TRANSMISSION LINES CONGESTION MANAGEMENT USING FLEXIBLE AC TRANSMISSION SYSTEM DEVICES

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Abstract— *This paper describes the load flow problem which is followed by the economic dispatch problem and the power flow model of Thyristor Controlled Series Compensator (TCSC). A program is developed in MATLAB for the power flow studies of an IEEE 9-bus, IEEE 14-bus and IEEE 30-bus test systems without and with TCSC. Additionally the optimal power flow problem using Newton's method and MABC algorithm has been solved for IEEE 9-bus, IEEE 14-bus and IEEE 30-bus test systems without TCSC and with TCSC using MABC algorithm. Additionally the location marginal price difference is calculated for finding the optimal location of TCSC in deregulated electricity market to reduce congestion in transmission lines.*

Keywords— Deregulated Power System; Double Auction Bidding; Social Welfare; Pool Market; TCSC; UPFC

1. INTRODUCTION

In today's world most of our major industries and hence economy depends on a reliable source of electricity. The present day scenario of power system transmission lines are becoming increasingly stressed, it is very difficult to operate with unscheduled power flows. Thus, it becomes necessary to continuously monitor the power flows and all transmission parameters continuously. Power flow analysis gives information about the bus bar values of voltage magnitude and phase difference, active and reactive power flows in the lines. In this project, the application of load flow analysis is exploited by converting it to Optimal Power Flow (OPF).

OPF is a static nonlinear programming problem that optimizes a certain objective function while satisfying a set of operational and physical constraints imposed by equipment limitations and security requirements. After obtaining the OPF solution, the implementation of the optimal control variables will bring the system to the "optimum" state. In this report Newton's algorithm and Modified Artificial Bee Colony (MABC) algorithms are discussed, which are classical and intelligence method of optimal power flow technique, suitable for incorporating the newly developed nonlinear and linearized Flexible AC Transmission Systems (FACTS) models. This concept was introduced in the late 1980's by the Electric Power Research Institute (EPRI). The objective of the FACTS devices is to bring a system under control and it also allows to increase the usable transmission capacity to its maximum thermal limits. The high voltage transmission systems are operating below their thermal ratings due to constraints such as voltage and stability limits. The voltage stability problem and the power transfer capacity of transmission line is improved by the use of equipment known as (FACTS) controllers.

There are no constrained interfaces and has one zone only in wales and England market. Under dispatch each and every constraint are considered and all bus are treated as zone and loads are not considered. ISO re-dispatches generators and gets compensation because of congestion. Extra charge because of congestion is distributed to consumers. In Pennsylvania-Jersey-Mary land (PJM), a centralized market dispatch is usually conducted by ISO in scheduling interval. Nodal prices and the dispatch are calculated corresponding to particular constraints. During congestion, each line is referred as inter-zonal interface and node is referred as zone with its zonal price. Electric Reliability Council of Texas (ERCOT) energy market is subdivided in to two submarkets which are local unit specific congestion market and zonal portfolio congestion management market. First market's task is to get the balancing energy bids in order to keep the power balance between ERCOT short term load forecast and qualifies scheduling entity's generating schedule. Second market task is to deploy particular unit balancing energy down and up bids to maintain and manage congestion locally. Two important methods of zonal pricing in Nord pool for inter-zonal and intra zonal purchases are utilized for congestion management. The system is split in to price zones in zonal pricing method. FACTS controllers for congestion management with its optimal location are described in [4]FACTS devices in FTR optimal auction model to manage congestion was proposed by Wang [9, 10]In order to predict and evaluate the reduction in cost of congestion with FACTS controllers are described by Brosda and Handschin [11]Optimal location of phase shifters based on generation cost minimization using mixed integer LP (MILP) is presented in [13] Further use of FACTS for congestion management are discussed in [5, 14].

2. LOAD FLOW ANALYSIS

The goal of load -flow study is to obtain complete voltage magnitude and angle information at each bus in a power system. Once knowing this information, the real and reactive power flow on each section as well as generator reactive power output can be analytically determined. Because of nonlinear nature of this problem, numerical methods are employed to obtain a solution that is within an acceptable tolerance. The solution of the power flow problem begins with single line diagram of the system, then identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus.

Slack bus: It is assumed that the voltage magnitude and angle is 1∠0°. It is only the one bus in the entire Power System network.

