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Transient Stability Enhancement in a Distribution Network Using FCL and SVC

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Abstract: **This paper presents a system stability study is the important parameter of economic, reliable and secure power system planning and operation. Power system studies are important during the planning and conceptual design stages of the project as well as during the operating life of the plant periodically. In this system stability study transient stability has a greater importance. In a radial distribution network during severe fault the transient stability of the network is much important which determines the stability of the system. During severe fault the rotor angle deviation of the generator connected to the distribution network is analyzed and is enhanced by adding fault current limiter. Fault Current Limiter (FCL) is a device which limits the prospective fault current when a fault occurs. The reliability of the system is analyzed by simulating the distribution network with a fault, and the transient stability is enhanced using FCL and SVC in ETAP for IEEE 59 bus test System.**

Keywords: **Fault Current Limiter (FCL), Static VAR Compensator (SVC) Radial Distribution System (RDS), Single Machine Infinite Bus (SMIB), Distribution Generator (DG), Transient Stability.**

I. INTRODUCTION

Utilities are continuously planning for the expansion of their electrical networks in order to face the load growth and to properly supply their consumers. The traditional solution was the construction of new substations or the expansion of those already existent. The key objective of any electricity utility company in the current deregulating environment is to maximize the quality of services by providing acceptable level of voltage and reliability and also at the same time reducing the electricity cost for customers with low investment, operation and maintenance costs. These goals together with the rising demands of customers have led to the increased growth of Distributed Generation (DG).Distributed Generation (DG) system is defined as an Electric power source of limited size (generally few kW-few MW) connected directly to the distribution level at substation or distribution feeder; or at customer level. DG may be either renewable or non-renewable energy to produce electricity with minimum emissions. There are many DG technologies including photovoltaic, wind turbine, fuel cells, small and micro-sized turbine packages, internal combustion engine generators, and reciprocating engine generators. Several of these have been developed only in the last few decades.

Main reasons for the increasing usage of Distributed Generation can be summed up as follows;

(i) It is easier to find land availability for small size generators.

(ii) Decreases related costs to transmission and distribution.

(iii) Reduces power loss and improves system voltage profile.

(iv) Renewable Distributed Generations can eliminate or reduce emissions.

(v) It is a feasible alternative for extending power source which improves system reliability and performance of the system.

Distribution systems are usually radial in nature for its simplicity. Radial distribution systems (RDSs) are fed at only one point which is the substation. The substation receives power from centralized generating stations through the interconnected transmission network. The end users of electricity receive electrical power from the substation through RDS which is a passive network. Hence, the power flow in RDS is unidirectional. High R/X ratios in distribution lines result in large voltage drops, low voltage stabilities and high power losses. Due to uncertainty of system loads on different feeders, which vary from time to time, the operation and control of distribution systems is more complex particularly in the areas where load density is high. Because of the dynamic nature of loads, total system load is more than its generation capacity that makes relieving of load on the feeders not possible and hence voltage profile of the system will not be improved to the required level. In order to meet required level of load demand, DG units are integrated in distribution network to improve voltage profile, to provide reliable and uninterrupted power supply and also to achieve economic benefits such as minimum power loss, energy efficiency and load leveling. Such embedded generations in a distribution system are called dispersed generations or distributed generations.

II. POWER SYSTEM STABILITY

Power system stability is the property of the system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance.The stability problem is concerned with the behavior of the synchronous machines after a disturbance. Stability problems are generally divided into two major categories-voltage stability and angle stability.

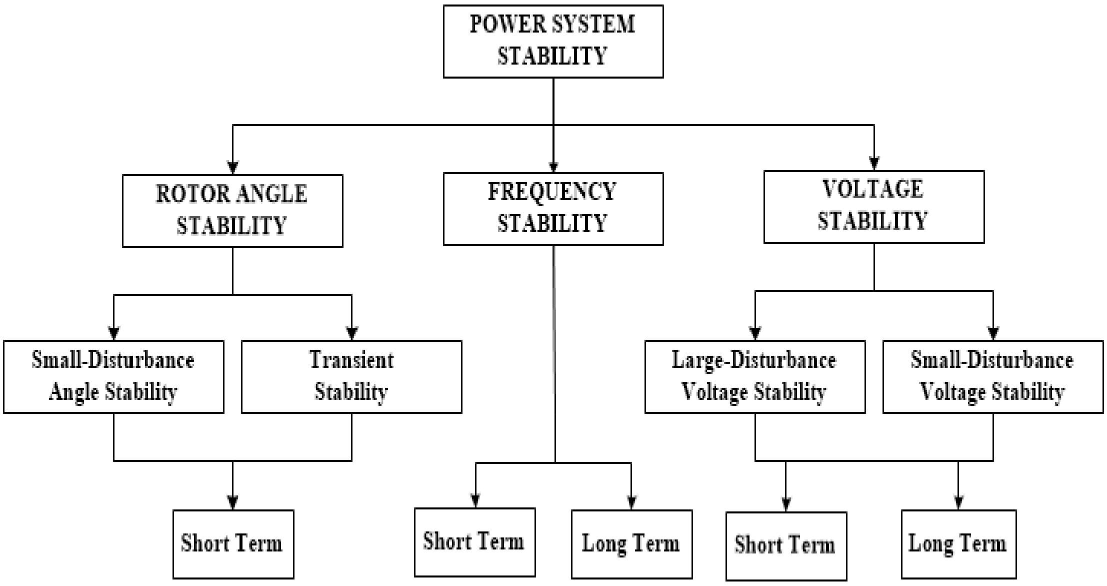

Fig.1. Classification of Power System Stability

III. ROTOR ANGLE STABILITY

Rotor angle stability is the stability of inter-connected synchronous machines of a power system to remain in synchronism. The stability problem involves the study of electromechanical oscillations involving exchange of energy between network and generator-mechanical system at or close to power frequency.

