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PRACTICAL IMPLEMENTATION OF FSC OF A 400KV TRANSMISSION LINE-CASE STUDY

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ABSTRACT

This paper presents a case study of practical implementation of fixed series compensation (FSC) for reliable and effective power flow in the specified line. The method for adjusting the line reactance as parameters by TCSC (Thyristor Controlled Series Compensator) in load flow studies. Proper adjustment of transmission line reactance as a parameter to regulate the required power flow in a desired line to the specified value. The ability to regulate power flow through certain paths in a power system networks is of particular importance, especially in deregulated electricity market. The proposed approach is a rigorous model without any approximations. It does not demand any extra row or column in Jacobian matrix of NR (Newton-Raphson) for accounting the adjustments of the line reactance is placed in required lines. The proposed technique has been tested on IEEE 30 bus system. The results are very accurate and method converged without any numerical convergence problems. The proposed method can be used to estimate the required level of compensation in a single line, multiple numbers of lines and group of line. Here power flow and optimum power flow is per formed for reduced fuel cost and total losses in the system

Keywords:-*Thyristor Controlled Series Compensator ,Thyristor Controlled Phase Shifter, Newton -Raphson, Optimal Power Flow.*

1. INTRODUCTION

Modern power systems are highly complex and are expected to full the growing demands of power wherever required, with acceptable quality and costs. The economic and environmental factors necessitate the location of generation at places away from load centres. . The restructuring of power utilities has increased the uncertainties in system operation. The regulatory constraints on the expansion of the transmission network has resulted in reduction of stability margins and increased the risks of cascading outages and blackouts. This problem can be effectively tackled by the introduction of high power electronic controllers for the regulation of power flows and voltages in AC transmission networks. This allows ‘flexible' operation of AC transmission systems whereby the changes can be accommodated easily without stressing the system. Power electronic based systems and other static equipment that provide controllability of power flow and voltage are termed as FACTS Controllers. It is to be noted that power electronic controllers were first introduced in HVDC transmission for not only regulation of power flow in HVDC links, but also for modulation to improve system stability (both angle and voltage). The technology of thyristor valves and digital controls was initially extended to the development of Static Var Compensator (SVC) for load compensation and voltage regulation in long transmission lines

In 1988,Dr.Narain G. Hingorani introduced the concept of Flexible AC Transmission Systems (FACTS) by incorporating power electronic controllers to enhance power transfer in existing AC transmission lines, improve voltage regulation and system security without adding new lines. The FACTS controllers can also be used to regulate power flow in critical lines and hence, ease congestion in electrical networks.

FACTS does not refer to any single device, but a host of controllers such as SVC, Thyristor Controlled Series Capacitor (TCSC), Static Phase Shifting Transformer (SPST), and newer controllers based on Voltage Source Converters (VSC) and current source converters (CSC) Static synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC) etc. The advent of FACTS controllers has already made a major impact on the planning and operation of power delivery systems. The concept of Custom Power introduced by Dr.Hingorani in 1995 has extended the application of FACTS controllers for distribution systems with the objective of improving power quality. An understanding of the working of individual FACTS controllers and issues that affct their operation under various conditions is essential for both students and engineers (in industry) who are interested in the subject. FACTS Controllers in Power Transmission and Distribution comprehensive and up-to-date coverage of the FACTS controllers that have been proposed and developed both for transmission and distribution. This paper proposes a reliable and effective method to adjust the variable parameters of by series FACTS devices.

2. BASIC CONCEPTS AND PROBLEM FORMULATION

2.1. N-R method:

The most widely used method for solving simultaneous nonlinear algebraic equations is the Newton-Raphson method (NR) .Newton's method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration. Since in the power flow problem real power and voltage magnitude are specified for the voltage-controlled buses, the power flow equation is formulated in polar form. This equation can be rewritten in admittance matrix as

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad \ldots\ldots (1)$$

In the above equation, j includes bus i.
expressing this
equation in polar form, we have

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j \qquad \ldots\ldots (2)$$

The complex power at bus i is

$$P_i - jQ_i = V_i^* I_i \qquad \ldots\ldots$$

(3)

Substituting form equation 2 for I_i in eq3

$$P_i - jQ_j = |V_i| \angle -\delta_i \sum_{j=1}^{n} |Y_{ij}|||V_j| \angle \theta_{ij} + \delta_j \qquad \ldots (4)$$

