STATIC VOLTAGE STABILITY ANALYSIS FOR ELECTRIC SUBTRANSMISSION SYSTEM

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ABSTRACT

The study of voltage stability as indicated in the Philippine Grid Code (PGC) is the center of this paper. Standards and industry practice for voltage stability problem-solving are cited and were referred when provided an example simulation. Voltage stability is a must when looking at a power system if it can handle load growth and at the same time maintaining acceptable voltage levels at all system nodes. The static voltage stability simulation utilized practical solutions for voltage instability which are discussed and evaluated using Power-Voltage (PV) and Voltage-MVAR (VQ) curves. This report serves as a tutorial for practicing electrical engineers on the important topic of voltage stability analysis.

Keywords: voltage stability, load growth, power system planning, reactive power compensation

I. INTRODUCTION

Voltage stability analysis is a branch of power system stability evaluation required to determining the capability of a power system to handle heavy loads or system disturbance and yet maintain voltage level within acceptable limits and avoid voltage collapse [1]. Voltage stability analysis is an evaluation study mandatory for planning and interconnection stated in the Philippine Grid Code (PGC) [2]. This type of study is not mentioned in the Philippine Distribution Code (PDC) [3] but must be made into consideration especially for large and medium distribution area franchises.

Voltage instability in power systems was a new and technical concern since 1990s. The increase of real power at load areas and absence of reactive power support will cause voltage collapse. Several techniques utilizing power flow and time domain computer simulations are utilized to provide a picture of voltage stability level in power systems. References [4]-[5] provide very well-founded theory on voltage stability which will not be repeated in this manuscript. Reactive power compensation requirements to support voltage stability are located and sized accordingly, where static and dynamic reactive power sources are classified. Further, reactive compensation have economic benefits [6]-[7], which are hand in hand done with the technical evaluation. The probable economic benefit of reactive compensation to avoid voltage collapse can be formulated as:

$$C_T = C_C + C_L + C_S + C_A \tag{1}$$

From the formula, C_T is the total savings, C_C is the total savings from added capacity, C_L is the total savings from reduction of losses, C_S is the total savings from shifting reactive power flow to real power flow [7], C_A is the total savings from decrease of reactive power ancillary service.

Voltage stability evaluation is conducted for transmission and distribution systems [4] and recent application was simulated for subtransmission system with wind power interconnection [8]. Western Electricity Coordinating Council (WECC) has provided an industry standard for voltage stability assessment in bulk power systems in United States (US) regional interconnections [9], [10] and [11]. These standards will be followed in this paper and concentrate on subtransmission system as numerical example. The numerical simulation is selected in the light of subtransmission development plans since real power flow is the only consideration in regulatory filings [12]-[13] and voltage stability or reactive power compensation is entirely ignored. The static voltage stability simulation will not consider any disturbance but includes load growth in the load areas in the frame of ten (10) years.

This paper is organized as follows: Section II presents the voltage stability consideration for static and dynamic time frames; Section III shows the example voltage stability simulation; Section IV includes the conclusions and details further recommendations.

II. VOLTAGE STABILITY ANALYSIS

A. Static Evaluation

Power-voltage (PV) curves and Voltage-MVAR (VQ) curves generation are utilized to assess static voltage stability. These techniques are industry standard accepted generally by power system engineers worldwide [4], [5], [9] and [10]. Using continuation power flow (CPF) or standard power flow algorithms, the demand at the load pocket is increase incrementally and the demand in MW and the bus voltage of focus are reported for the generation of the PV curve, as shown in figure 1. The PV curve is analyzed to identify the nose point or voltage collapse point. The impact of a disturbance or reactive power compensation can be evaluated by looking at a PV curve as shown in the said figure. Details of PV methodology are given in [9], [10] and [11].

