Feasibility Study of the Installation of Distributed Generation for Improving Voltage Stability

L. N. Ballester, J. Castillo, J. Durán, M. Dávila, J. Hernández

Abstract**-- In Venezuela, installation of power generation units of small and medium power requirements provides a way to improve the electrical service reliability and thus the power quality keeping the network technical parameters within acceptable levels. The main goal of the work presented here is to study the feasibility of installation of distributed generation (DG) in "La Fria II" Substation of the State of Tachira to improve the system voltage stability. Specifically this work looks for making a contrast between different scenarios that include interconnecting DG or interconnecting turbo generator in order to improve voltage profiles and guarantee the system stability. The approach here is the sequence of the following analyses: Continuation Power Flow, determination of P-V and Q-V curves and modal analysis.**

The results indicate that the best alternative to guarantee voltage stability in "La Fria II substation" is to consider the addition of two turbo generators and compensation, because it is the most robust solution for improving the voltage in all system buses.

Keywords**: Distributed generation, voltage stability, continuation power flow, P-V, Q-V curves, modal analysis.**

I. INTRODUCTION

During centuries the use of the electrical energy has represented a very important role in societies and their development. This has allowed the improvement of the systems that make the use of electrical energy possible. For decades and until the present time, the use and control of the electrical power are surely the source for the development and the base for productive and economic systems at the world-wide level. The continuous increase of the electrical demand has required the growth and the adaptation of the systems, having formed structures of greater complexity, capacity and penetration [1],[2].

The electric power system is structured in several fundamental subsystems, the more important are: the system of generation, the system of transmission or power networks, the distribution substations, the system of distribution and the center of consumption or load.

In Venezuela the generation of electricity comes in almost its totality from hydroelectric power, being the hydroelectric power station Simon Bolivar (also called Dam of the Guri), the one of greater capacity, providing approximately 70% of the electrical energy of the country. Dependency on this dam for provision of electrical energy in Venezuela is of great importance, for that reason when by natural causes the water level of dam decrease considerably, it affects significantly the generation of hydroelectric power, putting at risk the generation-load balance and thus leading to a point of planned blackouts.

Venezuelan electric energy policy has been focused lately in improving and the reliability of the electrical service and thus has settled plans to deploy distributed generation through out the country.

Distributed generation, generally it is understood as a decentralized generation composed by one or several generation units of small capacity using groups or individual units connected directly to the distribution network and as near as possible to the consumption center. Their maximum capacity does not surpass 60 MVA [3]. However, IEEE standard 1547 [10], defines DG as electric generation facilities connected to an area electric power system through a point of common coupling; or a subset of Distributed Resource, which are sources of electric power that are not directly connected to a bulk power transmission system [10].

Thus, the present paper is intended to conduct a study in the State of Tachira (western Venezuela), in "La Fria II" Substation (S/S), where it turns out from great interest to maintain the electrical parameters within national standards and thus to guarantee the reliability and continuity of electrical service since it feeds important circuits; as well as to study the

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impact in all buses of 115 kV level. Specifically, this study looks for establishing the best solution (13.8 kV or 115 kV) for the installation of Distributed Generation with reactive compensation or not.

II. SYSTEM DESCRIPTION

The interconnected national power system can be appreciated in Fig. 1, that shows the distribution of energy by region, the provision of energy of the country starts for the east with lines of 230 and 400 and 765 kV from the Guayana substation, crossing the Bolivar substations and "El Tigre" being these of greater impact. For the central region there are two networks of 400 kV without interconnection among them, the first one between the substations: "San Jeronimo – Santa Teresa – Ciudad Lozada" and the second one between "La Horqueta – La Arenosa – Planta Centro – Yaracuy". For the western region, the energy is exported from the Yaracuy substation in 765/400/230 kV by means of three lines of 400kV and one double circuit in 230 kV to "el Tablazo", that arrives at "Las morochas II" to feed the Andean region in 230 kV through the "Buena Vista" substation. From there, the power goes through "El Vigia II – Uribante substations and finally with two lines of 230kV that arrive in the substation the "Corozo" in the State of Tachira [4].

