Distributed FACT Controllers as an Effective Tool for Reduction in Environmental pollution due to Thermal Power Plant

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Abstract: - Flexible AC Transmission (FACTS) devices are installed in the transmission network to divert the power flow, minimize the power losses and to improve the line performance but it has some limitations and drawbacks. Distributed Flexible AC Transmission (D-FACTS) is a improved version of FACTS devices which is used to improve the security and reliability of the network in a cost effective manner. This paper discusses the concept of D-FACTS technology for saving of electrical energy, minimization of losses, reduction of coal consumption and minimization of environmental pollution from thermal power plants. This paper also discusses comparative evaluation of passive and active approaches in design of controllers for transmission line. Analysis also deals with computer simulation for reactances, equivalent voltages required for injection in the transmission line, and number of distributed modules per conductor per kilometre. Computations for saving of coal and associated environmental pollution have been achieved. System details are presented in the paper along with simulation results.

Key-Words: - Distributed series compensator, D-FACTS, FACTS, Electrical energy saving, Coal economics, Environmental pollution.

1 Introduction

An AC power system is a complex network of synchronous generators, transmission lines and loads. Each transmission line can be represented as a reactive ladder network composed of series inductors and shunt capacitors. The total series inductance which is proportional to the length of the line, at a given voltage determines the maximum transmittable power. The shunt capacitance influences the voltage profile along the transmission line.The transmitted power over a given line is determined by the line impedance, the magnitude and phase angle between the end voltages.

The most significant issue in terms of grid utilization is that of active power flow control and it is possible by reactive power compensation. Thus, control of real power flows at a particular instant on the network is of critical importance. Management of reactive power has prime importance to improve the performance of ac power system. Active power flow control requires cost effective ‘series VAR’ solutions that can alter the impedance of the power lines artificially or change the angle of voltage applied across the line, thus controlling the power flow [1].

Traditionally, reactive compensation and phase angle control have been applied by fixed or mechanically switched inductors, capacitors and tap changing transformers, to improve steady state power transmission. This traditional approach has several limitations and not fully controlled.

Series capacitors have been successfully used to enhance the stability and lodability of high voltage transmission network. The principle is to compensate the inductive voltage drop in the line by an inserted capacitive voltage which results in decrease of effective reactance of the transmission line. The inserted voltage provided by a series capacitor is in proportion to and in quadrature with the line current. Thus the generated reactive power provided by the capacitor is proportional to the square of the current. This means that a series capacitor has a self regulating impact but non controllable [2].

Considering economic, social and legislative development, Electric Power Research Institute formulated the vision of Flexible AC Transmission System (FACTS) in which various power electronic based controllers regulate the power flow and transmission voltage through rapid control action. The main objectives of FACTS are to increase the useable transmission capacity of lines and control power flow over designated transmission routes [3].

Even though FACTS technology is technically proven, it has not seen widespread commercial acceptance due to a number of reasons

- High-cost resulting from device complexity and component requirements
- High fault currents and insulation requirement, stress the power electronic system, making implementation of FACTS systems in particular series connected devices, very difficult and expensive
- Single point failure can cause the entire system to shut down
- Maintenance and on site repair requirements for a complex custom engineered systems adds significantly to system operating cost and increases mean time to repair
- Lumped nature of system and initial over rating of devices to accommodate future growth provides poor return on investment
- Custom engineered nature of system results in long design and build cycles, resulting in high system cost that will not easily scale down with volume [4]

FACTS devices like thyristor controlled series capacitor (TCSC) and the static synchronous series compensator (SSSC) can be used for controlling active power flow on transmission lines, close to its terminal capacity, without compromising its stability limits. Implementations of these devices are very difficult and expensive and have rarely been deployed [5].

Distributed Flexible AC Transmission (D-FACTS) system is the new concept for realizing the functionality of FACTS devices.

Advancement in computer technology associated with intellectual activities resulted in new field of artificial intelligence. Fuzzy and artificial neural intelligence are used to design the controller and for their optimal location [6].

For economic load flow the basic operating requirement of an AC power system is that the synchronous generators must remain in synchronism and the voltages must be kept close to their rated values. If synchronous generators are coal based then they must run at minimum environmental pollution level with minimum operating cost.

