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Case Study of IEEE-30 Bus System for The Congestion Management and Cost Calculation

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ABSTRACT:

An electricity market can be described as, "…a system for effecting the purchase and sale of electricity using supply and demand bids to set the price [3]". Over the years, the power industry remained vertically integrated, that is, a central authority monitored and controlled generation, transmission, and distribution. In the last decade, the industry has been evolving. It's being restructured, especially the separation of transmission and generation. A step in this direction is deregulation through which the state aims to lift conditions on units and individuals to boost efficiency.

Deregulation will promote competition which will lead to reduction in power cost. Therefore, it is imperative to set up a controlling agency, - a power system operator - to manage the dispatch of generating units and meet the demand from across the transmission grid. This operator must be independent of the market competition, and thus is usually called the Independent System Operator (ISO).

Privatization and deregulation will not only intensify competition in power market but also lead to additional production and consumption. This is likely to put a strain on the transmission system and congest the system. Hence, congestion management is a fundamental transmission management problem.

In this paper, a power market analysis tool is designed for congestion management. The tool develops an interface between Power World simulator professional software tool and MATLAB to compute power flow. The tool analyzes power flow results while batch-processing of large case studies are done in IEEE 30 bus bus system. This aids the user in congestion management.

This paper will use an optimal power flow framework (OPF) to deal with the congestion problem in a deregulated power market. In this research, the transmission lines are decongested using SVC method then, costs are calculated while considering the installation of the SVC in the transmission network to cut expenses. After detecting congested lines, we apply SVC on that particular bus. The IEEE-30 bus system is used to simulate the market and illustrate the proposed method. The simulation done is in MATLAB. The results show that when SVC is included the voltage profile of congested bus significantly improves, thus reducing the congestion. The results are verified in power world simulator software. Hence, it can be said that SVC is a viable option for congestion management, both from technical and economical point of views.

1. Cost Calculation

This paper aims to establish a methodology for evaluating wholesale or retail price of power that will not only ensure recovery of expense for utilities or regional networks but also rationalize tariff for consumers, thus reflecting the market competition [1].
Recently, deregulation of the power industry is taking place across the globe. The intent behind this is to make electricity affordable. Having enjoyed monopoly for a long time, power market could attain the goal only by introduction of competition. It has been established that competition is feasible and that power producers can benefit from such competition. In addition to this, competition also compels power companies to implement cost reduction measures while saving on investments [7] [3].
This paper aims to propose a theoretical method to devise reasonable electricity prices which are acceptable to both, the utility and the consumers in the market. Specifically, considering that the purchasing price from IPPs is decided through bidding, auction or negotiation, the derivation problem of prices on load buses is formulated as a nonlinear optimization problem. However, while attempting to maximize benefits for all players (the utility, power producers and customers) there are certain constraints. These include those found in OPF and cost-benefit balance conditions, which can ensure retrieving the expenses during operations. This paper focuses on finding an equilibrium price structure for electric utility, independent power producers and consumers. The utility needs to offer the lowest price and at the same time prevent itsef from plunging into losses [1][4][23].
The pricing mechanism in a deregulated electricity market is essential to achieve high competency in the power market. With development of electricity market, there is no shortage of consumers wanting to purchase power from generators [6][7].
Currently, many researchers are studying the transaction mode between generators and large consumers. In, trade modes based on auction theory was designed assuming that only one supplier and one consumer exists. But, the assumption seems unreasonable for that several generators and large consumers always participate in the power market. In, the negotiation based bilateral transaction mode and matchmaking based concentrated bidding transaction mode for generators and large consumers were put forward. But, it ignored the impact of power transmission cost. In, a method to build bidding strategies for power suppliers and large consumers in a pool co-type electricity market is presented under an assumption that each supplier/large consumer bids a linear supply/demand function, and the system is dispatched to maximize social welfare. This assumption also seems unreasonable for that each supplier/large consumer does not bid a linear supply/demand function, and at the same time the transaction cost is not taken into account[8][9][10][11].
By means of describing the clearing and transaction rules and by considering power transmission cost, a double auction model to structure optimal pricing mechanism for generators and large consumers in pool co-type electricity market is established. A numerical example with eight generators and eight large consumers serves to illustrate the essential features of the method. And, the analysis of the example shows that the auction model can increase the probability of big generators and big consumers win and transaction rules can optimize the overall cost. In addition to this, the system is dispatched to maximize social welfare considering transmission cost and transaction cost [12][13].
Further study can be done on optimal pricing mechanism for generators and big consumers considering that the bidding strategy functions are the common continuous functions [17].
Power utilities need to Fig. out the actual cost of providing unbundled services in order to set proper price for various types of services they should promote or curtail as per their obligations. Utilities also need to know such costs in order to make correct economic and

