Reliability and Continuity of Supply of the Venezuelan Electrical System

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Abstract—Since 1999 the Venezuelan Electrical System (SEV) is going through a crisis due to multiple events, which has become evident not only through an accelerated decline in service quality, but also because the high probability of having a system collapse at any time. This paper presents an analysis and detailed comparison of the multiple factors that, throughout the period 1999-2011, have caused and continue deteriorating the quality of the electrical service, as well as the solutions required to be taken to recuperate the reliability and continuity of supply and improve present power quality service.

Keywords-component: efficiency, distribution, generation, hydrothermal system, maintenance, obsolescence, power quality service, reliability, standards, transmission.

I. INTRODUCTION

Venezuela built a unique interconnected electric power system during the second half of the last century. Located in the southern region of the country, the Caroní River hydroelectric developments are (since 1950) the central piece of the national supply system, namely: Guri (10,000 MW), Macagua (2,500 MW), Caruachi (2,300 MW) and Tocoma (2014, 2,300 MW). The system long-term planning was driven by the stochastic behavior of the Caroní River and its day-to-day dispatch operation was regulated by the 2.5-years-ahead capacity embedded in the Guri reservoir (developed in two sequential stages starting in 1968 and ending in 1986). Currently the hydro-thermal power mix is 60:40.

Since demand markets were located alongside the north coast facing the Caribbean Sea, a quite robust high-voltage transmission network was in place, namely 2,000 kilometers at 765 kV, 3,000 kilometers at 400 kV and 6,000 kilometers at 230 kV. In such a context, Venezuela was keen to progressively create a worldwide standing professional class and, in particular, a planning school mastering the theory and mathematical modeling for the optimal administration of the Caroní hydro renewable resources, contributing nowadays with 500,000 oil equivalent barrels per day.

During the first thirty years of existence of the SIN-National Interconnected System (1968-1998), the Venezuelan electrical system was planned, built and operated according to the planning and operation criteria in force in OPSIS, the former SIN-Operation Office, developing an important infrastructure consisting of (Dec 1998):

- Installed generation capacity: 19,696 MW
- Hydroelectric capacity: 12,401 MW
- Thermoelectric generation capacity: 7,295 MW
- Interconnection levels: 765/400/230 kV
- National Interconnected System: 10,872 Km (Fig.1)
- Load peak demand : 10.854 MW

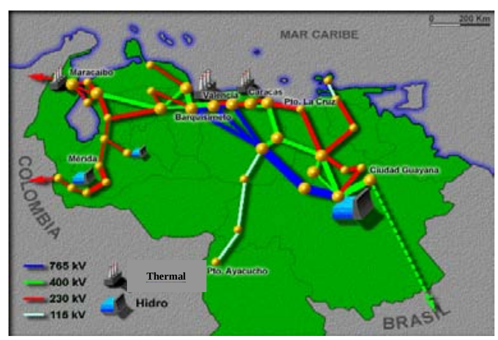

Fig. 1 National Interconnected System

In addition, a broad distribution network (22,000 Kms) that, as a whole, allowed providing high-quality services to 94% of the population during that thirty-year period.

In 1999, the SIN delivered to the new authorities of the Ministry of Energy and Mines (MEM), the 1999-2013 Expansion Plan developed according to the premises that always prevailed at OPSIS Planning Committee, which at that time, also counted with the participation of ENELVEN, a company in the western region of the country.

The plan was revised by the new authorities, who in 2001 developed the so-called National Electric System Plan (PSEN). Later in 2005, MEM developed what is known as the PDSEN-National Electric Sector Development Plan. The manner in which the PSEN and PDESEN were designed did no longer exactly respond to the concepts and methodologies used by the OPSIS Planning Committee, but rather became the beginning of a “Shopping List and Wishful Thinking” type of planning.

In a system as the Venezuelan, with 65% participation of hydroelectricity in total energy generation, the cyclic and random variations of hydraulicities, that is, power supply during dry periods, are the main determining factor for security of supply.

II. POWER QUALITY STANDARDS

Power service quality standards in force in Venezuela establish that power distribution activities shall be evaluated in the following areas:

1. Technical Product.
2. Technical Service.
3. Commercial Service.

Quality aspects of the *technical product* considered are:

1. Voltage level.
2. Voltage waveform disturbance.

To establish allowable supply voltage variation values, the following voltage levels are considered:

- High voltage: Voltage ≥ 69 kV
- Medium voltage: 1 kV < Voltage < 69 kV
- Low voltage: ≤ 1 kV

Allowed percentage variations of voltage levels measured at supply points with regard to the nominal voltage value are included in Table 1. Voltage waveform disturbances subject to control are fast voltage fluctuations (flicker) and harmonic distortion.

