Simulation Programs for Load Shedding Studies: Expermintal Results

Rasha M. El Azab and P.Lataire
Department Of Electrical Engineering And Energy Technology
Vrije Universiteit Brussel
Brussels, Belgium
rmohamed@vub.ac.be

E. H. Shehab Eldin and M. M. Sallam
Department Of Electrical Power Engineering
Helwan University
Cairo, Egypt
msallam@sallams.net

I. INTRODUCTION

In most of the recent blackouts in the world, the time period from the occurrence of dominating disturbance to the complete blackout is usually in the order of minutes and involves several stability problems, such as frequency stability, voltage stability and transient stability. Compared with the others, frequency stability is a system-wide and crucial issue in blackout evolution period. Without system frequency stability, reactive power balance and voltage profile cannot be held and the overall system may crash quickly. [1-4].

The aim of any load shedding scheme is to disconnect the minimum amount of loads required to arrest the falling frequency to an acceptable value.

Adaptive load shedding trips dynamic amount of load at each stage, taking into consideration the magnitude of disturbance, voltage and frequency characteristic of the system at each stage. [5-9].

Study of the different load shedding schemes is usually carried out through simulation programs of the real power network. As there are several simulation programs of power networks, the question is which one is more suitable for load shedding studies.

This question is dealt with in this paper, where a power system is simulated by three different simulation programs namely, MATLAB/ Simulink, MATLAB/ PSAT (Power System Analysis Toolbox) and ETAP, and the obtained results are compared with results obtained from experiments.

II. THE STUDIED SYSTEM

Single machine system is examined experimentally to study the frequency behavior during different over loading conditions. This system consists of a 380 V&20KVA synchronous machine driven by a DC machine as a prime over. The synchronous machine is connected to the load via a three phase RL series circuit, as shown in Fig.1.

The synchronous parameters are estimated by conventional tests such as, slip test, voltage recovery test and short circuit test [17]. The technical data of the generator are outlined as:

Rated voltage: V_n=380 V
Rated capacity: S_n =20KVA,
Rated frequency =50Hz
D-axis synchronous reactance: X_d=1.2887 p.u.,
D-axis transient reactance: $X_d^{/}$=0.4434 p.u.,
D-axis sub transient reactance: $A_d^{//}$=0.0909p.u.
Q-axis synchronous reactance: Ax=1.0168 put.
Q-axis sub transient reactance: $Xq^{//}$= 0.0869 p.u. and
Inertia Constant H=0.5625 sec.

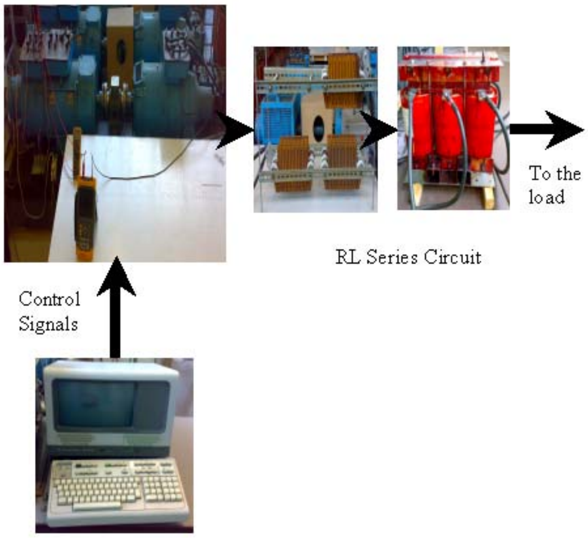


Fig.1: The studied single machine system

The synchronous machine exciter voltage, the DC armature current and the synchronous machine speed are controlled by PI controller circuits connected to a computer, as shown in fig.1, which makes the synchronous machine recover its speed, i.e. frequency, easily and in very fast way during any over load.

To have the similar behavior of practical turbine in power system, as discussed in [18],the reference armature current of the DC machine is limited to the values measured during normal loading. By this way the DC machine may be considered as a turbine with nearly no spinning reserve which is the worst case in over loading behavior.

