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Güç Sisteminin Kararlılığını İyileştirecek FACTS Cihazlarının Bağlantı Noktalarının Belirlenmesi[1]

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Öz

Bu çalışmada, tristör kontrollü seri kompanzator (TSCS) ve statik var kompanzator (SVC) denetleyicilerinin güç sistemi gerilim kararlılığına olan etkileri incelenmiştir. Çalışmalar IEEE'nin 9 baralı test sistemi üzerinde simülasyon programları kullanılarak gerçekleştirilmiştir. Sürekli güç akışı analizi yöntemi kullanılarak TSCS ve SVC'nin gerilim çökmeleri üzerindeki etkileri incelenmiştir. Hatların kararlılık indeksi değerleri ve yük baralarına ait voltaj kararlılık indeksi değerleri hesaplanmıştır. Bu indeks değerlerine göre güç sistemi esnek alternatif akım cihazları iletim cihazları (FACTS) bağlantı noktaları belirlenmiştir. FACTS cihazları bağlandıktan sonra simülasyon programı ile yük akışı çalışmaları yapılmıştır. Yapılan çalışma ile elde edilen sonuçlara göre güç sisteminin kararlılık sınır değerlerini iyileştirmede ve aktif güç kayıplarını azaltmada FACTS cihazlarının önemli bir etkiye sahip olduğu görülmüştür.

Anahtar Kelimeler: Güç Sistemi, Gerilim Kararlılığı, FACTS Cihazlar, TSCS, SVC

Determination of Connection Locations of FACTS Devices to Improve Power System Stability

Abstract

In this study, thyristor controlled series compensators (TSCS) and static var compensator (SVC) effects on voltage stability of power systems were investigated. The studies were carried out on the IEEE 9 bus test system using simulation programs. TSCS and SVC effects on the voltage drops were examined with continuous power flow analysis method. Line stability index values and voltage stability index values of load busses were calculated. According to these values FACTS devices connection points of power system were determined. After connecting Facts devices, load flow analysis were made by simulation programs. According to the results obtained from studies in improving the stability limit of the power system and reduce active power loss has been shown to have a significant impact of FACTS devices.

Keywords: Power System, Voltage Stability, FACTS Devices, TSCS, SVC

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1. Introduction

Depending on the developing technology, electricity demands are also increasing day by day. The increase in energy demand forces power systems to work in regions close to the limits of stability. This situation leads to a reduction in stability limits so the importance of voltage stability has gained increasingly importance in recent years [1]. Voltage stability can be defined as ability to hold between certain limits of voltage amplitude values of load buses of a power system in all conditions [2]. Various method are used to avoid voltage collapses, which is the most important problem in voltage stability. It is possible to increase the voltage stability limits by performing series and parallel compensation on the transmission lines and transformer control with tap changer [3].

It is ensured that the voltage values in the load buses are kept at the desired level thanks to transformer tap changer control [4]. Transmission line serial reactance is compensated by serial compensation and in this way the maximum power limits of the transmission line can be increased. It is possible to keep the voltage values at the desired values by supplying and removing reactive power from the system.

As demand for electrical energy increase, power systems become more complicated as well. Classical methods used to prevent voltage instability and collapses on growing and complex systems sometimes they can not met the system needs [5]. Thanks to flexible alternating current transmission system (FACTS) devices, voltage problems in complex and growing systems are solved more quickly and effectively. Besides, when FACTS devices are used properly, ensures the best use of available resources by increasing the stability limits of power systems [6].

The power system operator will be to have reliable, secure and efficient operation. To solve this problem FAC TS device can be used in the weak buses of the power system. They can control the power flow at regular and aberrant condition and can reduce power system loss and improve voItage stability. Effect of FAC TS devices on security, loadability and reliability should be studied for proper control purpose [7].

In this study firstly, the voltages, active and reactive power values of each buses, and transmitted power values are obtained with the Power World simulation program to the example nine-bus power system. Then, using Matlab program and bus reduction method, line stability index and voltage stability index values were found. Thyristor-Controlled Series Compensation (TSCS) was connected to the weakest transmission line of the example nine bus transmission system according to line stability index values. And similarly Static Var Compensators (SVC) was connected to the weakest load bus of the example nine bus transmission system according to voltage stability index values. Voltage stability, active and reactive losses in this power system were analyzed using the Power World program under different scenarios. As a results, the FACTS devices connection points have been determined to improve the voltage stability and to minimize the active power losses [8].

2. Material and Method

2.1. FACTS Devices

FACTS devices which make up modern compensation methods, the use of these devices have gained great importance on account of response in a very short time, individual controllability of each phase, unbalanced loads can be compensated [9 and 10]. FACTS control responds faster than conventional controllers because of its power electronics base. These devices increase the stability limits of the transmission lines when properly used. FACTS have two main purposes. The first is to increase the power transfer capacities of the transmission systems and the second is to control the power flow on the transmission lines. At the same time FACTC devices are also used to ensure voltage stability [11].

