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# VOLTAGE PROFILE IMPROVEMENT USING SVC INCORPORATING PARTICIPATION FACTOR

**Sunil Bhatt, Prachi Mafidar**
Department of Electrical Engineering
SGSITS, Indore (M.P)

## ABSTRACT

This Paper identify the weakest bus in a distribution network. In heavily loaded systems, voltage stability limit is usually dominant and voltage instability is usually observed following large disturbance. More attention is required to be paid to keep voltage profile and hold the voltage stability under control. In this paper simple voltage stability analysis is carried out for IEEE 30 Bus System using Bus participation factor. Paper presents a bus participation factor used to identify the weakest bus and SVCs are used to improve voltage profile.

**Keywords – Participation Factor, SVC**

## INTRODUCTION

Voltage stability and system security are of great concern to planning engineers in the electric power industry. The modern power system around the world has grown in complexity of large interconnection of the electric networks and power demand. The focus has shifted towards enhanced performance, reliable and clean power. The loads generally play a key role in voltage stability analysis and therefore the voltage stability is known as load stability [1].

. Keeping the voltage security in concern, power systems are provided with a lot of voltage controlling devices such as generators, tap changing transformers, shunt capacitors/reactors, synchronous condensers, and static VAR compensators etc. Either by the variation of load or by the variation of network configuration, a real time control employing those controlling devices is required to alleviate the problems that cannot be solved exactly [2].

The ability of the modal method to reveal the proximity and mechanisms of voltage instability, participation factor with critical modes are used to find the most effective location to site a static var compensator (SVC) to enhance system voltage stability [3]. The whole work is solved on placement of SVCs using bus participation factors.

In this work, the IEEE-30 bus system is used so that the method can be applied to more number of buses configurations.

## PROBLEM FORMULATION 1: IDENTIFICATION OF WEAK BUS

### Bus Participation Factor

Participation factor has been very useful and widely applied in various applications for voltage stability enhancement and other field of electric power system [7]. It gives the information on how effective reactive power compensation at a bus is required to increase the modal voltage at that bus. It is given by,

$$P_{ki} = \xi_{ki}\eta_{ik}$$

Where,

$P_{ki}$: is the participation factor of the bus k in the $i^{th}$ voltage variation mode.

$\xi_{ki}$, $\eta_{ik}$ : is the $k^{th}$ element of the right-column and left- row eigenvector, respectively associated with the $i^{th}$ mode eigenvalue $\lambda_i$.

Physically, $\xi_{ki}$ is a measure of the activity of bus k in the $i^{th}$ voltage variation mode, $\eta_{ik}$ is the weighting of the contribution of this activity, and so their product is a measure of net participation of bus k in the $i^{th}$ voltage variation mode.

Thus, $P_{ki}$ determines the contribution of $\lambda_i$ of mode i to V-Q Sensitivity at bus k. A bus with high participation factor indicates that it has large contribution to this mode. The size of bus participation in a given mode indicates effectiveness of remedial action applied at that bus. There are two modes:

1. **Local Modes:** It indicates the buses with high participation factor that need high reactive power compensation.
2. **Non Local Modes:** It indicates large number of buses with small participation factor that needs small reactive power compensation.

At the point of collapse, left Eigen vector identifies the most effective direction to maximize the voltage stability and provides valuable information regarding mechanism of voltage instability.

Bus participation factor in modal analysis indicates the contribution of the bus to the system instability. Bus with high participation factor are the firstly priority for the location of Load-Shedding [4], [5], [7].

### Weak Bus

A Weak Bus is defined as that bus that experiences as significant voltage and Reactive power deviation for a small load change. The buses of the system which are weak in nature .i.e., (weakest voltage) that need reactive power compensation to improve voltage profile [1].

## PROBLEM FORMULATION II: VOLTAGE PROFILE IMPROVEMENT USING SVC

### Static Var Compensator

“Static Var Compensator is a shunt-connected static Var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage).”

The Static Var Compensator (SVC) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. The reactive power is changed by switching or reactive power elements connected to the secondary side of the transformer. Capacitor bank is switched on and OFF by Thyristor valve (TSC). Reactor can be either switched (TSR) or controlled (TCR) by Thyristor valves.

