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Impact of Loads on Power Flow in Power Systems Using PowerApps and ETAP

***Abstract**. This paper presents a study of the impact of loads on power flow in power system. It deals with the impact of both the voltage nodes and the transmission of active and reactive power in lines, and therefore the loss of active and reactive power in the system. Flexible Alternating Current Transmission System (FACTS) devices are found to be encouraging in improving voltage stability limit in power systems. This paper investigates the application of FACTS devices (Static Var Compensator, SVC) on a 9-bus multimachine power system, it deal with the line losses and improving voltage stability limit. Amount of increased reactive power generation and line losses are taken as indicators of stressed conditions of a power system. The use of SVC is identified by PowerApps and ETAP software packages. Both software are used for IEEE 9 bus test system and the results obtained are presented and interpreted.*

Streszczenie.** Analizowano wpływ napięć w węzłach i przepływ mocy biernej i czynnej na pracę systemu energetycznego. Artykuł przedstawia badania zastosowania urządzeń FACTS w dziewi1)ęcioszynowym, wielomaszynowym systemie. Wykorzystano oprogramowanie ETAP. **Wpływ obciążeń na przepływy mocy w systemie wykorzystującym PowerApps i oprogramowanie ETAP

Keywords: Power Flow, FACTS, SVC, PowerApps, ETAP.
Słowa kluczowe: przepływy mocy, FACTS, Etap

Introduction

Load flow study in power system parlance is the steady state solution of the power system network [1]. The main information obtained from this study comprises the magnitudes and phase angles of load bus voltages, reactive powers at generators buses, real and reactive power flow on transmission lines [2], other variables being known. Usually a generating station is not situated near the load centre, but it may be away from load centre due to various circumstances. In order to meet the ever-growing power demand, utilities prefer to rely on already existing generation and power export/import transmission lines that are well below their thermal limits. However, certain lines are overloaded, which has an overall effect of deteriorating voltage profiles and decreasing system stability and security. In addition, existing traditional transmission facilities, in most cases, are not designed to handle the control requirements of complex, highly interconnected power systems [3].This overall situation requires the review of traditional transmission methods and practices, and the creation of new concepts, which would allow the use of existing generation and transmission lines up to their full capabilities without diminishing the system stability and security. Another reason that is forcing the review of traditional transmission methods is the tendency of modern power systems to follow the changes in today's global economy that are leading to deregulation of electrical power markets in order to stimulate competition between utilities.

Harmonic problems are not new to electric utility and industrial power systems. In the past, most harmonic-related problems were caused by large nonlinear loads such as arc furnaces. These types of problems have been effectively mitigated. However, due to the widespread proliferation of power electronic controlled devices nowadays, the problems caused by harmonics are of increasing importance [4]. Power electronic loads offer a number of advantages in controlling power flow and in efficiency, but they perform this by chopping, flatting, or shaping sinusoidal voltages and currents. Harmonics are produced in the process.

Harmonic Power Flow Studies

The number and significance of nonlinear harmonics producing devices [5] connected to the power system has increased substantially during the past few years. Principal reasons for this increase include the development of high power semiconductor switches and their application in rectifiers, inverters, and various electronic circuits, and FACTS.

Harmonic power flow analysis has been extensively used to study harmonic propagation in the network. The results of distortion level and voltage wave forms are useful to verify compliance with harmonic limits. Harmonic power flow can be presented mathematically as [6]:

$$[V_h] = [Z_h][I_h] \tag{1}$$

Where $[Z_h]$ is the network impedance matrix; $[I_h]$ is the vector of nodal harmonic current injection of each bus; $[V_h]$ is the resulting harmonic voltage; and h is the harmonic order. Harmonic assessment using harmonic power flow can be separately conducted for every single diagram applying for connection to the network. Modifying the diagram capacity or installing expensive harmonic filters is necessary when the proposal violates harmonic limits. However, solutions deemed reasonable for each individual connection could deliver poor results for the network as a whole. For example, an early and minor connection may prevent development of other larger sites due to adverse harmonic propagation impacts, effectively reducing the total hosting capacity of the network or increasing the cost of additional filters.