Today, many power flow controllers have been developed under the name FACTS. The most common of these can be denoted as Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Compensator (STATCOM), Unified Power Flow Controller (UPFC), Phase Shifting Transformer (PST) and Static Synchronous Series Capacitor (SSSC)

2.2. Static Var Compensator

The main task of the SVC is provide capacitive or inductive current to the bus depending on the control datas [12]. SVC allows to control the system voltage within the specified limits with reactive power control. The most well-known forms are the constant capacity thyristor controlled reactor (TCR) and the thyristor controlled capacitor (TSC). The simple structure of the SVC for voltage control is shown in Figure 1.

Working principle of SVC is based on obtaining shunt impedance with variable values depending on the calculated triggering angles of capacitorss and / or reactors. With appropriate triggering, a wide range of reactive power settings can be made on the bus from the maximum capacitive reactive power value to the maximum inductive reactive power value [13]. The inductance value determine capacitive or inductive working status of the device. The value of inductance is determined by equation (1) [14].

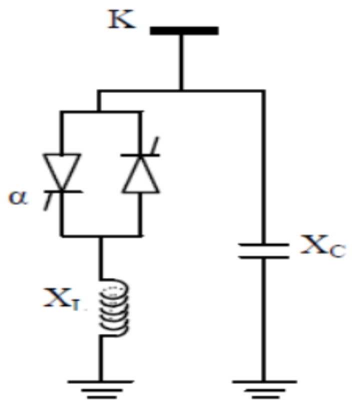

Figure 1. Basic Structure of SVC

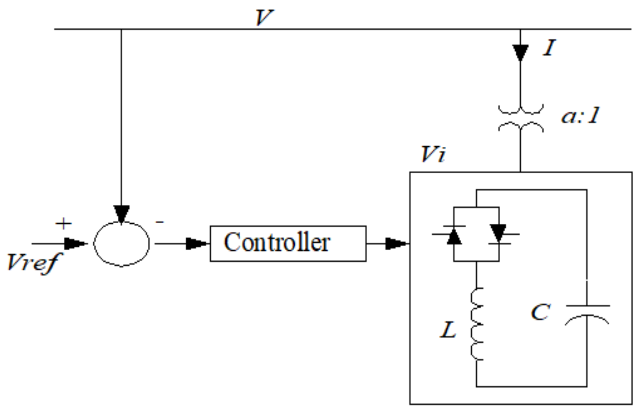

Figure 2. Schematic Model of SVC

$$X_V = X_L \frac{\pi}{2(\pi - \alpha) + \sin 2\alpha} \quad (1)$$

In Equation 1, XL express the uncontrolled fundamental inductive reactance of the thyristor and α express the trigger angle [15 and 16]. The total impedance of the controller is found by Equation (2).

$$X_e = X_C \frac{\pi / r_x}{\sin 2\alpha - 2\alpha + \pi(2 - \frac{1}{r_x})} \quad (2)$$

In Equation 2, rx = Xc / XL gives the limits of the triggering angles and the limit values of the controllers, Xc is the capacitive reactance. The output power of the SVC is determined by the Equation (3). V is the voltage of the transmission line in equation 3,

$$Q_c = \frac{V^2}{X_v} - \frac{V^2}{X_c} \quad (3)$$

The voltage control characteristic of the SVC under continuous operation is also shown in Figure 3 [17]. V_{ref} shows the voltage value under normal load condition, I_{max} indicates availability of all capacities, I_{min} indicates that all capacities are deactivated. Depending on these, it is ensured that the current supplied to the system is inductive or capacitive. In this system the SVC controls the power system to which it is connected by acting as an adjustable reactive power source.

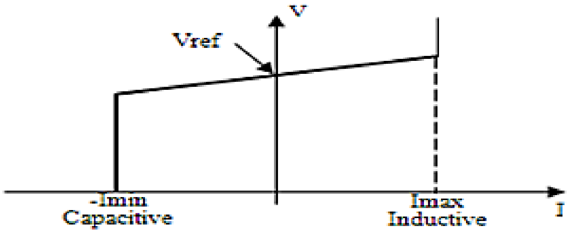

Figure 3. Typical Steady State V–I Characteristic of a SVC.

2.3. Thyristor Controlled Series Capacitor

TCSC is a typical serial FACTS device. TCSC configuration was shown in Figüre 4. TCSC uses a fixed capacitor (CF), thyristor controlled reactors (TCR) and a capacitor (C) connected in shunt with them [18]. The reactance can change smoothly and quickly with the control of the triggering angles of the thyristors. TCSC can directly regulate power flow and allow system to work closer to line limit values. It can improve the dynamic performance and stability of the power system due to its fast and flexible ability. The X-I characteristic of the TCSC was shown in Figure 5. For stability and damping control, the TCSC usually operates in the capacitive region. This situation was shown in Figure5 ABC field [19-21].

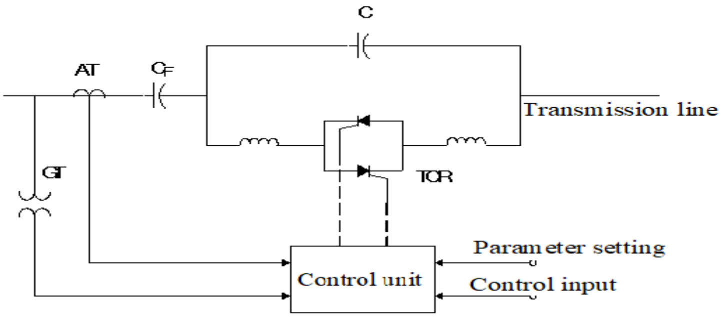

Figure 4. Modeling Circular of TCSC.