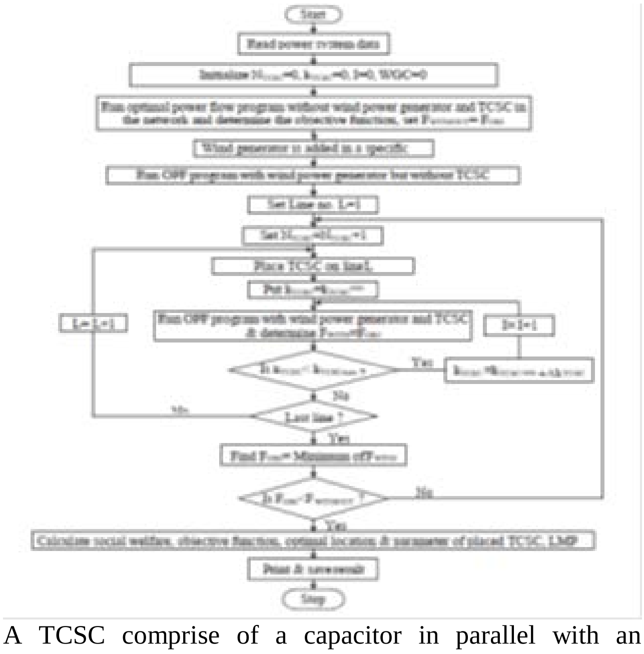
Generator Bus (PV-bus): A bus which is connected to at least one generator, in other words which is providing a variable reactive power. Some loads may connected to generator bus.

Load bus (PQ-bus): A bus without any generators connected to it is called a Load Bus.

The great importance of load-flow studies is in the planning the future expansion of power systems as well as in determining the best operation of existing systems. The mathematical formulation of the load flow problem results into nonlinear algebraic equations which can only be solved by iterative techniques.

3. SYSTEM DESCRIPTION AND MODELING

Static model of TCSC & UPFC have been used in this work for improving the economic profit by optimal allocation of TCSC & UPFC with wind power generators in double auction competitive power market.



A TCSC comprise of a capacitor in parallel with an inductor that is connected to a couple of opposite-poled thyristor. By adjusting the firing angle of the thyristor, the inductor reactance is varied and it can lead to change the effective impedance of TCSC.

Adding TCSC in series with the line reduces the transfer reactance of that line connected between bus ‘i’ and bus ‘j’ thereby increases the maximum power that can be transferred on that line in addition to reduction in effective reactive power losses. The TCSC can be operated as the capacitive or inductive compensation respectively by directly modifying the reactance of the transmission line. The static model of TCSC is considered in the current work (Fig. 1). For construct this model variable reactance is connected in series with transmission line. The reactance of TCSC is a function of the reactance of transmission line where TCSC is to be located:

Xline ¼ xij þ xtcsc

where, xTCSC ¼ kTCSC × xline

The range of the compensation level of TCSC is: —0.7 6 kTCSC 6 0.2.

The working range of reactance of TCSC has been fixed between —0.7 xline and 0.2 xline [19,20].

Due to the 100% compensation will raise a problem of series resonance in the system, normally up to 70% of line reactance is chosen for compensation.

The UPFC is the most versatile FACTS devices for regulation of voltage and power flow in the transmission line. It has the ability to adjust the control variables – magnitude & phase angle of the series injected voltage and reactive current drawn by the shunt connected voltage source converter, simultaneously or independently. The UPFC can be operated as the capacitive or inductive compensation respectively by modifying the series reactance of the transmission line along with shunt reactive power injections or extractions on the connected bus. In this proposed approach static model of UPFC is considered. For construct this model variable reactance is connected in series to modify the reactance of trans-mission line and a variable shunt reactive source is added at the bus connected to the same line. UPFC consists of two back-toback connected voltage source converters through a DC link. The static model of UPFC is shown in Fig. 2. The reactance of UPFC is a function of the reactance of transmission line where UPFC is to be located. where xUPFC ¼ KUPFC × xLINE The operating range of the compensation level of UPFC is:—0.7 6 KUPFC 6 0.2. Working range of series reactance of UPFC has been fixed between 0.7 xLINE and 0.2 xLINE [19,20]. Due to 100% compensation will raise a problem of series resonance in system; normally up to 70% of line reactance is chosen for compensation [21]. The shunt converter of UPFC has two operating characteristics: inductive or capacitive. For inductive, it absorbs reactive power from the system and for capacitive operation the reactive power is injected into the system. In the presented model, QUPFC is injected or extracted reactive power by shunt converter at the ‘from or start’ bus of the line where the UPFC is located. In this work, the operating range of QUPFC (MVAr) is taken as —100 6 QUPFC 6 100.