Modeling of FACTS Devices

FACTS technology opens up new opportunities for controlling line power flows [7], minimizing losses and maintaining bus voltages at desired level in a power system network. These are done by controlling one or more of the interrelated system parameters including series impedance, shunt impedance, current, voltage, phase angle etc. with the insertion of facts controllers in a power system network. The groups of FACTS controllers are:

- Static Var Compensator (SVC).
- Thyristor-Controlled Series Compensator (TCSC).
- Static Synchronous Series Compensator (SSSC).
- Static Synchronous Compensator (STATCOM).
- Unified Power Flow Controller (UPFC).
- Interline Power Flow Controller (IPFC)

Static Var Compensator (SVC) Description and Modeling

The SVC uses conventional thyristors to achieve fast control of shunt-connected capacitors and reactors. The configuration of the SVC is shown in Fig. 1, which basically consists of a constant capacitor(C) and a thyristor controlled reactor (L).The delay angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system [8].

New version of SVC is basically a shunt connected static Var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables; typically, the controlled variable is the SVC bus voltage [9].

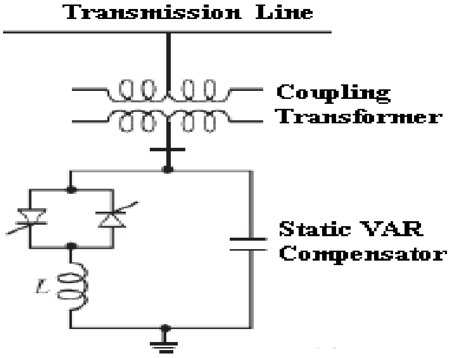

Fig.1. SVC connected to a transmission line

One of the major reasons for installing a SVC is to improve Dynamic voltage control and thus increase system load ability. An additional stabilizing signal, and supplementary control, super imposed on the voltage control loop of a SVC can provide damping of system oscillation as discussed [10].

The model considers SVC as shunt-connected variable susceptance, B_{SVC} which is adapted automatically to achieve the voltage control. The equivalent susceptance, B_{eq} is determined by the firing angle "of the thyristors that is defined as the delay angle measured from the peak of the capacitor voltage to the firing instant. The fundamental frequency equivalent neglecting harmonics of the current results.

(2) $$B_{eq} = B_L(\alpha) + B_c$$

(3) $$B_L(\alpha) = -\frac{1}{\omega L}(1 - \frac{2\alpha}{\pi} - \frac{\sin(2\alpha)}{\pi})$$

(4) $$B_c = \omega C$$

and $$0^\circ \le \alpha \le 90^\circ$$

If the real power consumed by the SVC is assumed to be zero, then:

(5) $$P_{SVC} = 0$$

The reactive power generated by SVC is given by:

(6) $$Q_{SVC} = -B_{SVC} * V^2$$

Where V is the bus voltage magnitude.

Description of the Computer Tools

PowerApps

PowerApps is a consortium of experienced professionals in the field of Power Systems Analysis & Simulation with an established reputation for customer responsiveness and technical expertise [11]. PowerApps offers an extensive line of Power System Engineering Software that feature some of the most advanced analysis tools for transmission, distribution and industrial power systems. It offers comprehensive services in order for customers to fully benefit from the PowerApps applications in their specific IT environment and to address their engineering analysis needs. This includes engineering studies, assistance to integration and comprehensive training.

The power analysis studies database serves as the basis for improving system performance and power quality, reducing operating costs, and providing a reliable supply of power during system operation. Using the PowerApps software tool, engineers can deliver complete system optimization.

Typical Power System Analysis

- Load Flow.
- Transient Motor Starting Studies.
- Short Circuit Analysis.
- Protective Device Coordination Study.
- Harmonic Study.
- Economic Load Dispatch.
- Optimal Power Flow.
- Load Frequency Control.

ETAP

ETAP is a fully graphical electrical power system analysis program that runs on Microsoft® Windows operating systems [12]. In addition to the standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, and high-speed intelligent load shedding.

ETAP has been designed and developed by engineers for engineers to handle the diverse discipline of power systems in one integrated package with multiple interface views such as AC and DC networks, cable raceways, ground grid, GIS, panels, protective device coordination/selectivity, and AC and DC control system diagrams.