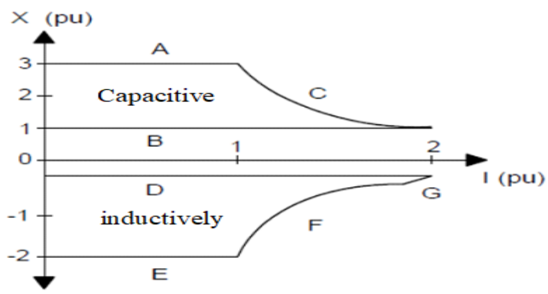

Figure 5. X-I Characteristic of TCSC.

In the Figure 5, A and E firing angle limit, B the situation where the thyristors are blocked, C maximum voltage limit, D thyristors are in full transmission region, F harmonic heating limiti, G Thyristor current limit (max.) are express respectively.

3. Results

3.1. System Simülations and Results

Based on the proposed cogeneration price function and the avoided costs concerning the loss and upgrade of transmission lines, computer simulations are conducted. Details are given in the following.

3.2. System Description and Methodology

To illustrate the correctness and practicality of the proposed price function, computer simulations for an IEEE-9 bus system shown in figure 6 are given. The system bus data and line parameters are listed in tables 1 and 2, respectively.

Table 1. Bus Data (base case) Base=100 MVA

Bus no.	Pg (PU)	Qg (PU)	PL (PU)	QL (PU)	Bus type
1	Swing	Swing	0.00	0.00	1
2	1.63	0.00	0.00	0.00	2
3	0.85	0.00	0.00	0.00	2
4	0.00	0.00	0.00	0.00	3
5	0.00	0.00	0.90	0.30	3
6	0.00	0.00	0.00	0.00	3
7	0.00	0.00	1.00	0.35	3
8	0.00	0.00	0.00	0.00	3
9	0.00	0.00	1.25	0.50	3

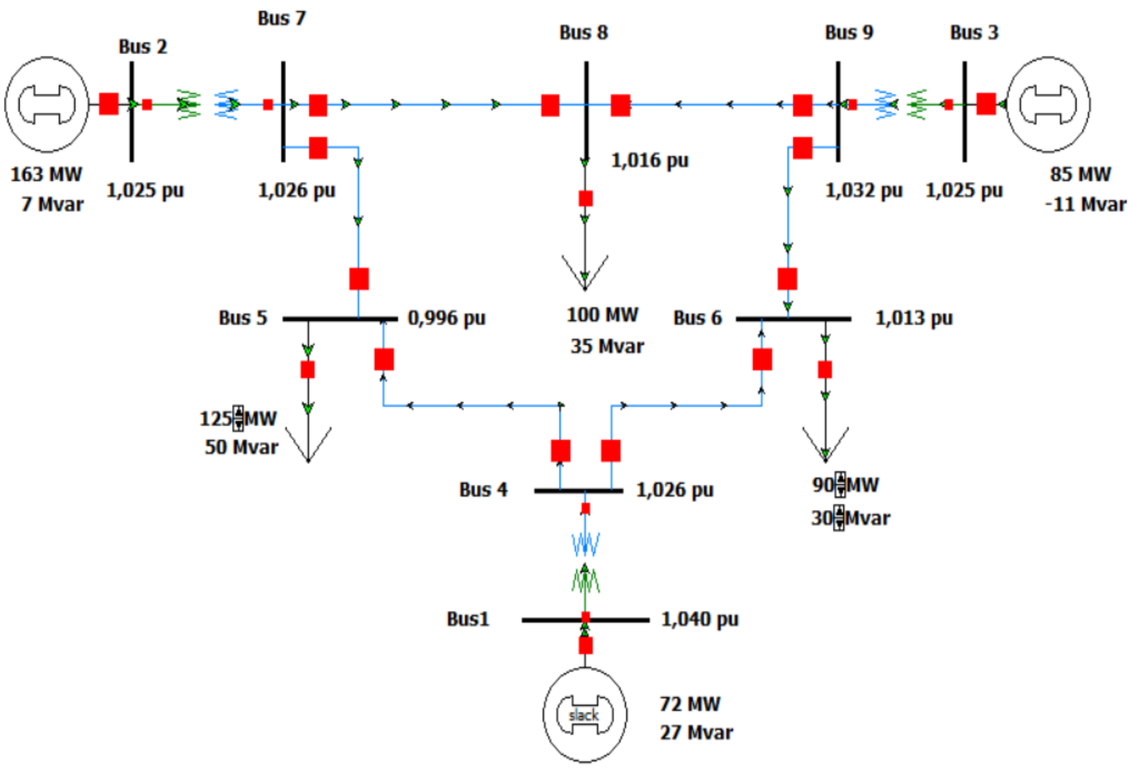

Figure 6. IEEE 9 Bus Model in Power World Simulator

Figure 6 to system with 9 buses and 3 generators. This particular test case also includes 3 two-winding transformers, 6 lines and 3 loads. The base kV levels are 13.8 kV, 16.5 kV, 18 kV, and 230 kV. The single-line diagram of the 9-bus case is shown below [22].