The problem is the manner in which output power of synchronous machines as rotor oscillates.The rotor angle stability phenomena can be divided into two categories,

(i) Small signal stability.

(ii) Large signal stability.

V. TRANSIENT STABILITY

Power system stability may be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating condition and to regain an acceptable state of equilibrium after being subjected to a disturbance.Instability in a power system may be manifested in many different ways depending on the system configuration and operating mode. Traditionally the stability problem has been one of maintaining synchronous operation.

A. ELEMENTRY VIEW OF TRANSIENT STABILITY:

The generator delivering power to a large system represented by an infinite bus through two transmission circuits.An infinite bus, represents a voltage magnitude and constant frequency from Fig:5

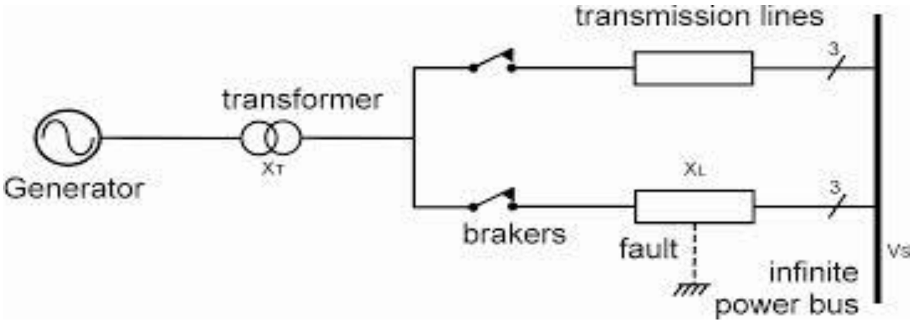

Fig.5. Single Machine Infinite Bus System

We will presents fundamental concepts and principles of transient stability by analysing the system response to large disturbance, using very simple models.

B. POWER ANGLE RELATIONSHIP:

We shall consider this relation for a lumped parameter lossless transmission line. Consider the single-machine-infinite-bus (SMIB) system. In this the reactance X includes the reactance of the transmission line and the synchronous reactance or the transient reactance of the generator. The sending end voltage is then the internal emf of the generator. Let the sending and receiving end voltages be given by

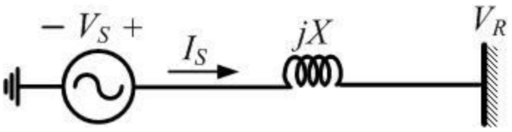

Fig.6. An SMIB system

$$P_e = P_S = P_R = \frac{V_1 V_2}{X}\sin\delta = P_{\max}\sin\delta$$

where $P_{\max} = V_1V_2/X$ is the maximum power that can be transmitted over the transmission line. The power-angle curve is shown in this figure we can see that for a given power P_0. There are two possible values of the angle δ – δ_0 and $\delta_{\max}$. The angles are given by

$$\delta_0 = \sin^{-1}\left(\frac{P_0}{P_{\max}}\right)$$

$$\delta_{\max} = 180° - \delta_0$$

Let us denote the angle of the terminal voltage by δ_t, while its magnitude by V_t. Since the generator delivers 0.9 per unit power to the constant voltage bus of magnitude 1.0 per unit through a 0.3 per unit reactance.

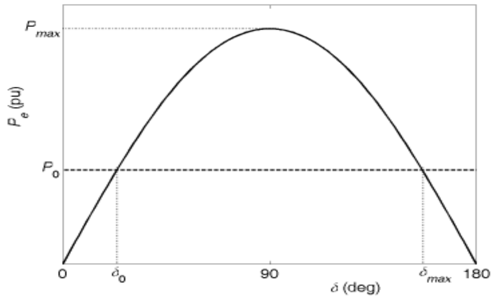

Fig.7. A Typical Power-Angle Curve

C. POWER ANGLE EQUAL CRITERIA:

Consider the power angle curve shown in Fig.7 Suppose the system is operating in the steady state delivering a power of P_m at an angle of δ_0 when due to malfunction of the line, circuit breakers open reducing the real power transferred to zero. Since P_m remains constant, the accelerating power P_a becomes equal to P_m. The difference in the power gives rise to the rate of change of stored kinetic energy in the rotor masses. Thus the rotor will accelerate under the constant influence of non-zero accelerating power and hence the load angle will increase. Now suppose the circuit breaker re-closes at an angle δ_c. The power will then revert back to the normal operating curve. At that point, the electrical power will be more than the mechanical power and the accelerating power will be negative. This will cause the machine decelerate. However, due to the inertia of the rotor masses, the load angle will still keep on increasing. The increase in this angle may eventually stop and the rotor may start decelerating.

