Power Flow Analysis Incorporating Renewable Energy Sources and FACTS Devices

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Abstract- This paper focuses on impact of renewable energy sources such as solar and wind on power flow control. The performance analysis of Flexible AC Transmission Systems (FACTS) devices namely SVC and TCSC in steady state power flow control without and with renewable energy sources is studied. Impact of renewable energy sources on thermal generating units and reduction in losses are discussed. Application of FACTS devices in a power system network is an efficient way for the control and transfer of bulk power for long distances. The performances of SVC and TCSC for reactive power injection, real power flow, power loss and voltage improvement are analyzed. Effective utilization of existing transmission line for the transfer of bulk power is demonstrated. The performance of FACTS devices during single line contingency is also analysed. The ability of SVC and TCSC to control power flow under various loading conditions and the modes of operation are discussed. Modelling of solar and wind farms is done using beta and weibull distribution functions respectively. SVC and TCSC are modelled using Variable Reactance modelling and are then incorporated into the existing Newton Raphson load flow algorithm. Numerical results on a benchmark 5 bus test system are presented.

Keywords FACTS; SVC; TCSC; Solar; Wind; beta distribution function; weibull distribution function.

1. Introduction

Available Transmission capacity shall often be limited by disbursement of transmission lines and losses, as well as problems occurring in building new lines. The number of transmission corridors is increased only to handle the active power transfer, ending up always, not being optimally utilize these facilities as built. One of the major reasons is the inability to push more active power in the given transmission line due to frequent line over loading and voltage related issues that are attributed to lack of reactive power management. In a modern electricity market an efficient electric grid is important for reliable supply of power [1]. In most of the today's power systems, the failure rate is increasing due to unexpected power demand. Congestion in transmission network is created with the unscheduled power flows and increased losses in the lines [2]. Every 1% reduction in the reactive power brings down reactive support by 2% , which further reduces voltage till the stabilized value of system operation. When the transmission losses are predominant, weakening of reactive power support to the system is large, brings down the voltage further. The electrical power system experiences voltage collapse where the system reaches unstable operating point with very low voltages across the system striving for the reactive support. To mitigate some of these difficulties and allow the utilities to get maximum service from their transmission facilities Onsite energy generation and Flexible AC Transmission Systems (FACTS) technology are necessary. Grid reliability can also be improved with Onsite energy generation (Distributed generation).

Onsite energy generation majorly includes renewable energy resources like solar, wind, biomass and hydro power. These power generations plants are installed at the load centres based on availability of resources [3] and are utilised locally. The main intention of this generation is to substitute the construction of new transmission corridors for fulfilling the increasing demand [4].

Reactive power control is required to improve the quality of power supply in ac power systems to have better utilization of existing equipment resulting in the deferment of new investment for equipments and transmission lines. Reactive power consumed by the load is fairly easy to understand, but the reactive power generated or consumed within the network is difficult to comprehend and is of major concern. FACTS Controllers helps to control voltages and power flows at required magnitude and locations of the network. The main objective of these controllers is to enhance transmission capability by allowing safer loading of the transmission lines up to their thermal limits [5]. These controllers have the ability to control the interrelated parameters of the transmission network like impedance, voltage, phase angle and current [6]. Various types of controllers have been developed based on the type of compensation. They are distinguished as series controllers, shunt controllers and combined series – shunt controllers [1]. Several FACTS Controllers exist and each one has its own abilities. The choice of a controller is always based on the objectives to be achieved.

The power flow problem is solved to determine the steady state complex voltages at all buses of the network, from which active and reactive power flows in every transmission line and transformer are calculated in ref [7]. Power flow analysis, involves solving a set of nonlinear algebraic equations whose results are ambiguous. These equations are solved using iterative techniques such as gauss seidel method, gauss elimination method, Fast Decoupled method and Newton Raphson (NR) method in [8]. NR method due to its quick convergence is widely used for power flow problem. With the prior information in regard to the power flows in the lines, it is possible to invoke efficient operation and control of present systems and also planning for new systems [8].