Table 2. Transmission Line Data 9 Bus System

Line no.	From bus	To bus	R	X	B
1	4	1	0.0000	0.0576	0.0000
2	2	7	0.0000	0.0625	0.0000
3	9	3	0.0000	0.0586	0.0000
4	5	4	0.0100	0.0850	0.1760
5	6	4	0.0170	0.0920	0.1580
6	7	5	0.0320	0.1610	0.3060
7	9	6	0.0390	0.1700	0.3580
8	7	8	0.0085	0.0720	0.1490
9	8	9	0.0119	0.1008	0.2090

Power flow analysis is called the backbone of power system analysis. Transient stability analysis of system fault analysis and its improvement is one of the basic problems in power system engineering. The single line diagram of IEEE 9 bus model is shown in figure 6.

Table 3. Bus Data of IEEE 9 Bus Test System

Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	16.5	1.04000	17.160	-0.00			71.63	27.02
2	18	1.02501	18.450	9.28			163.00	6.57
3	13.8	1.02501	14.145	4.67			85.00	-10.91
4	230	1.02580	235.935	-2.22				
5	230	0.99566	229.003	-3.99	125	50		
6	230	1.01268	232.916	-3.69	90	30		
7	230	1.02583	236.941	3.72				
8	230	1.01597	233.673	0.73	100	35		
9	230	1.03239	237.449	1.97				

Table 4. Power Flow List of IEEE 9 Bus Test System

From Bus	To Bus	Branch Device Type	MW From	Mvar From	MVA From	MW Loss	Mvar Loss
4	1	Transformer	-71.6	-23.9	75.5	0.0	3.12
2	7	Transformer	163.0	6.6	163.1	0.0	15.83
9	3	Transformer	-85.0	15.0	86.3	0.0	4.10
5	4	Line	-40.7	-38.7	56.1	0.26	-15.80
6	4	Line	-30.5	-16.5	34.7	0.17	-15.51
7	5	Line	86.6	-8.4	87.0	2.30	-19.69
9	6	Line	60.8	-18.1	63.5	1.35	-31.53
7	8	Line	76.4	-0.8	76.4	0.48	-11.51
8	9	Line	-24.1	-24.2	34.2	0.09	-21.18

3.3. Voltage and Line Stability Indexes of the Nine-Bus Test System

Active power loss values that obtained by power flow analysis for IEEE 9 bus test system are given in table 5. Power System Analysis Toolbox (PSAT) simulation program was used in analyzes. According to these values, the serial TSCS was connected to the transmission line with the most power losses (Between 7 and 5 buses) so that transmission line losses were minimized. In the case of using the PSAT program, a graph of the bus voltage values was obtained by continuous power flow analysis for the IEEE 9 Bus Test System. Voltage values were shown in figure 7. Due to the low voltage of the 5th bus, the SVC was connected to the 5th bus to increase and control the voltage values. SVC was selected between 2 and 15 MVAr power values.

Table 5. Power Losses IEEE 9 Bus Test System

From Bus	To Bus	Line	P Loss
9	8	1	0,00088
7	8	2	0,004753
9	6	3	0,013538
7	**5**	**4**	**0,023**
5	4	5	0,002575
6	4	6	0,001664
2	7	7	2,22E-16
3	9	8	0
1	4	9	0