- When system voltage is low, the SVC generates reactive power (SVC capacitive) and
- When system voltage is high, it absorbs reactive power (SVC inductive).

The SVC is in Reactive under low voltage conditions due to faults in the system. However, the clearing of the fault can result in temporary overvoltage due to load rejection, particularly under weak system conditions [1] ,[4], [6].

### Location of SVC

The location of SVC is an important issue. The location can be determined by the sensitivity of voltage at the critical buses with respect to the reactive power injection $\Delta V_i / \Delta Q_i$ .

- For long transmission line If the objective is to compensate a, the SVC is to be located at the midpoint of the line (if a single SVC is to be used).
- For very long lines, multiple SVC at regular intervals can be applied.

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The steady state control (V-I) characteristics are denoted by the SVC rating (in MVAR), range of the reference voltage (Vref) (typically from 0.95 pu to 1.05 pu) and the slope (varying from 2% to 10%). The slopes can be different in the capacitive and inductive modes of operation. The range of short circuit levels at the SVC bus is also an important parameter in the choice of the voltage regulator gain.

## CASE STUDY AND RESULTS

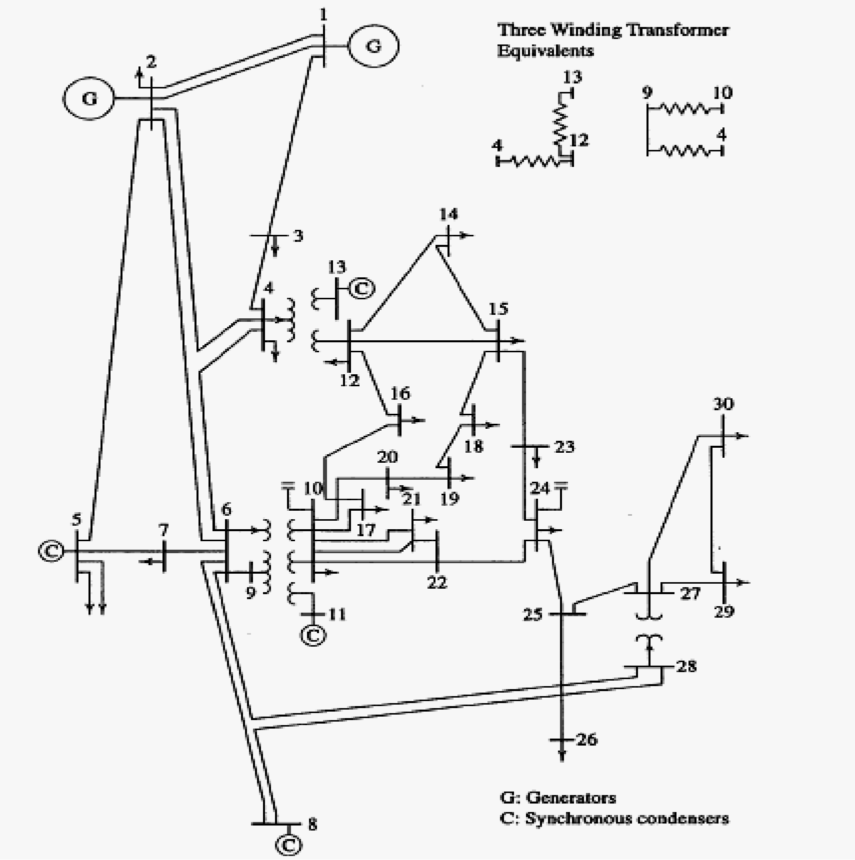

*Fig: IEEE 30-bus sample system.*

*Table 1: IEEE30-bus system bus data*

| Bus no. | Bus type | Voltage magnitude V | Voltage angle (δ) | Real power generated (Pgi) | Reactive power generated (Qgi) | Real power demand (Pdi) | Reactive power demand (Qdi) | Injected Mvar |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.06 | 0 |  | 0 | 0 | 0 | 0 |
| 2 | 2 | 1.043 | 0 | 40 | 50.0 | 21.7 | 12.7 | 0 |
| 3 | 3 | 1.0 | 0 | 0 | 0 | 2.4 | 1.2 | 0 |
| 4 | 3 | 1.06 | 0 | 0 | 0 | 7.6 | 1.6 | 0 |
| 5 | 2 | 1.01 | 0 | 0 | 37.0 | 94.2 | 19.0 | 0 |