1.1 Proposed Work

In this study initially, FACTS controllers (SVC and TCSC) are incorporated in the existing NR power flow algorithm and their performances are analysed. This analysis is performed under normal loading, increased loading and contingency conditions.

Further renewable energy resources (solar and wind) are incorporated in the Newton Raphson load flow and the analysis is performed.

The rest of the paper is organized as follows: Section 2 describes the modeling of FACTS devices, solar and wind generating systems. In Section 3 the simulation results with incorporation of FACTS devices and renewable energy sources is presented.

2. Modeling of Renewable Energy Sources and FACTS Devices

2.1 Modeling of SVC

SVC acts as a shunt connected variable reactance, which either injects or absorbs reactive power in order to regulate the voltage magnitude at the point of connection [9]. It provides instantaneous reactive power and voltage support. The SVC has two regions: Capacitive and Inductive. In capacitive mode the SVC injects reactive power and in inductive mode it absorbs reactive power [10]. The SVC is modeled as a variable susceptance and its value depends up on the requirement at the particular node. The equivalent circuit is shown in Fig 1.

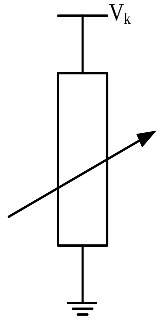

Fig. 1. Static Var Compensator

2.1.1 Power flow equations of SVC

Let us consider that an SVC is connected at bus *k*.
The reactive power absorbed or injected at bus *k* is given by [8],

$$Q_{SVC} = Q_k = -V_k^2 B_{SVC} \tag{1}$$

From Fig 1. The linearised equation taking B_{SVC} as state variable is given by [8]

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{pmatrix} 0 & 0 \\ 0 & Q_K \end{pmatrix}^{(i)} \begin{bmatrix} \Delta Q_K \\ \Delta B_{SVC} / B_{SVC} \end{bmatrix}^{(i)} \tag{2}$$

The susceptance B_{SVC}, is updated in every iteration is given by [5]

$$B_{SVC}{}^{(i)} = B_{SVC}{}^{(i-1)} + \left[\Delta B_{SVC} / B_{SVC} \right]^{(i)} B_{SVC}{}^{(i-1)} \tag{3}$$

The final value of susceptance represents the total susceptance required to maintain specified nodal voltage.

2.2 Modeling of TCSC

The impact of TCSC on a power network may be interpreted by a controllable reactance embedded in series to the related transmission line. Active power flow through the compensated transmission line may be kept up at a predefined level under extensive variety of working conditions [11]. A basic TCSC consists of Thyristor controlled reactor (TCR) in parallel with a fixed capacitor. The model of the network with TCSC connected between buses i and j is shown in Fig 2 and the equivalent circuit used for modeling is shown in Fig 3.

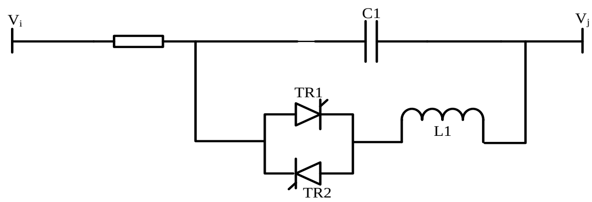

Fig. 2 TCSC connected in a transmission line

Fig. 3 Equivalent circuit of TCSC

2.2.1 Power flow equations of TCSC

The power flow equations of the branch with TCSC are given by [12]

$$P_{ij} = V_i^2 G_{ij} - V_i V_j G_{ij} \cos(\delta_i - \delta_j) - V_i V_j \sin(\delta_i - \delta_j) \quad (4)$$

$$Q_{ij} = -V_i^2 B_{ij} - V_i V_j G_{ij} \sin(\delta_i - \delta_j) + V_i V_j B_{ij} \cos(\delta_i - \delta_j) \quad (5)$$

Similarly the power flows from j^{th} to i^{th} bus are given by

$$P_{ji} = V_j^2 G_{ji} - V_j V_i G_{ji} \cos(\delta_i - \delta_j) + V_j V_i \sin(\delta_i - \delta_j) \quad (6)$$

$$Q_{ji} = -V_j^2 B_{ji} + V_j V_i G_{ji} \sin(\delta_i - \delta_j) + V_i V_j B_{ij} \cos(\delta_i - \delta_j) \quad (7)$$