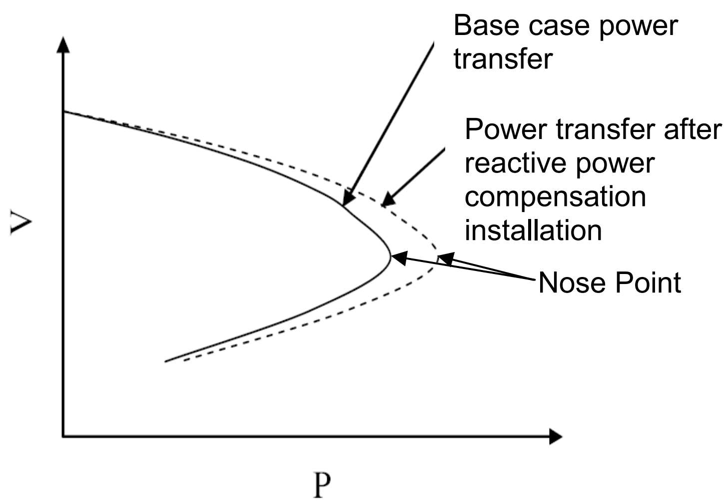

Figure 1. Power-voltage curve for static voltage stability.

Reactive power margin or deficit, as illustrated in figure 2, can be determined by generating the VQ graph. The independent variable, bus voltage, is varied to compute for the MVAR requirement which is the dependent variable. A dummy synchronous condenser is used for MVAR generation at the bus of focus, figure 2.

Standards [9], [10] and [11] detail the procedure for this area of static voltage stability.

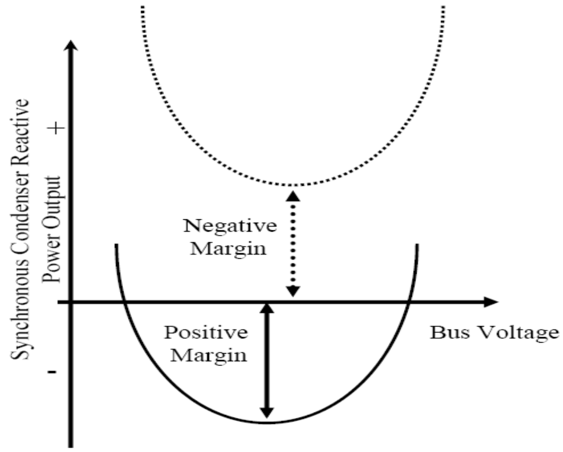

Figure 2. Voltage-MVAR (VQ) curve for static voltage stability [10].

Fixed capacitor banks are the most common type of static reactive power source being utilized in the industry.

B. Dynamic Evaluation

Short term of voltage stability evaluation requires dynamic or time domain simulation. In this study type, the bus voltage of focus is plotted accordingly with simulated disturbance if acceptable as per planning standards. WECC provides an illustration of the dynamic voltage stability planning standard shown in figure 3. Dynamic reactive sources are Static Var Compensators (SVC), synchronous condensers, generators' reactive supply and other power electronic based reactive power sources. Likewise WECC planning requirements state methodology for this type of study.

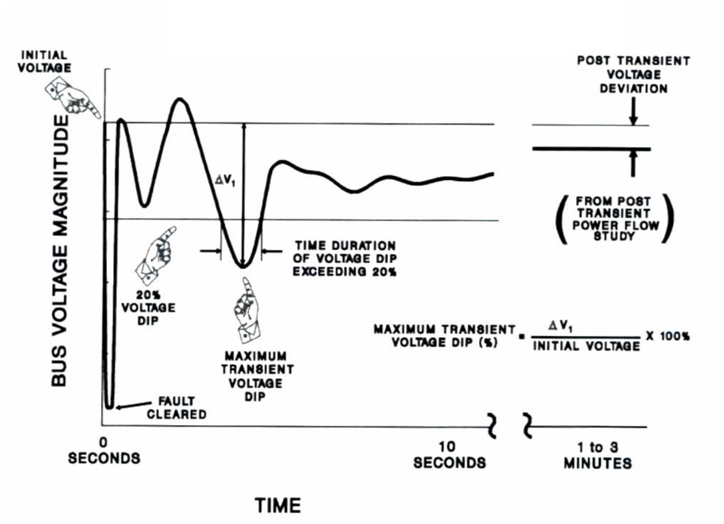

Figure 3. Dynamic voltage performance parameters as per WECC planning standards. (Source: WECC public documents)

