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STUDY THE COLTAGE STABILITY FOR APPLICATION TO VIETNAMESE POWER SYSTEM

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INTRODUCTION

1. The urgency of the subject

Voltage stability is an important issue in planning, designing and operation of power system. Currently, Vietnamese power transmission system is facing full-load operation and close to stable limit leading to reduction of security, reliability and voltage stability. The voltage instability might be appeared in case of short circuit in transmission line, loss of some power generators,… Some typical incidents occurred in Vietnamese power system on May 17, 2005 and July 25, 2009 were caused by voltage instability of power system leading to voltage collapse and wide area blackout.

The study and assessment of voltage stability and designing online monitoring model is necessary for solutions to ensure voltage stability in power system operation. One of the effective technical solution to improve the voltage quality and voltage stability is the application of SVC in power system.

For the above mentioned reasons, study the voltage stability for application to Vietnamese power system is really issential. Therefore, the author selected the topic of dissertation, namely ***"Study the voltage stability for application to Vietnamese power system"***.

2. Purpose of study

With the specific of Vietnamese power transmission system related to low storage of active power in power system, transmission high-power in transmission line, low voltage at the load buses and low storage of reactive power, therefore, the combination methods of analyzing voltage stability by PV, QV curves will be appropriate and effective to assess voltage stability of Vietnamese power system. The dissertation proposes indicators, coefficients of voltage stability assessment and application of analytical methods of PV, QV curve in conjunction with PMU to evaluate the voltage stability of Vietnamese power system. The dissertation analyses the effectiveness of SVC and proposes application in Vietnamese power system to improve voltage stability. These studies are calculated for Vietnamese power system in 2011-2015 period.

3. Content and methodology of study

Content of this dissertation includes voltage stable study and the application of voltage stable analysis methods of power system. Methodology of study is to select voltage stable analytical methods which are appropriate, propose indicators, coefficients of voltage stability to evaluate voltage stability of complex power system and Vietnamese power system. The solution in dissertation is based on new voltage stable indicator and the storage coefficients to create volatge stable assessment algorithms by using PV, QV curves in conjunction with PMU. Base on these algorithms, voltage stability of Vietnamese power system in 2011-2015 period has been analyzed to find out weak buses and determine the voltage stable margin. The dissertation also proposes a mode of voltage stability online monitoring for 500kV Vietnamese power system.

In the dissertation the effectiveness of SVC has been analyzed and studied for determining feasible location and capacity to install in 500kV Vietnamese power system for improving effective operation, voltage quality and voltage stability of Vietnamese power system.

4. Scientific meaning of the dissertation

Proposed voltage stable indicator based on the average sensitivity of the bus voltage to reactive power of load bus in conjunction with reactive power storage of load bus to assess voltage stability of power system by method of QV curve associate with data from PMU.

Applied voltage stable asessment methods of PV, QV curves in the PowerWorld software to calculate and analyze the voltage stability of Vietnamese power system in 2011-2015 period and proposed a mode of voltage stability online monitoring for 500kV Vietnamese power system to monitor and control Vietnamese power system operating in security, reliability and voltage stability.

SVC has been studied for determining feasible location and capacity to install in 500kV Vietnamese power system in order to improve the effective operation, voltage quality and voltage stability of Vietnamese power system.

5. Application scope

The proposed method of evaluating voltage stable limit of complex power system in conjunction with PMU and voltage stable indicators can be used as reference in operational management, in the planning and designing projects of power grid construction as well as caculated applications to choose the location and capacity of SVC for installing in 500kV Vietnamese power system.

6. Structure of dissertation

Besides the introduction, conclusion and annexes, content of the dissertation is divided into 5 chapters:

Chapter 1: Overview of voltage stable study in power system

Chapter 2: Analytical methods of voltage stability and indicators, coefficients of voltage stable assessment in power system

Chapter 3: Phase Measurement Unit (PMU) and analytical methods of voltage stability in conjunction with PMU.

Chapter 4: Voltage stable assessment of Vietnamese power system and study to design a mode of voltage stability online monitoring.

Chapter 5: Study the application of SVC to improve voltgae stability of Vietnamese power system.

Chapter 1: OVERVIEW OF VOLTAGE STABLE STUDY IN POWER SYSTEM

1.1. Overview of power system stability

1.1.1. Power system stability and classification

1.1.2. Voltage stability

1.1.2.1. Definitions of voltage stability

1.1.2.2. Phenomenon of voltage instability

a, Maximum load capacity

Solve the power flow equation of simple power system as follow:

$$V = \sqrt{\frac{E^2}{2} - QX \pm \sqrt{\frac{E^4}{4} - X^2P^2 - XE^2Q}} \qquad (1\text{-}3)$$

In the space (P,Q,V), (1-3) showed the change of the load bus voltage V with active power P and reactive power Q as figure 1.2.

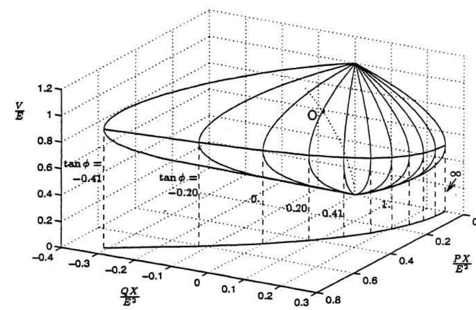


Figure 1.2 Graph of load bus voltage V by P and Q

b, Restore load capacity

1.1.2.3. Scenario type of voltage collapse and the preventive measures

a, Scenario type of voltage collapse

b, The preventive measures of voltage collapse

i. Designed measures of power system

- Application of reactive power compensation devices
- Combination of control and protection
- Control voltage regulator of transformer

- Load sheding by low voltage

ii. Operation methodology of power system

- Increase the voltage stability storage
- Provision for reactive power
- Control of the operation staff

1.1.3. Unstable non-cyclical standard and application to determine the voltage stability limit of power system

1.1.3.1. Unstable non-cyclical standard:

According to Gidanov, power system received stable limit when coefficient a_n of specific equation change the sign or power system keeps stable when $a_n > 0$.

1.1.3.2. Application of unstable non-cyclical standard to determine the voltage stability limit of power system:

Jacobian determinant of setting equations of power system will be identify with the free terms a_n of specific equation. Search sign Jacobian determinant in methods of PV, QV curves in conjunction with Newton-Raphson algorithm to assess voltage stability of setting power system.

1.2. Analysis of major voltage instable and voltage collapsable incidents

1.2.1. Some major voltage collapsable incidents in the world

1.2.1.1. Incident on July 02, 1996 in Western America power system: Due to loss of 345kV transmission line, voltage collapse has been in Western America power system and blakout.

1.2.1.2. Incidents on August 14, 2003 in power system of America and Canada: The incident had lost power in eight states of US, affecting on 50 million people, causing 61800MW loss and 6 billion USD loss.