| 6 | 3 | 1.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0 |
| 7 | 3 | 1.0 | 0 | 0 | 0 | 22.8 | 10.9 | 0 |
| 8 | 2 | 1.01 | 0 | 0 | 37.3 | 30.0 | 0 | 0 |
| 9 | 3 | 1.0 | 0 | 0 | 0 | 0.0 | 0.0 | 0 |
| 10 | 3 | 1.0 | 0 | 0 | 19.0 | 5.8 | 2.0 | 0 |
| 11 | 2 | 1.082 | 0 | 0 | 16.2 | 0.0 | 0.0 | 0 |
| 12 | 3 | 1.0 | 0 | 0 | 0 | 11.2 | 7.5 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **13** | **2** | **1.071** | **0** | **0** | **10.6** | **0.0** | **0.0** | **0** |
| **14** | **3** | **1.0** | **0** | **0** | **0** | **6.2** | **1.6** | **0** |
| **15** | **3** | **1.0** | **0** | **0** | **0** | **8.2** | **2.5** | **0** |
| **16** | **3** | **1.0** | **0** | **0** | **0** | **3.5** | **1.8** | **0** |
| **17** | **3** | **1.0** | **0** | **0** | **0** | **9.0** | **5.8** | **0** |
| **18** | **3** | **1.0** | **0** | **0** | **0** | **3.2** | **0.9** | **0** |
| **19** | **3** | **1.0** | **0** | **0** | **0** | **9.5** | **3.4** | **0** |
| **20** | **3** | **1.0** | **0** | **0** | **0** | **2.2** | **0.7** | **0** |
| **21** | **3** | **1.0** | **0** | **0** | **0** | **17.5** | **11.2** | **0** |
| **22** | **3** | **1.0** | **0** | **0** | **0** | **0.0** | **0.0** | **0** |
| **23** | **3** | **1.0** | **0** | **0** | **0** | **3.2** | **1.6** | **0** |
| **24** | **3** | **1.0** | **0** | **0** | **4.3** | **8.7** | **6.7** | **0** |
| **25** | **3** | **1.0** | **0** | **0** | **00.0** | **0.0** | **0.0** | **0** |
| **26** | **3** | **1.0** | **0** | **0** | **0** | **3.5** | **2.3** | **0** |
| **27** | **3** | **1.0** | **0** | **0** | **0** | **0.0** | **0.0** | **0** |
| **28** | **3** | **1.0** | **0** | **0** | **0** | **0.0** | **0.0** | **0** |
| **29** | **3** | **1.0** | **0** | **0** | **0** | **2.4** | **0.9** | **0** |
| **30** | **3** | **1.0** | **0** | **0** | **0** | **10.6** | **1.9** | **0** |

