

The Impact of Load Behavior on Voltage Stability, an Application Case in ENELVEN / VENEZUELA

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Abstract – Economical system expansion strategies and reliable system operation, requires comprehensive system simulation studies. If computer models fail to describe the real system behavior a risk to degrade operation performance is introduced. Consideration of typical models according to IEEE for prime mover and AVR's are often used. Improved load models accurately representing the steady state and dynamic behavior are seldom available and oversimplified models are used. This paper deals with the impact of load modeling on the validity of power system studies mainly concentrating on voltage stability. The reported results are based on detailed measurements and system simulation made at ENELVEN/Venezuela.

Keywords: Load Model – Voltage Stability – Steady State – Dynamic Behavior – Prime Mover – Automatic Voltage Regulator (AVR) – Reactive Power – Active Power – Frequency.

I. INTRODUCTION

It was observed in ENELVEN / Venezuela that since imported energy share increased, the ability to recover system voltage following system faults was decreasing. It was further found that the observed system behavior did not appropriately match the applied power system simulation models. Consequently, a more detailed and accurate analysis of the ENELVEN system behavior was necessary prior to the decision on effective measure for improving operation characteristics.

It was determined from various previous investigations that load characteristics as well as AVR response might have an important impact leading to the decision for the implementation of comprehensive system tests and modeling activities.

As AVR modeling and testing has already its well-known approach, load modeling is still in a research status. Consequently, this paper mainly concentrates on the aspects of load modeling with respect to the observed voltage stability impact.

In addition to the theoretical background of load modeling and the discussion of the validity of the various traditional models, a method for the determination of load parameters without disturbing customer with direct tests on load is presented. Finally, the application of the determined load models in the ENELVEN system as well as the discussion

of the impact on system expansion planning and operational aspects are presented and discussed.

II. CLASSIC LOAD MODELING

Traditionally, lumped feeder loads are represented as composite load models on the basis of constant power {P}, constant current {I} and constant impedance {Z} contributions. From the very beginning this type of load modeling was merely implemented because of restrictions on algorithms and computing capacity of some load flow and stability programs than on the certainty that this kind of modeling has a high degree of validity. However, in most stability programs these limitations are still present.

As reported [1] more adequate load models have been developed in Europe on the basis of comprehensive tests and measurement procedures. The finally promoted model is reflecting that constant {P,I,Z} modeling is preferably replaced by explicit P-Q models with linear dependency on voltage, thus reducing the number of required parameters to a clearly definable set of dependencies. It was further proposed that in the same way frequency dependency could easily be considered. In order to cope also with feeder loads representing a substantial amount of motor load a transient characteristic was introduced mainly by adding the load inertia leading to a dynamic load model as shown in Figure 1 below.

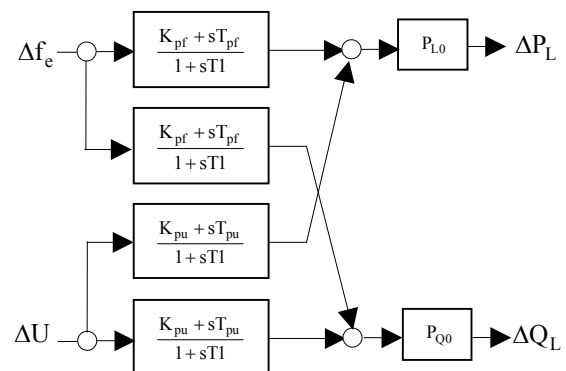


Fig. 1 Classical Dynamic Load Model (linear).

As further reported in [1], this load model was successfully applied in Europe where the system frequency fluctuations of the UCPTE system are very limited (+/- 20 mHz). In addition, due to short generation / load distances of around 80 km only, the voltage profile is quite constant with high short circuit

powers. However, the main drawbacks of this load model are as follows:

- The load model is linear having the consequence that under steady state as well as transient conditions the load deviation is always proportional to the voltage and frequency deviation. However, as it is known, motor loads are highly nonlinear, especially when considering the effects of motor stalling.
- The implementation of a linear motor load in stability programs is very questionable in the case of low voltage conditions where the change of load modeling would then be required for numerical reasons.

Keeping in mind that for the system under discussion, heavy voltage transients with sustained low voltage conditions must be considered, it was obvious that static, linearized load models would not be adequate to analyze the voltage stability problem.