III. SIMULATION PROGRAM

The machine is simulated by three different programs, MATLAB/ Simulink, MATLAB/ PSAT(Power System Analysis Toolbox) and ETAP. The machine simulations are validated by V –curves test. Figures 2,3&4 show the V-curves for three different active power loading

,5.5,11and 22 KW, obtained by simulation programs as well as those obtained from experiments.

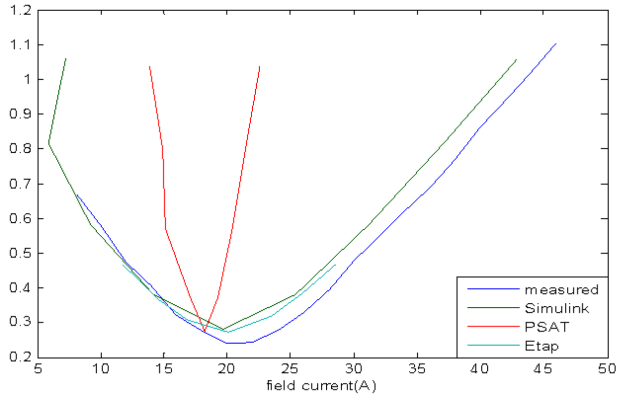


Fig. 2: measured and simulated V-curves for P=5.5KW.

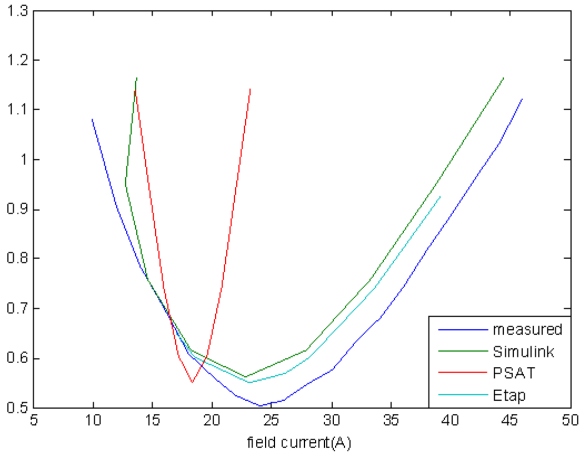


Fig. 3: measured and simulated Vcurves for P=11KW.

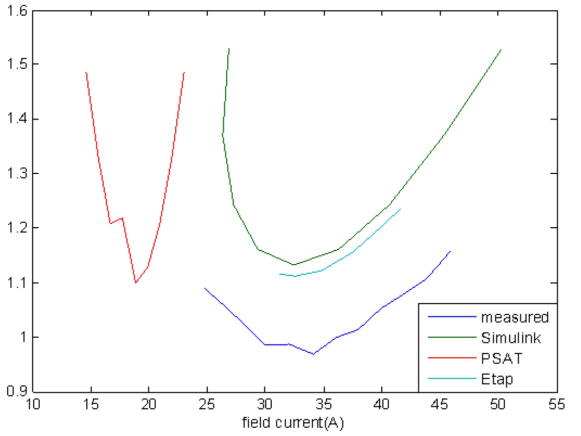


Fig. 4: measured and simulated V-curves for P=22KW.

As compared with the experimental measurements simulation by ETAP program is the most accurate. However, Simulink program may be acceptable, simulation with PSAT toolbox is not accurate enough.

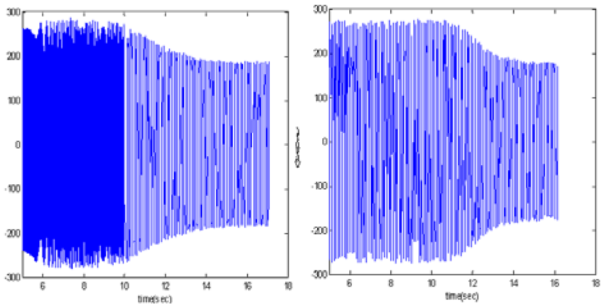
IV. PURE RESISTIVE LOADING:

The loads are taken as combinations of different three phase resistor banks which are available in the laboratory. These banks are composed of three sets of parallel connected resistors, 25, 50 and 100 ohms. The sets are Y connected. Three different loading levels are examined at rated voltage with three overloading cases for each as shown in Table I

Table I: tested loading and over loads cases

Normal loading	Case 1	Case 2	Case 3
25//100(45%)	20%	40%	60%
25//50(54.15%)	16.7%	33.3%	50%
25//25(72.2%)	12.5%	25%	50%

For each over load case the terminal voltage, active power and rotor speed, i.e. frequency, of the synchronous machine are measured and recorded. The synchronous generator is driven for each case twice, for frequency equal 50Hz & 60Hz, Figures 5, 6&7 show the measured signals for 45% loading level and 20% over loading level.

