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Enhancement of voltage profile for IEEE-14 Bus System by Using STATIC-VAR Compensation (SVC) when Subjected to Various Changes in Load

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Abstract: *After some damaging blackouts, voltage stability & collapse happening all over the world & across our nation has become a concern problem [1]. The major issue in these problem is the collapse of transmission system which is most suffered by the frequent variations load. In this paper, we focus on the reactive power of most majoring issue in IEEE – 14 bus system. For doing the above said we are using PSAT (Power System analysis toolbox) a MATLAB Based Simulink & Simulation toolbox which utilizes Newton-Raphson method for voltage stability analysis and reactive power controlling [1]. In this work, firstly we have analyzed IEEE-14 bus system under the standard test data & after that analysed IEEE-14 bus system with Static-Var-Compensation under the standard test data. After that, we have increased load data by 5%,10%,15%,20%, 25%,30%,35%,45% and so on then we have compared all the result with the original power flow results of IEEE-14 bus system for improving a Reactive power.*

Keywords: *Transmission System, PSAT, reactive power, voltage stability*

1. Introduction

In load flow, Reactive powe is the power taken by the reactance of the circuit. This power is not actually consumed but it flow forth and back between source and load. It's unit is Volt-Amp-reactive (VAr). Reactive power is the one which is mostly suffered by the changes in load demands.

In this paper, we are looking to improving the voltage profile by controlling the reactive power using FACTS devices in IEEE-14 bus system. Initially, we have analysed IEEE-14 bus system under the standard test data & after that analysed IEEE-14 bus system with Static Var Compensation (SVC) under the standard test data. After that, we have increased load data by 5%, 10%, 15%, 20%, 25%,30%,35%, 45% and so on then we have compared all the result with the original power flow results of IEEE-14 bus system for improving a Reactive power.

The Indian electrical infrastructure was generally considered unreliable. The Northern grid had previously collapsed in 2001. An estimated 27% of power generated was lost in transmission or stolen [6].Further, about 25% of the population, approximately 300 million people, had no electricity at all. Projections suggested India remained decades away from having sufficient energy supply [8].

The July 2012 India blackout was the largest power outage in history, occurring as two separate events on 30 and 31 July 2012. The outage affected over 620 million people, about 9% of the world population, or half of India's population, spread across 22 states in Northern, Eastern, and Northeast India. An estimated 32 giga-watts of generating capacity was taken offline in the outage [6].

It concluded that four factors were responsible for the two days of blackout [7].

Firstly, weak inter-regional power transmission corridors due to multiple existing outages (both scheduled and two forced).

Secondly, high loading on 400 kV line at Bina-3, Gwalior.-Agra link.

Thirdly, Inadequate response by State Load Dispatch Centers (SLDCs) to the instructions of Regional Load Dispatch Centers (RLDCs) to reduce overdraws by the Northern Region utilities and underdraw/excess generation by the Western Region 4utilities..

Finally, loss of 400 kV Bina-Gwalior link due to disoperation of its protection system.

If the weakest link (most sensitive to load changes) was known earlier & by applying some protection schemes the blackout would have been avoided. It is necessary to find out a sensitive node in the power system in order to avoid the above said problems.

2. Problem Domain

Voltage stability is a main issue in planning and operating power system and is factor leading to limit power transfer. Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all buses in the system under normal condition and after being subjected to a disturbance. A power system is set to have entered a state of voltage instability when a disturbance results in a progressive and uncontrollable decline in voltage.

Inadequate reactive power support from generator and transmission line leads to voltage instability or voltage collapse, which has resulted in several major system failures in the world. They are South Florida, USA, system disturbance of 17 May 1985, (transient, 4 sec). NREB grid disturbance in India in 1984 and 1987.