1.2.1.3. Incidents on September 23, 2003 in electric system of Sweden and Denmark: Due to loss of 400kV bus

1.2.2. Some major voltage instable incidents in VietNam

1.2.2.1. Incident on May 17, 2005: Due to loss of two 500kV serie capacitors under operation condition with high load, voltage of some 500kV bus reduced much. Its leaded to voltage instability and 500kV Vietnamese power system has splited. Loss of load is 1074MW.

1.2.2.2. Incidents on July 25, 2009: At 10:07, rapid drop in voltage at 500kV Da Nang substation (425kV) and 500kV Ha Tinh substation (415kV) has caused voltage collapse on 500kV power system.At Ha Tinh substation, low voltage protection (350kV) operated leading to cut two circuits of 500kV transmission line Ha Tinh-DaNang and to split the 500kV power system. The total loss of load is 1440MW.

1.3. The study situation on voltage stability

Basis theory of voltage stability, some methods of analyzing voltage stability,… of C. W. Taylor (1993), P. Kundur (1994) and Cutsem, Vournas (1998), C. A. Canizares,... PV curve has built by the continuation power flow method was used to analyse voltage sability of V. Ajjarapu (1992). Besides, there are many other studies on voltage stability of the scientists in the world and in Vietnam.

1.4. Conclusion

1. Dissertation choose definition of Kundur "Voltage stability is the ability of power system to maintain acceptable voltage at all buses in power system under normal operating conditions and after a disturbance" for studying, proposing indicator, method of analyzing voltage stability and creating algorithm for assess voltage stability.

2. Used unstable non-cyclical standard of Gidanov to define voltage stable margin of power system. From result of studies if the calculation program of setting model of power system using Newton-Raphson algorithm, search sign Jacobian determinant could be use to assess voltage stability of power system.

3. Major incidents due to voltage instability or voltage collapse were caused by loss of full load transmission line; loss of bus; system operation at voltage stabilization threshold at peak mode.

4. The studies of voltage stability in the world and methods of analyzing voltage stability has been present in the theory and in an application for almost all simple power system. In Vietnam, there are some studies of voltage stability but really still new. Therefore, study of voltage stability for application on Vietnamese power system are essential to assess voltage stability and make the remedy.

Chapter 2: ANALYTICAL METHODS OF VOLTAGE STABILITY AND INDICATORS, COEFFICIENTS OF VOLTAGE STABILITY ASSESSMENT IN POWER SYSTEM

2.1. Methods of determining the voltage stability margin

2.1.1. Analysis curve into voltage and active power relation

2.1.1.1. Survey the relation between active power and voltage

In this dissertation, a new approach to establish the formula calculation and built a program to examine the relationship PV in case of reactive power of load bus Q_2=0 and in case of $Q_2 \neq 0$ to establish relationships, analysis and comments in the changes of the load bus voltage V_2 corresponding to the changes of active power P_2.

a, Case of $\cos\varphi_2 = 1$ ($Q_2 = 0$):

b, Case of $\cos\varphi_2 < 1$ ($Q_2 \neq 0$):

$$\begin{cases} V_{2a} = \sqrt{\dfrac{1 - 2XP_2 tg\varphi_2 + \sqrt{1 - 4XP_2 tg\varphi_2 - 4X^2P_2^2}}{2}} \\ V_{2b} = \sqrt{\dfrac{1 - 2XP_2 tg\varphi_2 - \sqrt{1 - 4XP_2 tg\varphi_2 - 4X^2P_2^2}}{2}} \end{cases} \qquad (2\text{-}12)$$

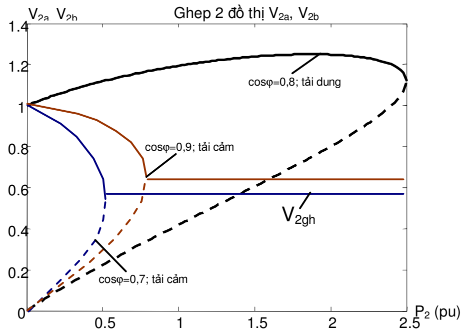


Figure 2.3. Relation graph between P_2V_2 and $\cos\varphi_2$

2.1.1.2.Review the relation between active power and load bus voltage

With constant power coefficient, increasing P_2 will make the decrease V_2, when P_2 is larger than P_{2gh} power system does not existed setting mode. This is the foundation for permission to use the calculation software of power system to establish PV curve for load bus through by mode of step by step increasing load until the problem does not converge to determine voltage stability margin point.

2.1.2. Analysis curve into voltage and reactive power relation

2.1.2.1. Establish curve into load bus voltage and reactive power relation

Relation between voltage and reactive power supply at load bus with the traditional method (variable voltage) can be determined by connecting a synchronous machine with active power value of zero and recording value of reactive power supply corresponding to the change of terminal voltage.

$$\frac{Q_C X}{E^2} = \frac{V^2}{E^2} - \frac{V}{E}\cos\theta + \frac{QX}{E^2} \qquad (2\text{-}21)$$

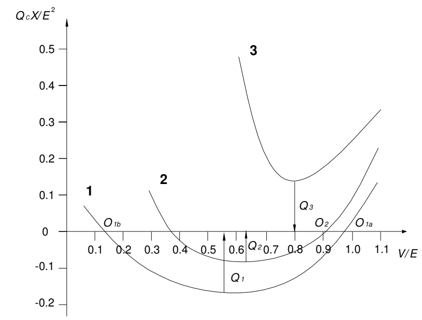


Figure 2.5. QV curves of operating modes

2.1.2.2. Comments about relation between reactive power and load bus voltage: By QV curves, it can be determined reactive power storage of load bus is the distance from operation point to limit point of the QV curve (Q_{dt}, V_{gh}), also known as voltage stability limit point.

2.1.2.3. The advantage of QV curve to voltage stability

Voltage stability has a close relationship to reactive power and QV curve show storage of reactive power at test bus.

2.1.3. Method of determination of the minimum distance leading to voltage instability on power plane

2.2. Methods of VQ sensitivity analysis and QV modal analysis

2.2.1. Method of VQ sensitivity analysis

In the problem of power flow calculation by Newton-Raphson method, when linearization and analysis, we have :

$$\Delta V = J_R^{-1} \Delta Q \quad (2-28)$$

Diagonal element of J_R^{-1} is the voltage sensitivity to the reactive power. If sensitivity values is small, the bus is voltage stability. If negative sensitivity value, it means that bus is voltage instability.