III. ENHANCED LOAD MODELING

On the basis of the DIGSILENT PowerFactory modeling techniques an advanced load model was developed. The load model was applied at the 24 kV distribution level (secondary side of the sub-transmission step-down transformer) having the following characteristics:

- The feeder lumped load models consists of a static part being purely depending on supply voltage described by the following parameter:

K_{pv} – voltage dependency of active power given in %/%.
 K_{qv} – voltage dependency of reactive power given in %/%.
 $\%_{dyn}$ – fraction of dynamic load with 100% - $\%_{dyn}$ equals to static load percentage.

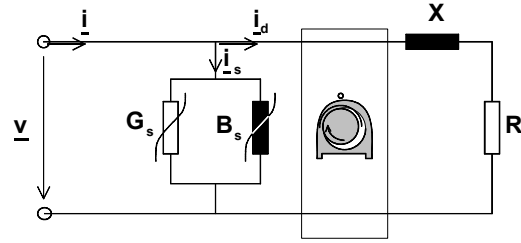
- In parallel to the static load, a motor model is connected being mainly described by the following parameters:

T_{am} - motor load inertia [s]
 S_{krit} - critical slip [%]
 S_{nom} - nominal slip [%]
 T_{exp} - mechanical torque exponent []

A more precise load model would of course require to introduce a frequency dependency also for the static load part. However, in the course of the identification process it was found that differentiating between static and dynamic part frequency dependency is practically impossible.

For the composite load model the frequency dependency is therefore fully described by the speed-torque characteristic of the dynamic load model contribution. The classical motor load equations were re-arranged such that an easy understanding and identification of model parameters is possible. Consequently, primary model parameter, respective

equivalent circuit model data like resistances and reactances have been avoided.



$$\underline{i}_s = (G_s + jB_s) \underline{v}$$

$$G_s = G_{s0} (v/v_0)^{(k_{pv}-2)}$$

$$B_s = B_{s0} (v/v_0)^{(k_{qv}-2)}$$

$$(d/dt) \underline{i}_d = (\underline{v} - (R/s + jX) \underline{i}_d) s \underline{\omega}_n / X$$

$$(d/dt) \text{speed} = (X_{me} - X_{mt}) / T_j$$

$$X_{me} = (v_i i_{di} + v_r i_{dr}) / (f_e P_0) = P_d / (f_e P_0)$$

Fig. 2 DIGSILENT Dynamic Load Model.

A further aspect of ENELVEN's unique load characteristic was observed for areas with specifically high contribution of air conditioning load as follows:

- In case of low voltage conditions, e.g. during a fault, load is automatically disconnected (load shedding) by consumers "out of nominal range" voltage supervision equipment.
- Upon voltage recovery, feeder load may be substantially higher than before the voltage sag. This type of load behavior, specifically valid for air-conditioning load was also reported in [2] and [3]. A feeder load demonstrating the mentioned load increase upon voltage recovery is captured with the DIGSILENT PowerFactory Monitor (see Fig. 3).

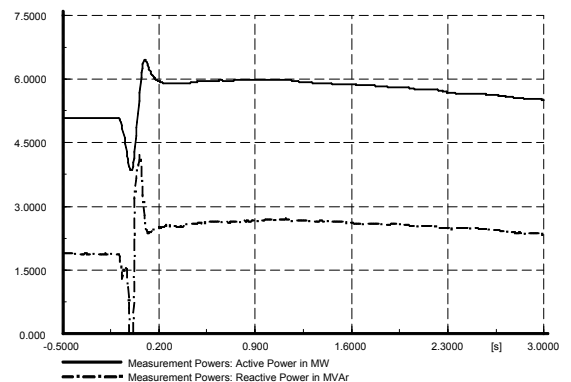


Fig. 3 Load active and reactive power increase.

A special stochastic model has been required to correctly describe the feeder load behavior following the voltage recovery. However, due to the statistical nature of the model,

further load measurements and respective observations on load recovery are needed to allow the application of these function with the required level of validity.