engineering decisions on upgrading and expanding their generation, transmission and distribution facilities [14][15][23].

As these trends show, the emphasis on providing unbundled transmission service has been increasing steadily. Therefore, knowing the cost of transmission services has become all the more important. Yet, evaluation of this cost is extremely complex.

In this paper, technical issues related to the cost of transmission transactions provided by a vertically integrated utility company have been discussed. Recognizing the complexities, emphasize is on clarity over exhaustiveness. Besides engineering terms, common economic terms too have been used in this context. The research stays clear of the subject of transmission pricing and rate design. Pricing of transmission transactions is considered here to be separate issue requiring separate treatment. Main goal is to provide basic guidelines for identifying and evaluating the cost of transmission transactions. These guidelines can work as a framework for further refinement and discussion [15][16][29].

2. Basic Concepts

A transmission transaction refers to the transmission component of the service provided by an electric utility — e.g., the transmission service associated with a power sale, a power purchase or a wheeling transaction.

There are various types of transmission transactions. There are several categories to which the type of transmission transaction may belong to. The cost of a transmission transaction depends on its type and consists of several components. [18][17]

3. Cost of Transmission Transactions

Here we discuss the cost components that apply to various transmission transactions. For example, all firm transmission transactions include the existing system cost component. Short-term transactions do not usually incur reinforcement costs. Those long-term firm transactions that are accommodated via transmission system reinforcements in order to mitigate operating constraints usually do not incur opportunity costs. All types of transmission transactions incur operating costs.

Not only do the cost components vary according to the type of transaction but also the cost evaluation process may be different depending on the transaction type. For example, as will be shown, opportunity cost is calculated differently for firm and non-firm transactions. Generally, for a transmission transaction: [19][17].

TCt = OPGt + OPYt + RFTt+ EXTf (1)

where, OPG^ is the operating cost, OPY^ the opportunity cost, RFTt the reinforcement cost, EXT^ the existing system cost, and TC^ the total cost of the transmission transaction.

In this section, we present a more detailed description of the components of the cost of transmission transaction and present methodologies to evaluate them [31][22].

3.1 Operating Cost

The operating cost of a transmission transaction is the production (fuels) cost that the utility incurs to accommodate the transaction. The operating cost is due to generation rescheduling and redispatch. Generation redispatch is caused by change in losses and by operating constraints such as transmission flow and bus voltage limits. Generation rescheduling is impacted by factors such as the start-up time and start-up cost of generating unit and the spinning reserve requirements.

We do not include the operation and maintenance costs for transmission system hardware facilities (hardware O&M cost) as part of the operating cost of the transmission transaction except for such incremental O&M costs that are directly attributable to the transaction. We deal with the O&M cost, in general, as part of the existing system cost.

The operating cost of a transmission transaction will be negative if the transaction reduces the production cost. Production cost is reduced via improving generation dispatch due to lower losses and/or mitigation of operating constraints and via improving generation scheduling [20][21] [22].