2.1 Reactive power and voltage collapse

Voltage collapse typically occurs in power system which is usually heavily loaded, faulted and/or has reactive power storage. Voltage collapse in a system in stability and in involve many power system component and there variable a once. Indeed, voltage collapse often involves entire power system all through it usually has a relatively large involvement in one particular section of the power system. Though a number of variables are typically involved some physical understanding into the nature of voltage collapse may be gained by examine the generation, transmission and consumption (Including surplus and deficit) of reactive power. Lamination on the production of power include generator and reactive power compensator limit and the reduce capacity reactive power by the line and fixed capacitor due to low voltage. The primary lamination on the transmission of power is the high reactive power loss on heavily loaded on long transmission line. There may also be outages and reduce transmission capacity. Reactive power demand of load increases, with increase in load, motor stalling or changing in load composition.

Voltage collapse can offer in transient time scale or in long terms time scale. Voltage collapse in long term time scale can include effect from the transient scale can include effect from transient time scale; for example, a slow voltage collapse taking several minute may end in fast voltage collapse in the transient time scale.

Voltage stability and voltage collapse are used somewhat interchangeably by many researchers.

Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to unacceptable voltage profile in a significant parts of the power system. It may be manifested in several different ways.

Voltage collapse may be characterized as follow:

1. The initiating event may be due to variety of reasons: small gradual system change such as natural increase in system load, or large sudden disturbances such as loss of a generating units or a heavily loaded line.
2. Reactive compensation can be made most effective by the judicious choice of a mixture of shunt capacitors, static-var system and possible synchronous condenser.

2.2 Factor Affecting Voltage Stability

It is well known that slower acting devices such as generator over- excitation limits, the characteristics of the system load, on load tap changing and compensation device will contribute to the evolution of voltage collapse. The modeling of power system is similar both in long terms voltage stability studies and load flow studies. Most components can be modeled with the existing model, control of HVDC and static Var compensator. These devices have contribution to voltage stability, particularly on short term voltage stability. The analysis and combination of fast and slow acting devices is also difficult with the traditional simulation tool, but may be easily analysis with a fast voltage stability analysis method.

2.3 Change in power system contribution to voltage collapse

There are several power system disturbances which contribute to voltage collapse. Such as, increase in inductive load, Reactive power limit attained by reactive power compensator and generator,OLTC operation, load recovery dynamics, Generator outage and line tripping.

The different methods of obtained by researchers for improving voltage stability are:

Voltage stability can be improved by adopting the following means:

a) Compensating the line length reduces net reactance and power flow increase.

b) HVDC tie may be used between regional grids.

c) Enhancing the localized reactive power support (SVC) is more effective and capacitor bank are more economical. FACTS devices or synchronous condenser may also be used.

2.4 FACTS Devices: An approach to improving voltage profile by controlling reactive power

The rapid development of power electronics technology provide exciting opportunities to develop new power system equipment for better utilization of the exciting system. Since 1990, a number of control devices under the terms FACTS technology have been proposed and implemented. FACTS device can be effectively used for power flow control, load sharing among parallel corridors, voltage regulation, and enhancement of transient stability and mitigation of the system oscillation. By giving additional flexibility, FACTS controllers can enable a line to Carrey power closer to its thermal rating. Mechanical switching has to be supplemented by rapid response power electronics. It may be noted that FACTS is an enabling technology, and a not a one a one substitute for mechanical switches.

FACTS employ high speed thyristor for switching in or out transmission line components such as capacitor, reactor or phase shifting transformer for some desirable system performance. The FACTS technology is not a single high power controller, but rather a collection of controller, which can be applied individually or in coordination with other to control one or more of the system parameter.

A flexible alternating current transmission system (FACTS) is a system composed of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics- based system. FACTS are defined as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.

We can now generalize the advantages of FACTS devices as follow:

1. Control of power flow(both active and reactive), as desired and within limits, is possible.
2. Reduction of voltage drop in power lines is possible. Regulation can be improved.
3. Reduction of reactive of burden on line allows more flow of active power in lines.
4. Loadablity of lines is increased.
5. Voltage stability and voltage security are enhanced.
6. Security of tie lines connecting two sub grids is increased.
7. Transient stability is increased.
8. Short circuit currents and overloads can be controlled up to certain limits.
9. Generation cost reduces.
10. Passive compensation requirement reduces.