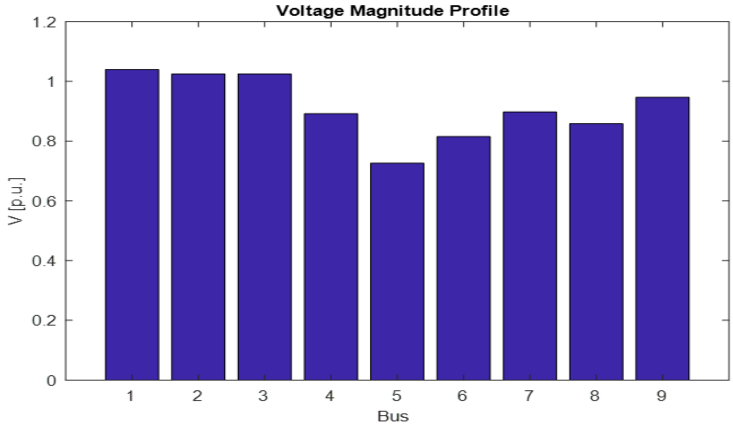

Figure 7. IEEE 9 Bus PSAT Simulator Voltage Values

3.4. Bus Voltage Values, After Placing The FACTS Devices On The 9 Bus Test System

Table 6. Bus Voltage Values , After TSCS

Bus No	%20		%40		%60		%80	
	Before placing the FACTS device	After placing the FACTS device	Before placing the FACTS device	After placing the FACTS device	Before placing the FACTS device	After placing the FACTS device	Before placing the FACTS device	After placing the FACTS device
1	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
2	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025
3	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025
4	1.0258	1.0246	1.0258	1.0262	1.0258	1.028	1.0258	1.03
5	0.99563	0.99316	0.99563	0.99702	0.99563	1.0014	0.99563	1.0063
6	1.0127	1.0109	1.0127	1.0124	1.0127	1.014	1.0127	1.0156
7	1.0258	1.0117	1.0258	1.0117	1.0258	1.0117	1.0258	1.0118
8	1.0159	1.006	1.0159	1.0062	1.0159	1.0063	1.0159	1.0065
9	1.0324	1.029	1.0324	1.0292	1.0324	1.0295	1.0324	1.0297
Real Power Losses [p.u.]	**0,04641**	**0,022027**	**0,04641**	**0,019891**	**0,04641**	**0,017996**	**0,04641**	**0,016471**
Reactive Power Losses [p.u.]	**-0,9216**	**-0,61061**	**-0,9216**	**-0,6438**	**-0,9216**	**-0,68036**	**-0,9216**	**-0,72076**

The TSCS was connected to the transmission line serially between bus number 5 and 4. So, the transmission line reactance becomes controllable between 20 % and 80 %. The results were given in table 6. According to the results, active and reactive power losses have been reduced and it has been understood that it has a positive effect on the stability of voltage.

Table 7. Bus Voltage Values, After Placing The SVCs On The 9 Bus Test System

Bus No	Before placing the FACTS device	SVC is worth 2 Mar	SVC is worth 4 Mar	SVC is worth 5 Mar	SVC is worth 8 Mar	SVC is worth 10 Mar	SVC is worth 15 Mar
1	1.04	1.04	1,04000	1,04000	1,04000	1,04000	1,04000
2	1.025	1.025	1,02500	1,02500	1,02500	1,02500	1,02500
3	1.025	1.025	1,02500	1,02500	1,02500	1,02500	1,02500
4	1.0258	1,02646	1,02714	1,02748	1,02851	1,02919	1,03092
5	0.99563	0,99743	0,99924	1,00015	1,00287	1,00470	1,00929
6	1.0127	1,01319	1,01373	1,01400	1,01481	1,01535	1,01671
7	1.0258	1,02622	1,02667	1,02689	1,02757	1,02802	1,02917
8	1.0159	1,01624	1,01660	1,01678	1,01732	1,01768	1,01859
9	1.0324	1,03256	1,03276	1,03286	1,03317	1,03338	1,03390
Real Power Losses [p.u.]	**0,04641**	**0,046**	**0,046**	**0,046**	**0,046**	**0,046**	**0,045**
Reactive Power Losses [p.u.]	**-0,9216**	**-0,925**	**-0,928**	**-0,93**	**-0,934**	**-0,937**	**-0,945**

SVC with different values between 2 MVAr and 15 MVAr was connected to number of 5 in the IEEE 9 bus test system. The results obtained were given in table 7. According to the results, active power losses have been reduced and it has been understood that it has a positive effect on the stability of voltage.

3.5. Both SVC and TSCS Connection Status For IEEE 9 Bus Test System

Table 8. Bus Voltage Values, In Case of 20% Serial Compensation (TSCS) and SVC Connected Together

Bus Number	Before placing the FACTS device	SVC 5 MVAr	SVC 10 MVAr	SVC 15 MVAr
1	1.04	1,04000	1,04000	1,04000
2	1.025	1,02500	1,02500	1,02500
3	1.025	1,02500	1,02500	1,02500
4	1.0258	1,02798	1,02958	1,03118
5	0.99563	1,00092	1,00515	1,00942
6	1.0127	1,01473	1,01601	1,01729
7	1.0258	1,02768	1,02890	1,03014
8	1.0159	1,01742	1,01838	1,01934
9	1.0324	1,03314	1,03366	1,03419
Real Power Losses [p.u.]	**0,04641**	**0,046**	**0,046**	**0,046**
Reactive Power Losses [p.u.]	**-0,9216**	**-0,956**	**-0,964**	**-0,97**

Table 9. Bus Voltage Values, In Case of 40% Serial Compensation (TSCS) and SVC Connected Together

Bus Number	Before placing the FACTS device	SVC 5 MVAr	SVC 10 MVAr	SVC 15 MVAr
1	1.04	1,04000	1,04000	1,04000
2	1.025	1,02500	1,02500	1,02500

3	1.025	1,02500	1,02500	1,02500
4	1.0258	1,02839	1,02985	1,03132
5	0.99563	1,00146	1,00531	1,00920
6	1.0127	1,01541	1,01659	1,01778
7	1.0258	1,02868	1,03002	1,03136
8	1.0159	1,01818	1,01921	1,02024
9	1.0324	1,03343	1,03395	1,03448
Real Power Losses [p.u.]	**0,04641**	**0,047**	**0,047**	**0,046**
Reactive Power Losses [p.u.]	**-0,9216**	**-0,985**	**-0,992**	**-0,998**

Table 10. Bus Voltage Values, In Case of 60% Serial Compensation (TSCS) and SVC Connected Together