***Table2: IEEE 30-bus system Line Data***

| **Sr. no.** | **From bus** | **To bus** | **Line Resistance R (pu)** | **Line Reactance X (pu)** | **Susceptance B/2(pu)** | **X'mer tap setting** |
|---|---|---|---|---|---|---|
| **1** | **1** | **2** | **0.0192** | **0.0575** | **0.0264** | **1** |
| **2** | **1** | **3** | **0.0452** | **0.01652** | **0.0204** | **1** |
| **3** | **2** | **4** | **0.0570** | **0.1737** | **0.0184** | **1** |
| **4** | **3** | **4** | **0.0132** | **0.0379** | **0.0042** | **1** |
| **5** | **2** | **5** | **0.0472** | **0.1983** | **0.0209** | **1** |
| **6** | **2** | **6** | **0.0581** | **0.1763** | **0.0187** | **1** |
| **7** | **4** | **6** | **0.0119** | **0.0414** | **0.0045** | **1** |
| **8** | **5** | **7** | **0.0460** | **0.1160** | **0.0102** | **1** |
| **9** | **6** | **7** | **0.0267** | **0.0820** | **0.0085** | **1** |
| **10** | **6** | **8** | **0.0120** | **0.0420** | **0.0045** | **1** |
| **11** | **6** | **9** | **0.0** | **0.2080** | **0.0** | **0.978** |
| **12** | **6** | **10** | **0.0** | **0.5560** | **0.0** | **0.969** |
| **13** | **9** | **11** | **0.0** | **0.2080** | **0.0** | **1** |
| **14** | **9** | **10** | **0.0** | **0.1100** | **0.0** | **1** |
| **15** | **4** | **12** | **0.0** | **0.2560** | **0.0** | **0.932** |
| **16** | **12** | **13** | **0.0** | **0.1400** | **0.0** | **1** |
| **17** | **12** | **14** | **0.1231** | **0.2559** | **0.0** | **1** |
| **18** | **12** | **15** | **0.0662** | **0.1304** | **0.0** | **1** |
| **19** | **12** | **16** | **0.0945** | **0.1987** | **0.0** | **1** |
| **20** | **14** | **15** | **0.2210** | **0.1997** | **0.0** | **1** |
| **21** | **16** | **17** | **0.0824** | **0.1923** | **0.0** | **1** |
| **22** | **15** | **18** | **0.1073** | **0.2185** | **0.0** | **1** |
| **23** | **18** | **19** | **0.0639** | **0.1292** | **0.0** | **1** |
| **24** | **19** | **20** | **0.0340** | **0.0680** | **0.0** | **1** |
| **25** | **10** | **20** | **0.0936** | **0.2092** | **0.0** | **1** |
| **26** | **10** | **17** | **0.0324** | **0.0845** | **0.0** | **1** |
| **27** | **10** | **21** | **0.0348** | **0.0749** | **0.0** | **1** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 28 | 10 | 22 | 0.0727 | 0.1499 | 0.0 | 1 |
| 29 | 21 | 23 | 0.0116 | 0.0236 | 0.0 | 1 |
| 30 | 15 | 23 | 0.1000 | 0.2020 | 0.0 | 1 |
| 31 | 22 | 24 | 0.1150 | 0.1790 | 0.0 | 1 |
| 32 | 23 | 24 | 0.1320 | 0.2700 | 0.0 | 1 |
| 33 | 24 | 25 | 0.1885 | 0.3292 | 0.0 | 1 |
| 34 | 25 | 26 | 0.2544 | 0.3800 | 0.0 | 1 |
| 35 | 25 | 27 | 0.1093 | 0.2087 | 0.0 | 1 |
| 36 | 28 | 27 | 0.0 | 0.3960 | 0.0 | 0.968 |
| 37 | 27 | 29 | 0.2198 | 0.4153 | 0.0 | 1 |
| 38 | 27 | 30 | 0.3202 | 0.6027 | 0.0 | 1 |
| 39 | 29 | 30 | 0.2399 | 0.4533 | 0.0.0 | 1 |
| 40 | 8 | 28 | 0.0636 | 0.2000 | 0.0214 | 1 |
| 41 | 6 | 28 | 0.0169 | 0.0599 | 0.065 | 1 |