Quality of the technical service provided is evaluated by considering indicators that show the frequency and total duration of interruptions in the power service. Distribution companies are responsible for conducting the survey and logging interruptions, establishing the corresponding indicators and payment of penalties for failure in the service to affected users.

Commercial service quality is evaluated through parameters that consider aspects related to the efficient and effective service to users, such as: measuring, invoices, connection and reconnection times, claims and tariffs, among others.

Until 2007, such standards were strictly met by private distribution companies which kept an automated log of all events occurring in their distribution systems. Such systems communicated with their commercial management systems for proper identification of affected clients for the purpose of establishing penalties to be paid to users, among others.

Table 1 Nominal Voltage Variations

Voltage/Area density	Variations
High voltage	+/- 5%
Medium voltage	+/- 6%
Low/Very high	+/- 6%
Low/High	+/- 6%
Low/Medium	+/- 8%
Low/Low	+/- 10%
Low/Very low	+/- 10%

After 2007, the entire electrical sector became public and provisions established in the quality standards were no longer met, as mentioned in Section III. In fact, the user becomes unattended, since there is no instance available to report the damages caused by failures at their homes and work sites.

Since November 2010, information related to the SIN’s performance was “temporarily” suspended. To date, July 2011, it has not been reestablished yet although the LOSSE-Organic Law of the Electric System and Service requires providing timely information to users regarding the development of the national electric sector activities. The reason given for such suspension is that such information affects the country’s security. .

III RELIABILITY CRITERIA

In the Venezuelan hydrothermal system, the reliability and continuity analysis of the supply, must take into account the following criteria:

1. The probability of energy deficit; and
2. The guaranty of supply at peak hour.

In the first ten years of the SIN the generation was predominantly thermal and the LOLP-Loss of load probability (2 days/year) was the criterion in use as the power deficit criterion. In1977 when hydroelectricity reached 43.7% of the installed capacity, a second criterion was included – reserve margin (30%) – to cover any energy deficit when simulating the system with average hydrology. The values of both indices were derived from good performance in the past. EDELCA – the owner and operator of the Guri dam – added a hydrothermal dispatch model [1] in 1991and it was used up to 1999 by the SIN for its economical dispatch.

The new reliability indices [2] incorporated since 1993 are:

1. Probability of energy deficit (PD) measured by the relative frequency of failed hydrological series within an n-year flow sequence (5%); and
2. Value of expected un-serviced energy (EUSE) expressed as a percentage of annual energy required by the system (1x 10^{-3}).

Considering that the probabilistic criteria should be periodically checked through its practical and regular application, once adopted , the following orders of magnitude were established to such effects: PD (1-5%) and EUSE (0.01-0.1%). When evaluating the reliability on future generation expansion plans, the SIN up to 1999 verified the power deficit indices (LOLP and reserve margin) and energy deficit (PD and EUSE). In addition, the deterministic firm energy criterion and the probabilistic guaranteed energy were also used in some evaluations. Transmission and transient reliability criteria [3] were also established and in use by the SIN.

IV. PARAMETERS OF THE CRISIS

The actual crisis of the Venezuelan electric sector [4] responds to a multiple simultaneous contingency situation that has at present a tremendous impact on its power service quality:

1. Current electric sector authorities do not have the appropriate *expertise and knowledge* to develop and operate the national hydrothermal system;
2. Due to *lack of maintenance*, there is 40% unavailability of thermal generation;
3. 64% of thermal generation has completed over 25 years of daily life operation, i.e., it is *technologically and operationally obsolete;*
4. Therefore, thermal generation *efficiency* is less than 30%;
5. Additionally, *availability* of hydrogeneration is only 72%;
6. In 12 years, no *expansion projects* of our 765 kV transmission system have been undertaken -- not even one kilometer;
7. Therefore, the 765 kV is operating for more than 12 hours/day exceeding the *transmission limits,*
8. A daily 300MW *load rationing* is being applied, having cities with more than 3 hours of rationing per day;
9. Just to mention another example of the impact of the crisis on its power service quality, in 12 years of the actual government, *failures* greater than 100MW are ten times more than in 1999; and
10. *Voltage and overload problems* in our T&D systems have tremendous impact on daily power service quality.