Further to the high percentage of ENELVEN's air- condition

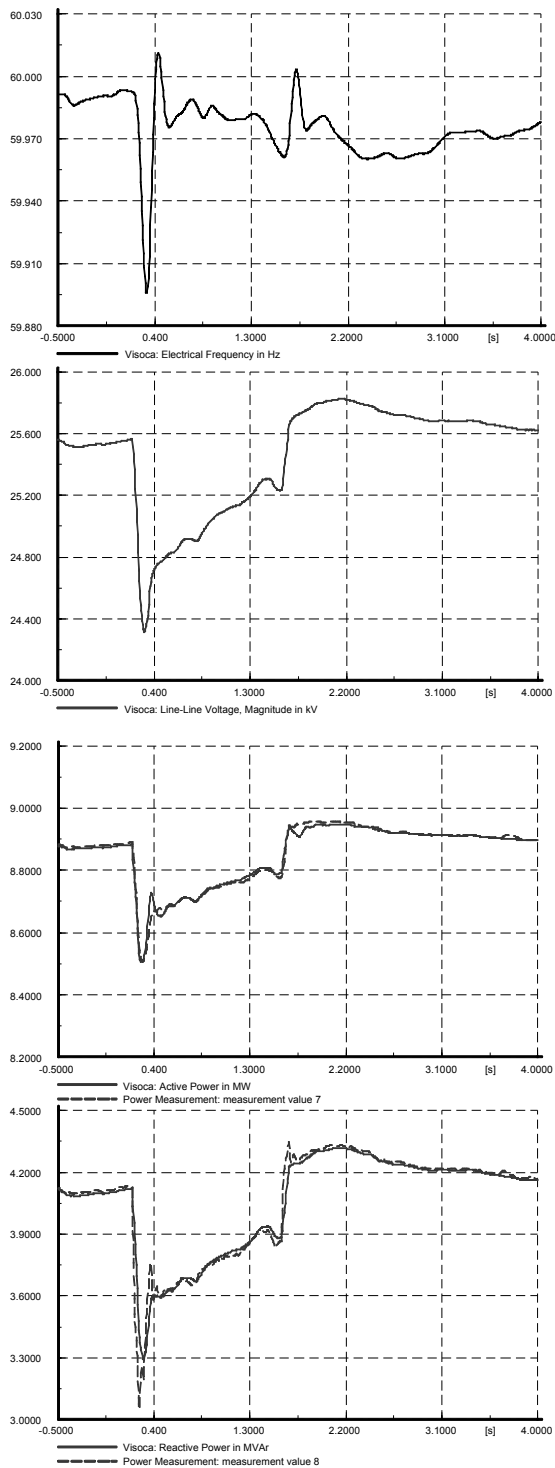


Fig. 4.1a-d Load Identification at Miranda Substation.

load the oil sector (Sector Petrolero) contributes with another 250 MW motor load leading to a total ENELVEN/ENELCO motor load of nearly 60%.

IV. LOAD PARAMETERS IDENTIFICATION

Load parameters have been determined via nonlinear MIMO identification methods based on recordings, which have