Note that

$$\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2 = 2\left(\frac{d\delta}{dt}\right)\left(\frac{d^2\delta}{dt^2}\right)$$

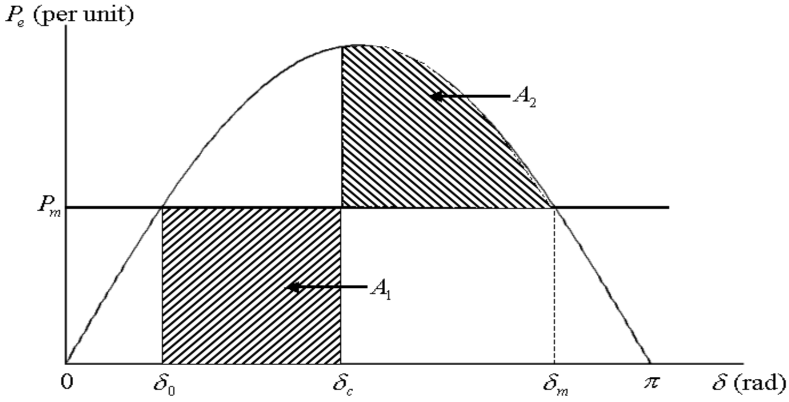

Fig.8. Power-Angle Curve For Equal Area Criterion

IV. STATIC VAR COMPENSATOR

A static VAR compensator is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics 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:

- Connected to the power system, to regulate the transmission voltage ("Transmission SVC")
- 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.

1. PRINCIPLE:

Typically, an SVC comprises one or more banks of fixed or switched shunt capacitors or reactors, of which at least one bank is switched by thyristors. Elements which may be used to make an SVC typically include:

- Thyristor controlled reactor (TCR), where the reactor may be air- or iron-cored.
- Thyristor switched capacitor (TSC)
- Harmonic filter(s)
- Mechanically switched capacitors or reactors (switched by a circuit breaker)

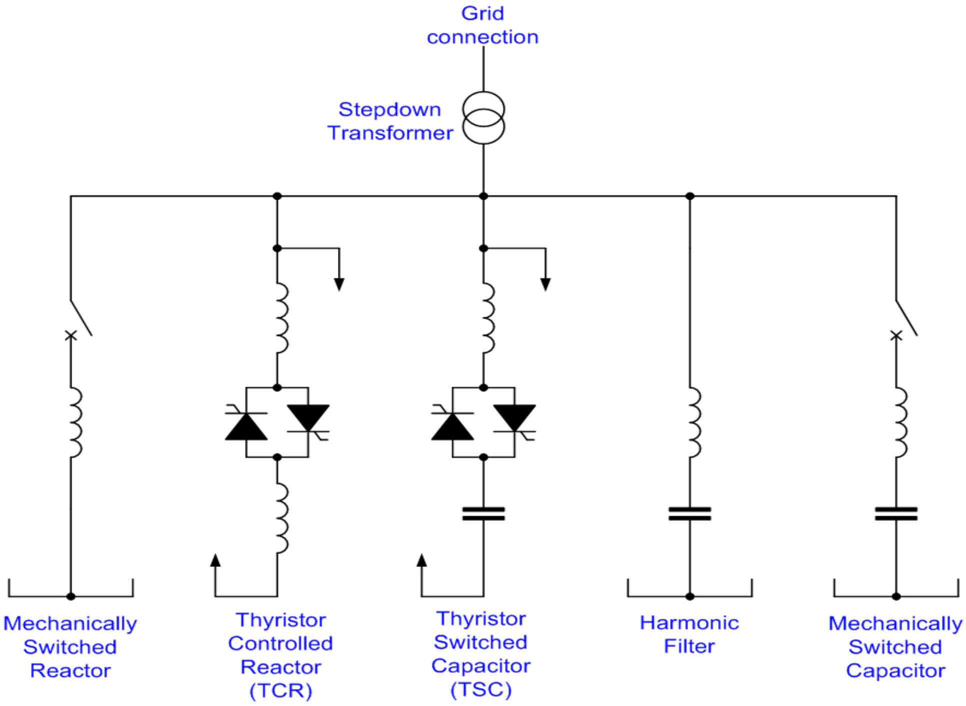

Fig. 9 One-line diagram

A typical SVC configuration; here employing a thyristor controlled reactor, a thyristor switched capacitor, a harmonic filter, a mechanically switched capacitor and a mechanically switched reactor by means of phase angle modulation switched by the thyristors, the reactor may be variably switched into the circuit and so provide a continuously variable MVAR injection (or absorption) to the electrical network. In this configuration, coarse voltage control is provided by the capacitors; the thyristor-controlled reactor is to provide smooth control. Smoother control and more flexibility can be provided with thyristor-controlled capacitor switching.