The hour-by-hour operating cost of a transmission transaction can be estimated using an optimal power flow (OPF) model that accounts for all operating constraints including transmission system constraints, generation scheduling constraints and security considerations. (Should the OPF model exclude these constraints, the only cost captured will be the cost of generation redispatch due to losses.) The cost function for the optimal power flow should correspond to the operating objective(s) of the utility. In most instances, the objective is to minimize the overall production cost. Existing OPF models, however, do not account for spinning reserve and unit start up constraints and costs. Hence, generation rescheduling cost portion of the operating cost cannot yet be calculated using an OPF-based approach. The operating cost may be calculated using two different approaches [23][24]

3.2 Opportunity Cost

Basically, the opportunity cost of a transmission transaction corresponds to the benefits unrealized due to operating constraints that are caused by the transaction (cost of lost opportunities). The benefits unrealized due to lost opportunities may arise through one or both of the following mechanisms:

Unrealized savings in production cost if the utility could not bring in cheaper energy due to operating constraints. A transmission transaction causing such constraints results in losses and hence escalates cost. The opposite is also true. If a transaction mitigates transmission congestions allowing additional transactions to take place, it provides some benefits and reduces cost[194].The opportunity cost is the most elusive component of the cost of a transmission transaction. There are questions and concerns on the justification and the evaluation of this cost. The main argument related to the opportunity cost of a transaction stems from the need to make assumptions about potential transactions that are foregone due to the transactions under consideration. There is also very little experience in evaluating opportunity costs for transmission transactions [29][24][25].

3.3 Existing System Cost

All the aforementioned components of the cost of a transmission transaction are directly caused by the transaction. These are the direct costs of providing transmission services. They are collectively called the incremental cost of the transmission transaction [26].

The existing system cost of a transmission transaction corresponds to the cost of existing transmission system that is to be allocated to that transaction. The cost of existing transmission system is the cost associated with the investment made in building and the expenses incurred on maintaining the existing transmission system. For example, the embedded and the O&M costs of transmission system hardware [27].

It is important to note that a transmission transaction does not actually cause any new costs involving the use of existing transmission facilities. These facilities have already been built and their costs already incurred. Hence, the actual question is not of incurred costs but of allocation of the cost of existing transmission system to those who use the system[28].

Because the cost of existing transmission system is generally large, the existing system cost of a transmission transaction is usually the largest component of the overall cost of the transaction. For this and other historical reasons, this cost has received the most attention from regulatory agencies overseeing revenue collection by the utilities[30]. Here, the major issues are:

- To whom the cost of existing transmission system should be allocated? There is no clear consensus on this issue. Some economists suggest that the cost of existing transmission system should not be allocated to new transmission transactions. Some believe that the cost of existing transmission system should be allocated to all users of the transmission system. Most interested parties, however, consider that the cost of existing transmission system must be shared by all customers of firm transmission transactions. The basis for this consideration is the obligation for the utility to reserve transmission capacity for firm transmission transactions at all time[17][25].

3.4 Reinforcement Cost

The reinforcement cost of a transmission transaction corresponds to the cost of all transmission reinforcements necessary to accommodate that transaction. Reinforcement cost can also be the cost of planned transmission reinforcements that are deferred by the transmission transaction. In its latter form, the reinforcement cost of a transmission transaction will be negative. As mentioned earlier, this component of the cost of transmission transactions and the discussion presented below apply only to firm transactions.
Although the concept of reinforcement cost is straightforward, this component of die cost of transmission transactions is very difficult to evaluate. Technically, the problem involves the solution of the least cost transmission expansion problem in response to a new transaction. This problem poses the following challenges:
An accurate methodology to identify the actual least cost plan in light of the "lumpy" nature of the transmission reinforcements (integer programming problem), the profusion of available solutions, and the profusion and uncertainty of the constraints is extremely difficult[17][25].
It is worth noting that the total cost of transmission lines is divided into two parts, namely the fixed and variable costs. The cost of construction, designing, measurement, and tax are so-called fixed costs of transmission lines. The operation as well as maintenance costs of transmission lines are named the variable costs. The transmission services pricing problem has been an attractive ongoing area of research which has eventuated in some remarkable number of papers revealed and still some others going to be published[31][26].
The operation of electrical systems faces technical constraints which still exist in liberalized and competitive markets. Satisfaction of technical constraints is usually assured by an agent usually referred as Transmission System Operator (TSO) or Independent System Operator (ISO)[22].

