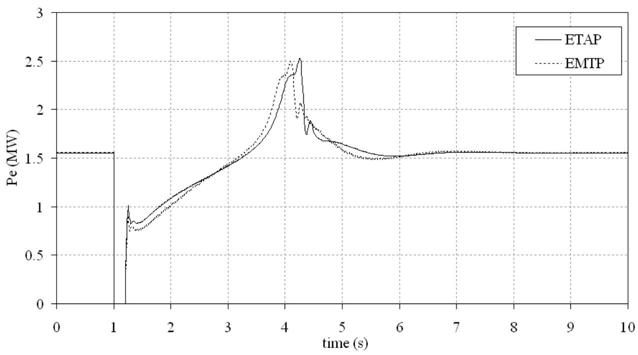


Fig. 16. Case 2 – Generator Active Power

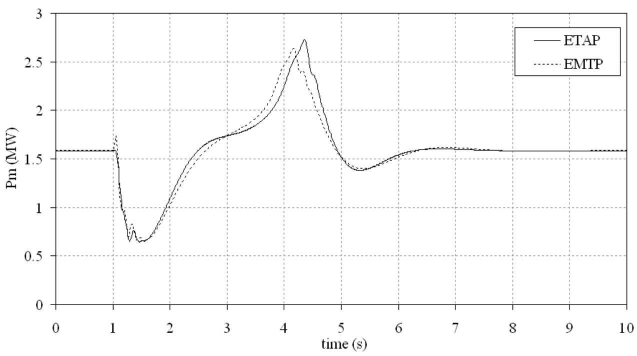


Fig. 17. Case 2 – Generator Mechanical Power

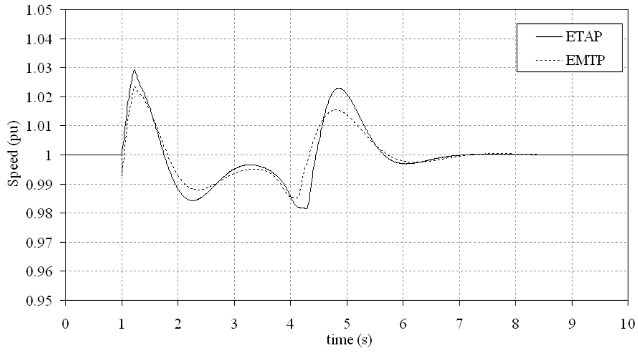


Fig. 18. Case 2 – Generator Speed

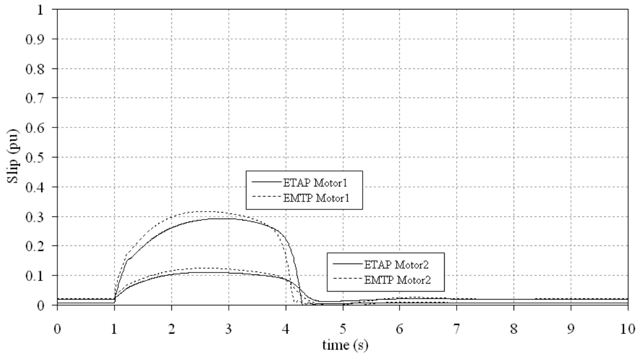


Fig. 19. Case 2 – Slip of Motor 1 and Motor 2

C. Case 3

The system was initially at steady state with all the loads in service. 3-Phase short circuit fault occurred at the Motor 1 terminal at 1 sec. The fault was removed after 0.2 sec. and at the same time the motor's protective device was opened

The results of the simulation are shown in Fig. 20 to Fig. 25. The voltage rose immediately after the removal of the short circuit fault and it settled in less than 3 sec. (Fig. 20). Moreover, the generator speed variation is in the maximum range of 1.5% only (Fig. 24). These manifestations are within acceptable range of stability. With regards to the comparison of ETAP and EMTP-RV, the results were very close in all of the plots.