2.3 Modeling of Solar farm

Solar farm is modeled by probabilistic approach using Beta distribution function. For statistical demonstration of output the most suitable function is Beta distribution. Historical data of site chosen is utilized for estimating the output from the solar panel. The solar irradiance distribution function is given by [13]

$$f_b(s) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} s^{(\alpha-1)} (1-s)^{(\beta-1)}; 0 \le s \le 1; \alpha, \beta \ge 0 \quad (8)$$

Using the historical data, the parameters of Beta distribution function are calculated as follows

$$\beta = (1-\mu)\left(\frac{\mu(1+\mu)}{\sigma^2} - 1\right) \quad (9)$$

$$\alpha = \frac{\mu\beta}{1-\mu} \quad (10)$$

Where Γ is the gamma function, s is the random variable of solar irradiance in kW/m^2. α and β are the parameters of Beta distribution function respectively, μ and σ are the mean and standard deviation of s. The specifications of solar panel and the corresponding equations are taken from [14, 19].

2.4 Modeling of Wind farm

Wind farm is modeled using weibull distribution function since it is best suited model compared to other distribution models. For estimating the output, wind site and turbine specifications play a key role. The wind probability function is given by[15,18]

$$f_v(v) = (k/c).(v/c)^{(k-1)}.e^{-(v/c)^k} \quad (11)$$

Where k,c are the shape factor, sclace factor of the weibull distribution function.
The output of a wind turbine for particular speed is given by

$$P_{wr} = \begin{cases} 0 & v < v_{in} \ or \ v > v_{out} \\ (a * v^3 + b * P_r) & v_{in} \le v \le v_r \\ P_r & v_r \le v \le v_{out} \end{cases} \quad (12)$$

While $a = \frac{P_r}{(v_r^3 - v_{in}^3)}$, $b = \frac{v_{in}^3}{(v_r^3 - v_{in}^3)}$ are the constants, v_{in}, v_{out}, v_r are the cutin, cutout and rated speeds respectively.

The expected power output at a desired time interval is $P_{we} = P_{wr} \times f_v(v)$ (13)
Where P_{we}, P_{wr} are the expected power and rated power output.

3. Results and Discussion

3.1 Analysis without Renewable energy sources

In this study, power flow analysis is carried out without incorporating renewable energy sources on a standard 5 bus system [16]. Initially power flow without FACTS devices is performed and later SVC, TCSC are incorporated individually and their performances are analysed.

3.1.1 Power flow analysis with SVC

The active and reactive power generations at the buses are presented without and with SVC in Table 1. When SVC is placed at the load buses it is observed that there is a very minute change in real power generation, but there is a significant change in reactive power generation. The generator at slack bus reduces it generation and the generator at bus 2 absorbs more reactive power compared to base case. This shows that SVC can inject reactive power into the bus which in turn reduces the reactive power burden on the generators.

The active and reactive power losses when SVC is placed at different locations are also given in Table 1. From the Table it is observed that the active power loss is reduced by 1.07% when SVC is placed at bus 3. Conversely, the real power loss has increased by 0.96% when SVC is placed in bus 5. This shows that the performance of FACTS devices depends upon the location in which they are placed. Reactive power loss has reduced significantly in all the cases with SVC.

Table 1 Comparison of Power flows without and with SVC

Parameter	Base Case	SVC at Bus 3	SVC at Bus 4	SVC at Bus 5
P_{G1} (MW)	131.12	131.06 (0.05%)	131.08 (-0.04%)	131.18 (0.05%)
P_{G2} (MW)	40	40	40	40
Q_{G1} (MVAr)	90.81	85.34 (6.03%)	85.51 (5.84%)	88.47 (-2.59%)
Q_{G2} (MVAr)	-61.59	-77.07 (25.1%)	-81.45 (32.2%)	-91.42 (48.4%)
P_L (MW)	6.122	6.056 (1.07%)	6.087 (0.5%)	6.181 (0.96%)
Q_L (MVAr)	-10.77	-11.254 (-4.4%)	-11.231 (-4.2%)	-10.955 (-1.7%)