4. Algorithm for Cost Calculation

In the context of competitive electricity markets, the electrical network is assumed as a natural monopoly. This is due to the economic (and sometimes even physical) impossibility of the existence of several alternative infrastructures as transmission networks. Anyway, this monopoly cannot constitute an obstacle for the activities of the agents who act in these markets. So, the existence of adequate regulation that guarantees the access to the transmission electrical network is required [21][22].
The TSO must assure open access to the transmission network, and operational and market constraints must be satisfied. Numerous buyers and sellers making multiple transactions complicate the problem of determining levels of transmission adequacy and identifying the possibility of conditions leading to transmission system congestion [22][23]. These situations must be handled using congestion management methodologies, keeping the technical constraints in mind.

In a pool, bids from the supply side (Gencos) must be matched with the offers from the demand side (Discoms and others). In this thesis, we consider a competitive electricity market environment, involving both a pool and bilateral contracts [29].
Congestion management methodologies can solve congestion considering different goals. In a competitive environment, these goals should not only take into account technical constraints and security of supply needs but also the concerns of market agents . Keeping this in mind, the methodology proposed in this thesis considers that the final dispatch should be as similar as the initial dispatch. Thus, the main goal is to obtain a feasible solution for the re-dispatch minimizing the changes in the dispatch proposed by the market operator. This is justified because the TSO should only interfere in the market as needed to solve the technical problems [32][33].
This paper presents a software tool to assist decision making in competitive market environment, guarantying the economic sustainability of the transmission system[22].
The initial dispatch is based on all the electricity transactions negotiated in the pool, and in bilateral contracts. This initial dispatch must be checked for congestion problems If congestion is detected, it must be solved. The flowchart shown in Fig. 1. is for cost calculation.

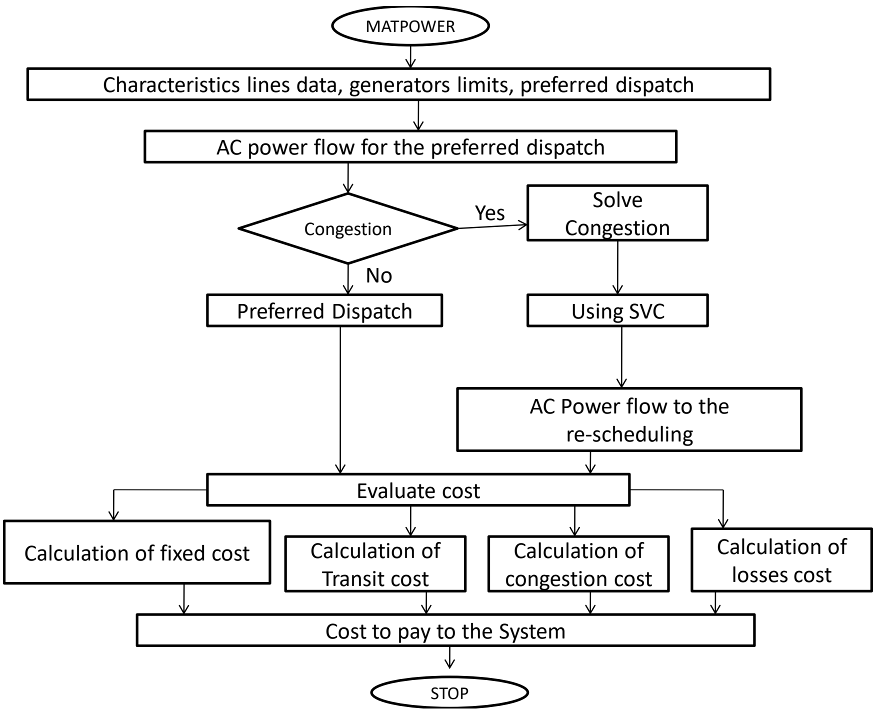

Fig. 1 : flowchart of Cost calculation.