2.2.2. Method of QV modal analysis

2.2.2. Relationship between QV sensitivity of bus and eigenvalue of Jacobian

2.3. Technical solutions to support for analyzing voltage stability

2.3.1. Technical of the continuation power flow analysis

2.1.3.1. Isues of the continuation power flow

2.1.3.2. Prediction in the trend of tangent and correction by method of locally parameter

2.1.3.3. Prediction in the trend of secant and correction by orthogona intersection method

2.3.2. Technique of the contingency analysis

2.4. Indicators, coefficients of voltage stability assessment

2.4.1.Coefficient of voltage storage

$$\delta V_{\min}\% = \frac{V_{lv} - V_{gh\min}}{V_{gh\min}}.100\% \tag{2-43}$$

2.4.2. Decreased voltage indicator L

$$L = \underset{j\in\alpha_L}{MAX}\left|1 - \frac{\sum_{i\in\alpha_G}\dot{F}_{ji}.\dot{U}_i}{\dot{U}_j}\right| \tag{2-57}$$

2.4.3. Coefficient of active power storage of power system

$$K_{dtP}\% = \frac{P_{\max HT} - P_{\Sigma pt}}{P_{\Sigma pt}}.100\% \tag{2-58}$$

2.4.4. Reactive power storage of the load bus

-For tradditionally analytical method of QV curve (variable V):

$$Q_{dt} = - Q_{gh} \tag{2-59}$$

- For analytical method of QV curve with variable Q:

$$Q_{dt} = Q_{max} - Q_0 \tag{2-60}$$

2.4.5. Voltage stability indicator based on the average sensitivity of bus voltage to the reactive power of load bus (CSDN)

Average sensitivity of V_{bus} with Q_{load}:

$$DNTB = \left|\frac{\Delta V}{\Delta Q}\right| = \left|\frac{V_{gh} - V_0}{Q_{dt}}\right| \tag{2-61}$$

Indicator CSDN was showed as expression:

$$CSDN = \frac{1}{DNTB} \tag{2-62}$$

With small CSDN indicator, the bus have low level of voltage stability and bus with lowest CSDN have the most unstable voltage.

2.5. Conclusion

1. In this dissertation, a new approach were used to establish calculated formula and establish program to examine into load bus

voltage and active power relation, set up relationship, analyzing and comment about the change of load bus voltage corresponding to the change of active power. The dissertation used the comment for voltage stability analysis in lagre power system and Vietnamese power system.

2. By method of QV curve analysis, the dissertation proposes voltage stability indicator based on the average sensitivity of bus voltage corresponding to load bus reactive power (CSDN). CSDN used in combination with coefficient of voltage storage and reactive power storage of load bus to assess the voltage stability in lagre power system and Vietnamese power system.

3. Dissertation proposes solution using combination of methods of analyzing PV, QV curves in conjunction with technique of the continuation power flow analysis, technique of the contingency analysis to determine weak bus, the reactive power storage of load bus and the active power storage of power system. These method used to assess voltage stability of Vietnamese power system as showed in Chapter 4 and 5.

Chapter 3: PHASOR MEASUREMENT UNITS (PMU) AND ANALYTICAL METHODS OF VOLTAGE STABILITY IN CONJUNCTION WITH PMU

3.1. Phase measurement unit (PMU)

3.1.1. Structure and operation principle of PMU

3.1.1.1. Structure of PMU

3.1.1.2. Operation principle of PMU

3.1.2. PMU application in analysis of Vietnamese power system

PMU is measurement devices of synchronized phase. It measures complex values of magnitude and phase angle. In power system, PMU measures magnitude, phase angle of voltage and current at different bus and identify the status of the device. These databases will synchronized with GPS at the same time and transfer data to the control center of power system to serve the purpose of managing the operation, monitoring voltage stability and controlling power system

3.2. Voltage stability assessment of power system by QV curve method in conjunction with PMU

3.2.1. Algorithm diagram of voltage stable assessment by QV curve method in conjunction with PMU

3.2.1.2. Power Flow Equations

3.2.1.2. Algorithm of of voltage stability assessment by QV curve method in combination with PMU (Figure 3.3)

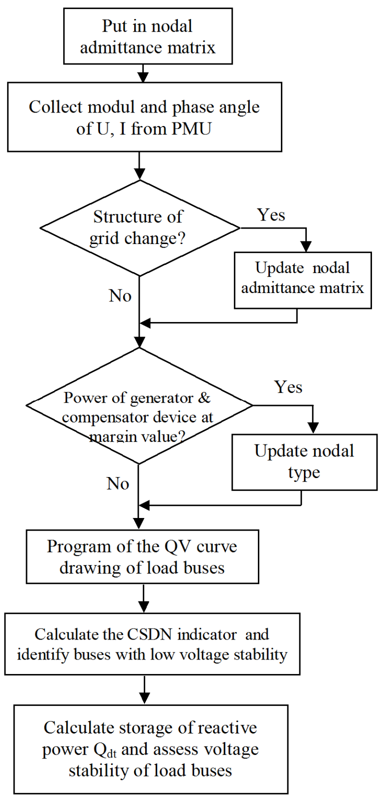


Figure 3.3. Algorithm diagram of voltage stable assessment by QV curve method in conjunction with PMU

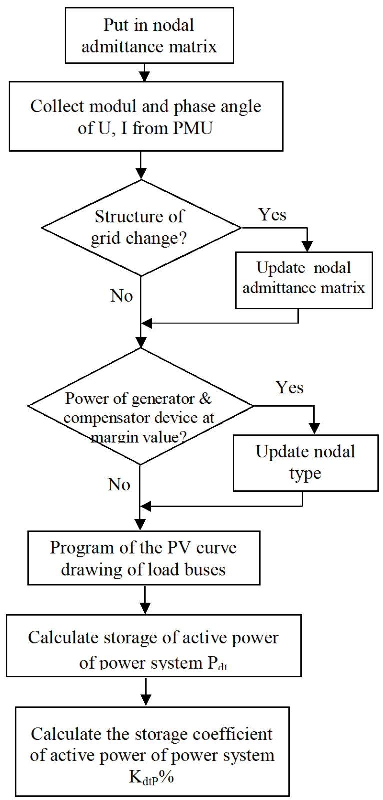
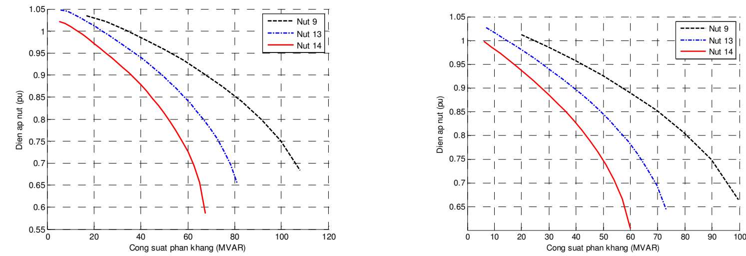


Figure 3.13. Algorithm diagram of voltage stable assessment of PV curve method in conjunction with PMU

3.2.2. Voltage stability assessment by voltage stability indicator CSDN and storage of reactive power Q_{dt}

Calculated result of model power system IEEE 14 bus and 57 bus : In case of increasing load or incident cutting a transmission line, the CSDN indicator and Q_{dt} of the load bus were decreased. The QV curves and calculated results of the program is shown in figure 3.4, table 3.1 and table 3.2.