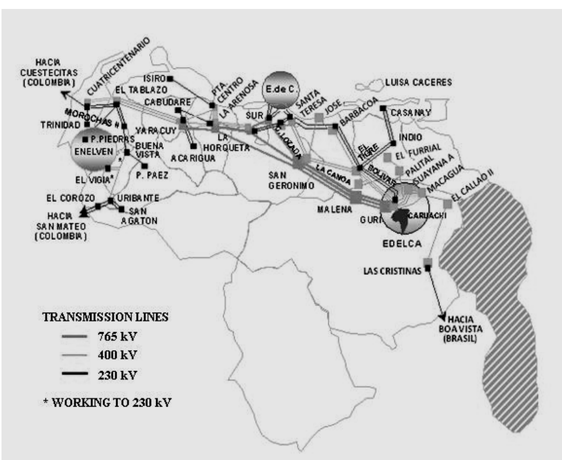

Fig. 1. Interconnected electrical national system (SIN) [4].

In view that the demand of the country cannot be satisfied only by hydroelectric generation, thermo electrical generation centers of considerable capacities exist in order to maintain the balance between generation and demand.

Besides this, the national electrical system has been affected by multiple problems during the past few years, as the reduction of water level of the Guri dam, the loss of generating units in many generation centers, the loss of transmission lines of energy, among others, forcing to realize cut off in the electrical supply; therefore, as a temporary solution to this situation, it has been required the installation of distributed generation with the purpose of improving the electrical quality and of keeping the voltage profiles within acceptable levels.

Description of the influence area.

"La Fria II" substation, is a substation of nodal III type, with arrivals of two lines of 115 kV ACAR 350 MCM conductor, which is formed by one double circuit of 5 km coming from Tachira power plant, a double circuit of 53 km towards of the S/S San Antonio and a double circuit of 80.7 km for the S/S Vigia I. "La Fria II" substation has two (2) transformers of 115/34,5 kV of 20MVA with a circuit breaker normally closed (N.C) to connection with the bus, feeding five (5) circuits of 34.5 kV, and two transformers of 20 MVA of 115/13.8 kV connected in parallel with five (5) circuits in 13.8 kV as can be observed in Fig. 2 [4].

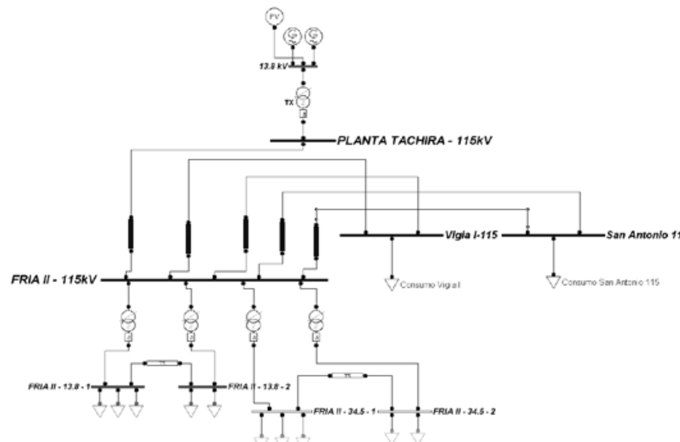

Fig. 2. Unifilar Diagram La Fria II Substation.

Tachira plant feeds "La Fria II" substation by means of two lines in 115 kV directly and the behavior of this substation depends strongly on the condition in which is the thermo electrical plant. This plant consists of fifteen (15) units of generation or turbo generators which burn fuel to generate electrical energy. These generating units generate directly in 115 kV through an elevating transformer of 13.8/115 kV with neutral tap, and the current status of the generation plant can be appreciated in Table I [4].

Besides the two lines that leave Tachira Plant toward "La Fria II" substation, also there are two lines of 25 km in 115 kV which leave from this plant towards "La Grita" substation, one line of 37 km towards "Palo Grande" substation and one line of 49 km towards "San Cristobal II" substation, which besides to receive energy of this plant, it receives power also through "Corozo" substation, that by means of a 230/115 kV transformer has connection with "Uribante" substation and from there with lines of 230 kV it receives energy of the hydroelectric power station of "San Agaton" in normal conditions.