The first task is to run an AC power flow to verify if there is congestion in the initial dispatch. After this, congestion that may exist is solved. It also determines costs distribution and evaluates the cost to be paid to the system as a reward by the transmission network use [188][194].

5. Allocated Transmission Cost

After validating the congestion, MATPOWER determines the cost to be paid to the system to pay the user transmission system.
Transmission cost can be distributed using several methodologies which can be defined according to the market rule [34][35].

Here, we are considering the existing system cost. Half of existing system cost is allocated to the load

A. The existing system costs (Fixed costs) correspond to the cost of the existing transmission system that are allocated to the transaction. These costs include the cost associated with building infrastructure, and the expenses incurred on maintaining the existing transmission system for simplicity purposes. The fixed cost are allocated to the generator and fixed cost allocated to the load. The total fixed cost is the sum of fixed cost allocated to the load and fixed cost allocated to the generator [22].
B. Allocated operation cost (Transit costs)

The evaluation of these cost take into account which percent of line capacity is used. According to the used capacity, the total cost is considered as the cost allocated to the load due to impact caused in power flow [22][23].

C. Congestion Cost

Congestion cost should be considered to evaluate transmission taxes because congestion situation can disrupt the transmission system. Congestion situation can even be created on purpose to prevent competition less electricity market. Due to this, MATPOWER finalizes the load. and the generator in the initial dispatch, impacting power flow in congested line [22][29].

The congestion cost is considered 25% of load and generation.

D. Losses cost

MATPOWER evaluated the losses and determine the losses. After evaluation, the losses of each line these cost are allocated to the generator. The distribution is done in the same proportion of the impact of each generator in the power flow. The loss is applicable to generator. And, the total losses cost is allocated to the system [22][24].

E. Payment of Electricity transmission system

Considering all costs, the MATPOWER evaluates how much the transmission system received from the generator and the load .The total value paid to the system is the sum of the total cost [22].

6. Case Study on IEEE 30 Bus System

The Single line diagram of an IEEE-30 Bus system is as shown in Fig.2. The congested lines are identified and presented in Table 2. After solving congestion situation using SVC the voltage profile of all the buses is changes which is presented in Table 3. and graphical representation is in Fig.3. is given. After solving congestion our simulator allocates cost to the agents (load and generator).We calculate the fixed cost on load and fixed cost on generator[21]. While calculating fixed cost on load we consider approximately 80% cost on load and for fixed cost on generator we consider approximately 50% cost on generator and congestion cost is 25% on load .

Firstly calculate the total cost on load without SVC. As the TLR sensitivity of bus no.2 is higher [3] so we apply SVC on Bus no. 2 and calculate the cost on load with SVC the detail has been given in Table 2 and Fig.3. Then the difference of total cost on load with and without SVC is calculated. So fixed cost on load without SVC is 438.54 in dollars while with SVC it is 304.40 in dollars. The difference in total cost on load with and without SVC is 30.5%.

Similarly we check the results for fixed cost on generator without SVC and with SVC is given in Table 3 and presented in Fig.4. So Fixed cost on generator without SVC is 157.98 in dollars while with SVC it is 157.51 in dollars. The difference is 0.02 %. The Table 3also gives idea about losses values Without SVC and With SVC for IEEE 30 bus system. Hence it is revealed that with the appropriate placement of FACTS devices losses were also minimized.