Hence, there is a national and continuous electricity crisis since 2010 due to mismanagement of the electrical network, all in public hands

V. IMPACT FACTORS THROUGH THE BUSINESS CHAIN

V. 1 GENERATION

From the total installed capacity (23,708 MW) in 2011, 62% is hydroelectricity (14,621 MW) and 38% (9,087 MW) is thermal power. For a stable and safe operation of the National Electrical System, availability of maximum (90-95%) thermal generation is required [5]:

1) Unfortunately, in the best case, only 63% (5,745 MW) of the thermal power is available; that is, 40% is unavailable;
2) Additionally, 64% of thermal capacity is over 25 years old, that is, obsolete technology;
3) Moreover, most thermal generation uses gas and gas oil below 30% efficiency, that is, their fuel consumption is higher than combined cycles, whose efficiency is above 48%;
4) One of the current problems of the national energy system is the unavailability of gas, thus requiring the use of technologies that with the same amount of gas, produce a larger volume of electric power, that is, more efficient machines;
5) With regard to hydroelectricity, from the total (14,621 MW) only 72% (10,531 MW) is available and 3,480 MW (23.8%) is at risk (problems in turbines and generators).

Replacement of 6,276.5 thermal MW, which are over 25 years old and below 30% efficiency, is required by combined cycles with efficiency above 48%. This would allow increasing generation with the same fuel used at present, eliminating the risk of the 3,480 MW from Guri (EDELCA), and continue developing the Upper Caroní.

One of the problems currently faced is that the Government's annual execution efficiency is only 13.47% since, from the 5,531 MW it promised to install in the year 2010, only 745 MW were actually installed, and it has additionally declared to consider as an impossible task for them to install 2,000 MW per year in order to meet the expected demand growth.

Plans for the period 2006-2010 included the installation of 5,899 MW, from which 2,660 MW were thermal power and 3,239 MW were hydro power. From the 5,899 MW, only 1,155 MW have been installed, that is, 19%.

V.2 TRANSMISSION

According to information from the-National Management Centre (former OPSIS), transmission limits are exceeded for more than 12 hours due to export from EDELCA (Fig.2) and import towards the Central Region, and for 24 hours for import from CADAFE Western Region (Fig.3).

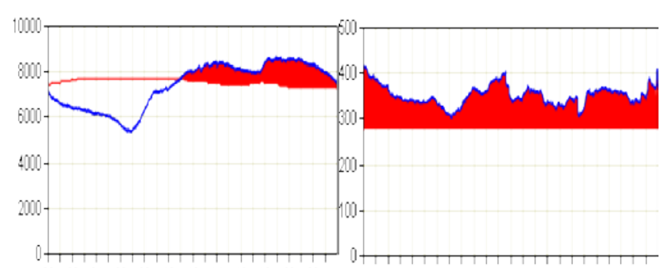

Fig. 2 Edelca export MW/day   Fig.3 CADAFE Import MW/day

The above causes imply that [6]:

- Any contingency in a 765 kV line would generate a collapse under maximum demand, as well as contingencies in 400 kV lines due to transmission limits;
- In fact, failures above 100 MVA have increased from 35 in 1999 to 337 in 2010, that is, ten more times in that period (Table 2);
- Voltages out of range are present: 18% at 230 kV, 44% at 115 kV, and 45% at 69 kV, completely violating allowed voltage variation standards (see Section II);
- Strong variation of the system's nominal frequency (60 Hz) during the daily operation (Fig. 4);
- Overloaded transformers at 230 kV are 16%, and more than 41% operate with a load above 80%;
- 37% of the substations have non-firm capacity; hence a loss in the transformer causes load rationing.

Replacement and installation of the necessary thermal backup in the Central and Western Region of the country is required in order to reduce export-import levels from Guayana (Southeast-Edelca), increase transmission capacity at 765 kV and 400 kV, and increase transformation capacity in all systems, including 115 kV.

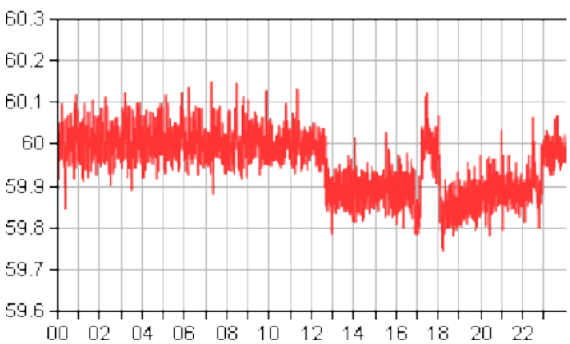

Fig.4 Daily frequency variation

The essence of a hydrothermal system is the thermal backup provided for the handling of hydraulicities by the hydroelectrical system during dry seasons. This was a concept totally and continuously put off by the Government during the last decade with the purpose of reducing the political cost implied in any rationing program. Unfortunately, due to that irresponsible and political handling of the Guri Dam, the probability of collapse is increasingly

.