Bus Number	Before placing the FACTS device	SVC 5 MVAr	SVC 10 MVAr	SVC 15 MVAr
1	1.04	1,04000	1,04000	1,04000
2	1.025	1,02500	1,02500	1,02500
3	1.025	1,02500	1,02500	1,02500
4	1.0258	1,02866	1,02994	1,03123
5	0.99563	1,00160	1,00498	1,00838
6	1.0127	1,01597	1,01704	1,01811
7	1.0258	1,02999	1,03146	1,03294
8	1.0159	1,01912	1,02023	1,02134
9	1.0324	1,03372	1,03425	1,03478
Real Power Losses [p.u.]	**0,04641**	**0,048**	**0,048**	**0,048**
Reactive Power Losses [p.u.]	**-0,9216**	**-1,017**	**-1,012**	**-1,028**

Table 11. Bus Voltage Values, In Case of 80% Serial Compensation (TSCS) and SVC Connected Together

Bus Number	Before placing the FACTS device	SVC 5 MVAr	SVC 10 MVAr	SVC 15 MVAr
1	1.04	1,04000	1,04000	1,04000
2	1.025	1,02500	1,02500	1,02500
3	1.025	1,02500	1,0250	1,02500
4	1.0258	1,02865	1,02972	1,03079
5	0.99563	1,00105	1,00383	1,00662
6	1.0127	1,01634	1,01726	1,01818
7	1.0258	1,03172	1,03336	1,03501
8	1.0159	1,02029	1,02150	1,02272
9	1.0324	1,03401	1,03455	1,03509
Real Power Losses [p.u.]	**0,04641**	**0,051**	**0,05**	**0,05**
Reactive Power Losses [p.u.]	**-0,9216**	**-1,05**	**-1,055**	**-1,06**

In case of TSCS and SVC connected together for IEEE 9 bus test system, the results were given in table 8-11. SVCs with different power ratings, such as 5 MVAr, 10 MVAr, and 15 MVAr and TSCS rates from 20% to 80%. According to the obtained results, If the SVC is 5 MVAr and TSCS is 20%, the power system can operate most stable, active and reactive power provides the best power transfer. As a result, by connecting the SVC and the TSCS to the connection points determined in the system, it is possible to provide much more stable operation of the system.

4. Discussion and Conclusion

SVC was connected to number of 5 in the IEEE 9 bus test system and also the TSCS was connected to the transmission line serially between bus number 4 and 5. In this case, Active Power, Reactive Power and Angle values result were given in table 12. According to these values, If 80 % TSCS and SVC with 15 MVAr are connected to the system, voltage stability and power transfer will be positively affected, both voltage stability and power transfer will be improved.

Table 12. Power Losses Before and After Inserting FACTS Devices

	Ploss	Qloss
Before placing the FACTS device	0.046	-0.0922
20% TSCS	0,047	-0,949
40% TSCS	0,047	-0,978
60% TSCS	0,049	-1,01
80% TSCS	0,051	-1,045
TSCS and SVC are connected together	0,045	-0,93

In this study, the effects of the transistor controlled series compensator (TSCS) and the static var compensator (SVC) controllers on the power system voltage stability were investigated. The studies have been done on the IEEE 9 bus test system. The effects of TSCS and SVC on voltage collapses were investigated using the continuous power flow analysis method. The stability index values of the lines and the voltage stability index values of the load buses were calculated. According to the results obtained by the study, it is seen that the FACTS devices have a significant effects on improving the stability limits of the power system and reducing active power losses.

The power loss values before and after placing FACTS devices were given in table 12. As a result, the points to connect the FACTS devices to improve the stability of the system have been determined. Thanks to the FACTS devices, significant improvement have been achieved for power transfer and voltage stability.

References

[1] Taylor, W., "Power System Voltage Stability", McGraw-Hill, New York, 1994.

[2] Yalçın, M.A. "Enerji Sistemlerinde Gerilim Kararlılığının Yeni Bir Yaklaşımla İncelenmesi", *Doktora Tezi*, İTÜ Elektrik-Elektronik Fakültesi, İstanbul,1995.

[3] Dirik, H. "STATCOM ve SSSC Denetleyicilerinin Güç Sistemi Gerilim Kararlılığı Üzerine Etkisinin İncelenmesi". *Yüksek Lisans Tezi,* Ondokuz Mayıs Üniversitesi, Samsun, Türkiye, 2006.

[4] Balanathan, R., "Techniques to efficiently improve power system voltage stability", *Doctor thesis*, The university of Auckland, New Zealand, 1998.

[5] Gümüş, T.E., and Yalçın, M.A., "Facts cihazlarının gerilim kararlılığına etkisinin İncelenmesi", SAÜ. *Fen Bil. Der.* 17. Cilt, 2. Sayı, s.1-6, 2013.

[6] Mithulananthan, N., Sode -Yome, A., and Acharya, N., "Application of FACTS Controllers in Thailand Power Systems, School of Environment", *Resources and Development Asian Institute of Technology*, Thailan, 2005.

[7] Hemasekhar, A., Lakshmi Devi, Dr. "Enhancement of Voltage Profile and Reduce Power System Losses by Using FACTS Devices, " *International Journal of Conceptions on Electrical and Electronics Engineering*. 2(1), pp.42-46, April 2014.