Separating the real and imaginary parts,

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots. (5)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots (6)$$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \qquad .\ldots\ldots (7)$$

By running the load flow analysis using NR-method we can fine the Power flows in individual lines and loss

2.1.1 Economic Dispatch Problem

The objective of conventional economic dispatch (ED) problems is to find the optimal combination of power generation that minimizes total generation costs while satisfying an equality constraint and several inequality constraints. The most simplified type of objective function in the ED problem can be expressed as a summation of all generating units' operating cost in the shape of a smooth function :

$$\text{Minimize} \quad \sum_{i \equiv I} F_i(P_i) \qquad \ldots\ldots\ldots(8)$$

$$F_i(P_i) = \alpha_i + \beta_i P_i + \gamma_i P_i^2$$

Where α_i, β_i, and γ_i represent cost coefficients of generating unit i,

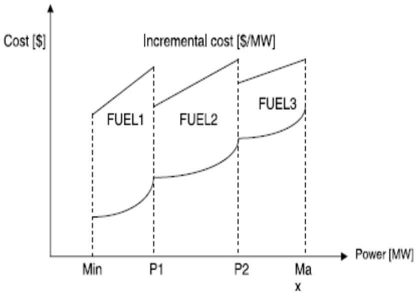
Pi the electrical output of generating unit i, and I indicates the set for all generating units. While minimizing the total generation cost, the following constraints should be satisfied. For energy balance, the following equality constraint should be satisfied as the following equation:

$$\Sigma P_i = D + P_{loss} \qquad \ldots\ldots (9)$$

Where D implies the total system demand, and P_{loss} means the total network losses. However, the transmission losses are not considered in this study. Also, generation of power from each unit should be between its maximum and minimum limits:

$$P_{i,\min} \le P_i \le P_{i,\max} \; i ᴪ \; I,$$

Where $P_{i\ \min}$ corresponds with the minimum output of unit i and $P_{i,\max}$ corresponds with the maximum output of unit i.To consider a more realistic and accurate representation of the objective function, non smooth cost functions with a few shapes have been applied to ED problem .That is, the objective function of an ED problem has discontinuous and non differentiable points according to valve loading, change of fuels, and prohibited zones. Therefore, it is more realistic to treat the cost function as a set of piecev ı below l proble



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F

$$F_i(P_i) = \begin{cases} \alpha_{i1} + \beta_{i1}P_i + \gamma_{i1}P_i^2 & \text{if } P_i^{\min} \le P_i \le P_{i1} \\ \alpha_{i2} + \beta_{i2}P_i + \gamma_{i2}P_i^2 & \text{if } P_{i1} \le P_i \le P_{i2} \\ \vdots & \vdots \\ \alpha_{im} + \beta_{im}P_i + \gamma_{im}P_i^2 & \text{if } P_{im-1} \le P_i \le P_i^{\max} \end{cases}$$

..

Where α_{ij}, β_{ij}, and γ_{ij} correspond with the cost coefficients of generating unit i for the jth power level, respectively.

2.2. Modelling of TCSC:

Consider a transmission line with its ABCD parameters and end bus voltages as shown below

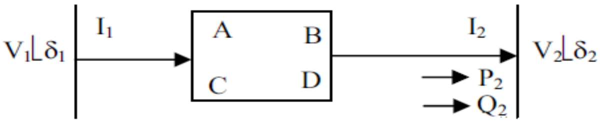


Figure2. Two port model of a Transmission line

The power at the receiving end P2 is given by

$$P_2 = \frac{|V_1||V_2|\cos(\beta - \delta) - |A||V_2|\cos(\beta - \alpha)}{|B|}$$

…. (11)

$$A = (1 + Y_{CP} * \frac{Z}{2}) = |A| \angle\alpha$$

…… (12)

$$B = |Z| \angle\beta, \beta = \tan^{-1}\left(\frac{X}{R}\right)$$

……(13)

$$\delta = \angle\delta_1 - \angle\delta_2$$

…...(14)

If series compensation is provided, then :

$$\beta = \tan^{-1}\left(\frac{X - X_C}{R}\right)$$

…… (15)