This paper discusses the concept of distributed flexible AC transmission (D-FACT) series type devices for power flow control and reduction in environmental pollution due to coal based thermal generation. The objective is to determine the ratings of the distributed module in terms of reactance and equivalent voltage required for the series injection in transmission line. For the analysis and simulation transmission network connected to coal base thermal power plant is considered. Calculations are made for total series reactance, reactance of distributed modules and equivalent voltages for injection in the transmission line. Quantity of distributed modules per phase per kilometre with their physical dimensions and cost are mentioned. Use of D-FACTS saves the electrical energy hence reduction in generation, coal consumption and minimization in environmental pollution. Saving of electrical energy, coal consumption and environmental pollution has been calculated. Computer simulation for two bus transmission network has been made with and without D-FACT devices for 1200 MW and for 1275 MW at 400KV.

2 Distributed Flexible AC Transmission (D-FACTS) Technology

D-FACT is a new concept for realising the functionality of FACTS devices. In this technology total impedance or voltage required for the compensation has been distributed along the transmission line in series. Impedance or equivalent injected by single turn transformer in series by mutual induction is of small magnitude. It can be considered as a synchronous voltage source as it can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle, in series with a transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage that is in phase with the line current provides the losses in the inverter. Most of the injected voltage, which is in quadrature with the line current, provides the effect of inserting an inductive or capacitive reactance in series with the transmission line. This variable reactance influences the electric power flow in the transmission line.Such a module could be low rated, light and small enough to be suspended from the power line, floating both electrically and mechanically on the transmission line itself. With the use of power electronics devices, injected voltages dynamically control the impedance of transmission line, allowing control of active power flow. The distributed module can be used to either increase or decrease the effective line impedance, allowing current to be pushed away from or pulled into transmission line. As the devices are float on the transmission line, all the issues related to voltage rating and insulation are avoided. Following characteristics and benefits may be realised for distributed series compensator system.

- Enhance asset utilization
- Reduce system congestion
- Increase available transfer capacity of the system
- Enhance system reliability and capacity under contingencies
- Enhance system stability
- Forcing power to flow along contract paths
- Marginal reduction of fault current
- High system reliability due to massive redundancy, single unit failure has negligible impact on system performance
- Can be used with conventional or advanced conductors
- Mass produced modules can be stocked on the shelf and repaired in the factory – does not require skilled staff on site
- Easy and rapid installation and

can do with lower capital and operating cost than most conventional single point lumped solutions, such as FACTS devices [7] – [8].

3 Economic Emission Load Dispatch

The combustion of coal in thermal power plant gives rise to particulate material and gaseous pollunts. The particulate materials, oxides of carbon (Cox), oxides of suplhur (Sox) and oxides of nitrogen (Nox) causes detrimental effects on human beings. The usual control practice is to reduce offensive emission through post combustion cleaning systems such as electrostatic precipitator, stack gas scrubbers or switching permanantly to fuels with low emissions potentials. There is a shee need for minimizing pollution level and it is possible by economic-emission load dispatch. The environmental / economic power dispatch problem is to minimization of two objective functions, fuel cost and emission due to impact of, oxides of carbon (Co_x), oxides of suplhur (So_x) and oxides of nitrogen (No_x), while satisfying equality and inequality constraints.

3.1 Economy objective

The fuel cost of a thermal unit is the main criterion for economic feasibility. The fuel cost curve is assumed to be approximated by a quadratic function of generator power output P_{gi} as,

$$F_1 = \sum_{i=1}^{NG} (a_i P_{g_i}{}^2 + b_i P_{gi} + c_i) \qquad \text{Rs/h} \qquad (1)$$

Where a_i, b_i and c_i are cost coefficients and NG is the number of generators.

3.2 Environmental objectives

The emission curves can be directly related to the cost curve through the emission rate per Mkcal, which is a constant factor for a given type of fuel. Therefore, the amount of NO_x emission is given as a quadratic function of generator output $P_{gi,}$ i.e,

$$F_2 = \sum_{i=1}^{NG} (d_{1_i} P_{g_i}{}^2 + e_{1_i} P_{gi} + f_{1_i}) \qquad \text{kg/h} \qquad (2)$$

Where d_{1i}, e_{1i} and f_{1i} are NO_x coefficients.