When SVC is incorporated at various locations in the test system, its ability to improve the bus voltage is analysed. Voltage profile improvement when SVC is incorporated at various buses is shown in Fig 4. For instance, SVC is placed in bus 3 to improve the bus voltage to 1.00 p.u. It injects a reactive power of 20.47 MVAr to maintain specified voltage level. Even though SVC is placed at bus 3 the voltage magnitudes of bus 4 and 5 are also improved by 0.7% and

0.4% respectively. This shows the capability of SVC to improve the voltage profile of the nearby buses also.

Table 2. SVC operating modes for specified voltage in standard 5 bus system

Specified Voltage	Q_{svc} (MVAr)	B_{SVC}	Mode
0.9	125.0	-1.544	Inductive
0.92	98.6	-1.166	Inductive
0.94	70.9	-0.8031	Inductive
0.96	41.86	-0.4542	Inductive
0.98	11.3	-0.1185	Inductive
0.987 (base case)	0.01	0.0001	In operative
0.99	-4.37	0.0446	Capacitive
1.0	-20.47	0.2047	Capacitive
1.05	-106.16	0.9629	Capacitive

Similarly SVC is incorporated at the load buses 4 & 5 and voltage profiles in various buses are shown in Fig 4. In most of the cases it is observe that SVC improves the voltage profile of the bus in which it is placed as well as the other buses also. The percentage improvement depends on the location. This is because the reactive power injected by the SVC improves the reactive power flow in the nearby transmission lines also.

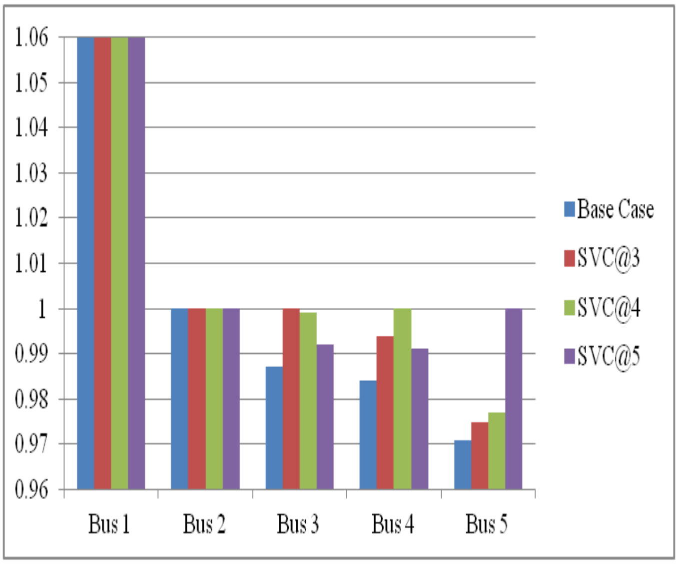

Fig.4 Voltage profile (p.u.) improvement when SVC is incorporated at various buses

Table 3. Effect of Increased Loading

Parameter		Base case	At Bus 3		At Bus 4		At Bus 5	
			Without SVC	With SVC	Without SVC	With SVC	Without SVC	With SVC
Voltage at the Buses	V1	1.06	1.06	1.06	1.06	1.06	1.06	1.06
	V2	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	V3	0.987	0.981	1.00	0.981	0.999 (1.83%)	0.983	0.991 (0.81%)
	V4	0.984	0.977	0.994 (1.74%)	0.977	1.00	0.979	0.99 (1.12%)
	V5	0.971	0.969	0.975 (0.61%)	0.969	0.976 (0.72%)	0.955	1.00
Power Generation	P_{G1} (MW)	131.12	155.19	155.04 (-0.06%)	152.54	152.49 (-0.03%)	163.86	163.93 (0.04%)
	Q_{G1} (MVAr)	90.81	88.85	78.94 (11.15%)	87.39	79.83 (8.65%)	83.414	79.79 (4.33%)
	P_{G2} (MW)	40	40	40	40	40	40	40
	Q_{G2} (MVAr)	-61.59	-47.17	-75.29 (59.61%)	-51.25	-79.64 (55.39%)	-40.74	-87.19 (114%)
Power Loss	P_{loss} (MW)	6.122	7.698	7.540 (-2.5%)	7.541	7.495 (-0.6%)	8.865	8.930 (0.73%)
	Q_{loss} (MVAr)	-10.77	-5.821	-6.799 (-16.8%)	-6.366	-7.004 (-10.02%)	-2.334	-2.695 (-15.5 %)