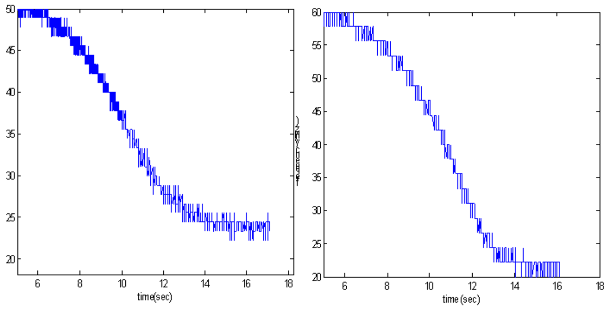


(a) (b)

Fig.5: phase a voltage during over load,(a) f=50Hz , (b) f=60 Hz.

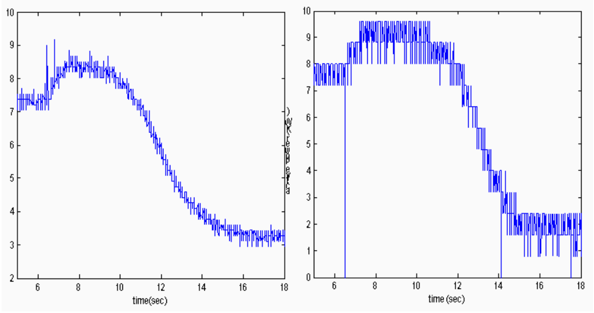
From previous figures, the voltage is held constant for few seconds, by the exciter controller, and then begins decaying. This decay may be due to the fact that the field reaches its limits and is held constant, so the voltage generated will be reduced as the speed decrease.

For the same reason, the voltage of 50Hz system may begin decaying earlier than the 60Hz one. The early decaying in voltage reduces the total resistive load power, which makes the system disturbance less severe than the slow decaying one, as shown in following figures.



(a) (b)

Fig. 6: the system frequency (a) f=50Hz , (b) f=60 Hz.



(a) (b)

Fig.7: the generator active power (a) f=50Hz , (b) f=60 Hz.

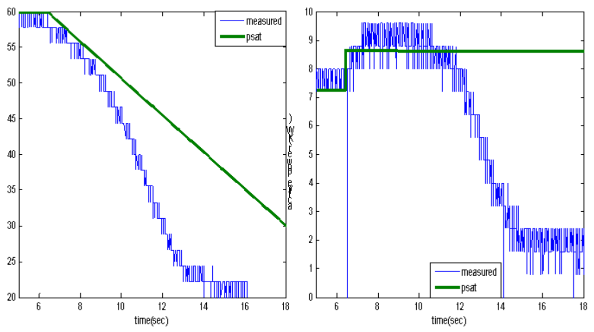
From previous figures, the frequency is decaying from 50 to 25 Hz or from 60 to 20 Hz, within about ten seconds of over loading. The active generated power is increased after the over loading instant, by about 1.5 KW or 104% of the over load power due to the conversion of part of the stored kinetic energy of the synchronous machine to compensate the shortage of active power in the system. The active power measurement may give a good indication of the over load magnitude as discussed in [5].

Mechanical input power of the synchronous machine which is proportion to its speed decreases during the frequency decay, introducing another challenge for simulation programs.

It is obvious that in systems with 60 Hz frequency collapse may be faster than with systems of 50Hz one.

Studied premonition programs can simulate constant power turbine or have their own turbine models, which increases the mechanical power during frequency reduction period. These built in models cannot simulate the studied constant torque case.

PSAT toolbox doesn't provide the ability of customizing new models of turbine by the user. So, the behavior of PSAT program cannot simulate the studied case, as shown in fig.8.



(a) (b)

Fig.8: the measured results with simulated ones by PSAT,
(a) frequency, (b) active power.