a, Base case   b, Case of cutting a line 6-13

Figure 3.4. QV curves of buses 9, 13 and 14 of power system IEEE 14 bus

Table 3.1. Q_{dt} (MVar) and CSDN indicator of power system IEEE 14 bus

Bus	Base case		From base case increasing load P 10% & Q 20%		Case of cutting line 13-14		Case of cutting line 6-13	
	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN
2	469.90	1235	419.10	1164	469.90	1204	463.55	1183
3	133.00	383	125.40	302	133.00	380	133.00	375
4	224.25	518	194.22	509	218.40	561	212.55	559
5	248.00	601	216.00	565	246.40	610	237.60	608
6	101.25	241	90.00	199	97.50	236	97.50	246
9	91.30	246	79.68	203	83.00	224	83.00	234
10	81.20	192	69.60	170	78.30	177	78.30	163
11	78.30	*159*	69.12	*143*	77.40	173	75.60	172
12	***65.60***	***146***	***58.56***	***127***	***62.40***	***140***	*55.20*	*126*
13	*75.40*	190	*66.12*	162	*69.60*	*153*	**43.50**	**97**
14	**62.50**	**139**	**54.00**	**125**	**40.00**	**99**	***50.00***	***112***

Table 3.2. Q_{dt} (MVar) and CSDN indicator of power system IEEE 57 bus

Bus	Method of QV curve (variable Q_{pt})						Traditional method of QV curve (variable V_{bus}) at base case	
	Base case		Case of increasing load 10%		Case of cutting line 12-13			
	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN
25	*11.20*	*28*	*8.80*	*21*	***9.60***	*26*	*11.61*	*30*
30	***10.80***	**24**	**7.92**	***19***	*9.90*	**22**	***10.85***	**29**
31	**10.15**	***25***	***7.97***	**18**	**8.70**	***23***	**10.63**	**29**
32	15.20	36	11.88	25	14.00	34	15.26	42
33	14.25	37	11.49	27	13.30	32	14.81	39

Results of Q_{dt} and CSDN of QV curve method (Q_{pt} variable) are compared with traditional method of QV curve method (V_{bus} variable) using MATLAB, PSS/E and PowerWorld softwares (table 3.3).

Table 3.3. Comparison of Q_{dt} and CSDN with IEEE 14 bus between method of QV (Q_{pt} variable) and traditional method of QV (V_{bus} variable) using MATLAB, PSS/E và PowerWorld software

Bus	QV method with variable Q_{pt} (MATLAB)		Traditional method of QV curve (variable V_{bus}) (MATLAB)		Traditional method of QV curve (variable V_{bus}) PSS/E		Traditional method of QV curve (variable V_{bus}) PowerWorld	
	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN
10	81.20	192	82.63	175	84.44	165	83.11	178
11	78.30	*159*	78.26	*163*	*78.86*	159	78.57	*159*
12	***65.60***	***146***	***66.01***	***135***	***66.47***	***132***	***66.14***	***136***
13	*75.40*	190	*77.68*	*163*	79.26	*153*	*77.94*	160
14	**62.50**	**139**	**62.75**	**135**	**64.13**	**131**	**62.93**	**134**

Comment: - Specifically calculated results of electric system of IEEE 14 and 57 bus showed that CSDN is indicated buses with weak stability voltage. Buses with the smallest CSDN value are the most unstable voltage buses. For power system IEEE 14 bus, bus No. 14 is the most unstable voltage bus (bold numbers) and for power system IEEE 57 bus, bus No. 30 or No. 31 is the most unstable voltage bus (bold numbers) depending on operation mode (CSDN of these bus are equal in the operational modes).

- Check and compare method of QV curve using V_{bus} variable with the MATLAB, PSS/E and PowerWorld softwares showed that calculated results of CSND indicator and Q_{dt} are nearly equal to one of the method of QV curve using Q_{pt} variable.

3.3. Voltage stability assessment of power system by method of PV curve in conjunction with PMU

3.3.1. Algorithm diagram of voltage stability assessment of PV curve method in conjunction with PMU

3.3.1.1. Method of continuation power flow of prediction in the trend of secant and correction by orthogonal intersection method

Step 1: Prediction in the trend of secant

In this dissertation, first selection of secant trend is the horizontal to predict with $\Delta z_0 = 0$ and any $\Delta\lambda_0 > 0$.

Step 2: Adjustment by orthogonal intersection method

3.3.1.2. Establish program of drawing PV curves

3.3.1.3. Algorithm diagram of voltage stable assessment of PV curve method in conjunction with PMU (figure 3.13)

3.3.2. Voltage stability assessment of power system by PV curve method and storage coefficient of power active

Calculation results for IEEE 14 and 57 bus as shown in tables 3.4, 3.5.

Table 3.4. Power active storage P_{dt} and power active storage coefficient K_{dtP}% of power system IEEE 14 at operated cases

Operated case	Base case	Increasing load 10%	Case of cutting line 13-14	Case of cutting line 6-13
P_{dt} (MW)	190.70	163.86	182.71	162.83
K_{dtP}%	73.58	63.27	70.54	62.87

Table 3.5. Power active storage P_{dt} and power active storage coefficient K_{dtP}% of power system IEEE 57 at operated cases

Operated case	Base case	Cutting line 3-4	Increasing load 10%	Increasing load P 10% and Q 50%
P_{dt} (MW)	494.14	449.88	365.71	156.22
K_{dtP}%	39.51	35.97	29,24	12.49

Comments: If active power of power system increase, voltage of load buses decrease. When heavily load or cutting one line, P_{dt} will decrease and system can be voltage instability in the contingency case.

3.4. Conclusion

1. Based on the advantages of PMU, which is the measured device of voltage modular and phase angle at the time synchronization with accuracy of less than 1µs, dissertation used PMU to collect opearting data for the purpose of voltage stability assessment.

2. Dissertation used method of QV curve with Q variable and create the algorithm for voltage stability assessment according to power flow problem in conjunction PMU to calculate voltage stability indicator based on the average sensitivity of bus voltage to Q_{pt} to identify buses with low voltage stability and to calculate Q_{dt} of load buses for assessment of voltage stability margin of power system.

3. The algorithm of voltage stable assessment by using PV curve in conjunction with PMU according to technique of the continuation power flow by secant method with the initial predict propossal forward to the horizontal to calculate the storage coefficient of active power of power system.

4. According to results by PV, QV curve methods of power system IEEE 14 and 57 bus by MATLAB software can be concluded that the algorithm of voltage stability assessment and CSDN indicator were proposed can be used to assess voltage stability of power system.

5. Dissertation was calculated, compared the PV, QV curve methods by MATLAB software and applied in the specialized softwares such as PSS/E, Power World to test the PV, QV curve methods and CSDN indicator recommended by dissertation can be used effectively in the analysis, assessment of voltage stability for complicated power system and applied in Vietnamese power system.