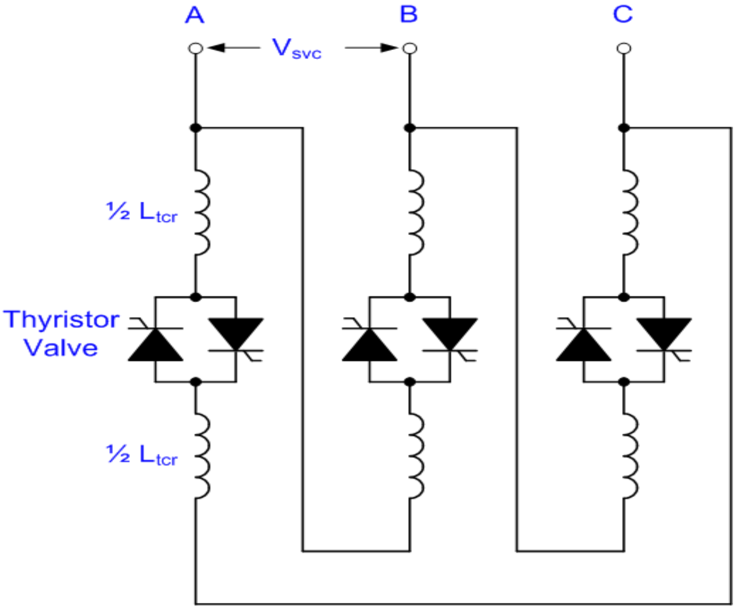

Fig.10 Thyristor Controlled Reactor(TCR), shown with Delta connection

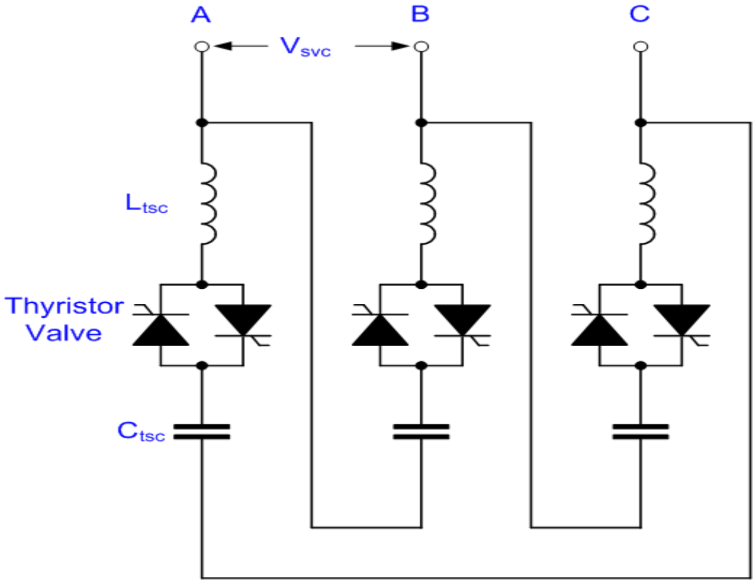

Fig.11 Thyristor Switched Capacitor (TSC), shown with Delta connection

The thyristors are electronically controlled. Thyristors, like all semiconductors, generate heat and deionized water is commonly used to cool them. Chopping reactive load into the circuit in this manner injects undesirable odd-order harmonics and so banks of high-power filters are usually provided to smooth the waveform. Since the filters themselves are capacitive, they also export MVARs to the power system.More complex arrangements are practical where precise voltage regulation is required. Voltage regulation is provided by means of a closed-loop controller. Remote supervisory control and manual adjustment of the voltage set-point are also common.

2. CONNECTION:

Generally, static VAR compensation is not done at line voltage; a bank of transformers steps the transmission voltage (for example, 230 kV) down to a much lower level (for example, 9.0 kV). This reduces the size and number of components needed in the SVC, although the conductors must be very large to handle the high currents associated with the lower voltage. In some static VAR compensators for industrial applications such as electric arc furnaces, where there may be an existing medium-voltage busbar present (for example at 33kV or 34.5kV), the static VAR compensator may be directly connected in order to save the cost of the transformer. Another common connection point for SVC is on the delta tertiary winding of Y-connected auto-transformers used to connect one transmission voltage to another voltage.The dynamic nature of the SVC lies in the use of thyristors connected in series and inverse-parallel, forming "thyristor valves"). The disc-shaped semiconductors, usually several inches in diameter, are usually located indoors in a "valve house".

3. ADVANTAGES:

The main advantage of SVCs over simple mechanically switched compensation schemes is their near-instantaneous response to changes in the system voltage.[7] For this reason they are often operated at close to their zero-point in order to maximise 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.[7] However, static VAR compensators are more expensive than mechanically switched capacitors, so many system operators use a combination of the two technologies .

V. TRANSIENT STABILITY ENHANCEMENT

The several methods to improve transient stability by achieving one or more effects:

(i) Reduction in the distributing influence by minimizing the fault severity and duration.

(ii) Reduction of the accelerating torque by applying artificial load these objective.

(iii) By using high speed fault clearing.

(iv) Reduction of transmission system reactance.

(v) Increase of the restoring synchronizing forces.

The following various methods of achieving these objectives.

A. High Speed Fault Clearing:

The amount of kinetic energy gained by the generators during a fault is directly proportional to the fault duration. The quicker the fault is cleared ,the less disturbance it cause. Two-cycle breakers together with high – speed relay and communication,are now widely used in the loacation where rapid fault clearing is important. In special circumstances even faster clearing may be desired.

B. Reduction Of Transmission System Reactance:

The series inductive reactances of transmission networks are primary determinants of stability limits. The reduction of reactances of various elements of transmition network improves transient stability by increasing postfault synchronizing power transfers. The following are additional methods of reducing the network reactances;

- Use of transformers with lower leakage reactances.
- Series capacitor compensation of transmission lines.

Protective relaying is made more complex when series compensation is used, particularly if the series capacitors are switched.

VI. OBJECTIVE OF LOAD FLOW STUDY

1. Power flow analysis is very important in planning stages of new networks or addition to existing ones like adding new generator sites, meeting increased load demand and locating new transmission sites.

2. The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels.

3. It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines. System transmission loss minimizes. Economic system operation with respect to fuel cost to generate all the power needed. The line flows can be known which helps in avoiding line overloading.

VII. BUS CLASSIFICATION

A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with quantities, such as magnitude of voltage, phage angle of voltage, active or true power and reactive power in load flow problem. Two out of these 4 quantities are specified and remaining 2 are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into 3 categories.

A. Load Bus:

No generator is connected to the bus. At this bus the Real and Reactive power of load is specified. It is desired to find out the voltage magnitude and phase angle through load flow solutions and voltage can be allowed to vary within the permissible values.

B. Generator Bus Or Voltage Controlled Bus:

Here the voltage magnitude corresponding to the generate voltage and real power P_g corresponds to its rating are specified. It is required to find out the reactive power generation Q_g and phase angle of the bus voltage.