Now assume that power flow in a line is to be regulated to a desired value ($P_{specified}$) P_{sp} , then the corresponding new value of B i.e B_{new} can be found out using the equation given below:

$$B_{new} = \frac{|V_1||V_2|\cos(\beta - \delta) - |A||V_2|\cos(\beta - \alpha)}{P_{specified}}$$

.. (16)

Note that B_{new} is also given by the equation $B_{new} - (R^2 + (X - X_c))^{\frac{1}{2}}$ from which Xc can be calculated.Consider the initial line reactance $X = X_{line}$ of uncompensated. With the Xc in the line the resultant line reactance is given by

$$X = X - X_c$$

…….. (17)

The equation (16) is a highly nonlinear equation and need to be solved iteratively and update X using eqn. (17) accordingly. With the series compensation in the line $\beta = \tan^{-1}\left(\frac{X - X_c}{R}\right)$ will be small compared to β of the uncompensated line. Keeping this fact in mind, the X_c calculations can be made in three stages as mentioned below.

2.2.1 Stage 1

Calculate $\beta = \tan^{-1}(X_{line} / R_{line})$, from uncompensated condition. Then consi-dering incremental approach to avoid the higher correction step, take

$$\beta_1 = 75\% \text{ of } \beta_{old}$$

…… (18)

Then solve equation (16) for finding B_{new} using the $V_1\angle\delta_1$ and $V_2\angle\delta_2$ of the desired line obtained from the converged voltages of base case loads flows. The corresponding X_c will be

$$X\text{-}X_c = (B_{new}^2 - R^2)^{1/2} \quad \ldots\ldots (19)$$
$$X_c\text{-}X = (B_{new}^2 - R^2)^{1/2} \quad \ldots\ldots (20)$$

With this X_c in the line, the resulting reactance is

$$X = X\text{-}X_c \quad \ldots\ldots (21)$$

2.2.2 Stage 2

With the above resulting $X=(X\text{-}X_c)$ as the effective or net reactance of the desired line, *re-run the load flow solution*. Now latest values of voltages of the line end buses i.e. $V_1\angle\delta_1\ and\ V_2\angle\delta_2$ are available.

Re compute the parameters A=| A |∠α and B=| B |∠ β_2, where β_1 from equation (18), and X given by equation (21) As the solution of equation (13) is nearer to the final solution, β_2 is to be taken as

$$\beta_2 = 90\%\ \text{of}\ \beta_1 \quad \ldots\ldots (22)$$

Once again solve equation (16) for finding B_{new} using latest values of $V_1\angle\delta_1\ and\ V_2\angle\delta_2$ and update the value of X using equations (20) and (21).

2.2.3 Stage 3

With the above resulting $X=(X\text{-}\ X_c)$ as the effective or net reactance of the desired line, *re-run the load flow solution*. Now latest values of voltages of the line end buses i.e. $V_1\angle\delta_1\ and\ V_2\angle\delta_2$ are available.

Recompute the parameters A=| A |∠α and B=| B |∠ β_2; where β_2 from equation (22), and X given by equation (21) As the solution of equation (13) is nearer to the final solution, β_3 is to be taken as

$$\beta_3 = 95\%\ \text{of}\ \beta_2 \quad \ldots\ldots (23)$$

Once again solve equation (16) for finding B_{new} using latest values of $V_1\angle\delta_1\ and\ V_2\angle\delta_2$ and update the value of X using equations (20) and (22).