MATLAB/ Simulink program can provide any control algorithm to the generator. By Simulink, The prime mover mechanical input power is simply modeled by two modes of control. First constant torque prime mover , equal to normal loading input power multiplied by the per unit rotor speed, during over load period. Second mode is a PI speed controller for period after load shedding. An embedded MATLAB function calculates the mechanical power during the over load and switches to the second mode of control according the time of load shedding, as shown in Fig.9.

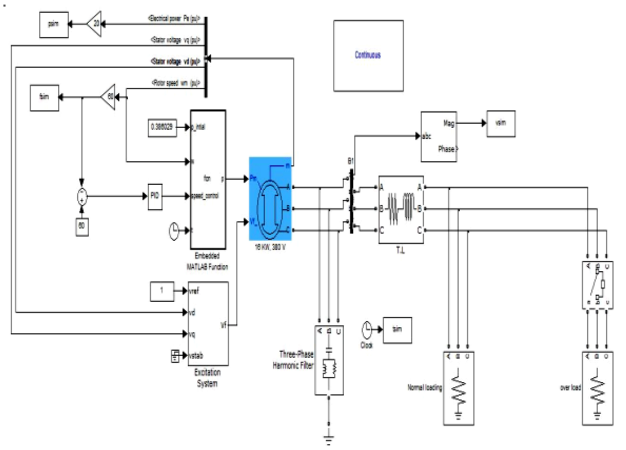


Fig. 9: single machine system Simulink model.

In ETAP program, the user can build his own turbine model using some of Simulink blocks and insert in ETAP, which is known as User Defined Model. Unfortunately, the constant torque model is unreliable in steady state operation, i.e. The period before the over load instant. For this reason, the over load connected to the system in zero time and the results are shifting in plotting to complete the comparison with the measured values.

Figures 10,11& 12 show the simulated voltage ,active power and frequency of the generator of the pre described case compared by the measured ones.

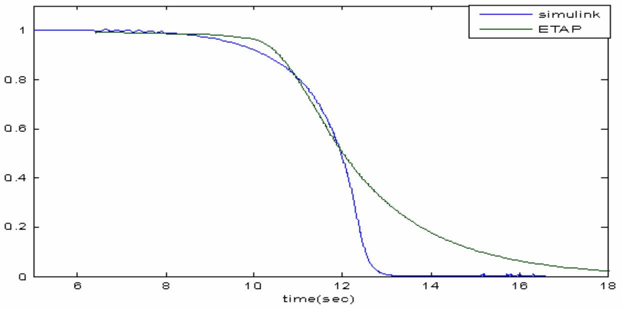


Fig.10 : simulated terminal voltage during the over load.

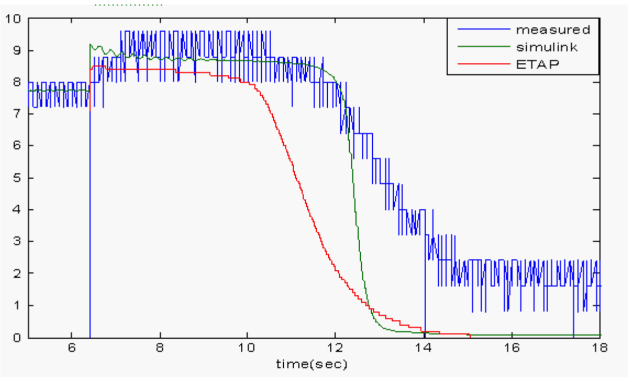


Fig.11: the simulated generator active power.

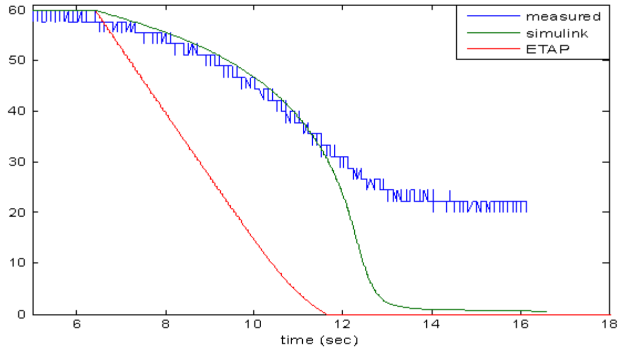


Fig. 12: the simulated frequency during the over load.