C. Slack Bus:

For the Slack Bus, it is assumed that the voltage magnitude $|V|$ and voltage phase θ are known, whereas real and reactive powers P_g and Q_g are obtained through the load flow solution.

VIII. NEWTON RAPHSON LOAD FLOW

To find a load flow the Newton Raphson algorithm is used.

Step1: Assume a suitable solution for all buses except slack bus. Assume,

V_p=1+j0.0 for p= 1, 2….n

Step 2: Convergence criterion is set to ∈ that means if the largest of absolute of the residues exceed ε the process repeated else terminated.

Step 3: Iteration count is set to K=0

Step4: Bus count is set to p=1

Step 5: Say p is slack bus .If yes skip to step 10.

Step 6: Real and Reactive powers $P_p and Q_P$ are calculated respectively using equations,

$$P_p = \sum_q^n = 1\{e_p(e_q G_{pq} + f_p B_{pq}) + f_p(f_p G_{pq} - e_q B_{pq})\} \ldots\ldots\ldots\ldots (1.0)$$

$$Q_p = \sum_q^n = 1\{f_p(e_q G_{pq} + f_q B_{pq}) - e_p(f_q G_{pq} - \ e_q B_{pq})\} \ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

Step 7: Calculate

$$\Delta P_p^k = P_{sp} - P_p^k \ldots\ldots\ldots. (1.2)$$

Step 8: Check for bus to be generator bus, if yes compare the reactive power Qp with the upper and lower limits.

If$Qgen>Qmax$set,= $Qmax$

Else if $Qgen<Qmin$ set, $Qgen= Qmin$

Else if the value is within the limit, the value is retained. If the limits are not violated, Voltage residue is evaluated as,

$$|\Delta Vp|^2 = |Vp|^2_{spec} - |V_p^k|^2 \quad \ldots\ldots(1.3)$$

And then go to step 10.

Step 9: Evaluate

$$\Delta Q_p^k = Q_{sp} - Q_p^k \ \ldots\ldots\ldots. (1.4)$$

Step 10: Bus count is incremented by 1, i.e p=p+1 and check if all buses have been accounted else, go to step 5.

Step 11: Determine the largest of the absolute value of residue. If the largest of absolute value of the residue is less than ∈ then go to step 16

Step 12: Jacobian matrix elements are evaluated.

Step 13: Voltage increments are calculated

Step 14: Calculate new bus voltages and phase angles.

$$e_p^{k+1} = e_p^k + \Delta e_p^k$$

………(1.5)

$$f_p^{k+1} = f_p^k + \Delta f_p^k$$

Step 15: Advance iteration count is K =K+1, then go to step 4

Step 16: Finally bus and line powers are evaluated and results are printed.