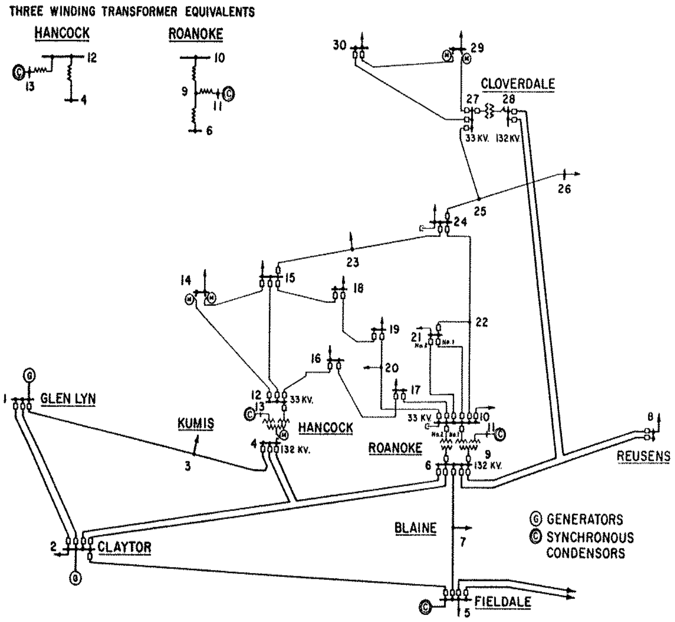
2.2.4 Stage 4

With the latest value of X (obtained in stage 3) in the desired line, re-run the load flow solution. Estimate the modified values of A=| A |∠α and B=| B |∠ β_2, Where β_3 from equation (23), X is the latest net reactance of the line. As the solution of β_3 is much more nearer to the final optimal solution take

$$\beta_3 = 100\%\ \text{of}\ \beta_2 \quad \ldots\ldots (24)$$

Re-run the load flow and compute the X_c and X_{final}.By the completion of the 3rd stage calculations, the accurate value of X_c is available. At every stage of the above approach calculate the power flow ($P_{calflow}$) of the line under consideration and its mismatch between Psp and $P_{calflow}$. Calculate the %error of the flow in the line at the end of 3rd stage. This error indicates the level of accuracy observed in the results produced by the newly proposed algorithm.

3. TEST CASE STEADY



3.1 Results for IEEE 30 Bus System

Comparison between power flow and optimal power flow with Beta Compensation

Table1. Power Flow Results for the Line 2-4 with
N-R Method

% of compensation (Beta new)	X p.u	Real Power MW	Reactive Power Mvar	Line Losses		Total System Losses MW	Total generation Cost $/h	Incremental Fuel cost $/MWh
				P MW	Q Mvar			
0	0.1737	35.644	3.765	0.683	-1.817	13.70	819.84	3.657
75	0.1199	43.604	1.957	1.004	-1.787	13.67	819.76	3.656
90	0.1018	46.104	0.625	1.168	-1.828	13.69	819.81	3.657
95	0.0948	47.061	0.786	1.150	-1.822	13.58	819.42	3.653
100	0.0913	47.441	0.494	1.183	-1.833	13.44	819.40	3.646

Table 2. Optimal Power Flow Results for the Line 2-4 with N-R Method

% of compensation (Beta new)	X p.u	Real Power MW	Reactive Power Mvar	Line Losses		Total System Losses MW	Total generation cost $/h	Incremental Fuel cost $/MWh
				PMW	QMvar			
0	0.1737	39.326	2.311	0.683	-1.817	10.462	748.20	3.5797
75	0.1199	47.913	-0.288	1.004	-1.787	10.45	748.12	3.5790
90	0.1018	51.677	-2.045	1.168	-1.828	10.44	748.17	3.5794
95	0.0948	51.777	-1.836	1.150	-1.822	10.34	747.80	3.5760
100	0.0913	51.997	-2.215	1.183	-1.833	10.212	747.31	3.5717

Table3. Power Flow Results for the Line 2-4 and 6-8 with N-R Method

% of compensation (Beta new)	X p.u	Real Power MW	Reactive Power Mvar	Line Losses		Total System Losses MW	Total generation cost $/h	Increm Fuel c $/MV...
				PMW	QMvar			
0	0.1737 0.0420	35.6 19.4	3.765 -10.17	0.683 0.192	-1.817 -0.729	13.82	820.2	3.651
75	0.1199 0.0328	43.5 19.7	1.695 -11.30	1.003 0.207	-1.792 -0.761	13.79	820.20	3.65
90	0.1018 0.0250	46.9 19.9	0.082 -12.94	1.157 0.226	-1.836 -0.788	13.70	819.87	3.65
95	0.0948 0.0116	48.3 20.2	-1.437 -16.86	1.227 0.276	-1.874 -0.848	13.59	819.46	3.65
100	0.0913 0.0116	49.0 20.2	-1.778 -16.92	1.269 0.277	-1.888 -0.848	13.44	818.88	3.64