3. Solution Domain

In this paper, voltage stability is improving by controlling the reactive power or using FACTS devices. In FACTS devices, Static-Var compensation (SVC) is used for improving voltage stability by connecting Static-Var compensation (SVC) at a weakest nodes.

SVC is an electrical device for providing fast-acting reactive power on high voltage electricity transmission networks. An SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or Fixed Capacitors (FC) tuned to Filters. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, and employing resin impregnated. The main advantage of SVCs over simple mechanically-switched compensation schemes is their near-instantaneous response to changes in the system voltage. For this reason they are often operated at close to their zero-point in order to maximize the reactive power correction they can rapidly provide when required. They are in general cheaper, higher-capacity, faster, and more reliable than dynamic compensation schemes such as synchronous condensers.

A static VAR compensator (SVC) is an electrical device for providing fast- active reactive power on high- voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than internal switchgear) . Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

(a) Connected to the power system, to regulate the transmission voltage (Transmission SVC)

(b) Connected near large industrial loads, to improve power quality (Industrial SVC)

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristor controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristor -controlled reactor, which is continuously variable, along with a capacitor bank step, the net result is continuously- variable leading or lagging power. In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage and improve the voltage stability reducing the reactive power. Thus, for improving voltage stability, keeping the constant real power and increasing the reactive load data by 5%, 10% and so on up-to 40%. In the proposed solution we are experimenting with IEEE-14 bus system. PSAT a MATLAB based Simulink & Simulation tool is used for Power System Analysis.

A simulink model of IEEE-14 bus system is being designed & have used. The standard test data for it is shown in figure 1.

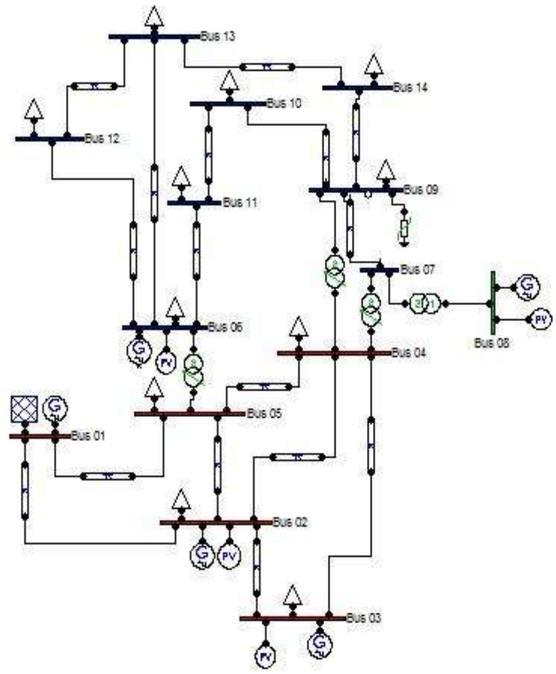

Figure 1. *PSAT Model of IEEE-14 bus system*

Table 1. *The input data for the above model is given below.*

Bus No.	GENERATION		LOAD	
	REAL (MW)	REACTIVE (MVAR)	REAL (MW)	REACTIVE (MVAR)
1	232.4	-16.9	0.0	0.0
2	40.0	42.4	21.7	12.7
3	0.0	23.4	94.2	19.0
4	0.0	0.0	47.8	3.9
5	0.0	0.0	7.6	1.6
6	0.0	12.2	11.2	7.5
7	0.0	0.0	0.0	0.0
8	0.0	17.4	0.0	0.0
9	0.0	0.0	29.5	16.6
10	0.0	0.0	9.0	5.8
11	0.0	0.0	3.5	1.8
12	0.0	0.0	6.1	1.6
13	0.0	0.0	13.5	5.8
14	0.0	0.0	14.9	5.0