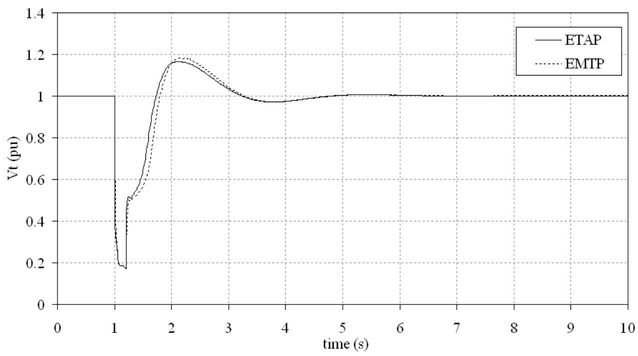


Fig. 20. Case 3 – Generator Terminal Voltage

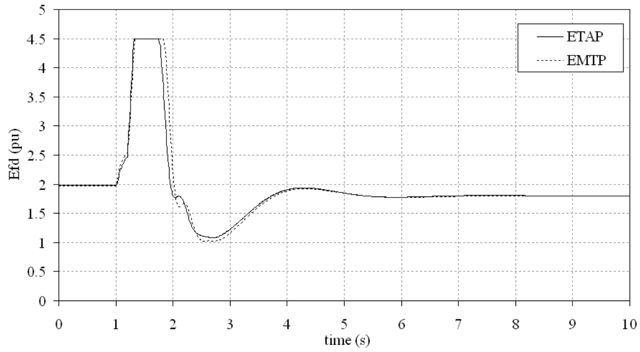


Fig. 21. Case 3 – Generator Exciter Voltage

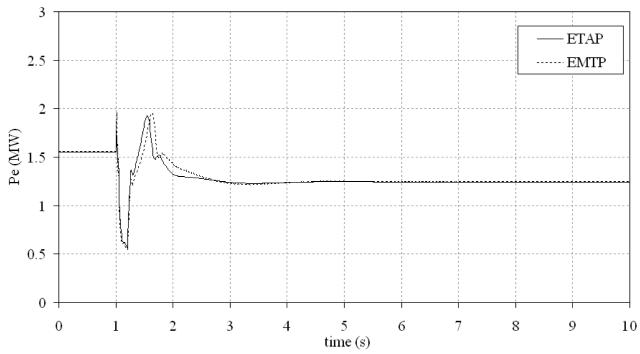


Fig. 22. Case 3 – Generator Active Power

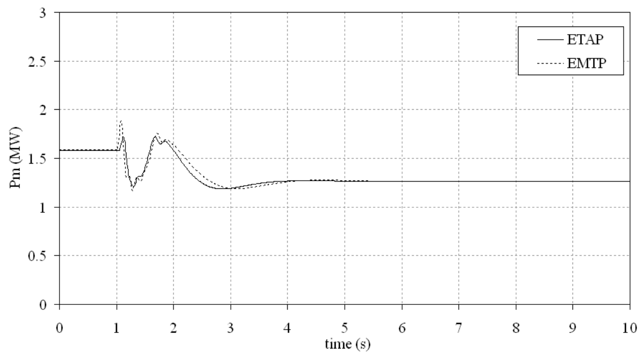


Fig. 23. Case 3 – Generator Mechanical Power

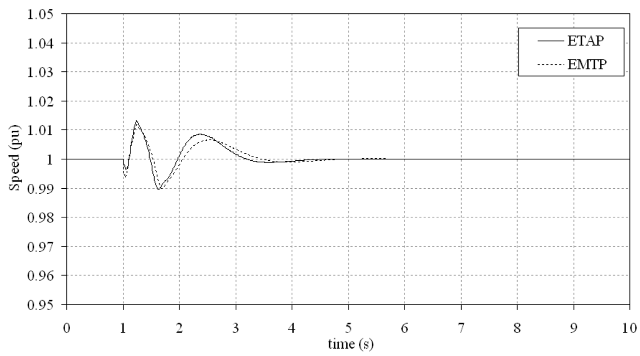


Fig. 24. Case 3 – Generator Speed

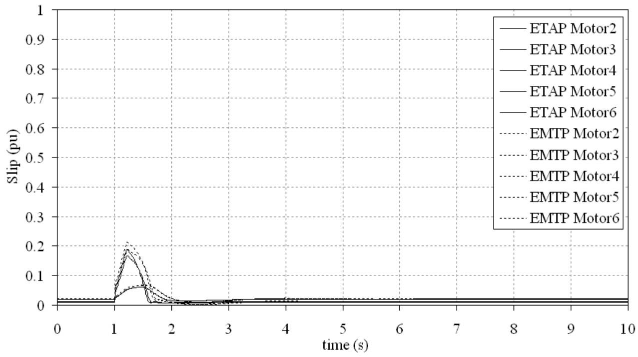


Fig. 25. Case 3 – Motor Slip

IV. Conclusion

Three test cases for motor dynamic acceleration and re-acceleration are constructed and executed to compare two popular electrical system simulation software, ETAP and EMTP-RV. These cases are comprehensive in terms of modeling synchronous generator machine dynamics, its excitation system and engine/governor system dynamics, as well as induction machine dynamics. The two programs exhibited practically identical results in all three study cases. This benchmark test can be used to validate both programs for electrical system dynamic analysis. To the users, the power and advantage of one software program over another is generally relative to the complexity of the system to be studied, the detail of the machines or component models, the type of analyses required, and the user-friendliness provided by the program.