TABLE I
BASIC CHARACTERISTICS OF TACHIRA PLANT GENERATORS [3]

TP	GU	Power [MVA]	Pg [MW]	V [kV]	fp	In [A]	Actual condi-tion
Tachira I	1	-	-	-	-	-	D
	2	-	-	-	-	-	D
	3	20	11	13.8	0.85	1194	Op
	4	-	-	-	-	-	D
	5	20	11	13.8	0.85	1194	Op
	6	20	0	13.8	0.90	1250	Os
	7	20	8	13.8	0.90	1250	Op
	8	20	8	13.8	0.90	1250	Op
	9	20	12	13,8	0,85	1194	Op
	10	20	0	13,8	0,85	1194	OS
Tachira II	11	20	8	13,8	0,85	1194	Op
	12	20	8	13,8	0,85	1194	Op
	13	-	-	-	-	-	D
	14	20	0	13,8	0,85	1194	OS
	15	70	31	13,8	0,90	3175	Op

D: Desincorporated
Op: Operative.
Os: Out of service

In order to conduct this study, it is considered a capacity of 22 MW of effective generation when DG is working to a 75% of its total capacity. The DG is connected to the buses of 13.8 kV in "La Fria II" S/E or in Tachira Plant in 115 kV. The study tries to determine what will be the most appropriated location of these plants of distributed generation in order to see the impact on the buses and lines, as well as to improve the voltage profile. Other alternative is to carry out the study with the turbo generators (TG) and the compensation looks for replacing in its totality the plants of distributed generation, because of TG present greater robustness can operate in continuous regimen, they have an easier control, do not require continuous supervision and they are more stable. The compensation would be a shunt compensation of 12 MVAr installed at the 115 kV level in Táchira Plant.

The single line diagram used to make the study is shown in Figure 3, where it is possible to view the representation of DG.

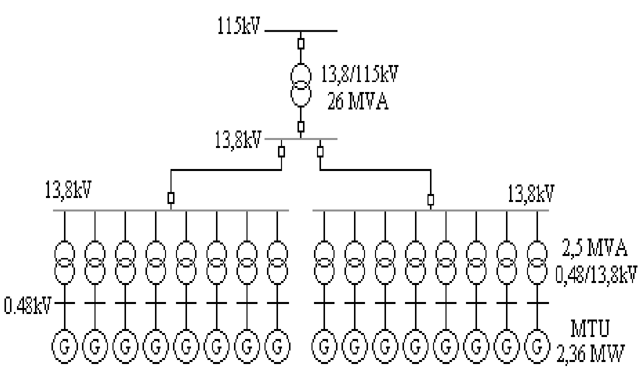

Fig. 3. Single line diagram of DG for stability study.

III. VOLTAGE STABILITY ANALYSIS

Voltage stability is the capacity of a power system to maintain the constant voltages in all the buses of the system after the occurrence of a disturbance, for a given initial condition. So that it exists instability of voltage in a system is only needed that a single bus would be unstable [5],[6].

A system becomes unstable when a disturbance increases the demand of the load, or changes to the conditions of the system causing a progressive and uncontrollable fall or ascent of voltage in some buses. Some possible results of the instability are the load drop in an area, or the outage of a transmission line and other elements by their protection systems.

Voltage instability takes place in an intrinsically weak system. The causes of the voltage instability are diverse; some authors indicate that the main factors that contribute to the voltage instability are [5]-[7]:

- Lack of provision of reactive power to the network.
- Control of the voltage limits.
- Characteristics of the load.
- Answer of the reactive adjusting devices.
- Actions to control the system voltage, *e.g.* transformer taps.

The voltage collapse is the process during which a sequence of events accompanied by voltage instability leads to the collapse or abnormal low voltages, outside the established limits, in a significant part of the power system.

The event that initiates the process can be due to several causes: small gradual changes in the system like increases in the load of the system, or a sudden disturbance like the loss of a generation unit or a transmission line considerably loaded. [5], [8].