Chapter 4: VOLTAGE STABLE ASSESSMENT OF VIETNAMESE POWER SYSTEM AND STUDY TO DESIGN A MODE OF VOLTAGE STABILITY ONLINE MONITORING

4.1. Status and development planning of Vietnamese power system

4.1.1. Background

4.1.2. Operation status of Vietnamese power system in 2011

4.1.3. Diagram and planning of Vietnamese power system to 2015

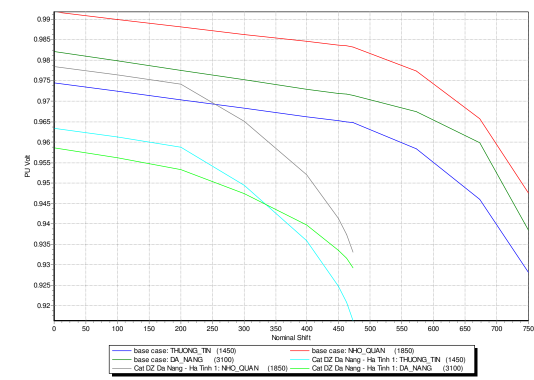
4.2. Voltage stability assessment of *Vietnamese power system in 2011*

4.2.1. Calculating active power storage of Vietnamese power system

4.2.1.1. Base case operation mode: Total active power of source/load of Vietnamese power system is 14936MW/14244MW.Calculated result of active power storage at base case is 750MW corresponding to active power storage coefficient of Vietnamese power system: $K_{ghP}\%=5,2\%$. When active power of 500kV Da Nang – Ha Tinh transmission line increases from 1120MW to 1400MW (active power of load is constant), active power storage of Vietnamese power system decrease to 300MW corresponding to $K_{ghP}\% =2,11\%$.

4.2.1.2. Contingency N-1 modes:

a, In case of cutting a 500kV transmission line:



- In case of cutting a 500kV Da Nang - Ha Tinh transmission line: Active power storage is 470MW ($K_{ghP}\%=3,3\%$). PV curves of Thuong Tin, Nho Quan and Da Nang bus in base case and one 500kV Da Nang - Ha Tinh line off as figure 4.7.

Figure 4.7. PV curves of Thuong Tin, Nho Quan and Da Nang bus in base case and in case of cutting a 500kV Da Nang - Ha Tinh line

b, In case of cutting a 500kV bus: In case of cutting one of 500kV buses Thuong Tin, Nho Quan, Ha Tinh, Da Nang, Pleiku, Tan Đinh, Phu My and Nha Be, power system will be unstable.

c, In case of cutting a generator:

d, In case of cutting a 500kV transformer:

4.2.2. Identify buses of low voltage stability of Vietnamese power system in 2011

Voltage V_{lv} and voltage storage coefficient $\delta V_{min}\%$ of 500kV load buses of Vietnamese power system in 2011 as table 4.5.

Table 4.5. Voltage V_{lv} and coefficient of voltage storage $\delta V_{min}\%$ of 500kV load buses at operated cases of Vietnamese power system in 2011

Bus name	Base case		Cutting a 500kV Danang-Hatinh		Cutting Phulam bus		Cutting a transformer of Nho Quan bus	
	V_{lv} (kV)	δV_{min} %	V_{lv} (kV)	δV_{min} %	V_{lv} (kV)	δV_{min} %	V_{lv} (kV)	δV_{min}%
Thường Tín	***487.2***	***8.27***	***481.7***	***7.05***	***489.8***	***8.83***	***482.2***	***7.15***
Quảng Ninh	**482.3**	**7.17**	**478.4**	**6.31**	**484.1**	**7.57**	**478.4**	**6.30**
Nho Quan	495.9	10.20	489.2	8.72	498.9	10.86	490.7	9.03
Hà Tĩnh	494.4	9.86	482.3	7.18	499.2	10.93	490.4	8.98
Đà Nẵng	*491.0*	*9.11*	***479.4***	***6.52***	***497.3***	***10.51***	***488.9***	***8.65***
Dốc Sỏi	***490.7***	***9.04***	480.9	6.87	**497.2**	**10.49**	***488.9***	***8.65***
Pleiku	497.0	10.45	491.2	9.16	503.9	11.98	496.0	10.22
Đak Nông	**476.4**	**5.86**	**472.7**	**5.04**	504.2	12.05	**475.7**	**5.71**
Di Linh	488.9	8.65	483.6	7.47	492.7	9.48	488.0	8.44
Tân Định	***478.5***	***6.33***	**474.5**	**5.45**	***478.5***	***6.33***	***477.8***	***6.17***
Phú Lâm	**477.7**	**6.16**	***474.7***	***5.49***	0.0	-	***477.1***	***6.03***
Nhà Bè	481.2	6.94	478.7	6.37	476.6	5.90	480.7	6.83

4.2.3. Voltage stability assessment by voltage stability indicator CSDN and the storage reactive power Q_{dt} of load buses

Using method of QV curve to calculate indicator CSDN and Q_{dt} of load buses in operated cases in 2011 with results as table 4.6.

QV curves of Tan Dinh bus in base case and one 500kV Da Nang - Ha Tinh line off as figure 4.15 and figure 4.16.

4.2.4. Comments:

In 2011, Vietmamese power system has very low active power storage and system is easy to be unstable voltage when a contingency N-1 case has been in power system.

From table 4.5, 500kV buses such as Thuong Tin, Quang Ninh, Da Nang,Doc Soi, DakNong,Tan Dinh and Phu Lam have lowest voltage.

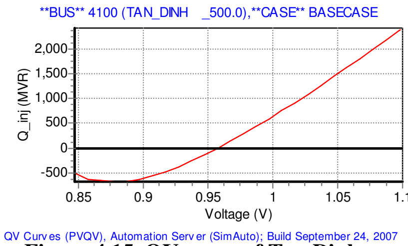


Figure 4.15. QV curve of Tan Dinh 500kV bus in base case in 2011

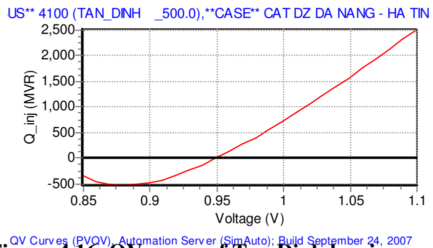


Figure 4.16. QV curve of Tan Dinh bus in case of cutting a 500kV Da Nang - Ha Tinh line in 2011

Table 4.6. Q_{dt} (MVAr) and indicator CSDN of 500kV load bus at operated cases of Vietnamese power system in 2011

Bus name	Base case		Cutting a 500kV Da Nang-Ha Tinh		Cutting Phu Lam bus		Cutting a transformer of Nho Quan bus	
	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN
Thường Tín	***568***	***4195***	***347***	***3575***	***612***	***4355***	**403**	***4698***
Quảng Ninh	**515**	**3800**	**339**	***3293***	**558**	**3671**	***437***	***3548***
Nho Quan	615	5201	346	4222	660	4995	475	5358
Hà Tĩnh	**555**	**5480**	**284**	**4372**	***600***	**5902**	**492**	**5513**
Đà Nẵng	***741***	6863	***472***	5190	517	9312	***673***	6584
Dốc Sỏi	775	***6030***	502	***5125***	**474**	***8516***	715	***5848***
Pleiku	872	10153	593	8714	452	10721	809	10371
Đak Nông	705	7241	548	6472	458	4103	676	7627
Di Linh	836	9072	584	8004	399	8931	783	***8319***
Tân Định	682	**8212**	524	**7374**	***263***	***6104***	649	**7680**
Phú Lâm	***637***	***8539***	***496***	8129	0	-	**613**	9331
Nhà Bè	**619**	9152	**486**	***7707***	**229**	**3423**	**595**	8685

From table 4.6, 500kV buses such as Thuong Tin, Quang Ninh, Ha Tinh, Da Nang, Doc Soi, Tan Dinh and Phu Lam have lowest CSDN indicator and reactive power storage Q_{dt} in operated cases.