These figures show very good matching of simulation results of Simulink compared with measured ones, especially before the voltage collapse, which is adequate for load shedding calculation. ETAP results are good enough for active power and voltage behavior. But it isn't accurate enough in frequency behavior.

V. LOAD SHEDDING SCHEME

Over load resistor banks will be shed via a circuit breaker triggered by a relay. The relay input is connected to an electronic circuit which compares the speed signal to the speed value of frequency 59.3 Hz, which will be the shedding frequency setting, as shown in fig. 13.

The time delay of the system is measured as 100 msec. Fig. 14 shows the simulated and measured frequency for 45% loading level and 20% over loading level.

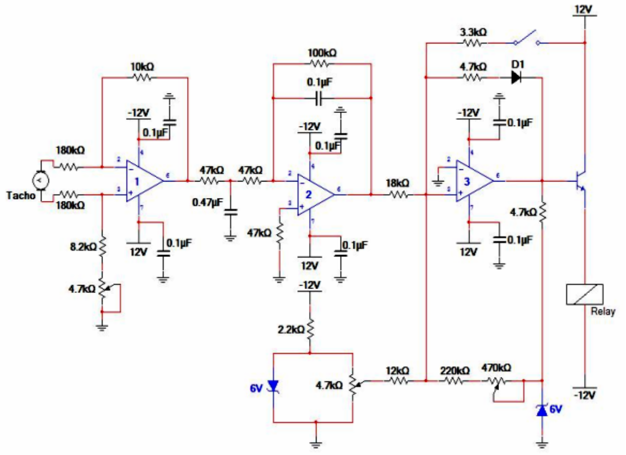


Fig. 13 : The triggering electronic circuit .

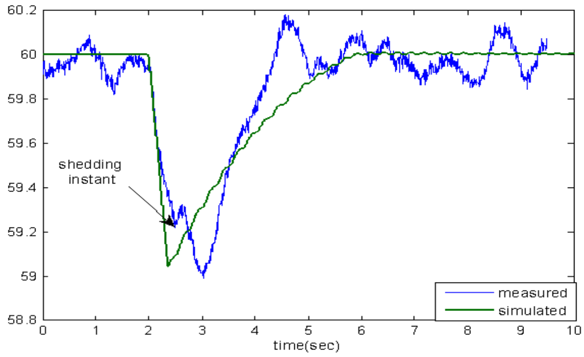


Fig. 14: the recovered frequency after load shedding

As shown in fig. 14, the frequency decayed a little after the shedding instant, this may be due to the sudden increase of voltage after shedding instant, which affects the power demand by the resistive load.

The frequency is recovered, by shedding the over load at time of f=59.3 + the system delay, in all of tested cases except in last two cases. Fig.15 shows the unrecovered frequency for 72.2% loading level and 50% over loading level.

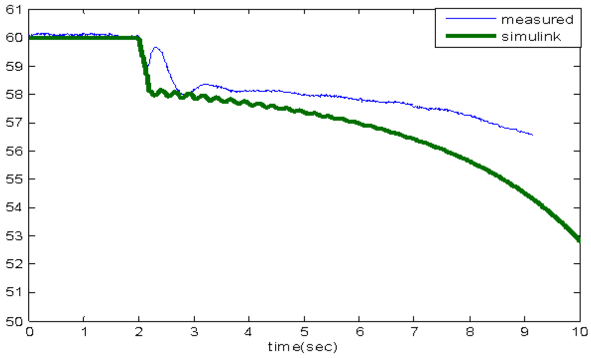


Fig. 15: the unrecovered frequency after load shedding

An additional 100 ohm load resistor bank, plus the real over load resistor banks, is shed to recover the frequency as shown in the following figure.