Table 4.Optimal Power Flow Results for the Line 2-4 and 6-8 with N-R Method

% of compensation (Beta new)	X p.u	Real Power MW	Reactive Power Mvar	Line Losses		Total System Losses MW	Total generation Cost $/h	Incremental Fuel cost $/MWh
				P MW	QMvar			
0	0.1737 0.0420	39.3 19.5	2.31 -6.68	0.68 0.19	-1.81 -0.72	10.57	748.60	3.585
75	0.1199 0.0328	47.9 19.8	-0.52 -9.86	1.00 0.20	-1.79 -0.76	10.55	748.51	3.582
90	0.1018 0.0250	51.4 20.1	-2.50 -11.47	1.15 0.22	-1.83 -0.78	10.46	748.22	3.580
95	0.0948 0.0116	53.0 20.2	-4.15 -15.13	1.22 0.27	-1.87 -0.84	10.35	747.83	3.576
100	0.0913 0.0116	53.6 20.4	-4.58 -15.23	1.25 0.27	-1.88 -0.84	10.21	747.31	3.571

Table 5.Power Flow Results for the Line2-4 and 6-8 and 6-28 with N-R Method

% of compensation (Beta new)	X p.u	Real Power MW	Reactive Power Mvar	Line Losses		Total System Losses MW	Total generation Cost $/h	Incremental Fuel cost $/MWh
				P MW	QMvar			
0	0.1737 0.0420 0.0599	35.6 19.4 18.0	3.76 -10.1 -7.3	0.683 0.192 0.054	-1.817 -0.729 -13.14	13.771	820.13	3.6535
75	0.1199 0.0328 0.0503	43.5 19.2 18.2	1.73 -10.91 -7.75	1.003 0.196 0.055	-1.792 -0.769 -13.18	13.750	820.03	3.653
90	0.1018 0.0250 0.0431	46.9 19.1 18.5	0.15 -12.23 -7.17	1.157 0.205 0.057	-1.836 -0.803 -13.21	13.690	819.81	3.6535
95	0.0948 0.0116 0.0420	48.4 18.8 18.8	-0.88 -13.56 -7.10	1.233 0.215 0.058	-1.870 -0.832 -13.24	13.587	819.42	3.651
100	0.0913 0.0116 0.0420	49.0 18.8 18.9	-1.31 -14.12 -7.06	1.263 0.221 0.059	-1.885 -0.841 -13.26	13.443	818.88	3.646

Table 6. Optimal Power Flow Results for the Line 2-4 and 6- 8, 6-28 with N-R Method

% of compensation (Beta new)	X p.u	Real Power MW	Reactive Power Mvar	Line Losses		Total System Losses MW	Total generation Cost $/h	Incremental Fuel cost $/MWh
				P MW	Q Mvar			
0	0.1737 0.0420 0.0599	39.3 19.5 17.9	2.311 -8.688 -7.234	0.68 0.19 0.05	-1.81 -0.72 -13.1	10.538	748.47	3.582
75	0.1199 0.0328 0.0503	47.8 19.4 18.1	-0.485 -9.477 -7.147	1.00 0.19 0.05	-1.79 -0.76 -13.1	10.512	748.38	3.581
90	0.1018 0.0250 0.0431	51.4 19.2 18.3	-2.434 -10.76 -7.101	1.15 0.20 0.05	-1.83 -0.80 -13.2	10.452	748.16	3.5795
95	0.0948 0.0116 0.0420	53.1 19.0 18.6	-3.644 -12.07 -7.051	1.23 0.21 0.05	-1.87 -0.83 -13.2	10.347	747.80	3.5761
100	0.0913 0.0116 0.0420	53.7 19.0 18.7	-4.150 -12.56 -7.012	1.26 0.22 0.05	-1.88 -0.84 -13.2	10.212	747.31	3.5717

From the above six tables i.e. table 1 to table 6.It is identified that the real and reactive power flow is improved and the optimal power flow is also improved when compared to power flow with beta compensation concept the various combinations of beta compensation for individual and group of lines is performed. It is also observed that the incremental fuel cost and total generation cost is also considerable reduced.