4.3. Voltage stability assessment of Vietnamese power system in 2015

4.3.1. Calculating active power storage of Vietnamese power system

Using data base by power planning No. 7 and application method of PV curve to calculate P_{dt} of Vietnamese power system in 2015.

4.3.1.1. Base case operation mode: Total active power of source/load of Vietnamese power system is 31671MW/30531MW respectively (active power of 500kV Vung Ang - Da Nang line is 2700MW). Active power storage is 1400MW corresponding to active power storage storage coefficient of Vietnamese power system K_{ghP}%=4,59%. When active power of 500kV Vung Ang - Da Nang line increases from 2700MW to 3020MW (active power of loads is constant), active power storage of Vietnamese power system decrease to 400MW corresponding to K_{ghP}% =1,31%.

4.3.1.2. Contingency N-1 modes:

a, In case of cutting a 500kV transmission line:

In case of cutting of Di Linh-Tan Dinh line, P_{dt} decrease to 400MW (K_{ghP}% = 1,31%). In case of cutting one of transmission lines, namely Vung Ang-Da Nang, Thanh My-Pleiku, Pleiku-Di Linh, Pleiku-Cau Bong and Dak Nong-Cau Bong, power system will be unstable.

Table 4.11. Voltage V_{lv} and δV_{min}% of 500kV load buses at operated cases of Vietnamese power system in 2015

Bus name	Base case		Cutting a 500kV Di Linh-Tan Dinh line		Cutting Duc Hoa bus		Cutting a transformer of Da Nang bus	
	V_{lv} (kV)	δV_{min}%	V_{lv} (kV)	δV_{min}%	V_{lv} (kV)	δV_{min}%	V_{lv} (kV)	δV_{min}%
Hiệp Hòa	502.5	11.68	501.5	11.45	501.7	11.48	502.2	11.60
Thường Tín	**482.0**	**7.11**	**480.7**	**6.82**	**480.9**	**6.87**	**481.8**	**7.07**
Phố Nối	486.6	8.13	485.6	7.90	485.7	7.94	486.5	8.10
Nho Quan	***483.4***	***7.42***	***481.4***	***6.98***	***481.8***	***7.06***	***483.2***	***7.37***
Việt Trì	495.7	10.15	495.0	9.99	495.1	10.02	495.6	10.13
Hà Tĩnh	**478.9**	**6.42**	**474.8**	**5.50**	***475.1***	***5.57***	**478.3**	**6.30**
Đà Nẵng	484.8	7.73	477.9	6.19	476.7	5.93	483.9	7.53
Thạnh Mỹ	505.4	12.31	497.7	10.60	495.3	10.06	504.2	12.05
Dốc Sỏi	***483.5***	***7.43***	***476.0***	***5.77***	**474.3**	**5.39**	***482.3***	***7.17***
Pleiku	501.5	11.45	492.7	9.48	489.5	8.78	500.8	11.28
Phú Lâm	488.2	8.49	474.2	5.38	472.2	4.94	487.7	8.38
Mỹ Tho	490.8	9.07	478.5	6.33	479.7	6.60	490.4	8.97
Di Linh	491.8	9.28	491.1	9.14	476.2	5.83	491.1	9.13
Tân Định	***484.9***	***7.76***	***470.2***	***4.49***	***467.4***	***3.86***	***484.4***	***7.64***
Nhà Bè	491.7	9.27	478.1	6.24	475.8	5.73	491.2	9.16
Đak Nông	496.4	10.30	481.6	7.03	482.0	7.10	495.7	10.15
Sông Mây	489.5	8.78	475.8	5.72	472.6	5.01	489.0	8.67
Tân Uyên	*485.5*	7.89	*471.7*	4.81	468.1	4.01	485.0	7.78
Cầu Bông	**483.3**	**7.40**	**467.9**	**3.97**	**465.7**	**3.48**	**482.7**	**7.27**
Đức Hòa	486.8	8.17	473.0	5.11	0.0	-	486.3	8.06

b, Case of cutting a 500kV bus: In case of cutting of Duc Hoa bus, P_{dt} decrease to 430MW corresponding to K_{ghP}% = 1,41%. In case of cutting one of buses, namely Pitoong, Quang Ninh, Nho Quan, Vinh

Tan, Vung Ang, Ha Tinh, Da Nang, Thanh My, Pleiku, Long Phu, O Mon,Doc Soi,My Tho,Di Linh,Tan Dinh,DakNong,PhuMy,Song May, Duyen Hai,Tan Uyen and Cau Bong, power system will be unstable.

c, Case of cutting a generator:

d, Case of cutting 500kV transformer:

4.3.2. Identify buses of low voltage stability of Vietnamese power system in 2015

Voltage V_{lv} and voltage storage coefficient $\delta V_{min}\%$ of 500kV load buses of Vietnamese power system in 2015 as table 4.11.

4.3.3. Voltage stability assessment by voltage stability indicator CSDN and reactive power storage Q_{dt} of load buses

Using method of QV curve to calculate indicator CSDN and Q_{dt} of load buses in operated cases in 2015 with results as table 4.12.

Table 4.12. Q_{dt} (MVAr) and indicator CSDN of 500kV load buses at operated cases of Vietnamese power system in 2015

Bus name	Base case		Cutting a 500kV Di Linh–Tan Dinh		Cutting Duc Hoa bus		Cutting a transformer of Da Nang bus	
	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN
Hiệp Hòa	1817	***10362***	1588	***12504***	1706	***11627***	1804	***10275***
Thường Tín	2005	12722	***1448***	15342	***1460***	14887	1966	12431
Phố Nối	1983	13508	1547	15637	1624	14966	1963	13347
Nho Quan	***1824***	13693	**1148**	17115	**1154**	17355	***1769***	14302
Việt Trì	**1558**	**6529**	1457	**7454**	1472	**7018**	***1548***	***6483***
Hà Tĩnh	1009	8992	530	10487	552	11078	957	***8436***
Đà Nẵng	805	***8898***	305	6877	340	7305	755	**8186**
Thạnh Mỹ	782	9796	***248***	**5631**	***268***	6877	745	9166
Dốc Sỏi	***778***	**7549**	278	7300	285	***6874***	***743***	8687
Pleiku	**718**	10709	**225**	***6516***	**238**	**5815**	**685**	10002
Phú Lâm	***546***	7420	***169***	*4069*	**182**	*5111*	***524***	*7025*
Mỹ Tho	***546***	7984	171	3973	186	4575	***524***	7576
Di Linh	600	7134	217	4546	204	5432	574	**6539**
Tân Định	561	**6928**	171	*4314*	***183***	5255	538	7550
Nhà Bè	550	8258	171	3902	***183***	4774	*528*	7822
Đak Nông	636	7288	201	5466	217	6015	609	7754
Sông Mây	575	7097	177	4590	190	***4235***	551	7658
Tân Uyên	554	***7018***	173	4712	*184*	**4197**	*532*	***6650***
Cầu Bông	556	7579	***170***	***3827***	*184*	*4765*	533	7148
Đức Hòa	**538**	*7026*	**168**	**3808**	0	-	**516**	7643