A review of the 2001-2005 period revealed that CADAFE only executed 24% of the 643 Km of lines it was supposed to execute during that period, that is, 155 Km.

Table 2 Number of interruptions higher than 100 MVA

Year	Interruptions
1999	**35**
2000	55
2001	52
2002	44
2003	56
2004	52
2005	86
2006	92
2007	113
2008	151
2009	339
2010	**337**

The lack of *maintenance* during the last decade is particularly noticeable in the case of a thermal power park with 38% participation (9,087 MW) in the total installed capacity (23,708 MW) but with present unavailability above 57% (5,180 MW). The most pathetic and illustrative example is Planta Centro, with five (5) units installed, 400 MW each, and operating today with only two (2) machines that together slightly exceed 550 MW.

Additionally, as already mentioned, more than 80% of the units are over 25 years old and efficiency is only 28%. There is evidently an urgent need to recuperate 80% of the present thermal power park with high-efficiency combined-cycle technologies.

Perhaps the most critical factor in the present electricity crisis is the lack of knowledge of the value of water, evidenced in the irresponsible operation of the Guri Dam since October 2009, when Caroní River flow contribution was insufficient, going to the extremes of using turbines to produce more than 5,000 m3/second when affluent do not reach 20% of the volume produced with the turbines.

The driest hydrological year for the Venezuelan electrical system was 2001 and the most severe dry season (January-April) was in 2003 when the Guri Dam reached its lowest level (244.55), and there was however, no rationing. Present rationing responds to transmission limits aggravated by the fact that operation is well above such limits (Figs. 2 & 3). The year with the highest historical hydrology for the Caroní River was 2010, and since October of that same year, daily rationing ranging from 300 to 600 MW has been applied throughout the country.

V.3. DISTRIBUTION

Until 2007, 11 electric utilities coexisted in CAVEINEL-Venezuelan Electric Industry Chamber: 7 private companies and 4 public companies. From those 11, the 4 public companies (Edelca, Cadafe, EdC and Enelven) as well as two private ones (Eleval and Seneca) were companies vertically integrated with generation, transmission and distribution. In 2007, the Government nationalized the entire private electricity sector, i.e., the entire SEV became public since 2007. Today [7][8] :

- From the 402 distribution substations, 34.5% are over 30 years old and 54% (219) faces voltage variation problems or has non-firm capacity (Fig.5);
- 36% of transformers and 43% of circuits are overloaded (Fig.6);
- From the 3,902 circuits, 60% equivalent to 2,341 present overload, voltage variation, or interruption problems, or are obsolete;
- Distribution system performance is compromised by illegal connections;
- Voltage profiles are out of range in all systems;

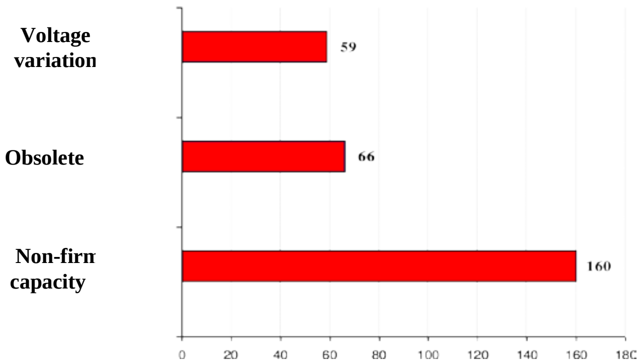

Fig. 5 Number of substations with a deteriorated service

- There is a large number of interruptions in all states of the country for a national average of 25.22 hours per year ;
- Until 2007, only the private companies [9] had control on fast voltage fluctuations (flicker) and harmonic distortion.
- Large deficit of revenues obtained from a frozen rate since the year 2000, lack of information and obsolescence;
- Losses exceed 38% of generated power, equivalent to the system's total thermal generation;
- Significant decrease in SEV's billing efficiency (25%);
- Instability of the companies' commercial management systems;
- Incompatible commercial management systems;
- Deficient information that hinders effective analysis and decision making.