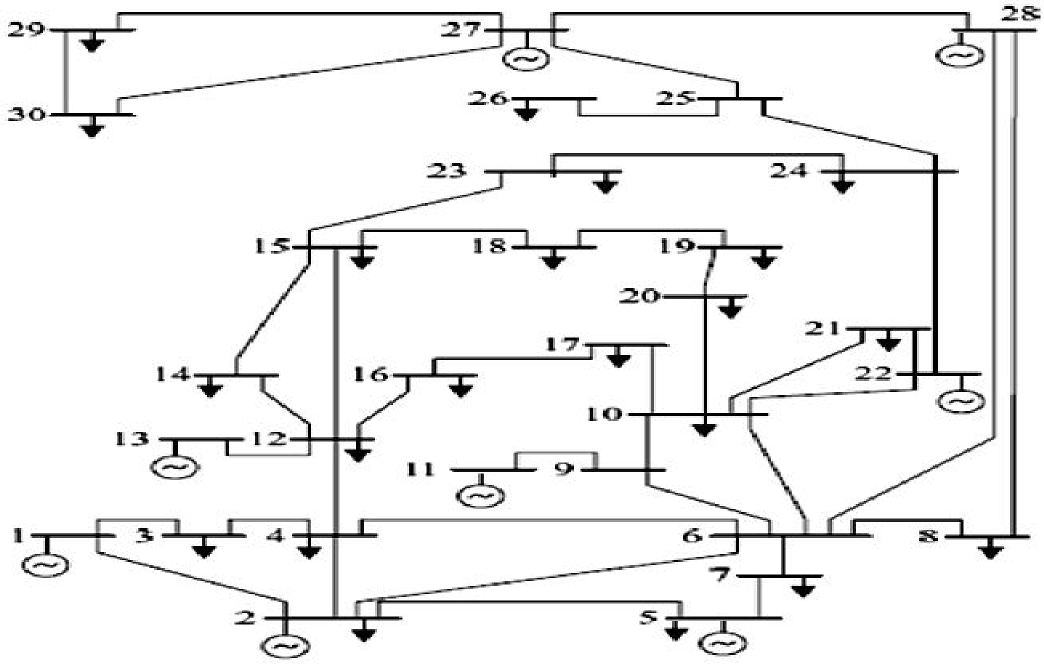

Fig. 2. Single Line Diagram of IEEE 30 bus test system

Table 1.: Results of Total Cost on Load without SVC and with SVC for IEEE 30-bus System

Bus	**Cost Without SVC in $**	**Cost With SVC in $**	**Difference in Percentage**
2	35.5880	26.035	34.85
3	3.9360	2.46	37.5
4	10.944	3.28	70
5	154.4880	102.5	33.65
7	37.3920	22.34	40.25
8	43.2	54	20
10	8.352	3.6	56.8
12	18.3680	15.375	16.25
14	8.928	2.88	67.7
15	11.808	4.5	61.8
16	5.04	3.24	35.7
17	12.96	10.44	19.4
18	4.608	1.62	64.8
19	13.67	6.12	55.2
20	3.168	1.26	60.2
21	25.2	20.16	20
23	4.608	2.88	37.5
24	12.528	12.06	3.7
26	5.04	4.14	17.8
29	3.456	1.845	46.6
30	15.264	3.67	75.9
Total	438.546	304.405	30.58