4. PRACTICAL CASE STUDY

The network for which these FSC systems are being installed in between Kadapa(YSR Disitrict) -Nagarjunsagar ,Andhra Pradesh ,India lines is as follows

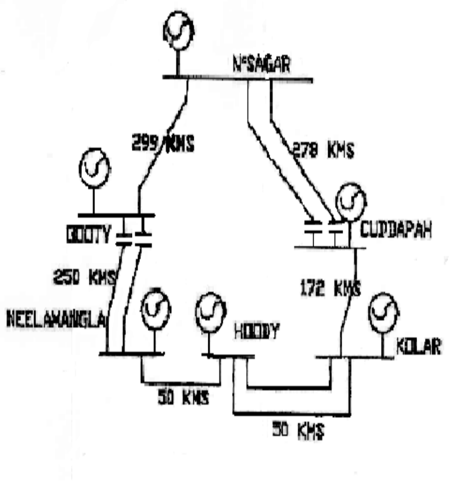


Figure 4.Practical test system

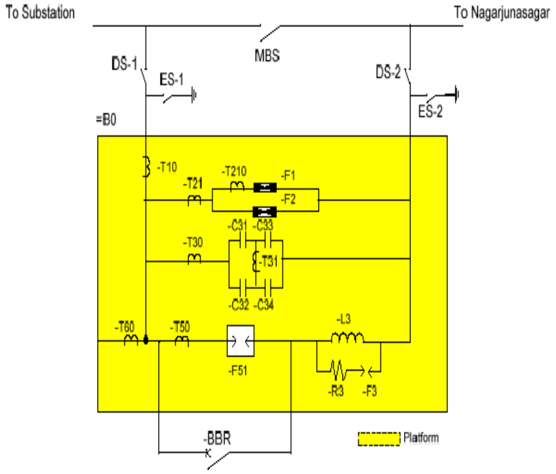


Figure 5.Implementation Scheme for transmission line

The main **components of** this FSC are:

1.Capacitor bank
2.MOV (Metal Oxide Varistor)
3.Spark Gap
4.Damping Circuit
5.Bypass Breaker

Data for the transmission line as follows:

Line parameters	Range
Resistance	0.2938 Ohm/km
Inductance	0.332 Ohm/km

5. PROTECTION OF CAPACITOR BANK:

The capacitor bank is the primary equipment. For protection of the capacitor bank, the equipment provided and their functions are listed below:

The MOV limits the voltage raise across the capacitor in cases of internal and external faults. The spark gap of the FSC is required for bypassing and protecting the capacitors and MOV's with in 1ms, since the Bypass Breaker needs to approx. 52ms closing time. The used spark gap is forced triggered and non-self extinguishing. The trigger signal is generated by the protection system by supervising currents and MOV energy status. The spark gap is controlled by the Gap Trigger Electronics (GTE), which is duplicated. The Bypass Breaker (BBR) bypasses the FSC and thereby controls the power flow of the line.

Also the bypass breaker will be closed to protect the bank against stresses due to overload or other fault situations. The bypass breaker is optimized to handle this kind of switching operation. The damping circuit is connected in series to the spark gap and bypass breaker. Main purpose of the damping circuit is to limit and dampen the discharge current of the capacitor during bypass operations to prevent damage on other equipment. The damping circuit consists of a parallel connection of damping reactor and damping resistor. In series with the damping resistor there is a small spark gap, which will switch the resistor into the circuit during the operation of the forced triggered spark gap of closing of the Bypass Breaker only.

Current transformers are provided at different locations to measure the current for different protection system. The disconnectors DS_1 and DS_2 (the platform disconnectors) are used for connecting the platform & platform equipment to the line or isolating the platform & platform equipment from the line. The main bypass switch is an off load disconnectors and can be used for keeping the line in service with the series capacitor banks bypassed. The earth switches ES_1 and ES_2 are used for ear thing the platform & platform equipment after the platform has been isolated from the line.