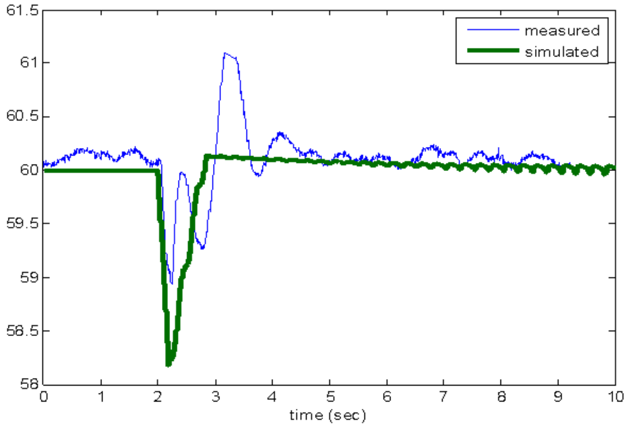


Fig. 16: the recovered frequency after over shedding

From previous figure, the measured system frequency is recovered and held at 60Hz by the prime over controller, DC machine controller.

VI. INDUCTION MACHINE LOAD:

A 19KW, 0.8 p.f., squirrel cage induction machine is connected to the system as a load to study the behavior of a dynamic load. An eddy current brake is connected to the induction machine as a mechanical load. The same premonition loading levels, 45%, 54.15% and 72.2%, with the induction machine load are examined. The same premonition overload resistor banks are connected to the system.

The induction machine load can be simulated in MATLAB / Simulink by two ways. First, by induction machine block and second, by dynamic load with zero dependant voltage coefficients for active and reactive power, which called constant power load model. Fig.17 shows the measured and simulated frequency for 45% loading and 20%over load.

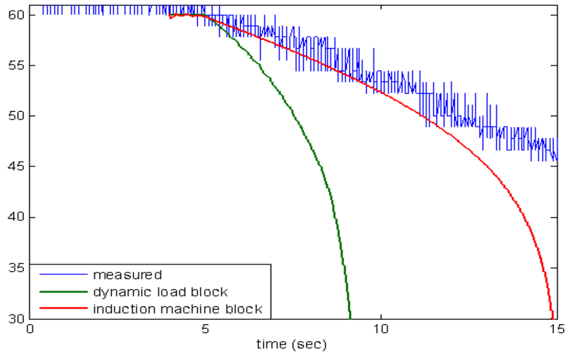


Fig. 17: measured and simulated frequency

Fig. 17 clears that, the induction machine model frequency has good matching with measured one. However, the dynamic model, constant power model, is more severe than real case, because this model doesn't increase the system inertia as in real system and it also has constant output power, while the real load power is decayed with frequency, as shown in fig. 18.

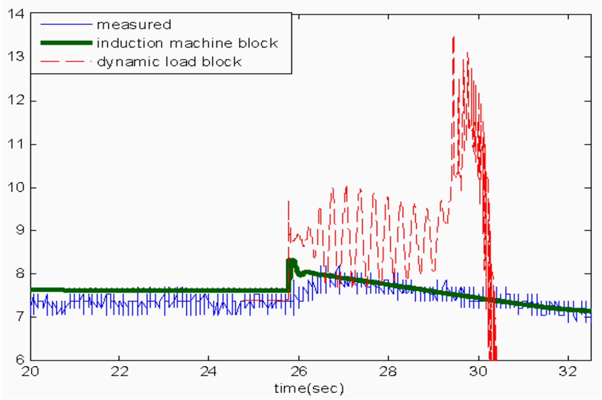


Fig. 18: measured and simulated active power

The frequency is recovered, by shedding the over load at time of f=59.3 + the system delay, in all of tested cases. Fig.19 shows the recovered frequency for 72.2% loading level and 50% over loading level.

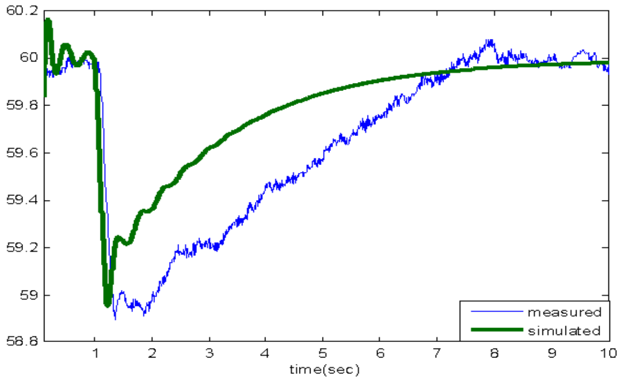


Fig. 19: the recovered frequency after shedding.

MATLAB/ Simulink provides very accurate simulation results compared to measured ones ,in both static and dynamic loading, during over loading and after load shedding process.