Table 2. *Bus Data*

Line No.	Bus No.	Line Impedance		Half line charging susceptance (p.u.)
		R (p.u.)	X (p.u.)	
1.	1-2	0.01938	0.05917	0.02640
2.	2-3	0.04699	0.19797	0.02190
3.	2-4	0.05811	0.17632	0.01870
4.	1-5	0.05403	0.22304	0.02460
5.	2-5	0.05695	0.17388	0.01700
6.	3-4	0.06701	0.17103	0.01730
7.	4-5	0.01335	0.04211	0.0064
8.	5-6	0.0	0.25202	0.0
9.	4-7	0.0	0.20912	0.0
10.	7-7	0.0	0.17615	0.0
11.	4-9	0.0	0.55618	0.0
12.	7-9	0.0	0.11001	0.0
13.	9-10	0.03181	0.08450	0.0
14.	6-11	0.09498	0.19890	0.0
15.	6-12	0.12291	0.25581	0.0
16.	6-13	0.06615	0.13027	0.0
17.	9-14	0.12711	0.27038	0.0
18.	10-11	0.08205	0.19207	0.0
19.	12-13	0.22092	0.19988	0.0
20.	13-14	0.01709	0.34802	0.0

Table 3. *Line Data*

Bus No.	Voltage magnitude (p.u.)	Reactive Power Limit	
		Minimum MVAR	Maximum MVAR
2	1.045	-40	50
3	1.01	0	40
6	1.07	-6	24
8	1.09	-6	24

Table 4. *Regulated Bus Data*

Transformer	B/W Buses	Tap-Setting
1	4-7	0.978
2	4-9	0.969
3	5-6	0.932

After feeding the data of table 1, table 2, table 3, table 4 in model of IEEE-14 bus system shown in figure 1, the power flow result of IEEE-14 bus without SVC by Newton-Raphson method is obtained as in table 5. Table 6 shows the power flow result of IEEE-14 bus system with static-var compensation.

Table 5. *Power flow result of IEEE-14 bus without SVC*

Bus No.	Voltage (p.u.)	Phase (rad)	P.Gen (p.u.)	Q.Gen (p.u.)	P.load (p.u.)	Q.load (p.u.)
1	1.06	0	1.0279	0.0812	0	0
2	1.045	-0.0359	0.4	0.1986	0.217	0.127
3	1.01	-0.1047	0.4	0.0613	0.942	0.19
4	1.0232	-0.0795	0	0	0.478	0.039
5	1.0273	-0.065	0	0	0.076	0.016
6	1.07	-0.0846	0.4	0.1255	0.112	0.075
7	1.0532	-0.069	0	0	0	0
8	1.09	-0.0076	0.4	0.2399	0	0
9	1.0359	-0.1038	0	0	0.295	0.166
10	1.0342	-0.1053	0	0	0.09	0.058
11	1.0482	-0.0971	0	0	0.035	0.018
12	1.0538	-0.1002	0	0	0.061	0.016
13	1.0473	-0.1018	0	0	0.135	0.058
14	1.0226	-0.1208	0	0	0.149	0.05

Table 6. *Power flow result of IEEE-14 bus with SVC*

Bus No.	**Voltage (p.u.)**	**Phase (rad)**	**P.Gen (p.u.)**	**Q.Gen (p.u.)**	**P.load (p.u.)**	**Q.load (p.u.)**
1	1.06	0	1.028	0.07104	0	0
2	1.045	-0.03586	0.4	0.16498	0.217	0.127
3	1.01	-0.10455	0.4	0.04075	0.942	0.19
4	1.0266	-0.08066	0	0	0.478	0.039
5	1.0296	-0.0654	0	0	0.076	0.016
6	1.07	-0.08186	0.4	0.03775	0.112	0.075
7	1.0644	-0.07199	0	0	0	0
8	1.09	-0.01122	0.4	0.17031	0	0
9	1.0581	-0.10654	0	0	0.295	-0.04674
10	1.0527	-0.1072	0	0	0.09	0.058
11	1.0576	-0.09694	0	0	0.035	0.018
12	1.0555	-0.0976	0	0	0.061	0.016
13	1.0506	-0.09992	0	0	0.135	0.058
14	1.0368	-0.1211	0	0	0.149	0.05