3.1.2 Modes of operation of SVC

The quantity of reactive power to be injected by SVC depends on required voltage magnitude and desired location in the test system. SVC is placed at bus 3 and the voltage magnitude is varied to determine the reactive power injected and susceptance value of SVC. Positive sign indicates SVC absorbs reactive power from the system and negative sign indicates injection of reactive power in to the system. Table 2 gives the values of reactive power injected and susceptance value of SVC for various voltage magnitudes specified. If the SVC has to maintain a voltage 1.00 p.u which is greater than base case (0.987 p.u.) then SVC injects 20.47 MVAr in to the system. Here the susceptance B_{SVC} is 0.2047 p.u. which shows the SVC is operating in capacitive mode. If the SVC has to maintain voltage 0.96 p.u. which is less than the base case then the SVC absorbs 41.86 MVAr from the system. Here the susceptance B_{SVC} is -0.45 p.u. which indicates that the SVC is operating in inductive mode. If the SVC has to maintain voltage which is equal to base case voltage it neither absorbs nor injects reactive power from the system. But here it absorbs a very small value of reactive power from the system almost equal to zero indicates that SVC is not operating.

3.1.3 Analysis with increased Load demand

Here the system is loaded from base to 150% of load at each bus, the voltage magnitudes and power generations at the buses and the power losses in transmission lines are observed without and with SVC.

Voltage profile without and with SVC at all the load buses is compared in Table 3. When the load is increased from base value to 150%, the voltage magnitudes at all load buses in the test system are decreased. Now SVC is incorporated at the bus in which load is increased and the performance is observed. Even at 150% of base loading, the voltage profile at all the buses is within the desired limits by the incorporation of SVC. Here the reactive power injected by SVC to maintain the voltage profile is increased compared to the base case.

The real power generation increases with increase in load. Even though SVC is incorporated at the load bus there is no significant change in real power generation. SVC aids in controlling the reactive power from the generators. The generator at the slack bus generates less reactive power compared to base case and the other generator at bus 2 absorbs more reactive power compared to base case. It is also observed that SVC supplies the desired reactive power with increased load and reduces the reactive power burden on the generators. The above discussed analysis is also given in Table 3.

The active and reactive power loss at the base case is compared with increase in 150% load without and with SVC. The results are given in Table 3. With the increase in load at the bus the overall active power loss is also increased. From the Table it is summarised that if SVC is placed at the bus 3, the loss is reduced by 2.5% of the loss with increased load. Conversely the real power loss is increased by 0.73% when SVC is placed in bus 5. This shows that the location of FACTS device plays an important role in the reduction of losses in a line. The reactive power loss is reduced significantly in all the cases with SVC.

3.1.4 Power flow analysis with TCSC

TCSC is accommodated in line 3-4 and the analysis is made in the standard 5 bus network. The power generations, voltage profile without and with TCSC are compared. An initial reactance of X=0.01 p.u is set and the power flow analysis is performed. The power flow of incorporated line is raised by 11.6% and it is noticed that TCSC maintains the target specified for a power mismatch of 1e-10 in 7 iterations. It is observed that there is no significant change in voltage profile with incorporation of TCSC which is given in Table 4.