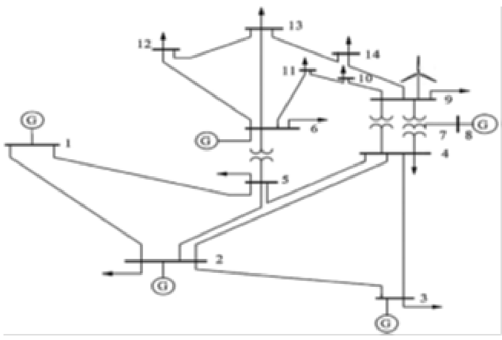


Fig: WPG connected at bus No. 9 (modified IEEE 14 bus system).

TABLE 1 OPTIMAL VALUE OF OBJECTIVE FUNCTION AND PROFIT AFTER PLACEMENT OF WPG & TCSC.

Optimal value of objective function and profit after placement of WPG & TCSC.

Sl. no.	WPG connected at bus no.	Wind gen. value (MW)	Gen. cost before TCSC ($/hr)	Opt. loc. of TCSC at line No.	x_{TCSC}	PQF (MVAr)	Gen. cost after TCSC ($/hr) (a)	Invst. cost of TCSC ($/hr) (b)	Invst. cost of WPG ($/hr) (c)	Obj. func. ($/hr) (a + b + c)	Profit (PBWF-OF)
1	9	2.5	540.12	3	0.20	0.7709	535.92	1.0451	9.375	546.365	3.702
2	9	3.5	536.16	3	0.20	0.7567	532.01	1.0820	13.125	546.197	3.869
3	9	4.5	532.21	3	0.20	0.7544	528.10	1.0787	16.875	546.040	4.027
4	11	2.5	540.24	3	0.20	0.7615	536.01	1.0684	9.375	546.455	3.612
5	11	3.5	536.33	3	0.20	0.7601	532.13	1.0667	13.125	546.327	3.740
6	12	2.5	540.25	3	0.20	0.7626	536.00	1.0704	9.375	546.447	3.619
7	12	3.5	536.35	3	0.20	0.7625	532.12	1.0698	13.125	546.322	3.745
8	12	4.5	532.47	3	0.20	0.7617	528.26	1.0690	16.875	546.211	3.856
9	13	2.5	540.21	3	0.20	0.7624	535.97	1.0700	9.375	546.415	3.651
10	13	3.5	536.30	3	0.20	0.7627	532.07	1.0690	13.125	546.271	3.795
11	13	4.5	532.39	3	0.20	0.7610	528.19	1.0679	16.875	546.138	3.928

Bold values represent the total profit achieved.

4. PROPOSED RESULTS

This system with 5 generators, 14 buses, 20 transmission lines and 10 loads has been used to test the effectiveness of the pro- posed approach. The test system data can be found in [25,26]. Sys- tem data and results are based on 100 MVA and bus 1 is the reference bus. For verify the proposed approach and illustrate the impacts of WPG & TCSC, three cases for test systems were investigated:

Application of proposed approach

To investigate the effectiveness of the proposed approach, presented work has been done in modified IEEE 14-bus & modified IEEE 118-bus test system. MATPOWER has been used in this paper to solve the optimal power flow problem.

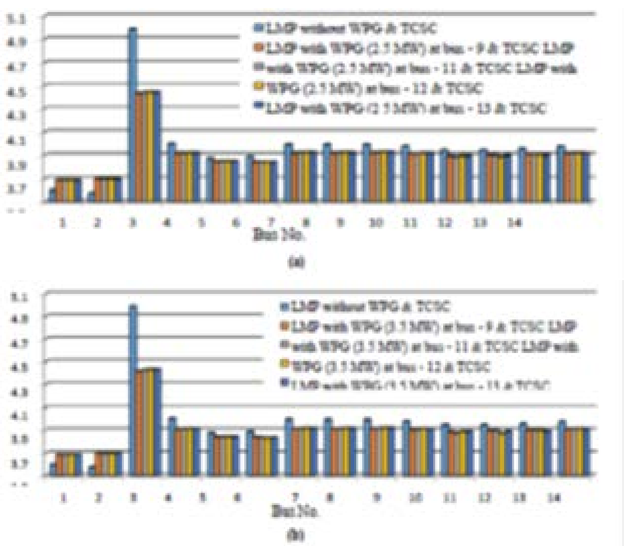
TCSC & WPG installation in modified IEEE 14 bus system