It is necessary that the Government attaches the corresponding importance to distribution as the last link in the chain of the electric system responsible for power supply to consumers, and assigns professional and experienced personnel for its management. Unfortunately, the Government did the opposite; it nationalized the most important distribution companies in the sector and immediately politicized and unprofessionalized them. Three years after nationalization, these companies are as inefficient as the public ones.

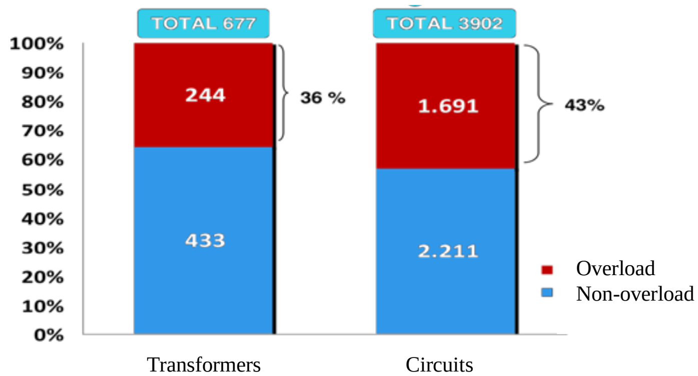

Fig. 6 Overloaded transformers and circuits

VI. ECONOMICS OF VENEZUELAN POWER SYSTEM RELIABILITY

The economic worth of reliability reflects the effects on the electricity demand i.e. the economic costs incurred by electricity users because of power shortages due to the un-serviced energy (USE) [10]. It is a conventional approach to measure the damage caused by the USE to the economy in terms of a certain monetary value, the OC-Outage Cost.

Based on the last demand forecasting published by the National Management Centre in its 2006 Annual Report [11], covering a five years period, the expected lower growth rate of energy demand was 3% for that period.

Since the energy consumption in year 2009 was 123.075 GWh, the expected energy demand in 2010 [12] was 126.767 GWh. Number of states actual energy consumption in 2010 (114.859 GWh), the electricity crisis peaked in that year with an un-serviced energy of 11.908 GWh (ca. 12 TWh) which represents ca. 9% of the expected energy demand. Almost 60% of the 2010 un-serviced energy corresponds to the load rationing imposed upon to the basics industries (aluminum, iron and steel) located in the southeast of the country near Guri, the biggest hydro reservoir in the country (52 TWh).

The last estimation of Venezuelan outage costs [13] reported a range of 1.97-2.38 US$/kWh, being the lowest value a reference to the national aggregated outage cost and the upper one to the aggregated value for all economics sectors. Assuming US$2 being the cost per kWh of un-serviced energy, it results in an estimated cost of US$23.8 billion attached to the un-serviced energy in Venezuela for year 2010, it amounting to ca. 7 % of the Internal Gross Product (viz. US$340 billion [14].

Regarding the assigned resources, it is enough to know that during the period 1999-2009, some US$35 billion were assigned to the electric sector between ordinary assignments, additional credits, and via the electric invoice.

VI. CONCLUSION

The culture of electric power quality service is evidenced in the manner in which electric utilities operate. The good operating performance of the company then reflects the cultural elements present in it: criteria, planning, operating efficiency, skills, knowledge, background, routines, standards, policies and procedures. If these aspects, which are the basis of a power quality service culture, are not present in the electric service regulating institutions, the main challenges to overcome are not those merely technical aspects derived from flickers and harmonic distortion, but those derived from the sector's institutional crisis.

Among the multiple factors that, throughout the 1999-2010 period, caused and continue deteriorating Venezuelan SIN's operation, but which may equally affect the electrical service in any country are:

1) Total absence of coherent *planning* not guided by subjective factors and improvisation;
2) Inability and total inefficiency in the *execution* of the works in general;
3) Total neglect of *maintenance* required in highly complex systems, such as the electric system;
4) Irresponsible ignorance of the *value of water* and operation of a hydrothermal system with high participation of hydroelectricity;
5) Waste of the huge amount of *economic resources* assigned to the SEV; and
6) Loss of electric sector institutions.

Therefore, the crisis the Venezuelan electrical system is going through turns the problem of lack of reliability on the service into a structural problem. The crisis is due to mismanagement in the planning, operation and maintenance of the electric system, and to the Government's inability to execute the required infrastructure works, and not only to the El Niño phenomenon. The lesson to be learned from the current disaster shall be on the firm resolution not to repeat the same mistakes by those assigned the reestablishment of the electric power supply reliability and continuity.

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