IV. CONCLUSION

The paper discusses the load shedding studies .as carried out by different simulation programs. These programs are MATLAB/SIMULINK, MATLAB/PSAT and ETAP.

The comparison of the results obtained by those simulation programs when compared with experimental results, reveals the following :

In spite of PSAT toolbox is a simple, reliable and vital toolbox in power system simulation, especially for multi machine system, its simulated V-curves are not accurate enough compared to experimentally measured ones. Also, the lack of customizing the control system in PSAT toolbox makes it unsuitable for simulation such studied experiments.

Although the ETAP program is a professional program in power network simulation with a very rich practical library, it doesn't have its own built in blocks for customizing the control system, which makes it unreliable for such special experimental system.

The MATLAB/SIMULINK provides good matching in simulating results in over loading and load shedding experiments due to its ability of simulating a lot of logical and physical control processes, beside the accurate simulation of synchronous machine behavior.

REFERENCES

[1] Damir Novosel ,Vahid Madani, "Shedding Light On Blackouts", IEEE power & energy magazine, JAN./FEB. 2004.

[2] "IEEE Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration", IEEE Std C37.117™-2007.

[3] Tomaž Tomšič, Gregor Verbič, "Revision of the under frequency load-shedding scheme of the Slovenian power system", Electric Power Systems Research 77(2007), 494-500.

[4] S.M. Chandekar, S.G. Tarnekar," Revised load shedding schedule for power system incorporating the effect of transmission line performance", ", Electric Power Systems Research 24(2002), 379-386.

[5] Rasha M. El Azab, E. H. Shehab Eldin, and M. M. Sallam,,"Adaptive Under Frequency Load Shedding Using PMU" , 7th IEEE International Conference on Industrial Informatics, 23-26 June 2009

[6] Vladimir V. Terzija," Adaptive Under-frequency Load Shedding Based on the Magnitude of the Disturbance Estimation", IEEE TRANS. ON POWER SYS., VOL. 21, NO. 3, AUG. 2006.

[7] Y. Yu, D. Gan , H. Wu, Z. Han, " Frequency induced risk assessment for a power system accounting uncertainties in operation of protective equipments", ", Electric Power Systems Research 32(2010), 688-696.

[8] " UFLS Design by using f and Integrating df/dt" ,IEEE Trans on power system ,Vol.1, Nov. 2006,Pages 1840:1844.

[9] Seyedi, H. Sanaye-Pasand, M. "New centralized adaptive load shedding algorithms to mitigate power system blackouts", Gen., Trans. & Distrib.,IET ,Jan. 2009.

[10] Miroslav Begovic, Damir Novosel , " ON Wide Area Protection", Power Engineering Society general meeting , 2007,24-28 J June 2007 , Pages 1-5.

[11] Elmo Price," Practical Considrations for Implementing Wide Area Monitoring Protection and Control",59th Annual Conference for Protective Relay Engineers,2006.
[12] Miroslav Begovic, Damir Novosel ,"Wide Area Protection and Emergency Control" ,Power Engineering Society General Meeting , 2004,6-10 June 2004.
[13] El Hadidy ,M,A, Helmi,D,H," Starting Synchrophasor Measurements in Egypt : Apilot Project Using Fault Recorder." Power system conference, MEPCON 2008, 12-15 Mach 2008, Pages: 157-161.
[14] MAO Anji, YU jiaxi," PMU Placment and Data Processing in WAMS that Complements SCADA", Power Engineering Society General Meeting , 2005 ,IEEE,12-16 June 2005 ,Pages 780-783.
[15] Phadke ,A.G.,Throp,J.S, " History and applications of Phasor Measurements", Power system Conference and Exposition 2006, IEEE PSCE, Nov. 2006.
[16] "IEEE Standard for Synchrophasors for Power Systems ", IEEE Std C37.118™-2005.
[17] IEEE Guide for Test Procedures for Synchronous Machines 2009
[18] H.A. Bauman, G.R. Hahn, C.N. Metcalf, .The Effect of Frequency Reduction on Plant Capacity and on System Operation,. AIEE Transactions on Power Apparatus and Systems, Vol PAS-74, p1632-1637, Feb. 1955.

.