III. APPLICATION TO SUBTRANSMISSION SYSTEM

A. Subtransmission Test System

A typical subtransmission system is selected for the numerical simulation. The test system can be considered under a medium sized distribution utility (DU). The system and relevant data are provided in figure 4. For 13.8kV nodal demand, we consider the data cited in [12]-[13] and distribute the load at the three (3) 13.8kV buses.

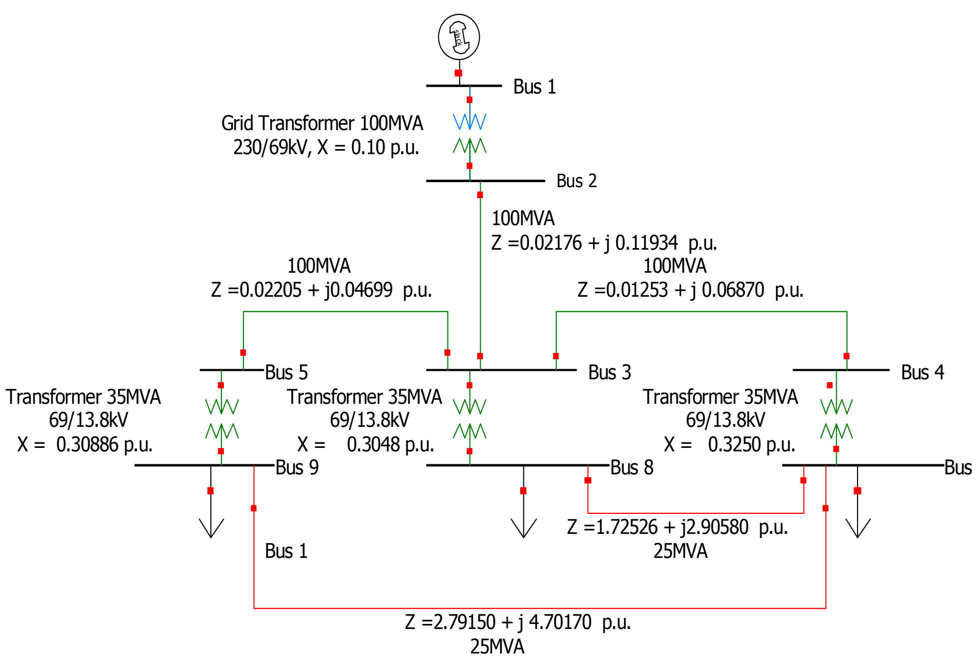

Figure 4. Subtransmission test system and relevant data.

The total demand of the system is 74.6MW at power factor of 0.92 with three percent (3%) increase every year up to 2016, where the demand reaching up to 100MW. The reactive power supplied by these generators plus the fairly good power factor of 0.92, can be assumed to include the capacitors installed in the feeders. For the present year 2007, the power flow base case is shown in figure 5. From the figure, the voltages at the DU's 69kV and 13.8kV buses are below the 1.0 per-unit. This indicates that even with a good margin of line capacity unused, the voltage drop with a significant amount which can be seen as voltage instability. If the demand is increased therefore, the voltage magnitude at the buses will decrease, voltage instability occurs, when no added reactive power source is integrated in the system. In the following part, the PV and QV curves are generated to analyze voltage stability of the subtransmission system using PowerWorld education/demo version [14].