V. Appendix

A. Generator Parameters

R_a	0.0184	pu
X_l	0.189	pu
X_d	1.50	pu
X_d’	0.32	pu
X_d”	0.23	pu
T_{d0}’	3.5	sec
T_{d0}”	0.05	sec
X_q	1.1278	pu
X_q’	1.1277	pu
X_q”	0.23	pu
T_{q0}’	5.0	sec
T_{q0}”	0.05	sec

B. Exciter/AVR Model

The following are the parameters of the AVR/Exciter IEEE transfer block diagram model given in Fig. 4:

$$\begin{aligned}
F_{EX} &= 1 - 0.577 \cdot I_N && (I_N < 0.433) \\
F_{EX} &= \sqrt{0.75 - I_N{}^2} && (0.433 < I_N < 0.75) \\
F_{EX} &= 1.732\,(1 - I_N) && (0.75 < I_N < 1) \\
F_{EX} &= 0 && (1 < I_N)
\end{aligned} \quad \cdots (1)$$

VR_{max}	4.5	pu
VR_{mim}	-1.2	pu
Efd_{max}	4.5	pu
K_A	25	pu
K_C	0.12	pu
K_E	1.00	pu
K_F	0.06	pu
K_I	0.00	pu
K_P	5.75	pu
T_A	0.150	sec
T_E	0.500	sec
T_F	0.500	sec
T_R	0.002	sec

C. *Engine/Governor Model*

The following are the parameters of Engine/Governor Woodward Diesel transfer block diagram model given in Fig. 5:

T_1	0.011	sec
T_2	0.042	sec
T_3	0.100	sec
T_4	0.250	sec
T_5	0.039	sec
T_6	0.009	sec
T_D	0.025	sec
K	17.368	pu
T_{max}	0.92	pu
T_{min}	-0.05	pu

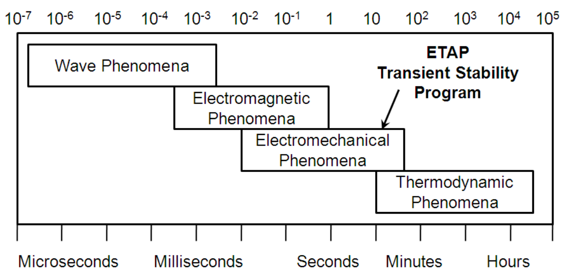
D. *Induction Motor Nameplate and Load Data*

	kV	HP	PF (%)	Eff (%)	Poles	Load "A"* ($A\omega^2$)	H**
Motor1	0.44	400	93.56	97.88	2	103.0	0.692
Motor2	0.44	225	78.87	94.14	10	89.0	2.009
Motor3	0.46	400	93.03	96.77	4	100.0	0.441
Motor4	0.46	225	78.87	94.14	10	89.0	2.014
Motor5	0.44	350	85.40	96.34	4	100.0	0.348
Motor6	0.44	350	85.40	96.34	4	100.0	0.348

*Percent of motor rated torque
** Combined motor and load inertia in MW-sec/MVA

E. *ETAP Application Range*

The following time frame of power system dynamic phenomena illustrates the application range of ETAP Transient Stability program. In the case of generator start-up simulation, ETAP uses (as an option) the frequency dependent models of network (i.e. lines and other branches), motors and generators.



VI. Acknowledgment

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VII. References

[1] ETAP Transient Stability V&V Documents, Test Case Number TCS-TS-181, 2005. Available: http://www.etap.com

[2] *IEEE Guide for Synchronous Generator Modeling Practices and Application in Power System Stability Analyses,* IEEE Standard 1110 - 2002

[3] *IEEE Recommended Practice for Excitation System Models for Power System Stability*, IEEE Standard 421.5-2005.

[4] P. Kundur, *"Power System Stability and Control",* New York: McGraw Hill, 1994

VIII. BIOGRAPHIES

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