Similarly the amount of SO_2 emission is given as a quadratic function of generator output P_{gi}, i.e,

$$F_3 = \sum_{i=1}^{NG} (d_{2i} P_{g_i}{}^2 + e_{2i} P_{gi} + f_{2i}) \quad \text{kg/h} \qquad (3)$$

Where d_{2i}, e_{2i} and f_{2i} are SO_2 coefficients.

Similarly the amount of CO_2 emission is given as a quadratic function of generator output P_{gi}, i.e,

$$F_4 = \sum_{i=1}^{NG} (d_{3i} P_{g_i}{}^2 + e_{3i} P_{gi} + f_{3i}) \quad \text{kg/h} \qquad (4)$$

Where d_{3i}, e_{3i} and f_{3i} are CO_2 coefficients.

3.3 Constraints

To insure a real power balance, an equality constraint is imposed, i.e,

$$\sum_{i=1}^{NG} P_{g_i} - (P_D + P_L) = 0 \qquad (5)$$

Where P_D is the power demand

P_L is the transmission losses, which are approximated in terms of B-coefficients as

$$P_L = B_{00} + \sum_{i=1}^{NG} B_{i0} P_{g_i} + \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_{gi} B_{ij} P_{gj} \quad \text{MW} \qquad (6)$$

The inequality constraints imposed on generator output are

$$P_{g_i}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (i = 1,2, \ldots\ldots \text{NG}) \quad (7)$$

Where P_{gi}^{min} is the lower limit and P_{gi}^{max} is the upper limit of generator output.

The multiobjective optimization problem is defined as, minimization of equations (1) to (4), subject to equations (5) and (7), [9]-[10].

For minimisation of total fuel cost of generation and environmental pollution caused by coal based thermal power plant, various techniques and approaches are available. Multiobjective Ant colony optimization (ACO) method is one of the approaches for optimal power flow [11]-[12].

A dynamic and linear programming based approach could be implemented for the generation scheduling of thermal units considering the voltage security and environmental constraints of electric power system [13].Several approaches are also available to reduce the environmental emissions mainly oxides of carbon (Co_x), oxides of suplhur (So_x) and oxides of nitrogen (No_x) [14]-[15].

Analytical approach used in this paper for the determination of cost and emission.

4 Principles of Active Power Flow Control

For controlling power flow on transmission lines, the series elements clearly have the highest potential and impact. The real and reactive power flow, P and Q, along a transmission line connecting two voltage buses is governed by two magnitudes V_1 and V_2 and the voltage phase angle difference $\delta = (\delta_1 - \delta_2)$ as,

$$P_{12} = \frac{V_1 V_2 \sin\delta}{X_L} \qquad (8)$$

$$Q_{12} = \frac{V_1^2 - V_1 V_2 \cos\delta}{X_L} \qquad (9)$$

Where X_L is the impedance of the line, assumed to be purely inductive. A series compensator is typically used to increase or decrease the effective reactance impedance X_L of the line, thus allowing control of real power flow between the two buses. The impedance change can be effected by series insertion of inductive or capacitive element in the line or by injecting equivalent voltage. The variation of power flow along a transmission line can be achieved by injecting passive impedance X_{ins} as,

$$P_{12} = \frac{V_1 V_2 \sin\delta}{X_L + X_{ins}} \qquad (10)$$

Where, X_{ins} is the variable passive impedance inserting in the line.

$X_{eff} = X_L + X_{ins}$ [16]

Typical series compensation system use capacitors to decrease effective reactance of a power line at rated frequency or by injecting equivalent voltage. The connection of a series capacitor generates reactive power that balances a line reactance. The result is improved functionality of the power transmission system through,

- Increased angular stability of the power corridor;
- Improved power handling capacity of transmission line;
- Optimized power sharing between the parallel circuits

5 An Example

For the analysis of distributed series compensator a simple two bus system is considered. The sending end terminal is connected to source with zero internal impedance hence voltage of that end is known and fixed, while the receiving end voltage depends on the power flow. The circuit is assumed to be balanced and the frequency variation is ignored. Fig. 1 shows simple example of two bus power system without any compensation. Two lines of unequal lengths are used to transfer power from bus 1 to bus 2. The assumed line parameters are listed in Table 1, [17]

Table 1, Line Parameters for Example of Fig. 1

Parameters	Rating
Length, Line 1	600 km
Length, Line 2	800 km
Sending & receiving end voltages $V_1=V_2=V$	400 Kv
Line Impedance	(0.31+j 0.327) ohms/Km
Line Thermal rating I Max	1064 A

Three analyses have been made on the system shown in fig. 1.