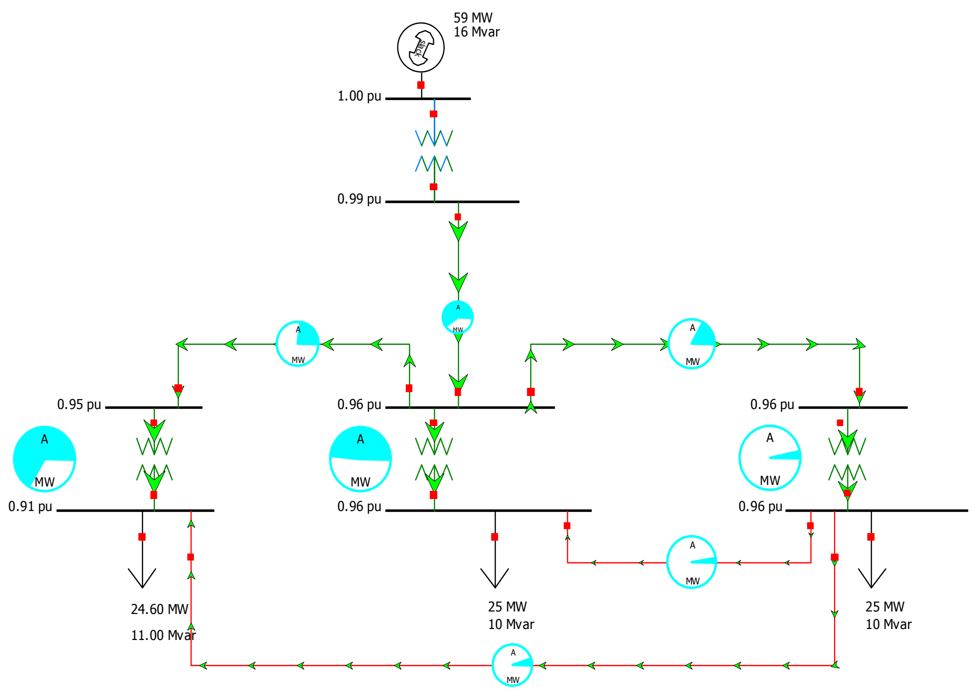

Figure 5. Power flow base case.

In this paper, five cases, including the base case, are presented and were formulated to solve voltage instability in the base case. The following cases, in table 1, are not exhaustive but can be considered in the planning and operations:

Table 1. Simulation cases.

Case Number	Description
1	Base Case
2	Connect a 40MVAR capacitor at bus 3
3	Connect a 40MVAR capacitor distributed at the 13.8kV buses
4	Connect a 40MVAR capacitor at bus 5
5	Connect a parallel and similar 69kV line from the grid to bus 3

B. PV and VQ Results

1. Base Case Results

The simulation for static voltage stability for the base case is shown in figure 6. From figure 6a, the 69kV nodal voltages are observed to be below 0.90 per-unit when the load would be 100MW. In the figure, bus 3 is stiffer than the other buses where buses 4 and 5 have similar response to load growth. For figure 6b, the PV response of 13.8kV buses clearly illustrates that the buses will have lower voltage levels at 100MW demand. Bus 9 in this case is the weakest bus while bus 7 is noted to be the stronger bus. For VQ analysis, the 69kV buses converged at 1.0 per-unit voltage with 40MVAR deficit as illustrated in figure 6c. The 69kV bus 3 has more reactive power deficit for voltage more than 1.0 per-unit. For the 13.8kV buses, the reactive power deficit is evident at all buses but technically needed at bus 7 which is approximately equal to 40MVAR.