Table-7. *14 bus integrated system results without SVC for varied reactive load*

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
Original Power Flow Result	1.06	1.045	1.01	1.0232	1.0272	1.07	1.0532	1.09	1.0359	1.0342	1.0482	1.0538	1.0473	1.0226
SET1(5% CHANGE)	1.06	1.045	1.01	1.0228	1.0271	1.07	1.0525	1.09	1.0344	1.0328	1.0474	1.0534	1.0467	1.0211
SET2(10% CHANGE)	1.06	1.045	1.01	1.0225	1.0269	1.07	1.0517	1.09	1.033	1.0314	1.0466	1.053	1.0461	1.0197
SET3(15% CHANGE)	1.06	1.045	1.01	1.0222	1.0267	1.07	1.0509	1.09	1.0315	1.0299	1.0457	1.0526	1.0455	1.0182
SET4(20% CHANGE)	1.06	1.045	1.01	1.0219	1.0264	1.07	1.0502	1.09	1.0301	1.0285	1.0449	1.0522	1.0449	1.0167
SET5(25% CHANGE)	1.06	1.045	1.01	1.0216	1.0262	1.07	1.0494	1.09	1.0286	1.027	1.0441	1.0517	1.0443	1.0152
SET6(30% CHANGE)	1.06	1.045	1.01	1.0212	1.026	1.07	1.0487	1.09	1.0271	1.0256	1.0433	1.0513	1.0438	1.0137
SET7(35% CHANGE)	1.06	1.045	1.01	1.0209	1.0257	1.07	1.0479	1.09	1.0256	1.0241	1.0425	1.0509	1.0432	1.0122
SET8(40% CHANGE)	1.06	1.045	1.01	1.0206	1.0255	1.07	1.0471	1.09	1.0242	1.0227	1.0416	1.0505	1.0426	1.0107
AVERAGE	1.06	1.045	1.01	1.0212	1.0264	1.07	1.0502	1.09	1.03	1.0285	1.0449	1.0522	1.045	1.0167
DIFFERENCE	0	0	0	0.0020	0.0008	0	0.0030	0	0.0059	0.0057	0.0033	0.0016	0.0028	0.0059

On comparing the results obtained in Table-5 & Table-6 i.e. power flow results of IEEE – 14 bus system with & without SVC we found out that there were several changes in voltage profiles, reactive power generation & its compensation on various buses which are listed below:

- Voltage profile of bus no: 4, 5, 7, 9, 10, 11, 12, 13, 14 have improved.
- Reactive power generation at bus no 1, 2, 3, 6 & 8 have been reduced.
- Reactive power have been compensated at bus no 9.

From here onwards, changing the reactive load data by 5%, 10% and so on up to 40% which are connected at bus number 2,3,4,5,6,9,10,12,13 and 14 respectively. The result obtained are tabulated at the last Table-7. Here the main focus is on the voltage profile. From the table we can note that the bus number 9 & 14 are undergoing maximum changes in reactive power. Hence, from the above we have concluded that we have to connect SVC

at bus no 9 & 14. But, after connecting SVC at bus number 9 & then on bus number 14 it was observed that the power flow results of the system were improved when we connect SVC at bus number 9 as compared to bus number 14. Hence, we have worked on bus number 9 of the IEEE – 14 bus system.

4. CONCLUSION

From table 7 it is clear that the voltage profile is weak at bus 9 & bus 14 when subjected to percentage changes in load which may result in voltage collapse. Hence a special protection scheme can be applied on these buses to prevent voltage collapse.

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