This system with 5 generators, 14 buses, 20 transmission lines and 10 loads has been used to test the effectiveness of the pro- posed approach. The test system data can be found in [25,26]. Sys- tem data and results are based on 100 MVA and bus 1 is the reference bus. For verify the proposed approach and illustrate the impacts of WPG & TCSC, three cases for test Systems were investigated:

Case 1. System Performance without WPG and TCSC

Case 2. System Performance with WPG but without TCSC.

Case 3. System Performance with WPG and optimal location of TCSC.



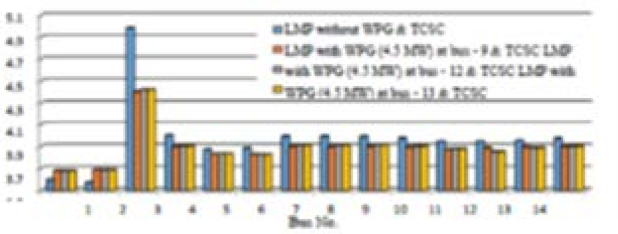


Fig: Objective function value (modified IEEE-14 bus system).

Case 1. In this case optimal power flow has been done without placement of WPG and TCSC in the modified IEEE 14-bus sys- tem and corresponding total generation cost (PBWF) has been found as 550.0674 $/hr.

Case 2. Three capacities of wind power generator (2.5 MW, 3.5 MW & 4.5 MW) are connected at bus No. 9, 11, 12 and 13 simultaneously. Single line diagram of this system with located WPG at bus No. 9 is shown in the Fig. 2. We select the bus number randomly in which WPG is connected. The optimal objective function value before and after installation

of WPG and TCSC can be seen in the Table 1. All the values have been taken in $/hr. From the reference [1,2] it has been found that the investment cost of wind power generator (for 1 MW capacity) is 3.75 $/hr (approx.).

Case 3. In this case TCSC has been also considered for optimal placement in the system. From Table 1 it can be seen that after installation of TCSC, total generation cost (including investment cost of WPG & TCSC) has been reduced and total generation cost

is reduced more in every cases when high capacity of wind power generator (here 4.5 MW) is connected in a bus. So, more profit has been obtained after installation of the high capacity of WPG in spite of investment cost is high (shown in Table 1).

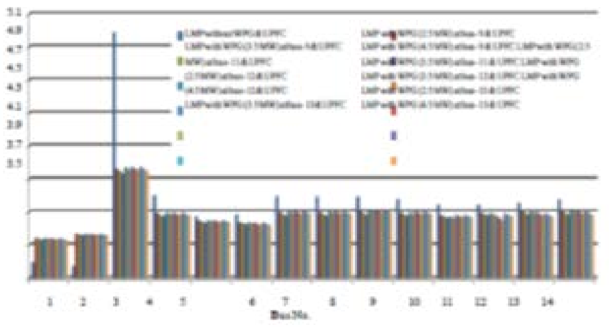
TABLE 2 OPTIMAL VALUE OF OBJECTIVE FUNCTION AND PROFIT AFTER PLACEMENT OF WPG & UPFC.

TCSC & WPG in modified IEEE 118 bus system

This system consists of 54 generators, 118 buses, 186 transmission lines and 99 loads have been used to test the effectiveness of the presented approach. The bus data, line data, generator data and cost co-efficient has been taken from [26]. System data and

results are based on a 100 MVA and bus 69 is the reference bus. Like modified IEEE- 14 bus case,