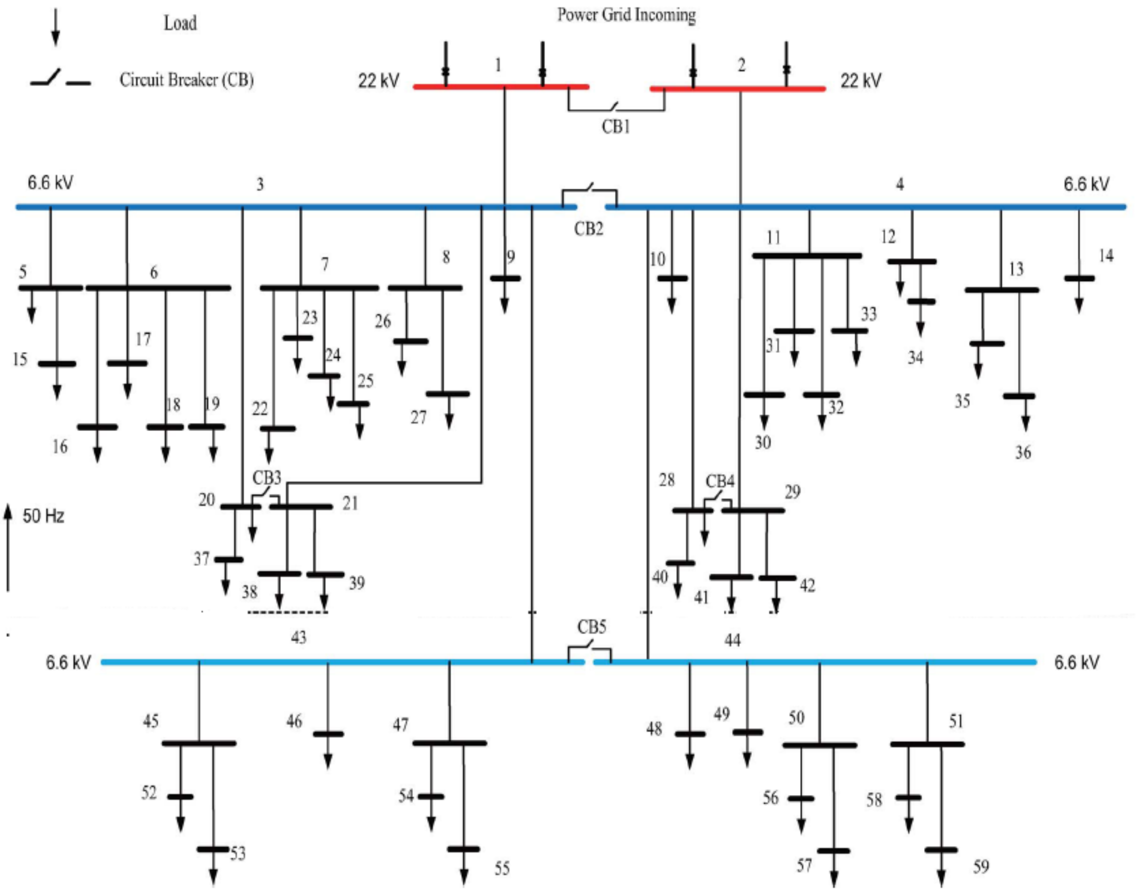

Fig.12 59 IEEE Bus System

Tab.1. 59 Bus System

VOLTAGE	BUS
2.2kv	1,2
6.6kv	3-14,43-45,47,50-51
0.4kv	15-42,46,4-49,52-59

Electrical grid system comprising 59 buses, three voltage levels, i.e., 0.4 kV, 6.6 kV, and 22 kV.All the buses in Tab.2. have been classified into three major groups based on their load types and historical load data.

Tab.2. Bus Classification

GROUP	BUS
1	5-9,15-27,37-39
2	10-14,28-36,40-42
3	45-59

A. Bus Load Data:

Tab.3.Bus Load Data

Bus No:	Load Data (MW & MVAr)	
5	0.638	0.395
9	0.383	0.237
10	0.850	0.527
12	0.638	0.395
14	1.200	0.900
15	0.850	0.527
16	0.638	0.395
17	1.700	1.054
18	0.298	0.184
19	0.298	0.184
20	0.190	0.062
21	2.650	1.366
22	0.383	0.237
23	0.383	0.237
24	0.383	0.237
25	0.383	0.237
26	0.850	0.527
27	0.850	0.527
28	0.638	0.395
30	0.680	0.421
31	0.680	0.421
32	0.680	0.421
33	0.680	0.421
34	0.850	0.527
35	1.275	0.790
36	0.638	0.395
37	0.034	0.021
38	0.043	0.026
39	0.085	0.053
40	0.028	0.079
41	0.018	0.009
42	0.014	0.007
46	0.383	0.237
48	0.383	0.237
49	0.383	0.237
50	0.085	0.053
51	0.213	0.132
52	0.298	0.184
53	0.383	0.237
54	0.638	0.395
55	0.638	0.395
56	0.383	0.237
57	0.638	0.395
58	0.638	0.395
59	0.468	0.290
Total	24.114	14.765

B. Line Data:

Tab.4.Line Data

From Bus No	To Bus No	Resistance (R)	Reactance (X)	Impedence (Z)
1	3	2.00	39.95	40.00
2	4	2.50	49.94	50.00
5	15	62.67	376.04	381.22
6	16	100.54	351.89	365.97
6	17	31.34	188.02	190.61
6	18	125.68	439.87	457.47
6	19	125.68	439.87	457.47
3	20	125.68	439.87	457.47
3	21	27.93	97.75	101.66
7	22	125.68	439.87	457.47
7	23	125.68	439.87	457.47
7	24	125.68	439.87	457.47
7	25	125.68	439.87	457.47
8	26	62.67	376.04	381.22
8	27	62.67	376.04	381.22
4	28	47.00	282.03	285.92
4	29	47.00	282.03	285.92
11	30	100.54	351.89	365.97
11	31	100.54	351.89	365.97
11	32	100.54	351.89	365.97
11	33	100.54	351.89	365.97
12	34	83.78	293.24	304.98
13	35	47.00	282.03	285.92
13	36	100.54	351.89	365.97
45	52	167.57	586.49	609.96
43	46	125.68	439.87	457.47
47	54	125.68	439.87	457.47
44	48	125.68	439.87	457.47
44	49	125.68	439.87	457.47
50	56	125.68	439.87	457.47
45	53	125.68	439.87	457.47
47	55	125.68	439.87	457.47
50	57	125.68	439.87	457.47
51	58	125.68	439.87	457.47
51	59	125.68	439.87	457.47
60	21	101.91	866.26	872.24
62	44	101.91	866.26	872.24

C. Cable data:

Tab.5.Cable Data

From Bus No:	To Bus No:	Resistance (R)	Reactance (X)	Impedence (Z)
3	5	9.11	7.57	11.84
3	6	19.00	10.30	21.62
3	7	9.19	9.44	13.17
3	8	9.11	7.57	11.84
3	9	8.06	5.51	9.76
4	10	9.67	6.62	11.71
4	11	9.19	9.44	13.17
4	12	10.21	10.49	14.64
4	13	12.16	15.63	19.80
4	14	6.50	5.41	8.46
20	37	6219.39	2342.37	6645.87
21	38	6219.39	2342.37	6645.87

21	39	3109.70	1171.18	3322.93
28	40	4729.86	1781.38	5054.19
29	41	6306.48	2375.17	6738.92
29	42	6306.48	2375.17	6738.92
43	45	6.50	5.41	8.46
43	47	5.10	5.25	7.32
44	50	7.81	6.49	10.15
44	51	6.50	5.41	8.46

IX. SIMULATION RESULTS & DISCUSSION

ETAP is a full spectrum analytical engineering firm specializing in the planning, design, analysis, operation, training, and computer simulation of power systems. ETAP is the most comprehensive power system enterprise solution. ETAP serves the power system needs from generation to utilization. ETAP employs a research and development team supported by a staff of engineers and scientists who have a combined knowledge of over 500 years' experience. It was incorporated in 1986; ETAP released the first version of Electrical Transient Analyzer Program (ETAP) power system analysis and design software. Today, ETAP is recognized as the global market leader in providing solutions for power systems analysis, design, simulation, operation, control, optimization, and automation.