ETAP allows user to work directly with graphical one-line diagrams, underground cable raceway systems, three-dimensional cable systems, advanced time-current coordination and selectivity plots, geographic information system schematics (GIS), as well as three-dimensional ground grid systems.

Typical Power System Analysis

- Load Flow Analysis.
- Short-Circuit Analysis.
- Motor Acceleration Analysis.
- Harmonic Analysis.
- Transient Stability Analysis.
- Optimal Power Flow.
- DC Load Flow and DC Short-Circuit Analysis.

System Description

A 9-bus 3-machine system [13], the system includes three generators and three large equivalent loads connected in a meshed transmission network through transmission lines as shown in Figure 2.

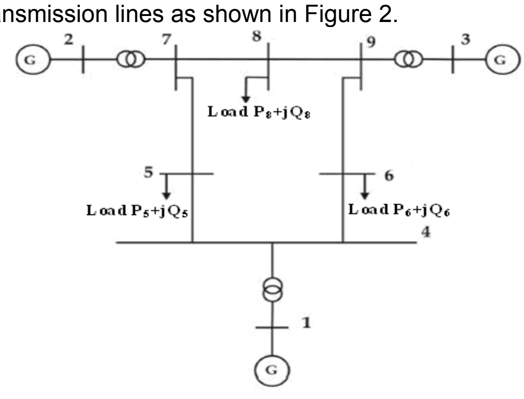

Fig.2. Synoptic scheme of System IEEE, 9 Bus

The total generation is 519.5MW and total load is 315MW. The test system contains 6 lines connecting the bus bars in the system. The generator is connected to network through step up transformer at 230kV transmission voltage, the generators are dynamically modelled with the classical equivalent model, where non linear loads we put a SVC in the node 8.

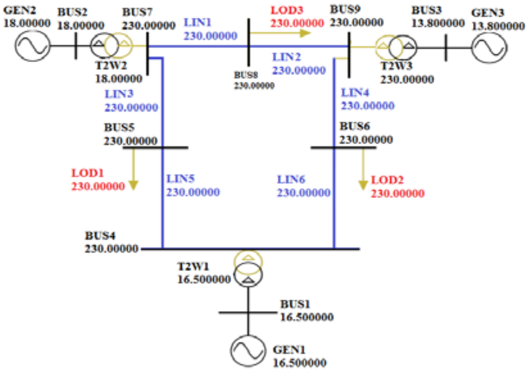

Fig.3. System IEEE, 9 Bus, with PowerApps.

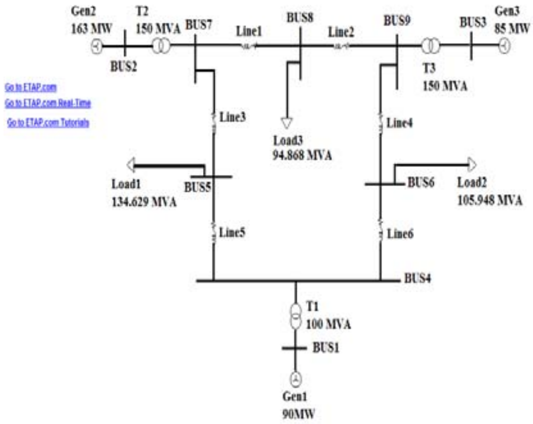

Fig.4. System IEEE, 9 Bus, with ETAP

Table 1. Bus Voltages with Linear Loads

Comparaison between ETAP and PowerApps for Voltages				
	PowerApps		ETAP	
Bus Name	Vmag(V)	Ang(deg)	Vmag(V)	Ang(deg)
1	1.040	0.000	1.0400	0.00
2	1.025	9.280	1.0250	9.30
3	1.025	4.665	1.0250	4.70
4	1.016	0.728	1.0258	0.27
5	1.032	1.967	1.032	2.60
6	1.013	-3.687	1.013	-2.63
7	1.026	-2.217	1.026	-3.37
8	1.026	3.720	1.026	3.07
9	0.996	-3.989	0.996	-3.20