For the study of stability of a power system it is necessary to follow a series of steps and to have the suitable considerations to obtain correct results, these steps and considerations are:

1. To define the zone of interest of the system of power and the reach that this presents, all the zones of impact as well as the components of the system that are outside the zone of study to model them by their respective equivalent networks.
2. Simulating the system using specialized software that allows realizing power flow studies and analysis of voltage stability; for this case, two computer softwares are used, they are: DigSILENT® and PSAT, both allow to include all the components of the network in study like generators, buses, transmission lines, transformers, capacitor banks and equivalent networks.
3. Modeling external networks that will be of the part of system under study through equivalent networks in a specific point of connection.

4. To identify the types of buses in the system, the reference bus or Slack bus, PV bus, PQ or compensation bus. Besides, data of other components must be collected such as generation, types of lines, types of loads and the current status of the system.
5. To determine the values of active and reactivate power that loads are consuming, as well as, if they have some type of compensation for the condition of operation of the system under study.
6. Realizing the network under study in the particular software, to calculate the power flow and to tune the simulation in order to have results according to the real behavior of the power system.
7. Once the power flow agrees with the real system values, the voltage stability studies are performed determining the condition of the system as well as its requirements for improvement.

Methods used for voltage stability studies are mention next:

A. *Continued power flow*

This method is a mathematical tool for the calculation of trajectories of state variables in systems of one or more parameters. Its objective is to look for continuous solutions of the power flow for variation between generation and load [2]. The trajectory that is generated is illustrated in Fig. 4, the trajectory is known as the P-V curve, where P stands for power and V for voltage. The availability of this information for all the buses of a power system provides information that allows a variety of studies.

The method of Newton Rapson for the calculation of a conventional power flow is the base of the continued power flow method since with small modifications of system loadability are managed to find the trajectories from the set of differential equations [9].

B. *Method of P-V and Q-V curves*

The analysis of the P-V curve, is the more used method for the prediction of the loadability margin due to voltage stability and the critical point of load voltage collapse. This curve allows determining the range between the present system loadability conditions and the condition that generates a critical voltage.

Using the P-V curve it can be determined how far is the point of voltage collapse and with which factor of power operates and not being able to elevate the tension by means of some contingency, to know what must be the condition to reach to manage and maintain the suitable voltage profiles, and if it is the case, to design the necessary type of compensation.

In contrast, the method of Q-V curve allows by means of a series of successive simulations of power flow to project the voltage in an anyone bus and to know its state for determining if it is a critical bus, thus to be able to consider the proximity of the voltage levels to the point of collapse with variation of the reactive power in the same bus.

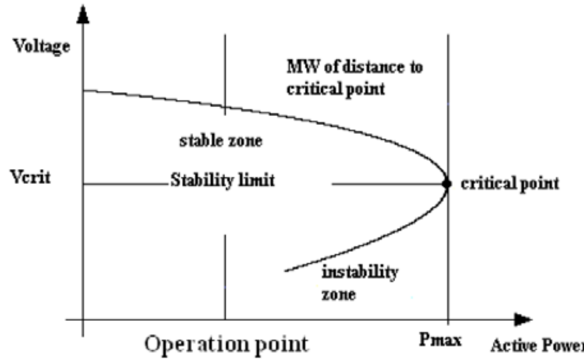

Fig. 4. Characteristics of PV Curve for a simple power system.

This method is typically used as an imperative tool for analysis of voltage stability. Additionally, it is used to establish criteria for designing, modifying of the topology of the network, load studies, compensation and to maintain the voltage profiles and reactive power within national electrical standards [2].

The Q-V Curve indicates the amount of reactive power that must be injected or be retired of the bus so that this can maintain the voltage level in its suitable value, allowing the system to extend the MW rank towards the loads. Fig. 5 showed the behavior of curve Q-V for the bus of a simple power system and in addition the amount to information that this curve can provide, like the limit of stability or critical point that appears when dQ/dV becomes zero, which modifies when varying the factor of power of the load, PR_{max} which is the maximum active power that can be transferred to the load with a power factor equal to the unity. [2], [9].