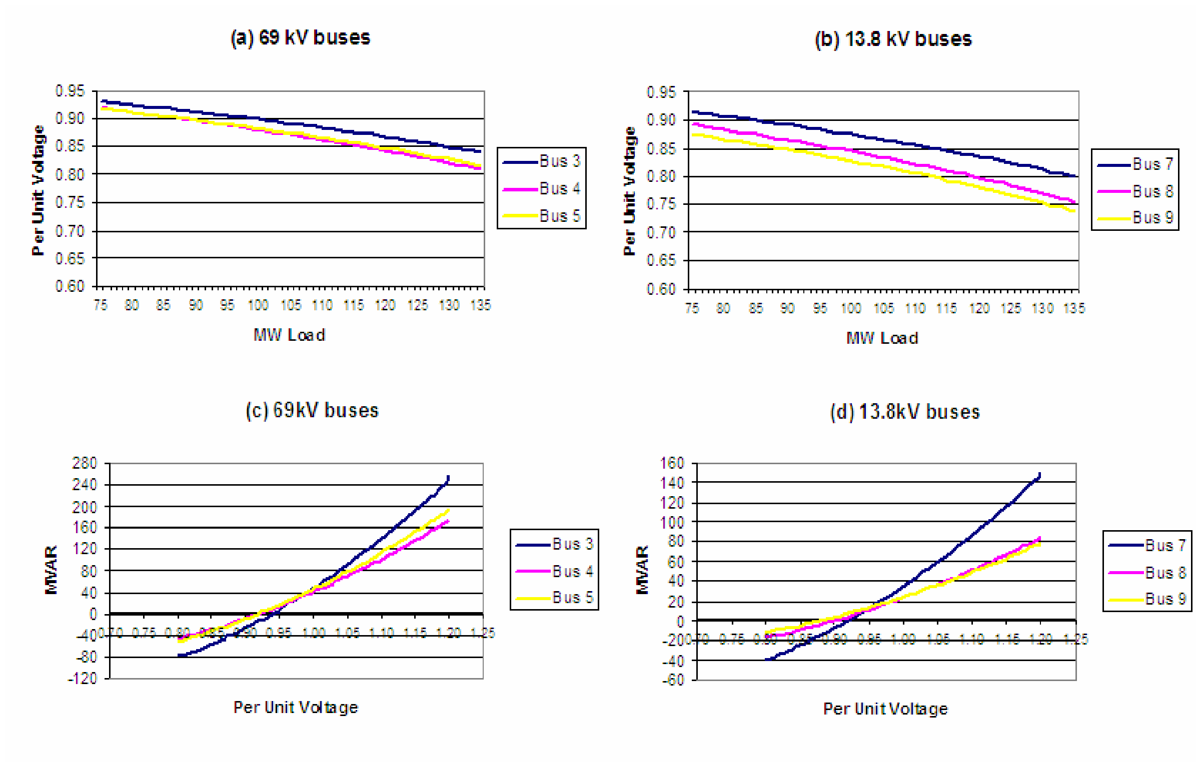

Figure 6. Base case results (a)-(b) PV Curves, (c)-(d) VQ Curves.

2. Summary of Results of Cases 2-5

For brevity, the summary of the preceding simulation cases are reported herein. Buses are chosen and then the results are superimposed to provide observation effectively to arrest voltage instability which is given in figure 7.

From figure 7a, the PV curves for bus 5 reveals that all solutions to voltage instability maintains the voltage magnitude above 0.90 per-unit even when the demand reaches up to 100MW. The installation of a 40MVAR capacitor, case 4, at this particular bus provides more MW margin than the other solutions or cases. The PV curves at 13.8kV bus 9 reveals that the voltage can be stable at 100MW demand only for cases 3 and 4 since voltage will drop below 0.90 per-unit for cases 2 and 5. At this bus, the distributed installation of capacitors at the distribution buses seems to be the most technically viable solution.