Table 2. Bus Voltages with non Linear Loads

Comparaison between ETAP and PowerApps for Voltages, SVC at Bus8				
	PowerApps		ETAP	
Bus Name	Vmag(V)	Ang(deg)	Vmag(V)	Ang(deg)
1	1.0400	0.000	1.0400	0.00
2	1.0450	0.1649	1.0450	9.30
3	1.0450	0.8063	1.0450	4.70
4	1.0736	-0.0386	1.0756	0.28
5	1.0556	-0.0695	1.0600	2.60
6	1.0726	-0.0643	1.0722	-2.63
7	1.0757	0.0638	1.0750	-3.37
8	1.0658	0.0116	1.0589	3.07
9	1.0723	0.0337	1.0712	-3.20

Results

A series of results obtained using PowerApps and ETAP software packaged are presented in tables 1 to 4.

Bus Voltages Using PowerApps and ETAP
Load Flow Using PowerApps and ETAP.

Table. 3. Load Flow with Linear Loads

Comparaison between PowerApps and ETAP for Load Flow					
From	To	PowerApps		ETAP	
Bus	Bus	MW	MVar	MW	Mvar
1	4	71.60	27	71.64	27.05
2	7	163	6.70	163	6.65
3	9	85	-10.90	85	-10.86
4	5	40.90	22.90	40.49	22.89
4	6	30.70	1.03	30.7	1.03
6	9	-59.50	-13.50	-59.46	-13.46
7	5	86.60	-8.40	86.62	-8.38
7	8	76.40	-0.80	76.38	-0.8
8	9	-24.10	-24.30	-24.1	-24.3
9	8	24.20	3.12	24.18	3.12

Table. 4. Load Flow with non Linear Loads

Comparaison between PowerApps and ETAP for Load Flow, **SVC** at bus8					
From	To	PowerApps		ETAP	
Bus	Bus	MW	MVar	MW	Mvar
1	4	71.62	27.82	71.64	27.85
2	7	163.1	6.80	163.2	6.85
3	9	85.1	-10.95	85	-10.99
4	5	40.95	22.94	40.90	22.97
4	6	30.72	1.07	30.7	1.07
6	9	-59.52	-13.70	-59.48	-13.76
7	5	86.61	-8.60	86.62	-8.68
7	8	76.43	-0.90	76.38	-0.93
8	9	-24.12	-24.50	-24.11	-24.56
9	8	24.23	3.18	24.20	3.20

Lines Active Power With and Without FACTS

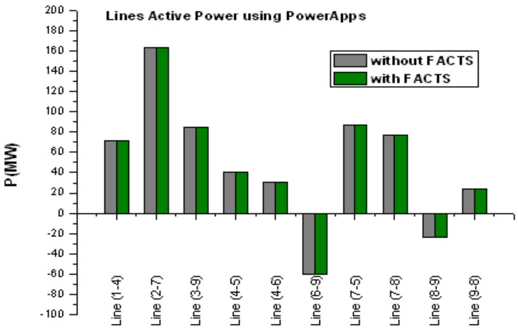

Fig.5. Lines Active Power with PowerApps

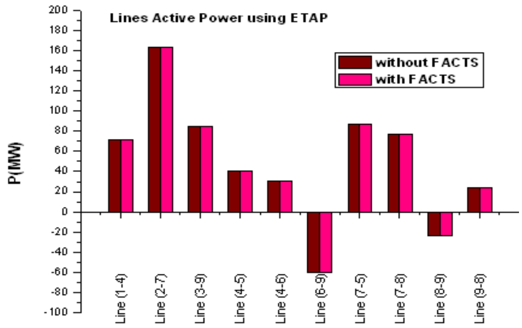

Fig.6. Lines Active Power with ETAP

Lines Reactive Power With and Without FACTS.