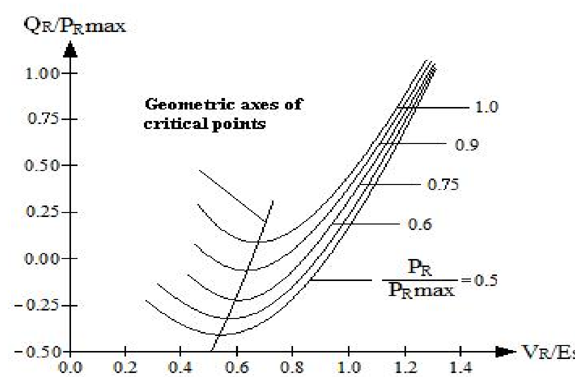

Fig. 5. Characteristics of Q-V Curve for a simple power system.

C. *Modal analysis*

This method was proposed by Gao, Morrison and Kundur in 1992, calculates the specific number of eigenvalues of the reduced Jacobean matrix, the associate minors and their eigenvalues using a method of stationary state of the system.

Each one of the voltage eigenvalues is associated with a way of variation of reactive power which offers a measurement relative of the proximity of the voltage instability. On the other hand the eigenvalues describe the mechanisms of loss of stability like the elements of the network as buses, lines and generators that participate in each mode [2],[7].

This method this strongly related with the sensitivity of the Q-V curve of a system, thus a system is stable in relation to the voltage, if the index of sensitivity Q-V for each bus is positive and unstable if the index Q-V is negative for at least one bus of the system. The modal analysis depends on the Jacobean matrix of the power flow equations [5].

D. Q-V sensitivity analysis

In a power system, the Q-V sensitivity analysis is conducted by observing the slope of Q-V curve for a specific bus. The value of sensitivity indicates how stable is the system, i.e. if sensitivity is positive, it is an indication that the system is stable. In contrast, if the value of sensitivity is negative, it indicates that the system operates in an non-stable state, having an infinite sensitivity in the stability limit.

IV. Scenarios

The stability studies are presented here using different scenarios that represent diverse alternatives to the use of DG for the power system under consideration. Operating conditions for each generator are: supply only active power at constant power factor, this is a typical operation mode established by the standards. A more detailed explanation of the scenarios is presented next:

A. Normal condition or Base case (BC): It is the basic scenario, it represents the condition of system at maximum demand, it is the most critical condition of the system. Other scenarios are based upon it.

B. Distributed Generation installed at the bus of 13,8kV of S/S Fria II (DG13,8): This scenario represents the impact that produces on the power system the installation of distributed generation plants in the bus of 13,8 kV of Fria II S/S with percentage of generation of the 50% and 75%.

C. Distributed Generation installed at the bus of 115kV of Táchira Plant (DG 115.): This scenario represents the impact that produces on the power system the installation of distributed generation plants in the bus of 115 kV of Tachira Plant with percentage of generation of the 50% and 75%.

D. Turbo generators installed at the bus of 115kV of Tachira Plant (Turbo): This scenario represents the impact that produces on the power system the installation of two (2) turbo generators at the bus of 115kV of Tachira Plant with percentage of generation of the 50% and 75%.

E. Turbo generators and reactive compensation installed at the bus of 115kV of Tachira Plant (Turbo+Comp): This scenario represents the impact that produces on the power system the installation of two (2) turbo generators and a reactive compensation bank of 12 MVAr at the bus of 115kV of Tachira Plant with the turbo generators operating at 75% of its nominal capacity.

With these scenarios, the main goal is to compare which of them represents the best alternative for solving problems of voltage stability in "La Fria" town and all Tachira State. In addition, for each scenario, the paper also looks for evaluating what is the impact of DG plants on the actual power system taking in to account their operating conditions. Additionally, from these scenarios, it can be obtained a technical evaluation related to interconnecting DG in different voltage levels contrasting with alternative of installing turbo generators which besides to represent a more expensive solution (last one), it would permit supply more active power even it permits the possibility to supply reactive power.