Table 4. Effect of incorporating TCSC in Line 3-4

Parameter		Base case	With TCSC
Voltage at the Buses	V1	1.06	1.06
	V2	1.00	1
	V3	0.9870	0.9870
	V4	0.9840	0.9844
	V5	0.9712	0.9718
Power Generation	P_{G1} (MW)	131.12	131.13
	Q_{G1} (MVAr)	90.81	90.94
	P_{G2} (MW)	40	40
	Q_{G2} (MVAr)	-61.59	-61.80

3.1.5 Modes of operation of TCSC

The modes of operation of TCSC for active power flow are discussed in this section and the results are furnished in Table 5. TCSC is placed in line 3-4 in standard 5 bus system and the performance is analysed. The base case power flow in line 3-4 is 19.38 MW. For instance if the power flow is increased by 50% (29.16 MW) then the TCSC reactance is -0.0958 which shows that it is in capacitive mode. We can also observe the power flows in certain lines are increased and in some lines it is decreased. Now if the power flow in line 3-4 is decreased by 50% (9.70 MW) then the TCSC reactance is 0.2581 which shows it is in Inductive mode. So we observe that TCSC not only helps in improving Power flow in a line, it also helps in reducing the power flow if required.

Table 5. Modes of operation of TCSC

Line/ reactance	Actual Power Flow (MW)	Rise 50% (MW) in Line 3-4	Decrease 50% (MW) in Line 3-4
1--2	89.33	85.43	93.27
1--3	41.79	45.79	37.88
2--3	24.47	30.68	18.28
2--4	27.71	21.02	34.36
2--5	54.65	51.32	58.04
3--4	**19.38**	**29.16**	**9.70**
4--5	6.59	9.83	3.34
Reactance	--	-0.0958	0.2581
Mode	--	Capacitive	Inductive

3.1.6 Analysis with single line contingency in Standard 5 bus system with TCSC

The performance of TCSC for single line contingency is shown in Table 6. Line 2-4 of standard 5 bus system is considered as line with contingency. It is observed that the power flow of other lines is increased and the line 2-5 carries a highest power flow of 62.73MW. Now TCSC is placed in line 3-4 and the power flow in that line is raised from 39.03MW to 45.21MW. With this the over loading of the line 2-5 is reduced to 56.32MW which is an acceptable value. The power flows in remaining lines are also in desirable limits. With contingency the losses in the lines are increased but they were in acceptable limits. The power flows of all the lines before and after contingency with placing TCSC in line 3-4 are given in Table 6.

Table 6. Power flow in Standard 5 bus system during contingency

Line	Actual Power Flow (MW)	Line 2-4 removed	
		Power Flow without TCSC	Power Flow with TCSC in Line 3-4.
1--2	89.33	82.10	79.61
1--3	41.79	49.92	52.49
2--3	24.47	37.04	41.01
2--4	27.71	--	--
2--5	54.65	62.73	56.32
3--4	19.38	39.03	45.21
4--5	6.59	-1.127	5.00
P_L	6.12	7.03	7.10

3.2 Power flow analysis with Renewable energy sources

In standard 5 bus system power flow analysis is carried out by incorporating renewable energy sources. A wind farm of 15 MW and a solar farm of 30 MW are incorporated in the test system at buses 4 and 5 respectively. It is assumed that these renewable generators operate at unity power factor. The output from the wind and solar farms are estimated from the historical data [17] using weibull distribution and beta distribution functions respectively as explained in section 2.3 and 2.4. The parameters of renewable energy sources and the output expected are given in Table 7.

The probability distribution curves obtained for the wind speed and solar irradiance are shown in Fig 5 and Fig 6. When the power generated from these renewable energy sources is supplied at the load bus locally, the overall demand on the system is significantly reduced. This helps in improving the voltage profile and minimising power loss. The power generated, line loss and bus voltages are given in Table 8.

Table 7. Parameters of renewable energy sources

Parameter		Value
Solar	Mean	0.853 kW/m^2
	Std Dev	0.147
	Installed Capacity	30 MW
	Output	24.645 MW
Wind	Mean	12.46 m/s
	Std Dev	3.92
	Installed Capacity	15 MW
	Output	11.70 MW

From Table 8 it can be inferred that the burden on thermal generators is significantly reduced and the voltage profile at all the load buses is improved. The power loss is reduced by 33.34% (2.04 MW).