4.3.4. Comments:

4.4. Study to design a mode of voltage stability online monitored system of 500kV Vietnamese power system

Study to built a mode of voltage stability online monitored system of 500kV Vietnamese power system such as figure 4.25. PMU will be installed at 500kV buses and main power plants. Voltage, current of buses will be online measured from PMU and sending to data acquisition system Phasor for signal processing and transfering to system of voltage stability monitoring of power system. The system will control data and calculate, analyze voltage stability to take note about voltage stability of 500kV power system and to give controlled commands to program of emergency voltage stability controlling.

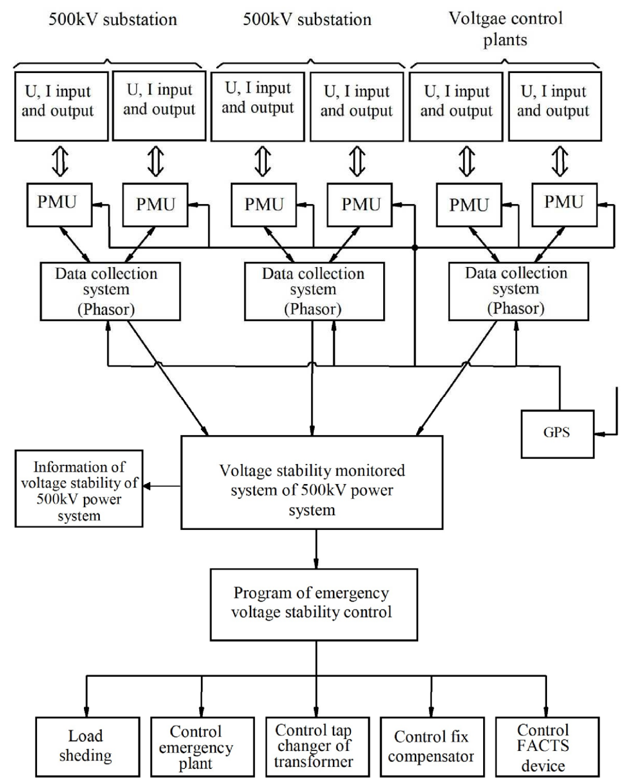


Figure 4.25. Mode of voltage stability online monitored system of 500kV Vietnamese power system

4.5. Conclusion

1. The dissertation uses methods of PV, QV curve and voltage stability coefficients, new indicator to assess voltage stability of complex power system and application in Vietnamese power system.

2. The dissertation was applied PV, QV curves to calculate Vietnamese power system in 2011 and 2015. It is showed that Vietnamese power system has very low active power storage and the storage will decrease much when a contingency N-1 case has been in power system.

3. Conclusion for the calculation of Vietnamese power system:

- In 2011, Thuong Tin, Quang Ninh, Da Nang, Ha Tinh, Tan Dinh and Phu Lam buses have weak voltage, low voltage stability indicator and low reactive power storage in opearated cases.

- In 2015, Thuong Tin, Nho Quan, Ha Tinh, Doc Soi, Tan Dinh, Cau Bong buses have low voltage and buses of Viet Tri, Nho Quan, Hiep Hoa (North area), Doc Soi, Da Nang, Thanh My (Middle area), Tan Dinh, Tan Uyen, Duc Hoa, Cau Bong, Phu Lam, My Tho (South area) have low voltage stability indicator and lowest reactive power storage in opearated cases.

4. The dissertation proposed a mode of voltage stability online monitored system of 500kV Vietnamese power system with PMU and FACTS devives to control power system security and voltage stability.

Chapter 5:STUDY THE APPLICATION OF SVC TO IMPROVE VOLTAGE STABILITY OF VIETNAMESE POWER SYTEM

5.1. Role of FACTS devices

5.1.1. Flexible alternating current transmission systems (FACTS)

5.1.2. The efficiency of FACTS devices in operating power system

5.1.3. Introduction some FACTS devices

5.1.3.1. Static var compensator (SVC)

5.1.3.2. Static synchronous Compensator (STATCOM)

5.1.3.3. Thyristor Controlled Series Capacitor (TCSC)

5.1.3.4. Unified Power Flow Controller (UPFC)

5.2. Structure, operating principle and calculating mode of SVC

5.2.1. Definition and structure of SVC

5.2.2. Operating principle of SVC

5.2.2.1. Operating principle of elements of SVC

5.2.2.2. Operating principle of SVC device

5.2.3. Utilizable efficiency of SVC for voltage control and improve voltage stability of power system

5.2.3.1. Voltage control and power flow

5.2.3.2. Improve voltage quality and short-range voltage stability
5.2.3.3. Decrease time and over voltage intensity in contingency case

5.2.4. Calculating model of SVC operation

5.2.4.1. Calculate reactance of SVC
5.2.4.2. Calculating model of SVC

In manual control mode, SVC controls the changes of system voltage through controlling opening angle α of TCR to control reactive power exchanging with system at test bus U_2. In automatic control mode, to keep stable voltage of test bus U_2 following the value of U_{YC}, voltage at test bus will be provide to the controller of the SVC, then if there is a change operation mode causing $U_2 \neq U_{YC}$, so operated controller will control reactive power volume of SVC exchanging with the system while ensuring that $U_2 \approx U_{YC}$.

5.3. Calculation to install SVC on 500kV Vietnamese power system to improve voltage stability

5.3.2. Background

5.3.2 Calculate, evaluate the effectiveness for installing SVC to improve voltage stability of Vietnamese power system

Based on the results in Chapter 4, it has identified some buses, which have weak voltage and lowest voltage stability. Dissertation has analyzed and choosed installation SVC at 500kV Thuong Tin, Doc Soi, Tan Dinh and Cau Bong buses. To promote efficiency of SVC as well as calculating many study cases, Dissertation is suggested to install SVC at 500 kV Thuong Tin bus and 500kV Tan Dinh bus (or Cau Bong bus) with SVC capacity of 500MVAr.

5.3.2.1. Calculate the active power storage of Vietnamese power system in 2015 when using SVC

Calculate for Vietnamese power system in 2015 when using SVC installing at Thuong Tin bus and Tan Dinh bus (TH1) or Cau Bong (TH2) with capacity of SVC of 500MVAr.