V. Results

Results obtained from all scenarios revealed that DG installed at the 13.8 kV level and the alternative of Turbo generators plus compensation represent a better option for improving voltage stability in the area of influence. This situation can be observed in Fig. 6, which shows that in "La Fria II 115 kV" bus, with DG 13.8 and Turbo + C scenarios, voltage and loading parameter improve in comparison with the base case, having the possibility of taking the loading parameter near to a bifurcation point at 1.8 per unit (p.u.) in the base case to a situation with a voltage of 0.99 p.u. which is within of acceptable levels of network technical parameters.

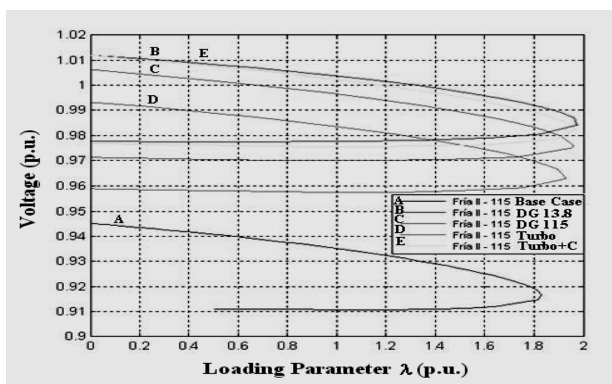

Fig. 6. PV curves at the Fria II 115 bus, for all scenarios considered.

On the other hand, in Fig. 7, it is shown a Q-V curve for the reactive power requirements are needed for maintaining the voltage within acceptable levels. In this figure, it is shown that “DG 13” scenario represents the better behavior for the system under study, because of to maintain the voltage at 1 p.u., DG13.8 does not require any additional compensation. However, Turbo +Comp scenario has a similar behavior when compared to DG13.8, with the difference that for obtaining it, it is necessary to install a compensation of 12 MVAr.

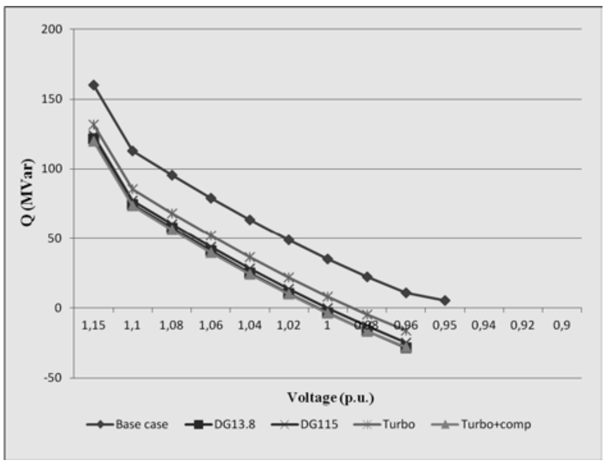

Fig. 7. Q-V curves at the Fria II 115 bus, for all scenarios considered.

Results of Modal analysis method are presented in Table II, which contains the eigenvalues for all more representative buses. In the more significant scenarios emphasizing that all eigenvalues only have a real component, being cero its imaginary part in all cases. Can be observed that mean while the eigenvalue is more distant to cero, the voltage stability is improved.

TABLE II
RESULTS OF MODAL ANALYSIS FOR MORE SIGNIFICANT SCENARIOS CONSIDERED

Eigenvalue	Associated bus	Real component Base case	Real component GD 13.8	Real component Turbo + comp
Eig Jlfr # 1	Vigia I-115	317562,9262	343316,996	342767,254
Eig Jlfr # 2	San An 115	275327,568	293101,909	292912,981
Eig Jlfr # 3	SC. I 115	274703,6624	290694,653	290851,534
Eig Jlfr # 4	FII-34.5 - 2	274844,8266	295926,876	295476,037
Eig Jlfr # 5	Corozo 115	190453,2182	199429,241	199499,285
Eig Jlfr # 6	LG 115	185083,0207	197504,21	197657,654
Eig Jlfr # 8	FII-13.8 - 2	181179,397	202370,1	195075,017
Eig Jlfr #11	FII-34.5 - 1	91615,71636	98643,1292	98492,8482
Eig Jlfr #14	Uribte 230	300,96153	305,42991	305,46476
Eig Jlfr #16	FII - 115	118,21087	126,93444	126,71642
Eig Jlfr #17	Corozo 230	93,14402	96,97721	97,00723
Eig Jlfr #18	Corozo 230	57,99777	60,00564	60,02138
Eig Jlfr #19	San Ag G2	38,18274	38,73096	38,73513
Eig Jlfr #21	Uribte 115	22,11057	22,39046	22,39273
Eig Jlfr #22	P. Gde 115	18,22194	19,19545	19,20489
Eig Jlfr #23	San Ag G2	16,73146	16,49276	16,49089