5.1 Case1. Power Flow over parallel lines without compensation.

Power flow of the system shown in fig.1 is carried out by computer simulation. Power available on reference bus 1 is 1200 MW and transmitted through line 1 and line 2 to bus 2. The power transmitted through line 1 (P_1) and line 2 (P_2) are 685.7 MW and 514.3 MW respectively. Power received at bus 2 is 1089.4 MW with power loss of 110.6 MW. i.e. 9.22%. Current flowing through line 1 (I_1) and line 2 (I_2) are 1064A and 798A respectively. For the power flow, power angle (δ) observed is -54.04^0.

As per the simulation for 1275 MW power transfer, power losses are 156.44 MW (12.27 %). Current flowing through line 1 is more than its thermal capacity which is not desirable. Compensation is applied to the lines to divert the additional current through line 2 which has unutilized capacity. Power flow for 1200 MW is shown on fig. 1.

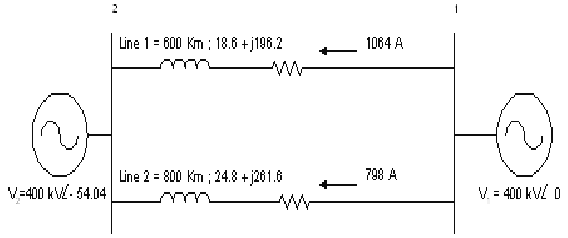

Fig.1, Power Flow over parallel lines without compensation

This analysis shows that for 1200 MW power flow, current flowing through the lines is within the thermal limit. Line 1 reaches to thermal limit before line 2 does. At that point no power can be transferred without overloading line 1, even though line 2 has additional unutilized capacity. Transmission and sub-transmission system today tend to be increasingly meshed and interconnected. The ability to switch out faulted lines without impacting service has a dramatic impact on system reliability. However, in such interconnected systems, current flow is determined by line impedances and the system operator has very limited ability to control where the current flow in the network. In such systems, the first line to reach thermal capacity limits the capacity of the entire network, even as other lines remain considerably under utilized. For 1200 MW power flow voltage drop across line 1 and 2 are 347.93 v/Km and 260.95 v/Km respectively.

5.2 Case 2. Power Flow over parallel lines with increased power and compensation

Power available on reference bus is 1275 MW and the objective of this case is to divert additional power of 75 MW through line 2, as line 1 is already at its maximum thermal limit. To divert this power flow through line 2 compensation of 9% is required.

For equivalent reactance compensation approach insertion of 0.0294 ohms/Km inductive reactance in line 1 and capacitive reactance in line 2 is required. Total inductive reactance inserted in line 1 is 17.66 ohms and capacitive reactance inserted in line 2 is 23.54 ohms. As per D-FACTS voltage injection of 31.32 v/km and 23.48 v/km is required in line 1 and line 2 respectively. Total voltage injected is 18.78 Kv.

Power available on reference bus 1 is 1275 MW and transmitted through line 1 and line 2 to bus 2. The power transmitted through line 1 (P_1) and line 2 (P_2) are 669.9 MW and 605.1 MW respectively. Power received at bus 2 is 1144 MW with power loss of 131 MW. i.e. 10.27%. Current flowing through line 1 (I_1) and line 2 (I_2) are 1064A and 954.4A respectively. For the power flow, power angle (δ) observed is -59.28^0. Power angle in this case is larger than case 1. It is the indication of system instability. The power transfer through line 2 has been increased by approximately 90 MW, while line 1 has been controlled to well within its thermal limit. System representation and simulation results for passive and active compensation are shown in fig. 2 and 3.