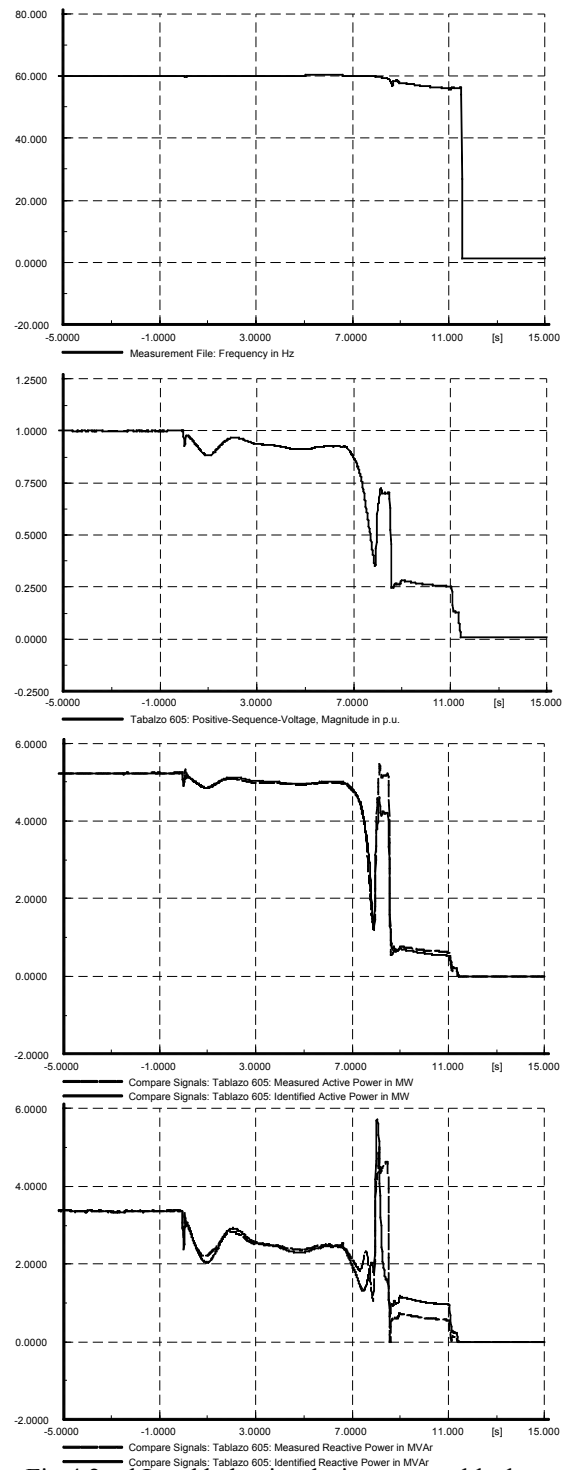


Fig 4.2a-d Load behavior during system blackout.

automatically been triggered by voltage or frequency events. The recordings have been made during the period of September, 1996 to September 1997 on various ENELVEN substations using the DIGSILENT PowerFactory Load

Measurement System featuring a full integration with the DigSILENT software PowerFactory identification tools.

Figure 4.1a-d demonstrates the model validity which has been reached for the Miranda S/S. In this case, the recorded signals do not show that post-fault feeder load will stabilize above its pre-fault value due to automatic re-start of air-conditioning compressors. In this case, the load increase is only caused by high voltage transients. The recorded signals further indicate that motor load inertia causes a fast bus frequency transient with an total amplitude of around 100 mHz.

Based on the various automatic recordings, a total of 4 typical load areas have been identified. The finally determined average load characteristics are summarized in the table below:

Load Type	%dyn	Kpv	Kqv	Tam
Commercial	55	1.0	7.0	0.5
Residential	40	1.6	5.0	0.4
Rural	50	0.7	3.3	0.5
Industrial	70	1.8	5.0	1.2

The ENELVEN system black out dated 23.6.1998 allowed to verify the overall load model validity. The recorded signals are shown in Fig. 4.2a-d. In Fig. 4.2a the decrease of system frequency and the final loss of generation is clearly observable. At the same time (Fig.4.2b) heavy voltage transients are observed with a temporary voltage recovery at t=8 seconds due to load shedding. Figures 4.2c-d demonstrate the large scale validity of the feeder load model. Except for the voltage recovery phase, where obviously motoric load restart was triggered the large scale validity of the developed composite load model is clearly shown.

V. GENERATION MODELING

In order to complete the generation-load balance, the generation model parameters were developed through three tests (two static and one dynamic) to record the active and reactive behavior. This was done by means of DigSILENT Medinas General Purpose Measurement System recording equipment.

The static tests were as follows:

- Off line unit, spinning at rated speed, aiming to test generator saturation.
- On line unit, aiming to test the control valve characteristic.

The dynamic test consisted of a load shedding of the unit, but making sure that a fraction of the load is kept on the unit, in order to avoid total closure of control valves. With this test, both, prime mover and AVR were dynamic response were recorded.

Generation parameters have been also determined via nonlinear identification methods based on the recordings, that had been performed on all steam units and on each type (Five in total) of gas turbine units.

The recorded variables for generators were as follows:

- For generators:
 - Excitation Voltage
 - Excitation Voltage Set Point
 - Excitation Current
 - Generator voltage output
 - Generator voltage current
 - Active and reactive power of generator output calculated by soft-transducer
 - Frequency of generator output (interpreted also as RPM) calculated by soft-transducer
- For prime-movers (as applicable):
 - Fuel Valve position
 - Exhaust gases temperature
 - Regulating steam valve position
 - Pressure and temperature of steam intake to HP turbine
 - Pressure and temperature of steam output from reheater
 - Steam mass flow

Based on the parameters found, not only a more updated and accurate model of generation was acquired, but also some conclusions on generating units control adjustments were drawn. The implementation of the new recommended adjustments will also help in making them more prone to stabilize the system in disturbed conditions.

VI. IMPACT ON SYSTEM BEHAVIOR MODELING

During the process of fine tuning of the whole system model (Venezuelan power system is of about 11.000 MW peak demand) some assumptions were made on the model outside ENELVEN supplied by OPSIS. This leads to the conclusion that additional measurement and analysis is required, in order to end up with a comprehensive model of the whole system. This fine tuning was done basically with the support of recorded oscillographic data of well documented faults.

Compared to the traditional load modeling practice considering only static load dependencies in voltage, the load model developed for ENELVEN clearly demonstrates that the classical approach does not allow to correctly represent system contingencies such as stalling of system load in case of low voltage conditions as well as the re-acceleration process upon voltage recovery.