Sl. no	WPG connect at bus no.	Wind gen. value (MW)	Gen. cost before UPFC ($/hr)	Opt. loc. Of UPFC at line no.	Opt. loc. Of Qsig at bus no.	[illegible]	[illegible]	PQF (MVAr)	Gen. cost after TCSC ($/hr) (a)	Invst. cost of TCSC ($/hr) (b)	Invst. cost of WPG ($/hr) (c)	Obj. func. ($/hr) (a + b + c)	Profit (PBWF-OF) ($/hr)
1	9	2.5	540.12	6	3	−0.40	2.09	1.1584	535.22	1.090	9.375	546.588	3.481
2	9	3.5	536.16	6	3	−0.40	2.09	1.1830	531.32	2.001	13.125	546.452	3.615
3	9	4.5	532.21	6	3	−0.40	2.09	1.0812	527.44	1.878	16.875	546.193	3.874
4	11	2.5	540.24	6	3	−0.40	2.09	1.1548	535.28	1.087	9.375	546.655	3.412
5	11	3.5	536.33	6	3	−0.40	2.09	1.1408	531.42	1.098	13.125	546.551	3.516
6	12	2.5	540.25	6	3	−0.40	2.09	1.1535	535.27	1.081	9.375	546.634	3.433
7	12	3.5	536.35	6	3	−0.40	2.09	1.1590	531.40	1.094	13.125	546.527	3.54
8	12	4.5	532.47	6	3	−0.40	2.09	1.0845	527.55	2.004	16.875	546.435	3.632
9	13	2.5	540.21	6	3	−0.40	2.09	1.1537	535.24	1.085	9.375	546.605	3.462
10	13	3.5	536.30	6	3	−0.40	2.09	1.1593	531.36	1.085	13.125	546.481	3.588
11	13	4.5	532.39	6	3	−0.40	2.09	1.0848	527.48	2.005	16.875	546.368	3.699



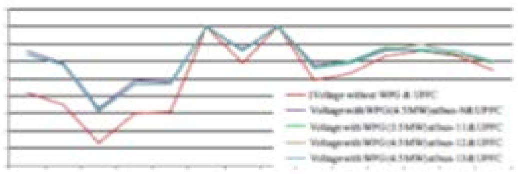


Fig 5. LMP improvement after placement buses & UPFC

in order to verify the presented approach and illustrate the impacts of TCSC in the hybrid system, three cases for test systems were investigated: (1) System Performance without WPG and TCSC, (2) System Performance with WPG but without TCSC & (3) System Performance with WPG and Optimal location of TCSC. At first OPF has been done without WPG and TCSC, and get corresponding total generation cost (PBWF) as 16537.3954 \$/hr. WPG of 2.5 MW, 3.5 MW, 4.5 MW capacities has been connected at bus No. 20, 33, 50, 53, 86, 115 simultaneously like previous case study. The optimal function value before & after installation of WPG & TCSC has been seen in the Table 2. Like previous case study it has been shown from Table 2 that when high capacity of wind power generator (here 4.5 MW) are connected in a bus then the total cost is decreased more in every case. So it has been decided from this two case studies that more profit has been obtained after installation of the high capacity of WPG. When we has been calculated the LMP for modified IEEE-118 bus, we seen that LMP improvement of system is very less, because only one TCSC is used which do not affected in large network. If large numbers of TCSC are used then LMP may be improved in whole network.

5. CONCLUSION

In this paper, Congestion management is an important issue in deregulated power system. For reducing the congestion, Thyristor controlled series capacitor (TCSC) is used instead of introducing the new transmission lines. The development of simple and efficient models for optimal location of TCSC is that it can be used for congestion management by controlling their parameters optimally.

In this report the power flow studies without TCSC has been carried out for IEEE 9-bus, IEEE 14-bus and IEEE 30-bus test systems, modelling of TCSC in power flow studies is being carried out for IEEE 9-bus, IEEE 14-bus and IEEE 30-bus test systems. TCSC in the system enables effective active power flow regulation in the compensated line. Finally the optimal power flow problem using Newton's method and MABC algorithm without TCSC has been solved for IEEE 9-bus, IEEE 14-bus and IEEE 30-bus test systems. It has been observed that there is a redistribution of power generation and the losses are reduced as compared to the normal power flow results.

Usage of optimal power flow for finding the local marginal price, LMP difference and congestion rent contributions are calculated for locating FACTS (TCSC) device to manage congestion in deregulated electricity markets. The optimal power flow problem using MABC algorithm with TCSC has been solved for IEEE 9-bus, IEEE 14-bus and IEEE 30-bus test systems. The effect of TCSC on overloading line has also been studied, it is observed from the results of overloading line that can relieve congestion by setting the installed TCSC.

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