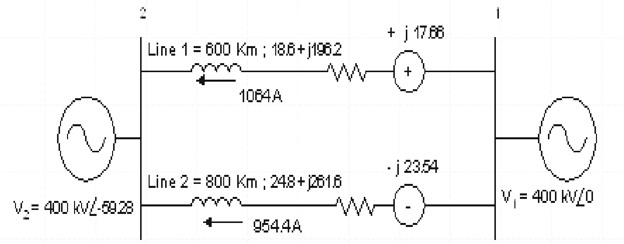

Fig. 2, Power Flow over parallel lines with 9% passive compensation

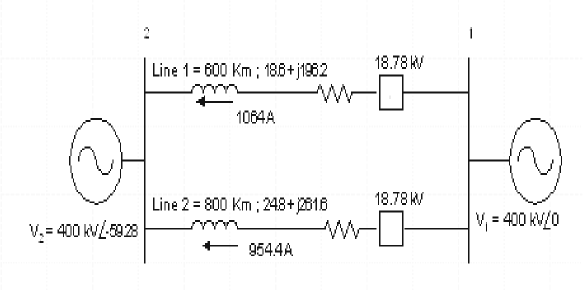

Fig. 3, Power Flow over parallel lines with 9% active compensation

5.3 Case 3. Power Flow over parallel lines with compensation for system stability

In case 2 additional power is diverted through line 2, but power angle (δ) changes from -54.04^0 to -59.28^0, it is indication of loss of system stability. To regain system stability i.e to maintain power angle (δ) and to maintain line capacity, 20 % compensation in line 2 is calculated, keeping same compensation in line 1. The effective capacitive reactance inserted in line 2 is 52.32 ohms and the equivalent voltage is 41.75 Kv. Total capacitive reactance inserted in line 2 is 52.32 ohms. Total voltage injected is 41.75 Kv.

Power available on reference bus 1 is 1275 MW and transmitted through line 1 and line 2 to bus 2. The power transmitted through line 1 (P_1) and line 2 (P_2) are 627.8 MW and 647.2 MW respectively. Power received at bus 2 is 1148 MW with power loss of 137 MW. i.e. 9.96%. Current flowing through line 1 (I_1) and line 2 (I_2) are 977.6A and 995.8A respectively. The power transfer through line 2 has been increased by 42 MW and the power transfer through line 1 decreases by 57 MW with decreasing δ from -59.28^0 to $-54.04^{0.}$ It is observed that system stability improves and the current flow through each line is within the thermal capacity of the lines with saving of 0.31% power. System representation and simulation results for passive and active compensation are shown in fig. 4 and 5.

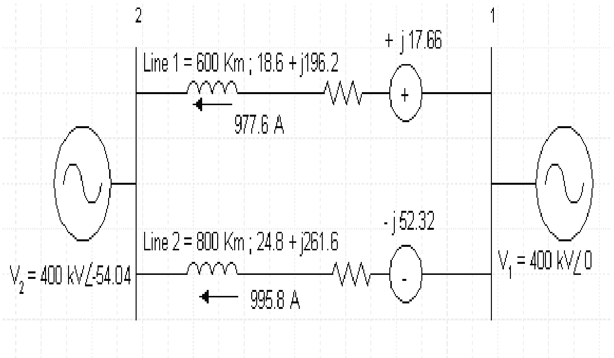

Fig. 4, Power Flow over parallel lines with compensation for system stability

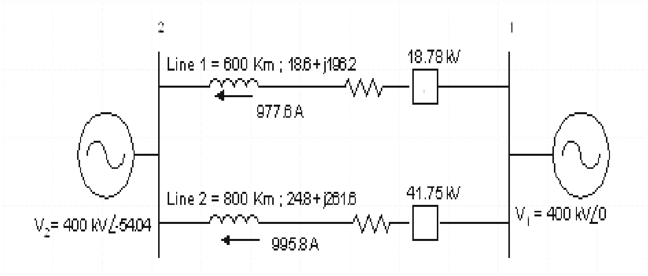

Fig. 5, Power Flow over parallel lines with active compensation for system stability

This simple example confirms the ability of series controllers to control loop flows, to manage congestion and to increase the power handling capacity of transmission lines. Inserted reactances and injected voltages for each case are shown in Table 2. Results of all these three cases are summarized in Table 3.