5.1 Single line diagram of FSC:

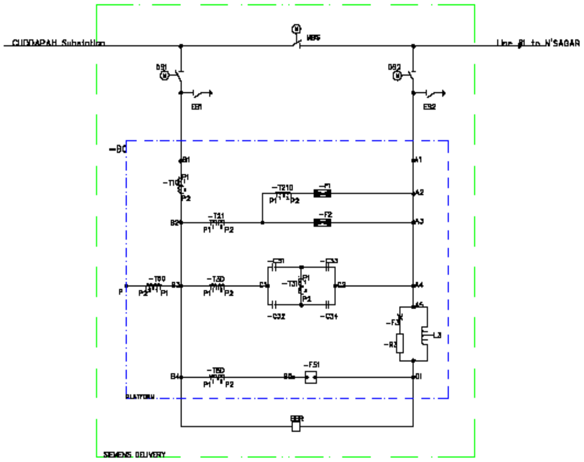


Figure 6.Single line diagram of FSC

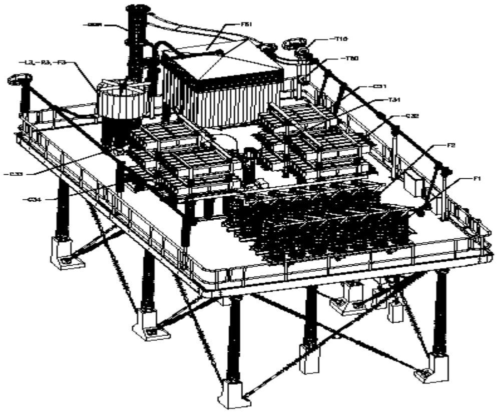
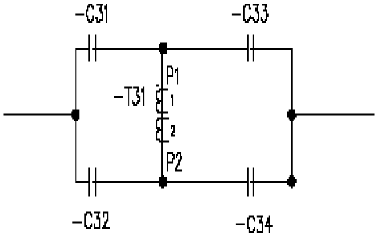


Figure 7. Layout of FSC

5.2 Component Ratings and Capacitor banks:

The capacitor bank is divided into four capacitor segments which are connected to an H-scheme per phase. Please refer to figure below.



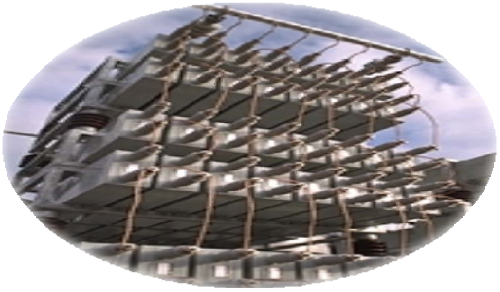


Figure 9.Capacior banks

The segments C31, C32, C33 and C34 represent each 5 parallel and 5 serial capacitor cans. The capacitors are internally fused. –T31 is the current transformer for measurement of the unbalance current.

Table 7.Technical Data of Capacitor Banks:

Main Data of the Capacitor bank	Kadapa	Unit
Rated impedance	36.9	Ohm
Capacitance	86.26	µF
Rated current	1350	A
Overload currents -for 8h in a 12h period - for 30 min in a 6h period -for 10 min in a 2 h period	 1485 1823 2035	 A A A
Rated Power 3 Phases	201.8	MVAR
Protective Level	2.22 156.1	Pu KVp

Table 8.Technical data of MOV units:

Nominal voltage	49.8 KV
Rated voltage V_r	84KV
MCOV	58KV
Limiting voltage Max.	156.1KV
MOV current	14.5KA
Arrester height	1180mm
Creepage	3005 mm
MO disk type	E78SR123
Parallel columns	(N2)
Serial blocks	4
	18

5.3 Metal oxide varistor:

Metal Oxide Varistors are typically placed in parallel with series capacitors. These devices, known as MOV's are crucial in the protection in the protection schemes of these capacitors. When a fault occurs and line current surges to a level significantly higher than normal, damage to the dielectric in the capacitor can occur. The MOV placed in parallel with the capacitor prevents this by acting in a manner similar to a zener diode.

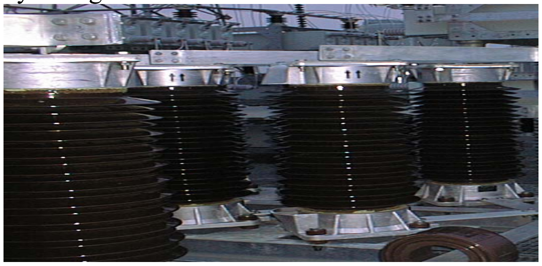


Figure 10. MOV on the platform

5.4 Spark gap

The spark gap of an FSC installation is used to protect the MOV arresters and capacitors against short time over voltage /overload during internal and external faults and during system contingencies. The spark gap is connected in parallel to the capacitors and the MOV arrestors