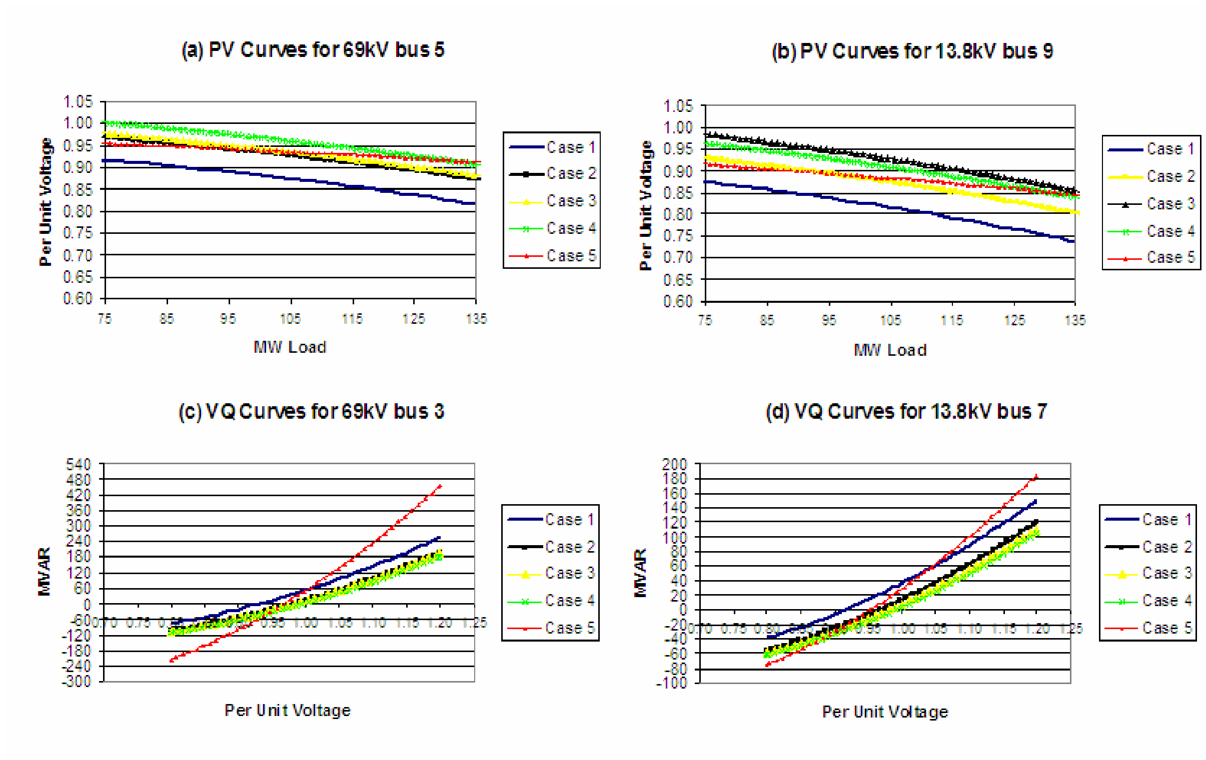

Figure 7. Summary of results for PV and VQ curves.

For VQ analysis, the results for bus 3 indicates that cases 2, 3 and 4 maintains the voltage magnitude at 1.0 per-unit as compared to case 5. For the lower voltage level, the VQ results for bus 7 reveal the same evaluation as for bus 3. This means that in order to maintain 1.0 per-unit at 69kV level and 13.8kV level, the installation of 40MVAR capacitor at bus 3 or bus 5 or distributedly installed at 13.8kV buses is to be considered.

The technical feasibility of the solutions to voltage instability is provided above does not conclude which solution must be implemented because the economic evaluation of these approaches must be look into to arrive to the preferred action.

IV. CONCLUSIONS

This manuscript has discussed the need for voltage stability analysis in planning electric power systems. Resources citing the importance of voltage stability in power systems were discussed and industry standards for voltage stability planning were presented and utilized for a numerical example involving a subtransmission system typical in the Philippines. Static and dynamic stability approaches were presented to provide background to the topic of consideration. The numerical simulation illustrated a practical voltage problem and non-exhaustive solutions of voltage stability. The technical viability of the voltage security approaches was discussed but this should be coupled with economic feasibility to come up with the most acceptable voltage stability solution.

V. REFERENCES

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