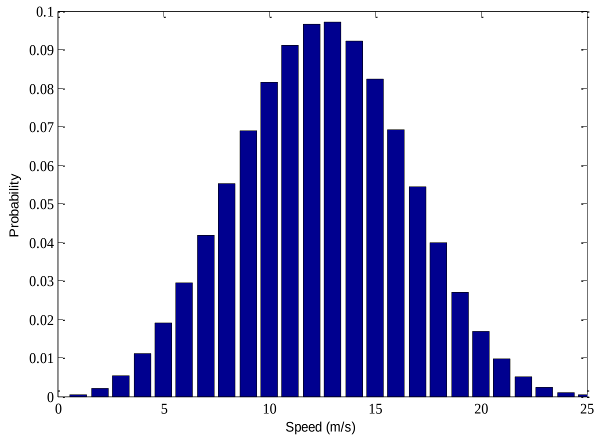

Fig 5. Wind speed probability distribution

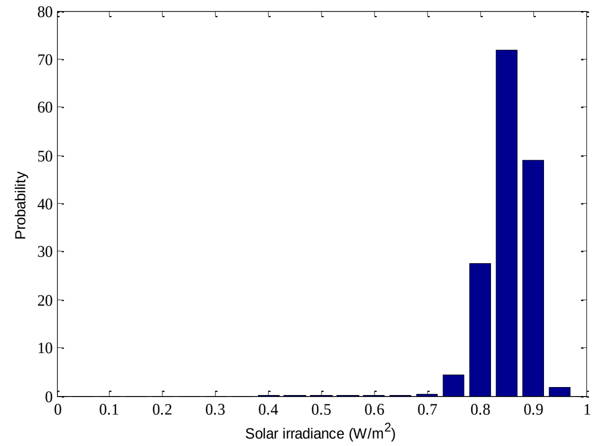

Fig 6. Solar irradiance probability distribution

Table 8. Power flow analysis incorporating renewable energy sources

Parameter		Base case	With Renewable
Voltage at the Buses	V1	1.06	1.06
	V2	1.00	1
	V3	0.9870	0.9916
	V4	0.9840	0.9894
	V5	0.9712	0.9813
Power Generation (MW)	P_{G1}	131.12	92.7435
	P_{G2}	40	40
	P_{Gs}	-	24.645
	P_{Gw}	-	11.70
Power Loss	P_L	6.12	4.08

3.2.1 Analysis incorporating SVC

SVC is incorporated at bus 3 and the power analysis with renewable energy sources is performed. The SVC injects 13.48 MVAr of reactive power to maintain the voltage profile at bus 3 to 1 p.u. The voltage at buses 4 and 5 are also significantly improved which can be observed from Fig 7.

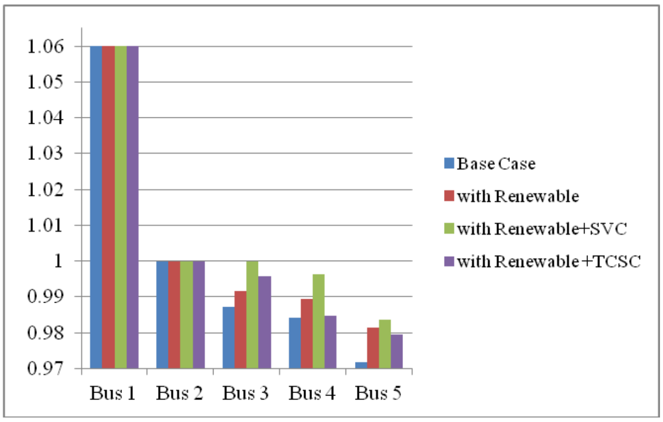

Fig 7. Voltage profile (p.u.) at the buses with renewable energy sources and FACTS devices

The active and reactive power generations, power flows in each line are clearly represented in Fig 8. From the Fig, it can be inferred that the power generated by the thermal generators is significantly reduced which helps in minimising the overall power loss of the system. The burden on SVC is reduced with the addition of renewable energy sources in the system. The power loss for this case is 4.04 MW which is better than the base case. Since the running cost for generating power from solar and wind farms are almost negligible huge savings can be achieved by promoting these sources.