Figure 11. Inner View of Spark Gap

Flash over range -90 to 160 kV (peak)
Setting of the forced triggered operation (U_{1m})-156.1kV (peak)
Tolerance - ± 5 %
Thermal fault current carrying capability 40 kA (rms), 1s

5.5 Damping circuit:

Damping reactor is provided to limit the peak value current of the discharging capacitor. The damping resistor is connected in parallel with the damping reactor for obtaining the appropriate damping. Due to this a damping frequency is evolved which can be used for the damping resistor, a small spark gap is also included in series with the damping resistor which fires for over voltages of the capacitor.

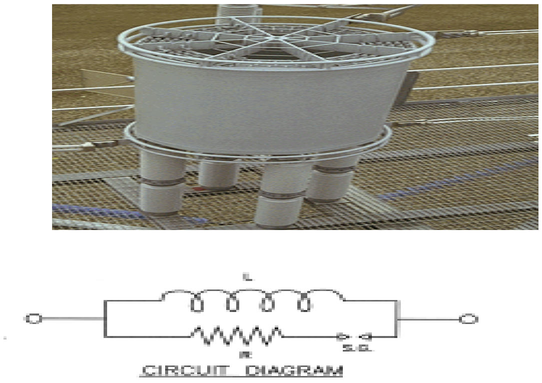


Figure 12 .Damping circuit

6.0 CALCULATIONS AND RESULTS

Fixed series compensation for various degree of compensation is shown in the table

Series compensation for nagarjuna sagar to kadapa line:

The transmission line parameters are as follows:

Resistance = 0.298 Ω / Km
Capacitance = 11.04 nF / Km
Inductance = 0.332 Ω / Km

Length of Nagarjuna Sagar to Kadapa line = 278 Kms

Line reactance of Nagarjuna Sagar to Kadapa line X_L= 0.332 * 278= 92.296 Ω

Degree of Compensation fixed = 40%

Capacitive reactance required for Nagarjuna Sagar to Kadapa line= X_{C1} = 0.4 * 92.29 = 36.9184 Ω

Capacitance of Nagarjuna Sagar to Kadapa line

$$C = 1 / (\omega X_{C1}) = 86026\ \mu F$$

Rated current = 1350 A

Rated voltage / phase = 1350 * 36.9 = 49.815 KV

Rated line voltage = 49.815 * √3 = 86.282 KV

Rated power = √3 * 86.282 * 1350 = 201.75 MVAR

Protective level = 22.2 Pu= 22.2 * √2 * 49.815 = 156.4 KV (peak)

Power transfer capability before compensation,

P_1 = √3 * 400 * 1350 = 935.307 MVA

Power transfer capability after compensation,

$P_2 = (X_1 / X_2) * P_1$ = (92.296 / (92.296 – 36.9)) * 935.307

= 1558.845 MVA

Therefore power increase is nearly 66%.

Table 9. Practical results for degree of compensation

S. No.	Degree Of Compensation (%)	Power before compensation (MVA)	Power after compensation (MVA)	Increase in Power (%)
1	30	935.307	1336.11	42
2	35	935.307	1438.834	53.8
3	40	935.307	1558.845	66
4	45	935.307	1700.46	81.8
5	50	935.307	1870.49	99.9

7.0 CONCLUSIONS

In this paper a practical implementation of FSC of a 400 Kv transmission line is considered and various degree of compensation for the line with increased power transfer capability is also presented in table no.10 and it reliable and effective method of compensation. An algorithm has been considered in this paper for estimation of required level of series compensation to regulate the specified amount of power flow in selected line or lines. The mathematical model is derived on strong fundamentals using ABCD parameters with no approximations. This method does not modify the structure or size of the Jacobian matrix of conventional N-R method. It can be used for single line or multi lines compensation calculations without much extra computational burden. The method is highly reliable and fast as it retains the quadratic convergence characteristics of N-R method. This new method can also be used for estimation of the required phase angle of a phase shifter to regulate the line flow of the selected line. In fact it has been tested on IEEE 30 bus system. Here an optimal power flow with equality and inequality constraints is performed for optimal fuel cost, incremental fuel cost and the results are presented in tables.

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