(i) ETAP is the only power system analysis software approved for use in nuclear / high-impact facilities

(ii) ETAP released the first 32-bit power system analysis program for Windows

(iii) ETAP Real-Time was launched to meet the growing demands for online system monitoring, simulation, control, and automation

(iv) ETAP has grown to be the world's largest power system analysis software company

(v) ETAP continues to meet client needs by incorporating the latest advances in power and software technologies.

In 1996 ETAP released the first, true 32-bit, power system analysis program on the market for Windows. ETAP is designed for Microsoft Windows and contains many advanced features including ODBC, multidimensional database, composite network nesting, and more. ETAP developed ETAP Real-Time to provide online (real-time) monitoring, simulation, control, and supervisory control capabilities. ETAP Real Time uses real-time data and system topology (ETAP database) to estimate unmonitored power flows and voltages throughout the system.

A. LOAD FLOW ANALYSER:

ETAP Load Flow software performs power flow analysis and voltage drop calculations with accurate and reliable results. Built-in features like automatic equipment evaluation, alerts and warnings summary, load flow result analyzer, and intelligent graphics make it the most efficient electrical. ETAP load flow calculation problems calculates bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with unlimited power grids and generator connections. This load flow calculation software is capable of performing analysis on both radial and loop systems. ETAP allows you to select from several different load flow calculation methods in order to achieve the most efficient and accurate results.

B.TRANSIENT STABILITY ANALYSER:

The electrical power transient stability calculation program enables engineers to accurately model power system dynamics and transients by simulating system disturbances and other events.Typical transient stability studies include identifying critical fault clearing time, checking generator rotor angle stability, assessing system stability margin, evaluating motor dynamic acceleration and reacceleration impact, preparing and testing load shedding schedule, computing fast bus transfer timing, calibrating and evaluating relay setting and simulating generator start-up.You can split a system or combine multiple subsystems, simulate automatic relay actions and associated circuit breaker operations, and start or auto-start motors. Combined with enhanced plotting and graphical results, engineers can truly use transient stability analysis program to master power system stability studies.

WAVEFORM FOR TRANSIENT STABILITY:

The results obtained for transient stability from ETAP are simulated and result is obtained.

- From the below fig the fault occurs in the system for more than 7millisecond.
- So, to reduce that fault timing by using Fault Current Limiter.

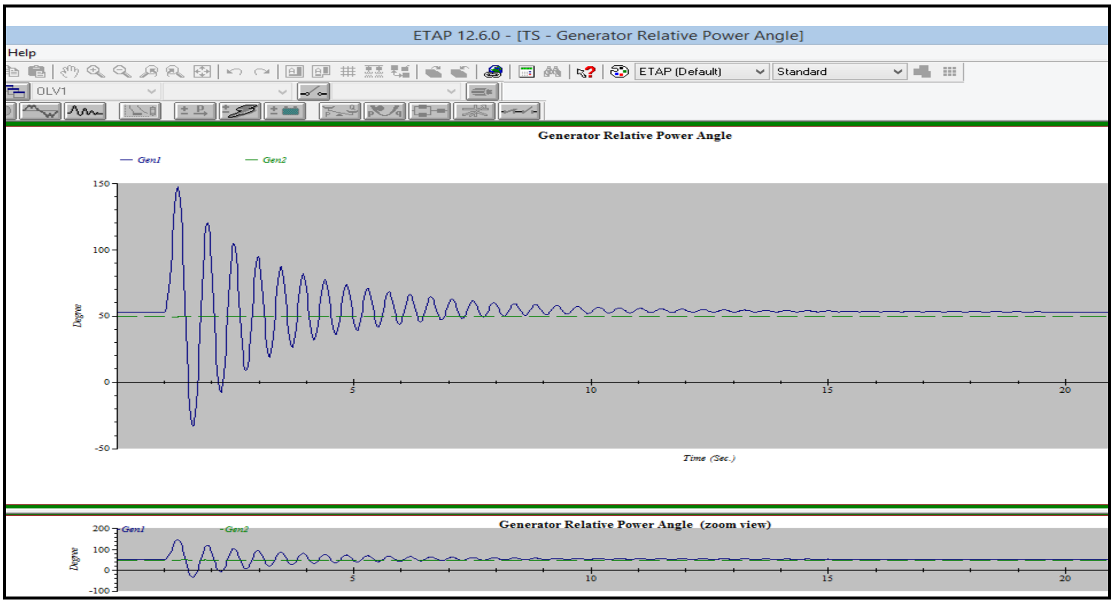

Fig.12.TS Output In ETAP PARAMETER

Tab.6.Waveform Parameters

EVENT ID	TIME(sec)	DEVICE TYPE	DEVICE ID	ACTION
fault	1.000	bus	Bus 20	3 phase fault
clear	1.200	bus	Bus 20	clear

WAVEFORM FOR FCL:

By using fault current limiter the fault occur time is being reduced in ETAP.See the below fig.11