Table 2, Inserted reactances and injected voltages for each case

Case	X_L Ω	X_{inj} Ω	X_{eff} Ω	Voltage injected kv
1.Line1	196.2	0	196.2	0
Line2	261.6	0	261.6	0
2.Line1+9%	196.2	+17.66	213.86	18.78
Line2+9% Compens.	261.6	-23.54	238.06	18.78
3.Line1+9%	196.2	+17.66	213.86	18.78
Line2+20% compens.	261.6	-52.32	209.28	41.75

Table 3, Summarized Results

Case	Power Angle (δ)	Current A Rms	Power flow MW
1.Line1	-54.04 `	1064	685.7
Line2		798	514.3
2.Line1+9%	-59.28	1064	669.9
Line2+9% compens.		954.4	605.1
3.Line1+9%	-54.04	977.6	627.8
Line2+20% compens.		995.8	647.2

6 Specifications and Calculations for Distributed Modules

For a typical 400 kV transmission line the impedance X_L is 0.327 ohms/km. Current through line 1 is 1064 A and through line 2 is 798 A. A 9% change in line impendence would thus require injection of 0.02943 ohms/ km. This translates in to an inductance of 93.67 µH or 33.31 KVAR (31.31 V at 1064 A). From the simulation results it is found that to divert a 75 MW power through line 2 and to maintain the system stability, 9% line compensation is required in line 1 and 20 % compensation in line 2.

Taking the example of 400 kv line, it is seen that the reactive voltage drop is 347.93 v/km at rated current (corresponding to 0.327 ohms/km). The rating of active module on three phase basis in KVA/km is 100 KVA. Considering 10 KVA module optimal in all respect, then for 100 KVA, 10 of 10 KVA module / km or approximately 3 modules per conductor per km will be inserted.

A compensation of 20% needs 222.19 KVA i.e approximately 240 KVA or 24 of the 10 KVA module / km or 8 modules per conductor per km. Table 4 shows details of per km. distributed modules with 9% line compensation.

To achieve the different objectives various compensations are required in line 1 and 2. On the basis of 10 KVA module, total number of modules have been calculated and shown in Table 4. Analysis represents 9 % to 20% variation in the compensation. Maximum control action takes place is 215.66 MVA.

Table 4, Per Km Distributed Modules With 9% Line Compensation

Line voltage	400 KV
Thermal line capacity	737 MVA
Current carrying capacity	1064 A
Line reactance	0.327 ohms/km
active voltage drop/km	347.93 v/km
9% compensation/km	31.31 v/km
Active module KVA/km with 9% compensation	100KVA
Total 10 KVA active module/km/9% compensation	10 (3 modules/km/conductor)

In line 1 control action is achieved with 5996 distributed module of 10 KVA spread over 600 km.Maximum control action of 215.62 MVA is achieved with 21562 modules of 10 KVA per km. Ratings for the single lumped unit are shown in Table 5 and Table 6 shows the ratings and number of distributed modules.

Table 5, Ratings for single module

Case	Distri. KVA Per km(3Φ)	Distri. KVA Per km(1Φ)	Lumped MVA (3Φ)
Line1+9% compens.	100	33.33	60
Line2+9% Compens.	80.42	26.81	64.35
Line1+9% compens.	100	33.33	60
Line2+20% compens.	194.58	64.86	155.66

Table 6, Total distributed modules

Case	10 KVA module Per km(3Φ)	10 KVA module/ conductor/ km(1Φ)	10 KVA total module
Line1+9% compens.	10	3.33 (3)	5996
Line2+9% Compens.	8	2.68 (4)	6435
Line1+9% compens.	10	3.33 (3)	5996
Line2+20% compens.	19.46	6.48 (7)	15566

7 Physical Status and Economics for Distributed Module

As the module is to be clamped on the line, it does not see the line voltages and does not need to meet the BIL limits. The unit can thus be applied at any line voltage. The critical issue with the distributed series impedance module is its weight and physical dimensions. As per the latest design of tower and the mechanical specifications of transmission line, a module weight of 50-60 kg is deemed acceptable. Utilities already use 50 kg zinc dampers on the power lines to prevent the oscillations.

If actual reactors (Passive)are to be added then weight (135 Kg. per KVA) and physical dimensions will be very high as compare to D-FACTS (Active) technology in which voltages are injected. In D-FACTS technology the heaviest component is the single turn transformer. For a distributed module of 10 KVA, with a proper selection of core material, the weight of single turn transformer could be reduced and total weight of the module including thyristors and other accessories would be in the range of 50-60 kg. Such a module could be small and light enough to be suspended from the power lines, floating both electrically and mechanically on the line itself.