[8] ÖZTÜRK, A., BOZALİ, B., Tosun, S., "Güç Sistemi Kararlılığını İyileştirecek Facts Cihazlarının Bağlantı Noktalarının Belirlenmesi", *Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 4 (2016) 812-825.*

[9] TMMOB, “TMMOB Reaktif Güç Kompanzasyonu Seminer Notları”, İstanbul EMO, 1999.

[10] Bayram, M., “Reaktif Güç Kompanzasyonu”, *ENTES,* İstanbul, 1997.

[11] Hasanovic, A., “Modeling and Control of The Unified Power Flow Controller (UPFC)”, MA Thesis, West Virginia Uni., 2000.

[12] IEEE FACTS working group 15.05.15, “FACTS Application”, December 1995.

[13] Arifoğlu, U., “Güç Sistemlerinin Bilgisayar Destekli Analizi”, *Alfa Yayınları*, İstanbul, 2002.

[14] Canizares, C.A., Zeno T.F., “Analysis of SVC and TCSC Controllers in Voltage Collapse”, *IEEE Transactions on Power Systems*, Vol. 14, No. 1., 1999.

[15] Canlzares, C.A., Faur, Z.T., “Analysis SVC and TCSC Controllers in Voltage Collapse”, *IEEE Transactions on the power systems*, vol. 14, No. 1, February 1999, pp. 158-165.

[16] Talebi, N., Ehsan, M., Bathaee, S.M.T., “Effects of SVC and TCSC Control Strategies on Static Voltage Collapse Phenomena”, *IEEE Proceedings*, Southeast Con, pp. 161 - 168, Mar., 2004.

[17] Canizares, C.A., “Power Flow and Transient Stability Models of FACTS Controllers for Voltage and Angle Stability Studies”. *In Proc. of IEEE/PES Winter Meeting, Singapore*, January 2000.

[18] Tiwari, P.K., Sood, Y.R., “Optimal Location Of Facts Devices İn Power System Using Genetic Algorithm”, *Nature & Biologically İnspired Computing*, Nabic 2009. World Congress On, Pages: 1034 – 1040, 2009.

[19] Larsen, E., Clark V., Miske K., Urbanek S., A., “Characteristics and rating considerations of thyristor-controlled series compensation”, *IEEE/PES Summer meeting*, paper no 93 SM 433-3 PWRD, Vancouver Canada, july 18-22., 1993.

[20] Bowler, C., Larsen, E., Damsky, B., Nilsson, S., “Benefits of thyristor-controlled series compensation”, *CIGRE,* paper No. 14/37/38-04, 1992.

[21] Medina, A., Ramos-Paz, A., Fuerte-Esquivel, C.R., “Swift computation of the periodic steady state solution of power systems containing tcscs”, *Elsevier*, Electrical Power and Energy Systems 25, 689–694, 2003.

[22] Anderson, P. M., and Fouad, A. A., “Power System Control and Stability”, *2nd ed. New York: IEEE*, 2003 Press,

Uzun özet

Gerilim kararlılığında en önemli problem olan gerilim çökmelerinin önüne geçebilmek için çeşitli yöntemler kullanılmaktadır. Kademe değiştiricili trafo denetimi, hızlı arıza temizleme iletim hatlarına seri ve paralel kompanzasyon yapılarak gerilim kararlılığı sınırlarını arttırmak mümkündür. Kademe dönüştürme oranları sayesinde yük baralarındaki gerilimi istenilen seviyede tutmaya imkân sağlar. İletim hatlarına seri kompanzasyon yapılarak hattın seri reaktansı kompanze edilir ve bu sayede hattın taşıyabileceği maksimum güç sınırları arttırılabilir. İletim hattına seri kompanzasyon yapılarak sisteme reaktif güç verilmesi sistemden reaktif güç çekilmesi ile gerilim değeri istenilen değerde tutmak mümkündür.

Elektrik enerjisine olan talep arttıkça güç sistemleri de büyüyerek karmaşık hale gelmektedir. Büyüyen ve karmaşıklaşan sistemlerde gerilim kararsızlığı ve çökmelerini önlemek için kullanılan klasik yöntemler bazen sistem ihtiyaçlarını karşılayamamaktadır. Günümüzde gelişen güç elektroniği elemanları tabanlı FACTS cihazları sayesinde karmaşıklaşan ve büyüyen sistemlerin gerilim problemleri daha hızlı ve etkin şekilde çözülmektedir. Bunun yanı sıra

FACTS cihazları uygun olarak kullanıldıkları zaman güç sistemlerinin kararlılık sınırlarını arttırarak mevcut kaynakların en iyi şekilde kullanılmasını sağlamaktadır.