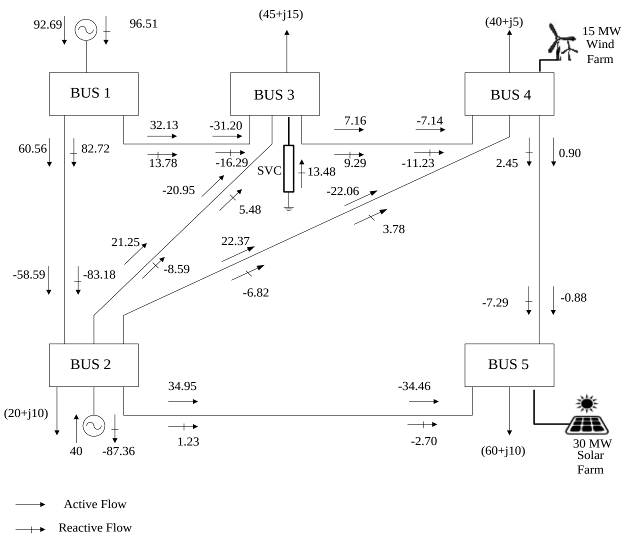

Fig 8. Power flow analysis in standard 5 bus system with SVC and renewables.

3.2.2 Analysis incorporating TCSC

In this case TCSC is incorporated in line 3-4, simultaneously with the renewable energy sources. TCSC helps in controlling the power flows in the line. Initially line 3-4 carries 19.34 MW to serve the demand at buses 4 and 5. With the addition of wind and solar farms, the power flow in this line is reduced to 7.04 MW. The TCSC can be used in either ways i.e for improving the power flows as well as for controlling the power flows. In this case the active power flow in the line is even more reduced to 2 MW. By this control the voltage profile at the buses are enhanced and powr loss is also reduced ehich can be observed from Fig 9.

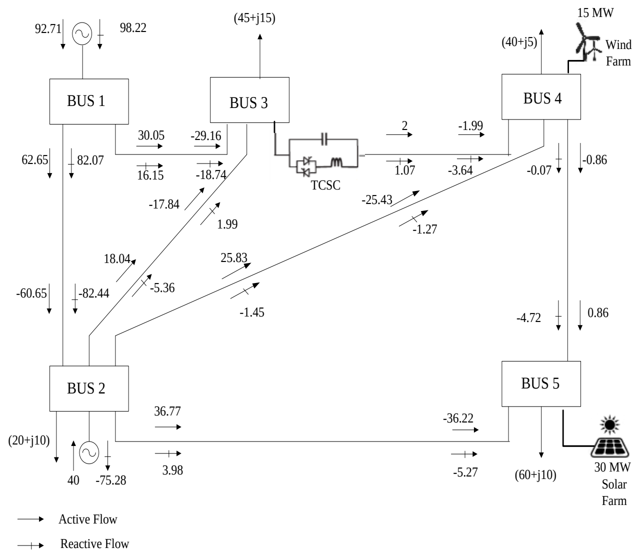

Fig 9. Power flow analysis of standard 5 bus system with TCSC and renewable.

The active and reactive power generations, power flows in each line are clearly represented in Fig 9. From the Fig, it can be inferred that addition of renewable energy sources and controlling of power using TCSC combinedly helps in minimising the power loss, improving voltage profile and also economy of the system in long run.

4. Conclusion

This paper investigates the effects of installing SVC and TCSC in the power system network in terms of voltage profile, power flows and losses in transmission lines without and with renewable energy sources. Power flow analysis with SVC and TCSC is carried on standard 5 bus system. Operating intermittent power sources and by installing the FACTS devices helps to improve the voltage profile at the buses and also reduces power loss in the lines. The transmission lines can be loaded above or below the base value with incorporation of TCSC to meet the required load demand. TCSC helps in controlling power flows in lines to an acceptable value in case of contingency as shown. This analysis shows that incorporation of renewable energy sources and FACTS devices improves the performance of existing power transmission networks.

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