Comparatively cost of D-FACTS module is high but the weight is low and there is scope for the cost reduction due to day by day advancement in power electronics. High installation cost in D-FACTS technology is compensated in long term application. Cost of D-FACT module is estimated as Rs. 4000 / KVA, including installation and commissioning costs, where as cost of FACTS module is Rs. 12000 / KVA which is three times more.

Other important issues which are also considered in the design are high electrostatic fields and minimization of corona discharge, sealing of the unit against rain and moisture, and ability to operate while clamped on the power line without damaging the conductor. Finally for the application to have commercial viability, the module must be extremely low cost and it is possible by mass production and the advancement in power electronics technology. With this discussion D-FACTS is the best solution on single lumped controller.

8 Results and Conclusions

Two bus system with two unequal transmission lines is considered for the simulation distributed controller. Power flow has been carried out by power world simulator for 1200 MW and 1275 MW without and with controllers. Transmission lines have thermal capacity of 1064 A which is fully utilised in line 1 and some unutilised capacity in line 2 for 1200 MW power flow. In the power flow of 1275 MW, additional power of 75 MW is diverted through line 2 with the insertion of D-FACTS controller. For equivalent reactance compensation approach insertion of 0.0294 ohms/Km reactance is required. As per D-FACTS technology total voltage injection of 18.78 Kv and 41.75 Kv is injected in line 1 and line 2 respectively.

Simulation for 1275 MW power transfer gaves, 156.44 MW (12.27%) and 131 MW (10.27%) power losses without and with compensations respectively. Around 2% (25.44 MW) power has been saved by D-FACTS technology. With the application of D-FACTS series module, reduction in power losses has been estimated and associated saving of electrical energy (25.44 MWh). Saving of electrical energy reflects on coal consumption and environmental pollution.

0.77 Kg. of standard Indian coal is required for the generation of one unit (1KWh) of electrical energy [18]. About 770 kilogram coal is required to generate 1MWh electricity. For loss of 25.44 MWh units of electricity, 19.59 Tonne coal is required. In the power plant expenses are also required for various operations and processes like emission control mechanism, handling of coal, transportation of coal etc. Total cost for the generation of 1 MWh electricity is Rs. 1836. Amount saving on coal for unit of 25.44 MWh is Rs. 46708. Details of expenses to generate 1 MWh electricity are shown in Table 7.

Ratings of the controllers have been estimated. Single lumped controller of 215 MVA is required to divert the additional power flow and to maintain the system stability. As per D-FACTS , considering 10 KVA modules as an optimal module in all respect, 21562 modules are required in the ratio of 10 modules per conductor per kilometre. These modules are light enough to installed on the transmission line.

Table 7, Cost for generation of 1 MWh electricity

Steps for coal saving	Cost in Rs.
Coal (at source 2260 Rs. /Tonne)	1740
Emission control mechanism (2% of coal)	35
Coal handling plant expenses (2% of coal)	35
Transportation (1.5% of coal)	26
Total cost	1836

Consumption of coal in conventional large power plants brings serious environmental problems related to various air pollutants. Coal based thermal power plant is a major polluter in terms of Carbon dioxide (CO_2), Sulphur dioxide (SO_2), Nitrogen oxide (NO) and suspended particulate matter (SPM) emission [19]-[20]. Average values of Pollutants in gm/KWh are considered for the estimation of total emissions. These major emissions are shown in Table 8. Total emission of major pollutants is approximately 1000 gm/KWh (1Tonne/MWh). Environmental pollution saved towards the generation of 25.44 MWh units electricity is 25.44 Tonne.

Table 8, Major emissions from coal based thermal power plant for 1 KWh [21]

Major pollutants	Emission gm/KWh
Carbon dioxide (CO_2)	991.0
Sulphur dioxide (SO_2)	7.6
Nitrogen oxide (NO)	4.8
suspended particulate matter (SPM)	2.3
Total Emission gm/KWh	1005.7

Insertion of D-FACTS devices in the transmission line, results in stability of power system, enhancement in system reliability and performance of transmission line. This technology reduces the power loss in transmission line and hence the saving of electrical energy. Saving of electrical energy reduces the burdon on thermal power plant and reduces the consumption of coal and associated environmental pollution.

D-FACTS technology also reduces the cost for installation, controller and solves the problem of insulation. With entire discussion D-FACTS controller is one of the tool to reduce environmental pollution due to thermal power plant.

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