Bu çalışmada PSAT programı kullanılarak hatların kararlılık indeksi değerleri güç akışı yapılarak elde edilen güç kayıpları tablolar halinde verilmiştir. Bu değerlere göre güç kaybı 0.023 pu ile en fala olan (7-5 baralar arası) iletim hattına sistemin kararlılığını ve kayıpları minimum yapmak için %20 ile %80 artan değerlerde seri TSCS bağlanmıştır. IEEE 9 baralı sistemi PSAT ortamında güç akışı ve sürekli yük akışı yapılarak bara voltaj değerlerin grafiği elde edilmiştir. Bu değerlere göre 5 nolu bara gerilim düşük olduğundan gerilimi yükseltmek için baraya paralel olarak SVC bağlanmıştır. 5 nolu bara sistemin kararlılığını ve kayıpları minimum yapmak için 2 Mar-15 Mar değerleri arasında değer verilerek SVC bağlanmış ve en iyi farklı senaryolar altında FACTS cihazlarının bağlantı noktaları belirlenmiştir.

7-5 baralar arası iletim hattına seri olarak %20 ile %80 artan değerlerde TSCS bağlayarak elde edilen sonuçlar yukarıda tablo halinde verilmiş olup, sonuçlara göre güç acısından aktif güç kayıplarını azalırken, reaktif güç kayıplarını TSCS bağlanmadan önceki değerlere göre azaldığı görülmüş ve gerilim kararlılığına da olumlu etkisi olduğu anlaşılmıştır. Beş nolu baraya 2 Mar ile 15 Mar arasında farklı değerler verilerek SVC bağlanmıştır. Elde edilen sonuçlar yukarıda tabloda verilmiştir. Sonuçlara göre güç acısından SVC aktif güç kayıplarını azaltmış, aşırı kompanzasyon üzerine ve gerilim kararlılığına olumlu etkisi olduğu anlaşılmıştır.

5 Mar ile 15 Mar arasın da farklı değerlerde beş nolu baraya SVC ve %20 ile %80 arasın da farklı yük değerlerinde 7-5 nolu baralar arası iletim hattına seri TSCS birlikte IEEE 9 baralı sisteme tek tek veriler uygulayarak sonuçları elde edilmiştir. Elde edilen sonuçlara göre, SVC 5 Mar değerinde ve TSCS %20 reaktif güç yük değerinde sistem en kararlı çalıştığı, aktif güç kayıp değeri 0.046 pu ve reaktif güç kayıp değeri -0.956 pu değerleri ile minimum olduğu en iyi güç transferi sağlandığı anlaşılmıştır.

FACTS cihazları bağlamadan önce aktif güç kaybı 0.046 pu ve reaktif güç kaybı-0.0922 pu dir. %20'lik TSCS sisteme bağlandığında aktif güç kaybı 0.047 pu ve reaktif güç kaybı -0.949 pu olarak elde ediliyor. %40'lik TSCS sisteme bağlandığında aktif güç kaybı 0.047 pu ve reaktif güç kaybı -0.978 pu olarak elde ediliyor. %60'lik TSCS sisteme bağlandığında aktif güç kaybı 0.049 pu ve reaktif güç kaybı -1.01 pu olarak elde ediliyor. %80'lik TSCS sisteme bağlandığında aktif güç kaybı 0.051 pu ve reaktif güç kaybı -1.045 pu olarak elde ediliyor. Sisteme hem TSCS ve hem de SVC birlikte bağlandığında aktif güç kaybı 0.045 pu ve reaktif güç kaybı -0.93 pu olarak elde ediliyor. Sonuçlara incelendiğinde sisteme hem TSCS ve SVC bağlandığında aktif güç kaybı en düşük ve reaktif güç kabı en düşük seviyededir. Sistemde belirlenen bağlantı noktalarının SVC ve TSCS bağlayarak, siteme endüktif ve kapasitif enerji vererek sistemin çok daha kararlı çalışması sağlanmıştır.

Bu çalışmada, tristör kontrollü seri kompanzatör (TSCS) ve statik var kompanzator (SVC) denetleyicilerinin güç sistemi gerilim kararlılığına olan etkileri incelenmiştir. İncelemeler IEEE 9 baralı sistem üzerinde yapılmıştır. Sürekli güç akışı analizi yöntemi kullanılarak TSCS ve SVC'nin gerilim çökmeleri üzerindeki etkileri incelenmiştir. Hatların kararlılık indeksi değerleri ve yük baralarına ait voltaj kararlılık indeksi değerleri hesaplanmıştır. Bu index değerlerine göre güç sistemi esnek alternatif akım cihazları iletim cihazları (FACTS) bağlantı noktaları belirlenmiştir. Yapılan çalışma ile elde edilen sonuçlara göre güç sisteminin kararlılık sınır değerlerini iyileştirmede ve aktif güç kayıplarını azaltmada FACTS cihazlarının önemli bir etkiye sahip olduğu görülmüştür.

Sonuç olarak sistemin kararlılığının iyileştirilecek FACTS cihazlarının bağlanacağı noktalar belirlenmiştir. Sistem kararsızlaştığında sisteme beş nolu yük barasına SVC ve dört nolu iletim hattına TSCS bağlanmıştır. Farklı yük ve güç değerleri denenmesi sayesinde sistemin endüktif veya kapasitif enerji vererek dokuz baralı iletim sistemin çok daha kararlı, gerilim kararlılığını ve güç transferini olumlu çalışacak değerler ve gerilim kararlılığı hem de güç transferi iyileştirecek bağlandı noktaları elde edilmiştir.