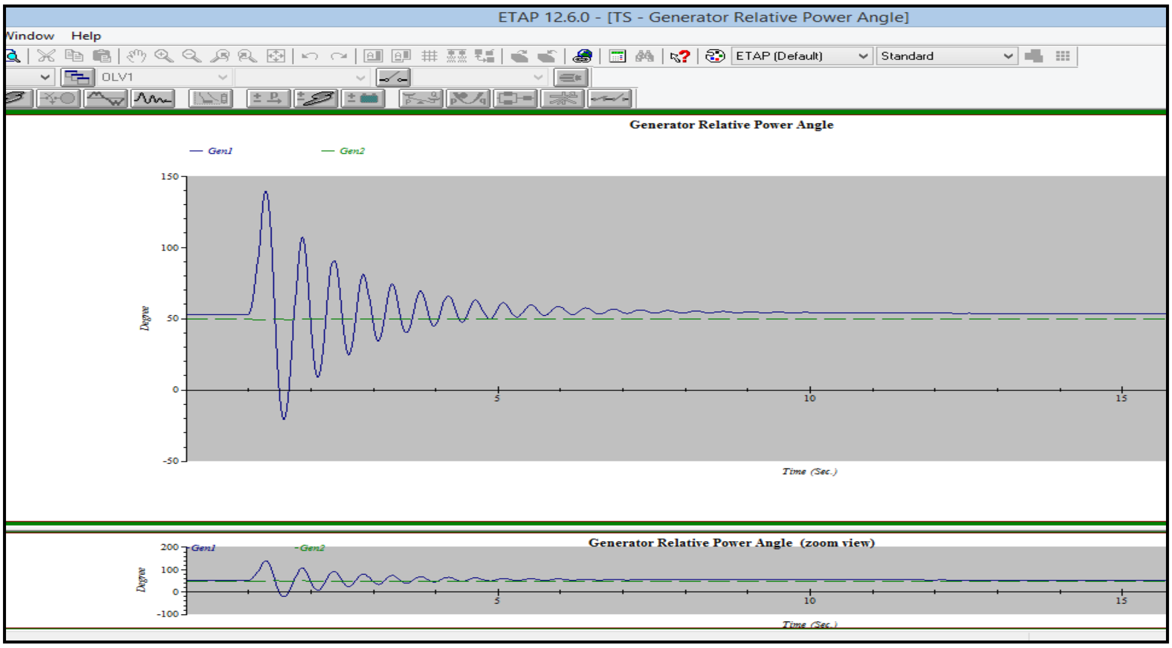

Fig.13.FCL Output In ETAP

WAVEFORM FOR SVC:

By using Static VAR Compensator the fault occurrence time is being reduced.see the below fig.12

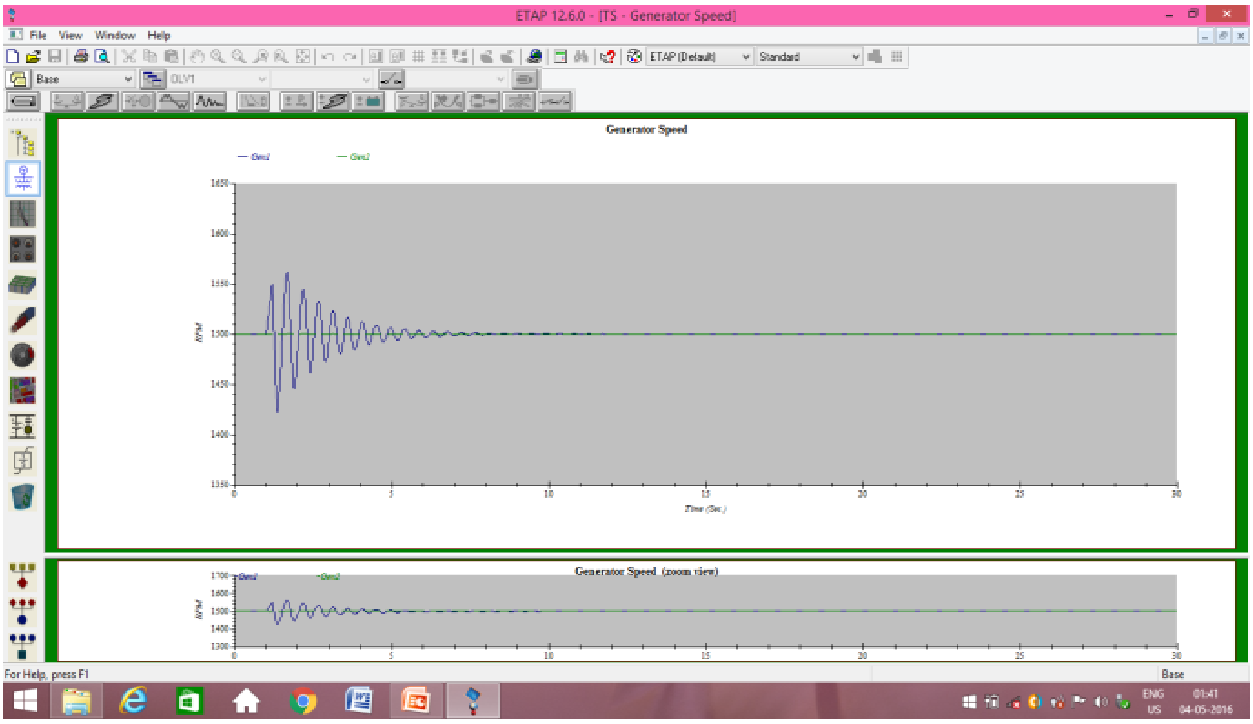

Fig.14.SVC Output In ETAP

X. CONCLUSION

In this paper, the transient stability enhancement in a distribution network is improved by fault current limiter. But when compare FCL and SVC the Static VAR Compensator reduces fault in 2ms. The dynamics of the system is studied at the event of a major disturbance. It is clear from the simulation results that there is a considerable improvement in the system performance with the presence of FCL for which the settling time is reduced. The result is verified using software ETAP 12.6.0 . ETAP is a real time software, hence the result is obtained.

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