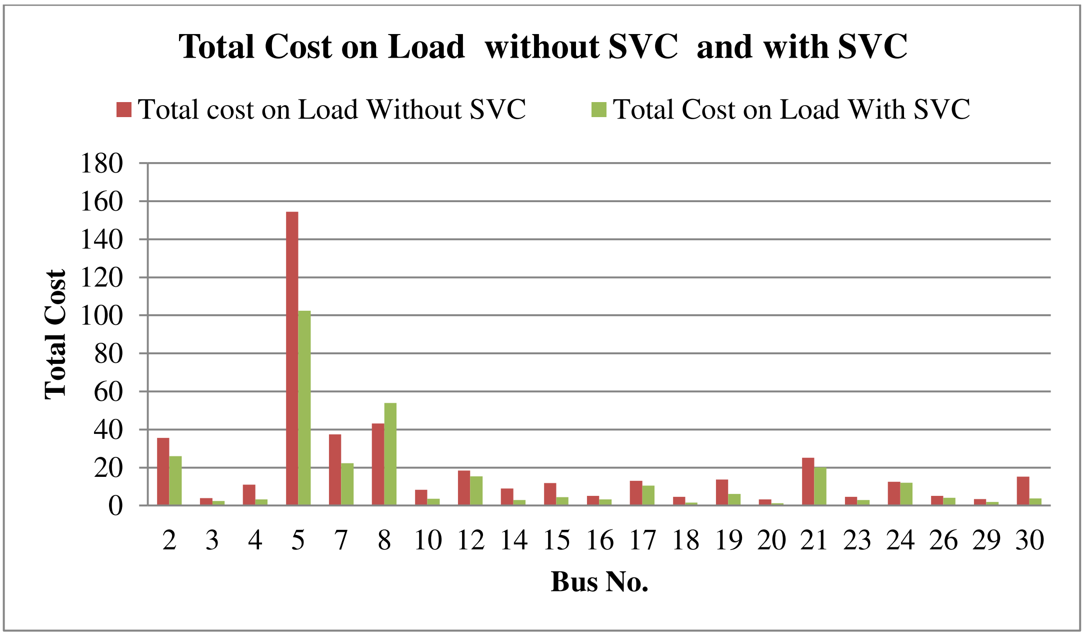

Fig. 3. Total Cost due to Load at different buses with and without SVC for IEEE 30 bus system

Table 2.: Total Cost due to Generator at different buses without and with SVC for IEEE 30 bus system

Bus No.	Total Cost on Generator without SVC in $	Total Cost on Generator With SVC in $	Difference in Percentage
1	48.11	36.58	23.9
2	12.05	15.82	-23.8
5	32.68	31.757	2.8
11	20.60	16.49	19.9
13	19.75	16.49	16.5
22	11.7865	21.0141	-43.91
27	5.412	9.8757	-45.19
28	7.601	9.4891	-19.89
Total	157.983	157.51	0.2