After analyzing the obtained results, it is necessary to compare them to identify what is the best solution. Therefore, it is decided to make an evaluation of the better scenarios by using metric indexed. Specifically, it is desirable to evaluate in a quantitative way what of alternatives of solution between DG13.8 and Turbo +Comp would be the best. In order to accomplish this goal, it has been considered to use the following techniques: (1) the first one is to compare them using the maximum and minimum deviation of the voltage in each bus with respect the nominal value 1.0 p.u.; (2) the second one is using a metric known as Total Mean Quadratic Error (TMQE), which is the total addition of the quadratic deviation of the voltage in each bus with respect to the nominal voltage of 1 p.u.. These techniques are implemented using the voltage profile of the more representative buses of the power system. In Fig. 8, the voltage level in buses for all scenarios considered is represented.

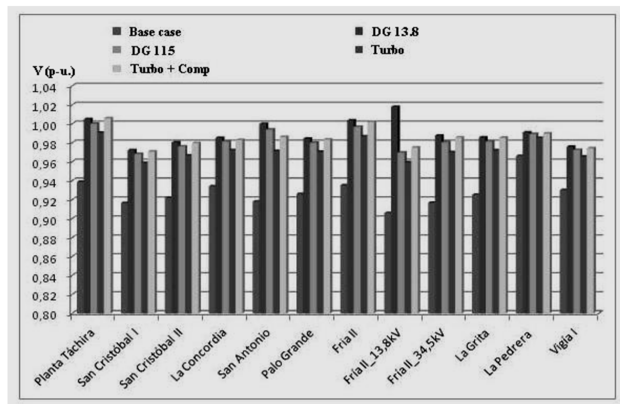

Fig. 8. Voltage profile in the more significant buses for all scenarios considered.

From Fig. 8, it can be observed that there are two scenarios that offer better voltage profiles for all buses, they are DG13.8 and Turbo + comp. With the results of voltage profile of these scenarios, it will be compared with the base case, the DG13.8 and the Turbo + comp scenarios using techniques before mentioned. The comparison is presented in Table III.

TABLE III
SCENARIOS COMPARISON INDEXES

Index	Scenario		
	BC	DG13.8	Turbo + comp
TMQE	0,0751	0,0059	0,0069
V_{MIN}	0,9060	0,9635	0,9618
V_{MAX}	1,0013	1,0239	1,0227
IQR	0,0205	0,0237	0,0177

Considering the TMQE index, DG13.8 is lower than Turbo + comp; this shows that this alternative is better than the other. When analyzing V_{MIN}, it can observe that DG13.8 again is the best option, because that index is the highest value and represents the lowest deviation between voltage profile in each bus and the nominal voltage (1 p.u.). When analyzing V_{MAX}, it is noticed that Turbo + comp is the best option, because that index is the lowest value and represents the lowest deviation between voltage profile in each bus and the nominal voltage (1 p.u.). On the basis of these results, it can be determined that DG 13.8 is the best option for improving voltage stability, however, it is precise to make an analysis about the dispersion of the voltage in each bus with respect to nominal value, since it is very important to have a smaller dispersion of these values. Therefore, the interquartile range (IQR) is analyzed and in fact this index shows that the smaller dispersion of the rank of values is in the alternative Turbo + comp. With this important result it has a greater accurateness to asseverate that the best option is installing Turbo generator plus reactive compensation.