In base case operation mode, total active power of source/load of Vietnamese power system is 31671MW/30531MW respectively. Active power storage of Vietnamese power system having SVC TH1 is 2125MW and TH2 is 2130MW.

5.3.2.2. Identify buses of low voltage stability of Vietnamese power system in 2015 when installing SVC

From calculated results of voltage storage coefficient showed that voltage quality of all buses has increased significantly nearly norminal vallue in most of the operation modes.

5.3.2.3. Voltage stability assessment by indicator CSDN and reactive power storage Q_{dt} of load buses when installing SVC

Table 5.11. Q_{dt} (MVAr) and indicator CSDN of 500kV load buses at operated cases of Vietnamese power system in 2015 when installing SVC (TH2)

Bus name	Base case		Cutting a 500kV line Pleiku – Cau Bong		Cutting O Mon bus		Cutting a generator of Nhon Trach plant	
	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN	Q_{dt}	CSDN
Hiệp Hòa	2211	10359	1995	12781	2168	10623	380	16097
Thường Tín	2622	14321	1908	17714	2495	14323	210	21608
Phố Nối	2494	13917	2014	15154	2446	13583	231	18453
Nho Quan	2473	14810	1423	15142	2313	15558	155	12928
Việt Trì	**1839**	**6611**	**1699**	**7360**	**1812**	**6738**	**349**	**12495**
Hà Tĩnh	1460	9151	671	9065	1062	10278	66	10320
Đà Nẵng	1253	9889	500	8549	681	10986	**53**	**3581**
Thạnh Mỹ	1346	9983	451	8009	565	11303	59	4091
Dốc Sỏi	**1237**	**8935**	468	6561	636	**8600**	54	8381
Pleiku	1337	12231	**398**	**6151**	**521**	11454	57	4008
Phú Lâm	1054	10364	320	5275	372	7401	60	3663
Mỹ Tho	1034	11523	333	6097	356	7282	64	3575
Di Linh	1118	8232	330	4991	448	7102	57	3758
Tân Định	1084	11228	324	5292	404	7435	58	2403
Nhà Bè	1058	11018	324	5058	377	6954	61	3040
Đak Nông	1189	9399	348	5972	455	7153	58	2346
Sông Mây	1104	10058	334	5496	410	8644	60	2477
Tân Uyên	1056	**8966**	323	5500	397	8721	60	2591
Cầu Bông	1088	11249	321	5362	393	7156	**57**	**2336**
Đức Hòa	**1032**	9838	**318**	**5022**	**370**	**6881**	60	3292

Comment: Calculated results in 2015 when installing SVC showed that Vietnamese power system operates with high active power storage, increasing voltage quality as well as reactive power storage during the operation modes. When comparing TH1 and TH2, it is recognized that the voltage and reactive power of load buses Q_{dt} when installing SVC at Thuong Tin bus and Cau Bong bus (TH2) (table 5.11) are higher than TH1.

5.3.3. Comments

5.4. Summary:

1. On the basis of analysis, comparison of the function of FACTS, it is defined SVC, STATCOM are equipments which have many advantages in voltage control, voltage stable improvement. However, SVC is much cheaper compare to STATCOM and other FACTS. Therefore, the dissertation proposes to select SVC for installing in 500kV Vietnamese power system.

2. Results of study showed that SVC installation in 500kV Vietnamese power system at Thuong Tin bus and Cau Bong bus with SVC capacity of 500MVAr was calculated and determined the effectiveness for improving voltage quality as well as increasing voltage stability of Vietnamese power system.

3. Analyzing calculated results for Vietnamese power system in 2015 when installing SVC at 500kV Cau Bong bus and 500kV Thuong Tin bus by methods of PV, QV curve showed that the coefficient of active power storage is become higher than 3.5%, coefficient of voltage storage is increasing by more than 6% and reactive power storage of load bus is higher than 300MVAr. This suggests that voltage quality and voltage stability margin is higher when installing SVC in Vietnamese power system.

CONCLUSION AND PETITION

I. Conclusion

1. Based on the theory of voltage stability and analysis of typical incidents, the dissertation proposes using methods of analyzing PV, QV curve in combination with problem of power flow with Newton-Raphson method and technique of contingency analysis are effective method to assess voltage stability in complicated power system.

2. By using new approach, the dissertation created program of drawing PV curve for simple power system; designed calculated program of PV curve with application technique of continuation power flow. Simultaneously, the dissertation proposed algorithm of voltage stable assessment byusing method of PV curve in conjunction with PMU to identify voltage stability storage of power system.

3. The dissertation proposed voltage stable indicator based on the average sensitivity of bus voltage to reactive power of load bus (CSDN) to identify buses with low voltage stability. The dissertation has used CSDN indicator in conjunction with coefficient of voltage storage, reactive power storage of load buses in algorithm of voltage stable assessment by using method of QV curve with Q variable conjunction with PMU to assess voltage stability of load buses in

power system. The dissertation has calculated, compared to method of traditional QV curve with Q variable. This proposal has applied in the dissertation to assess voltage stability of Vietnamese power system.

4. According to the result of calculation by QV curve method of power system IEEE 14 bus and 57 bus by MATLAB software, the dissertation has compared to function of QV curve in the specialized softwares such as PSS/E, Power World to showed that CSDN indicator and reactive power storage of load bus can be used effectively to identify buses with low voltage stability and to assess voltage stability of Vietnamese power system.

5. From calculated results of Vietnamese power system in the 2011-2015 by combining methods of PV, QV curve in conjunction with storaged coefficients and voltage stable indicator was proposed by the dissertation can assess operating situation of Vietnamese power system as follows:

- Active power storage of power system is low in peak load case or when contingency N-1 and in some incidents, Vietnamese power system has been unstable.
- In 2011, 500kV Thuong Tin, Quang Ninh, Ha Tinh, Da Nang, Tan Dinh and Phu Lam buses have low voltage stability.
- In 2015, 500kV Thuong Tin, Nho Quan, Ha Tinh, Doc Soi, Tan Dinh, Cau Bong buses have low voltage and buses of Viet Tri, Nho Quan, Hiep Hoa, Doc Soi, Da Nang, Thanh My, Tan Dinh, Tan Uyen, Duc Hoa, Cau Bong, Phu Lam, My Tho have low voltage stability indicator and lowest reactive power storage in opearated cases.

6. The dissertation proposed a mode of voltage stability online monitored system of 500kV Vietnamese power system with PMU and FACTS devives to control power system security and voltage stability.

7. Results of study showed that SVC installation in 500kV Vietnamese power system at bus Thuong Tin and bus Cau Bong with SVC capacity of 500MVAr was calculated and determined effectiveness for improving voltage quality as well as voltage stability storage of Vietnamese power system.

II. Petition

- To study and formulate quick voltage stability assessment by the implementation time of 500kV Vietnam electricity system.
- Compare the effectiveness of SVC installed at 500kV buses needs to be calculated more efficiently to the offset capacity level, the different operating modes including N-2 mode to select the location, capacity of SVC to maximize the economic and technical items.