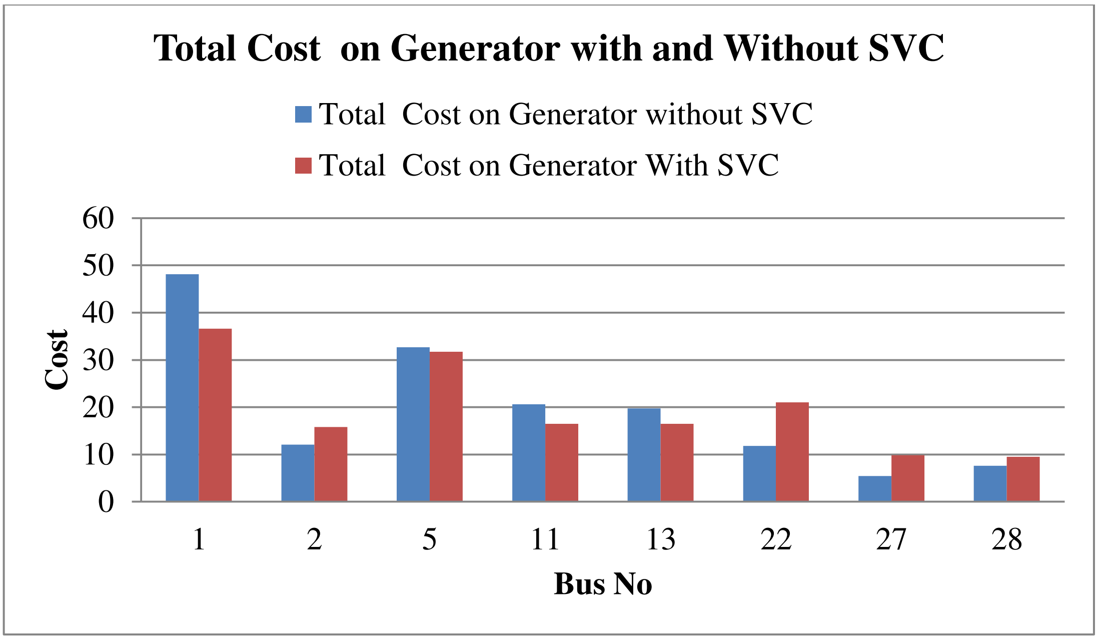

Fig. 4. Total Cost due to Generator at different buses without and with SVC for IEEE 30 bus system

Table 3.: Results of Total Loss on Line without SVC and with SVC for IEEE 30-bus System

Branch	**From**	**To**	**Loss without SVC**	**Loss with SVC**	**Difference**	**Change in percentage**
1	1	2	0.443	0.066	0.377	14.898
2	1	3	0.183	0.031	0.152	16.939
3	2	4	0.074	0.014	0.06	18.918
4	3	4	0.028	0.003	0.025	10.714
5	2	5	0.408	0.051	0.357	12.50
6	2	6	0.110	0.042	0.068	38.181
7	4	6	0.032	0.013	0.019	40.625
8	5	7	0.073	0.070	0.003	95.89
9	6	7	0.252	0.097	0.155	38.492
10	6	8	0.084	0.080	0.004	95.238
17	12	14	0.045	0.044	0.041	97.77
18	12	15	0.094	0.086	0.008	91.48
19	12	16	0.006	0.004	0.002	66.66
21	16	17	0.008	0.005	0.003	62.5
22	15	18	0.014	0.011	0.003	78.571
23	18	19	0.001	0.000	0	0
24	19	20	0.032	0.031	0.001	96.87
25	10	20	0.142	0.139	0.008	97.88
26	10	17	0.053	0.048	0.002	90.566
27	10	21	0.023	0.027	0	0
28	10	22	0.043	0.040	0.003	93.02
29	21	22	0.080	0.080	0.00	0
30	15	23	0.002	0.000	0.002	0
31	22	24	0.174	0.045	0.001	25.86
32	23	24	0.028	0.023	0.003	82.142

Branch	From	To	Loss without SVC	Loss with SVC	Difference	Change in percentage
33	24	25	0.029	0.006	0.482	20.68
34	25	26	0.043	0.041	-0.004	95.34
35	25	27	0.006	0.002	0.003	33.33
37	27	29	0.081	0.081	0	0
38	27	30	0.155	0.153	0.002	98.709
39	29	30	0.031	0.031	0	0
40	8	28	0.085	0.076	0.005	89.411
41	6	28	0.095	0.091	0.023	95.789

7. Conclusion

In this paper, Static Var Compensator as a first remedy is shown to be an efficient in managing congestion in the competitive market. The use of SVC in aiding congestion management is shown to provide additional benefit to the system, in terms of both clearing the congestion and reduction of total congestion cost. With SVC, the contracts after market Re-dispatch are more or less the same as the originally scheduled, which is highly appreciated by both suppliers and customers. The results were tasted on IEEE 30 bus system. Simulation were carried out in MATLAB. Here we discuss the congestion problem in the deregulated electricity market using an optimal power flow. The congestion management method considered here is based on a constrained SVC of generation schedule which are formed by the market. From congestion management Cost can be evaluated. With the help of result it is indicated that the SVC is applied on bus no. 2 for IEEE 30 bus system which reduces the cost as well as losses.

Simulation results shows clear possibility of optimized location of SVC and relaxation of congestion. Congestion management along with SVC strategy to ease out congestion proves to be of technical as well as economical benefits. Here the FACTS device location considered economic saving function. It not only reduces the congestion but also reduces the cost which is appreciated by both the suppliers and consumers end. Hence this paper presents techno economic benefit of SVC.

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