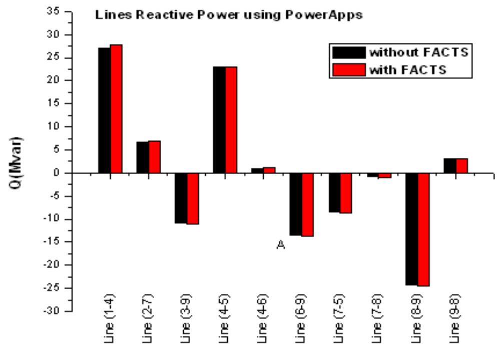

Fig.7. Lines Reactive Power with PowerApps

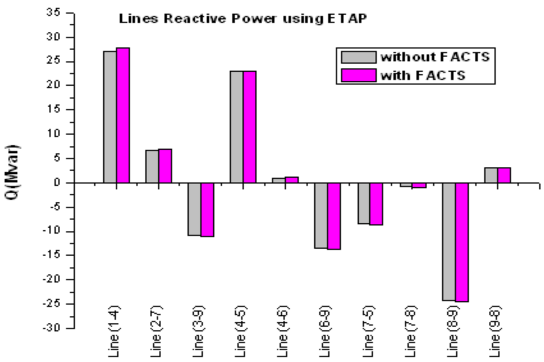

Fig.8. Lines Reactive Power with ETAP

Analysis of Results

If SVC is connected to bus 8, the aim of control is to increase the voltage in all buses of our system. Here the SVC injects the reactive power to bus 8 in order to keep the voltage magnitude at 1.0658 pu. Table 2 gives the voltage magnitude in pu for all buses of the system with SVC. The results obtained had shown the improvement of voltage magnitude in almost all buses as compared to the system without SVC (see Table 1).

We observe that for our Example (the network system IEEE 9 bus), in normal case (linear loads), and after calculated the power flow in nodes and lines by the software's PowerApps and ETAP, we obtain a value of 0.217MW for active power losses in the lines, and a value of 1,316 MVar for reactive power losses, by cons if you place a SVC in the node 8, the active power is increased slightly (see fig.5 and fig.6), but the reactive power has increased a significant way (see fig.7 and fig.8), which involved an increase of the losses of active power range by 1%, and increase of the losses of reactive power range by 3%,

Conclusion

In this paper, the power flow of the standard IEEE -9-bus test system with base case and SVC is studied.

FACTS device such as SVC is employed for enhancing voltage stability. The simulated results shown in Table 2 clearly shows the voltage magnitude of bus 8 which were identified as weakest buses with SVC are maintained and there is a voltage improvement in other buses of the test system also.

The results were almost consistent and show the influence of non linear loads on power losses in electrical networks. The losses of active power and reactive power increases due to reactive power injected by SVC.

The results have virtually the same appearance and overlap completely with those obtained with the PowerApps and ETAP, which shows the reliability of both software PowerApps and ETAP in the study of the power flow.

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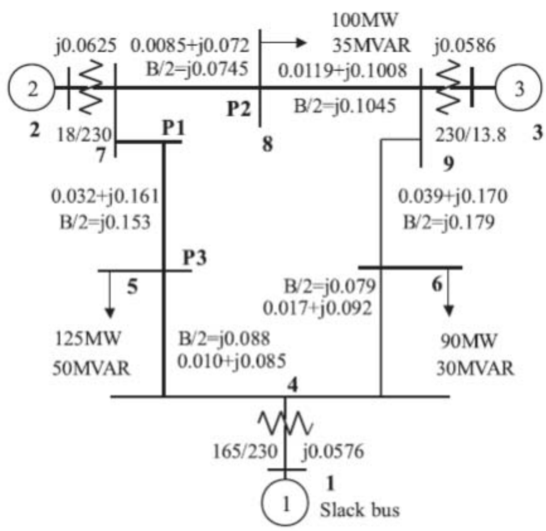
Appendix
9 Bus System Data Line Parameters:



Line	Resistance (pu)	Reactance (pu)	Susceptance (pu)
1-4	0.0000	0.0576	0.0000
4-5	0.0100	0.0850	0.1760
4-6	0.0170	0.0920	0.1580
5-7	0.0320	0.1610	0.3060
6-9	0.0390	0.1700	0.3580
2-7	0.0000	0.0625	0.0000
3-9	0.0000	0.0586	0.0000
7-8	0.0085	0.0720	0.0149
8-9	0.0119	0.1008	0.2090

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