For the different scenarios it is a remarkable fact that the distributed generation improves in to a great extent the voltage stability of the system, pronouncing itself like the best option over the other scenarios, however, due to the difficulty that present DG machines to maintain a stable operation condition and the efficiency of all the group, another more robust solution is considered. As a matter of fact, the result give indication that replacing of all group of distributed generation for turbo generators in Tachira Plant and the necessary the use of compensators appear as a solution that is studied in detail.

VI. Conclusions and Recommendations

- The network working in conditions of maximum demand represent the limit of voltage stability, which can generate load shedding to prevent that the system approaches a point of voltage collapse that it prevents to recover the system.
- Distributed generation is a good alternative to improve the voltage stability of the system, but it does not have the capacity to stay in continuous operation. It is useful during hours of maximum demand.
- Distributed generation as well as the turbo generators installed in “La Fria” Substation at the 115 kV level, in spite of improving the voltage stability, are not the best option to be used in condition of maximum demand.
- Turbo generators plus a capacitive compensation of the system provide good results and it is the best alternative to guarantee robustness in the voltage stability of the system in conditions of maximum demand.
- Buses of “La Fria” substation II, improve in a great extent the voltage stability for anyone of the scenarios.
- The margin of voltage stability is increased with respect to the normal condition for all considered scenarios, moving the point of voltage collapse and making to all buses stable but when varying the load.

In order to obtain new and important results, the authors recommend:

- To develop studies for the optimal relocation of the distributed generation plants.
- To maintain update all power system with respect to the changes in the topology of the network, as well as update of the generation systems, transmission, distribution and load.
- To realize specialized studies concerning the incorporation to the system of distributed generation, to maintain the efficiency of the machines and the adapted operation.

VII. Acknowledgment

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VIII. References

[1] Arreaza C. Alex D., (2008). Feasibility study for the installation of distributed generation at the Electricity of Caracas Company. University Central of Venezuela, Venezuela, 2008. [Online]. Available: http://saber.ucv.ve/jspui/handle/123456789/1364.

[2] Segura S. Cresencio S. Determination of the critical point of voltage Collapse in interconnected electrical systems. National University of Engineering, mechanic engineering faculty. Lima, Peru.

[3] Ceballos L. Mariana, Gallego R., Hincapié R. (2010, Apr.). “Improvement of the Voltage Profile in Distribution System using Distributed Generation”. Scientia et Technica Año XVI. No 44. University of Technology of Pereira. [Online]. Available: http://revistas.utp.edu.co/index.php/revistaciencia/article/view/1757/1167.

[4] CORPOELEC (2011). Corporación Eléctrica Nacional. Departamento de Planificación.

[5] Kundur, P. Power System Stability and Control. Electric Power Research Institute. McGraw-Hill Inc. 2006.

[6] Kundur P., Paserva J., Ajjarapu V., Andersson G., Bose A., Cañizares C., Hatziargyriou N., Hill D., Stankovic A., Carson T., Van Cutsem T., Vittal V. (2004, May). “Definition and Classification of Power System Stability”. IEEE/CIGRE Joint Task Force on Stability Terms and Definitions. IEEE Transactions on Power Systems, Vol. 19, NO. 2.

[7] Gong, Bo. “Voltage Stability Enhancement via Model Predictive Control”, Doctoral Thesis dissertation. University of Wisconsin – Madison., 2008.

[8] Philip P. Barker. “ Determining the Impact of Distributed Generation Power System: Part 1 – Radial Distribution System”. in Proc. 2000 IEEE Power Engineering Power Society Summer Meeting. Conf., pp. 1645-1656, vol. 3. [Online]. Available: https://filer.case.edu/dav/cxw166/Written%20Document/Solar%20Research/Distributed%20Generation.pdf

[9] Nava M. Carlos O. “ Study and analysis of voltage stability of Sub transmission- distribution network of Merida city using PSAT.” Graduated dissertation. Dept. Power. Eng., Univ. of Los Andes, Mérida, Venezuela, 2011.

[10] IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems. IEEE Standard 1547 – 2003, July 2003.