In figure 6.1a voltage behavior at Trinidad S/S 24KV is shown. This S/S has a good voltage support from a 230/138KV 333 MVA interconnection transformer and distribution transformers are 83 MVA capacity. Even though, it is observable that with the new load model, the voltage

response is not acceptable, but with the traditional model, it is too optimistically good. It is also seen that if the inertia considered is high, (similar to the one used in the old model) the system will also behave optimistically.

The explanation of the difference in results drawn from the new load model and the old is found in Figures 5b-c where a large MVar requirement is seen compared to traditional load model. Again if used inertia is overestimated, the results will be optimistic.

In figure 6.1b a reduction of active power after fault clearing is observed, but the amount is not so drastic as to cope with the drastic reactive power increase so at the end, the system represented with the traditional model is more optimistic.

During further simulations, it was shown that the newly developed model comes out with a less damped system than that drawn from the old model. Also, due to smaller inertia, load motors stall faster and the after fault clearing increase of reactive load is better represented by the new model.

VII. FINDINGS

Based on the newly developed model for ENELVEN and having it tuned to the Venezuelan system, it was possible to study the solution of the problem that led us to here: Inappropriate voltage recovery after faults clearing.

Several solutions were tested: increase of the number of transmission lines interconnecting ENELVEN to national system, Series capacitors, SVC in several locations, Etc. but no one was seen as fully satisfactory. But increase of short circuit power (which also means addition of inertia to the system) did show a sensitive improve in the system. For the present system figures of 600 to 800 MVA of nominal power were seen. This increment can be achieved by additional Generation or Synchronous compensation.

Additional studies are necessary to determine the most suitable location and coordination with the long term generation expansion plan.

Meanwhile, a centralized load shedding system whose trigger would be transient voltage behavior is advisable to cope with MVar overloads. The criteria for choosing load to shed would be to pick up for shedding those loads whose MVar consumption typically increase dramatically with voltage collapse.

Also, it was drawn that system behavior is better when pre-fault voltage is higher, so static switchable compensation should be used extensively, in order to keep a robust voltage profile during all operating conditions. In addition, it allows to keep more reactive power reserve at generation Units.

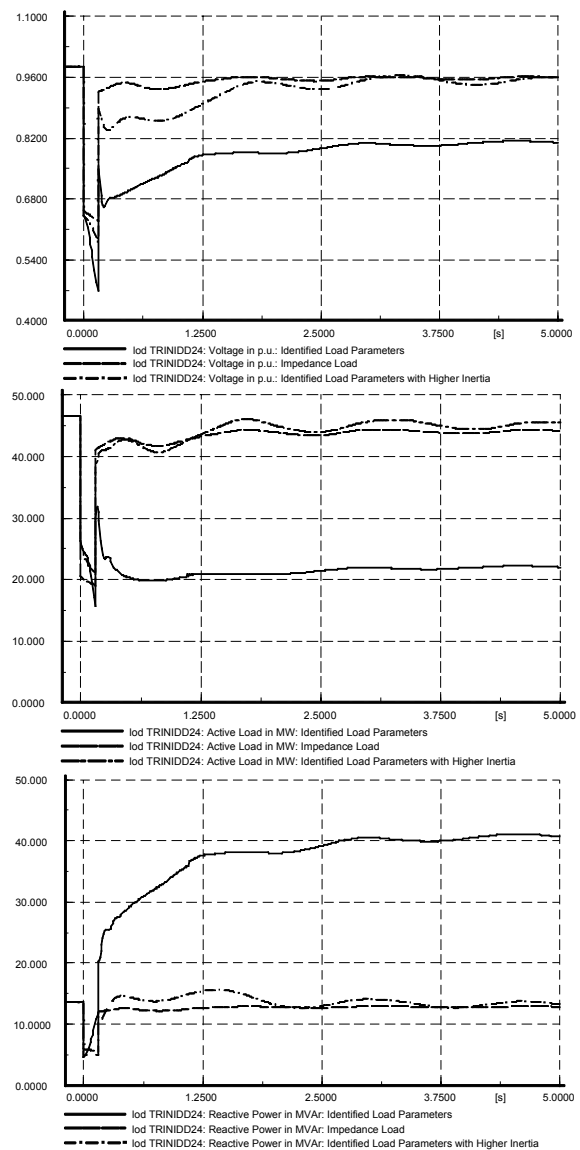


Fig. 5a-c Impact of System Load Modeling.

VIII. REFERENCES

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