*Table: Result for 30-bus test system (without loading)*

| Sr. no. | Bus no. | Voltage(v) | Angle delta | P calculated | Q calculated |
|---|---|---|---|---|---|
| 1 | 1 | 1.0600 | 0 | 0.1921 | 0.5875 |
| 2 | 2 | 1.0430 | 0.0018 | -0.0082 | -0.0677 |
| 3 | 3 | 1.0173 | -0.0003 | -0.5842 | -1.7744 |
| 4 | 4 | 1.0457 | -0.0003 | 0.9598 | 3.2272 |
| 5 | 5 | 1.0100 | -0.0247 | -0.0080 | -0.1156 |
| 6 | 6 | 1.0071 | -0.0001 - | -0.5202 | -1.8800 |
| 7 | 7 | 1.0012 | -0.0035 | -0.0295 | -0.0932 |
| 8 | 8 | 1.0100 | -0.0041 | 0.0787 | 0.2418 |
| 9 | 9 | 1.0081 | -0.0000 | 0.0000 | -0.3942 |
| 10 | 10 | 1.0016 | -0.0011 | -0.0000 | -0.0000 |
| 11 | 11 | 1.0820 | -0.0000 | 0.0000 | 0.4266 |
| 12 | 12 | 1.0077 | -0.0035 | -0.0000 | -0.7415 |
| 13 | 13 | 1.0710 | 0.0000 | 0.0000 | 0.5431 |
| 14 | 14 | 0.9992 | -0.0025 | -0.0000 | 0.0000 |
| 15 | 15 | 1.0000 | -0.0013 | -0.0000 | -0.0000 |
| 16 | 16 | 1.0002 | -0.0010 | -0.0000 | 0.0000 |
| 17 | 17 | 0.9987 | -0.0014 | -0.0000 | 0.0000 |
| 18 | 18 | 0.9992 | -0.0008 | -0.0000 | 0 |
| 19 | 19 | 0.9987 | -0.0012 | -0.0000 | 0 |
| 20 | 20 | 0.9997 | -0.0004 | 0 | -0.0000 |
| 21 | 21 | 0.9989 | -0.0008 | -0.0000 | 0.0000 |
| 22 | 22 | 1.0002 | -0.0002 | -0.0000 | 0.0000 |
| 23 | 23 | 0.9996 | -0.0002 | -0.0000 | 0.0000 |
| 24 | 24 | 0.9980 | -0.0020 | 0.0000 | 0.0000 |
| 25 | 25 | 0.9995 | -0.0001 | -0.0000 | 0 |
| 26 | 26 | 0.9940 | -0.0025 | -0.0000 | 0.0000 |
| 27 | 27 | 1.0001 | -0.0002 | 0.0000 | -0.0000 |
| 28 | 28 | 1.0036 | -0.0003 | -0.0144 | -0.1318 |
| 29 | 29 | 0.9975 | -0.0019 | -0.0000 | 0.0000 |
| 30 | 30 | 0.9881 | -0.0146 | -0.0000 | 0.0000 |

*Table: voltage at 400 MW loading with and without SVC*

| Sr. no. | Bus no. | Voltage without SVC | Voltage with SVC |
|---|---|---|---|
| 1 | 1 | 1.06 | 1.06 |
| 2 | 2 | 1.043 | 1.043 |
| 3 | 3 | 1.0157 | 1.0171 |
| 4 | 4 | 1.0079 | 1.0096 |
| 5 | 5 | 1.01 | 1.01 |
| 6 | 6 | 1.0064 | 1.0086 |
| 7 | 7 | 0.9964 | 0.9977 |
| 8 | 8 | 1.01 | 1.01 |
| 9 | 9 | 1.022 | 1.0256 |
| 10 | 10 | 1.0011 | 1.0074 |
| 11 | 11 | 1.082 | 1.082 |
| 12 | 12 | 1.0196 | 1.0223 |
| 13 | 13 | 1.071 | 1.071 |
| 14 | 14 | 0.9982 | 1.002 |
| 15 | 15 | 0.992 | 0.9967 |
| 16 | 16 | 1.0013 | 1.0056 |
| 17 | 17 | 0.9934 | 0.9991 |
| 18 | 18 | 0.9773 | 0.9827 |
| 19 | 19 | 0.9733 | 0.979 |
| 20 | 20 | 0.9791 | 0.9849 |
| 21 | 21 | 0.9792 | 0.9867 |
| 22 | 22 | 0.9873 | 0.9979 |
| 23 | 23 | 0.9788 | 0.9866 |
| 24 | 24 | 0.9686 | 0.9846 |
| 25 | 25 | 0.9636 | 0.999 |
| 26 | 26 | 0.9374 | 0.9737 |
| 27 | 27 | 0.9733 | 1.0202 |
| 28 | 28 | 1.0038 | 1.0099 |
| 29 | 29 | 0.9434 | 0.9919 |
| 30 | 30 | 0.9262 | 0.9756 |

*Table: voltages profile at 500 MW loading with and without SVC*

| Sr. no. | Bus no. | Voltage without SVC | Voltage with SVC |
|---|---|---|---|
| 1 | 1 | 1.06 | 1.06 |
| 2 | 2 | 1.043 | 1.043 |
| 3 | 3 | 1.0013 | 1.0046 |
| 4 | 4 | 0.9935 | 0.9977 |
| 5 | 5 | 1.01 | 1.01 |
| 6 | 6 | 0.9962 | 1.0013 |
| 7 | 7 | 0.9868 | 0.9899 |
| 8 | 8 | 1.01 | 1.01 |
| 9 | 9 | 1.0065 | 1.0152 |
| 10 | 10 | 0.9764 | 0.9913 |
| 11 | 11 | 1.082 | 1.082 |
| 12 | 12 | 1.003 | 1.0097 |
| 13 | 13 | 1.071 | 1.071 |

| | | | |
|---|---|---|---|
| **14** | **14** | **0.9748** | **0.984** |
| **15** | **15** | **0.9662** | **0.9777** |
| **16** | **16** | **0.9783** | **0.9886** |
| **17** | **17** | **0.967** | **0.9807** |
| **18** | **18** | **0.9466** | **0.9596** |
| **19** | **19** | **0.941** | **0.9548** |
| **20** | **20** | **0.9483** | **0.9624** |
| **21** | **21** | **0.9483** | **0.9662** |
| **22** | **22** | **0.9583** | **0.9833** |
| **23** | **23** | **0.9478** | **0.9666** |
| **24** | **24** | **0.9339** | **0.9716** |
| **25** | **25** | **0.9302** | **1.0123** |
| **26** | **26** | **0.8958** | **0.9809** |
| **27** | **27** | **0.9447** | **1.0529** |
| **28** | **28** | **0.9924** | **1.0066** |
| **29** | **29** | **0.905** | **1.0181** |
| **30** | **30** | **0.8821** | **0.9981** |

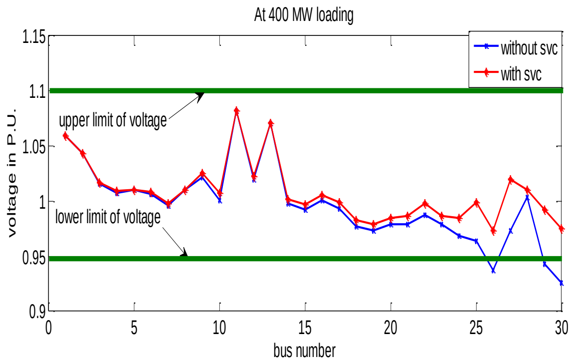

*Fig: Voltage profile graph at 400 MW with and without SVC*

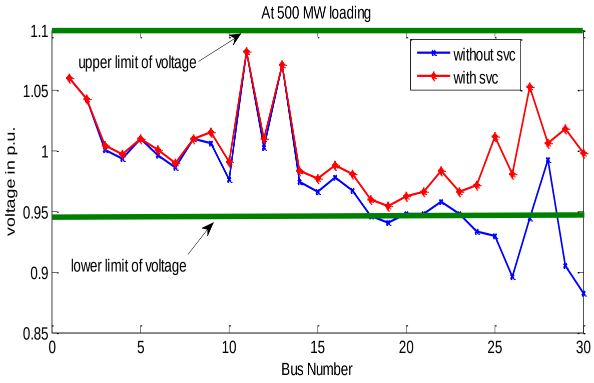

*Fig: Voltage profile graph at 500 MW with and without SVC*

## FUTURE SCOPE

In future Optimizations techniques can be used to find optimal location and the optimal sizing of FACTS devices can be obtained by these soft computing techniques. Also both the objectives can simultaneously be fulfilled by the same.

Locating FACTS devices at different bus locations enhances the system stability as well as the significance amount of reduction in the active and reactive power losses can be achieved.

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