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Analysis of Marmara Region Electrical Power System Stability under the Critical Fault Conditions

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Abstract. Electrical power systems are such nonlinear systems that the ever changing working environments. Generator outputs, loads and the electrical power system parameters are continuously changing. In recent years, because of economic and environmental conditions, electrical power systems have been forced to work nearly maximum load capacity with the most efficient operating conditions. Accordingly, also, power flow and critical fault conditions analysis is a significant criterion for operation of electrical power systems. Modern power systems are planned for high level, multi-variable dynamic systems. In this study, 16 busbar section from 118 busbar interconnected 420 and 170 kV Marmara region electrical power system transmission lines are discussed. Electrical power system stability is investigated under the critical fault conditions. Power flow and critical fault condition analysis of newly installed transmission lines, additional power transformers and power generating units possibly installed in coming future was performed. Power flow and fault analysis of mentioned electrical power system are solved by using the Power System Analysis Toolbox 2.1.9 (PSAT) software

Keywords: Critical Fault Condition, Electrical Power System Stability, PSAT

1. Introduction

Electrical energy is the most widely used type of energy and it is very valuable. But electrical energy is most expensive type of energy. Energy power system planners must make all kinds of researches and developments such as minimum cost, consumption and savings analyses. Electrical power systems are nonlinear systems that have ever-changing working environments. Loads, generator outputs and the system parameters are continuously changing.

In recent years, economic and environmental conditions have forced electrical power systems to work close to the border points of the most efficient operating conditions. Accordingly, analysis of electrical power systems is an important criterion for operation. Modern electrical power systems are planned high level and multi variable dynamic systems. In general, the distortions in the electrical power system parameters are triggered by different characteristics of system components [1]. Owing to ease of use, easily conversion of other types of energy and widespread use in daily life electric energy consumption has increased from year to year, and today the most important indicator for development level of countries is electrical energy consumption rates. The most appropriate way to meet these growing demands is possible with future planning schemes [2]. For this reason, application of power flow analysis has become more important in electrical power systems.

System optimal operating points are determined by power flow method, and then parameters extracted from mentioned solution method consisted voltage magnitude and voltage angles of the busbar except the swing busbar. Following, active – reactive powers delivered in transmission lines and loss of transmission lines are calculated.

Optimal power flow analysis satisfies such a load capacity scheme that minimizing system installation costs in power generating units, and by the same time the amplitudes and angles of all the bus voltages and reactive power calculations are successes. Design and operation of a power system is a very complex problem [3]. As a result of advances in computer technology, many simulation software packages have been created for power system analysis. The most general and reliable algorithm to solve the power flow problem is Newton-Raphson method [4, 5].

In Newton-Raphson method, the basic principle of the load flow problem is solving the voltage of the busbar with generators and power system installation using the system loads given into non-linear equations. Load flow methods make calculation of the maximum loading point easy and also all the PV curve is drawn by Newton-Raphson method. PV curve is usually used as an aid for electrical power system planning and analysis.
Increased load models under conditions of high voltage borders are difficult to predict. Mostly this can be estimated by using these curves. Almost all load flow methods are based on the prediction approach. In this case, the load demand during the power systems maximum loading point, the power system is meant to reach a balanced point of voltage limit. Under normal circumstances, load flow equations have possible two solutions and one of them gives operational point of electrical power system [6, 7].
In this study, 16 buses section from 118 buses interconnected 420 and 170 kV Marmara region electrical power transmission lines are discussed. Additionally, power flow and critical fault condition analysis of newly installed transmission lines, additional transformers and generating power units possibly installed in coming future was performed.
Power flow and critical fault condition analysis of mentioned electrical power system are solved by using the PSAT 2.1.9 software [8]. This study consists of four chapters and appendices. In the first section, the subject of paper introduced in general and some studies relative with the subject are presented. In the second section, Marmara region electrical power system briefly introduced. In the third section implementing PSAT 2.1.9 software programs in Marmara region electrical power system is described and data network, optimal load flow analysis was conducted with three steps critical fault condition analysis.
These steps include outage of shunt capacitor unit analysis, outage of series capacitor unit analysis, and inline of critical short circuit analysis. The fourth section is conclusion part of this study. This section summarizes effects of Marmara region electrical power system stability under the critical fault condition analysis on power transmission lines.

2. Description of the Marmara Region Electrical Power System

Marmara region electrical power system is required to ensure continuous operation of production-consumption balance. This is a central control and direction system to ensure mentioned power balance. In very large power systems, system areas are divided into more than one region and these divided substations are controlled under their local centers. One of the power system regions in Turkey electrical transmission network is the Marmara region electrical power transmission network. Production and consumption balance must be kept continuously in interconnected system operating. It is possible to keep this balance thereby controlling from one center. For very big systems, these zones are controlled from their own centers thereby dividing the system as zones more than one. Marmara region electrical power transmission zone is one of zones in Turkey. Reduced 16 buses section from Marmara region electrical power system map is given in figure 1.

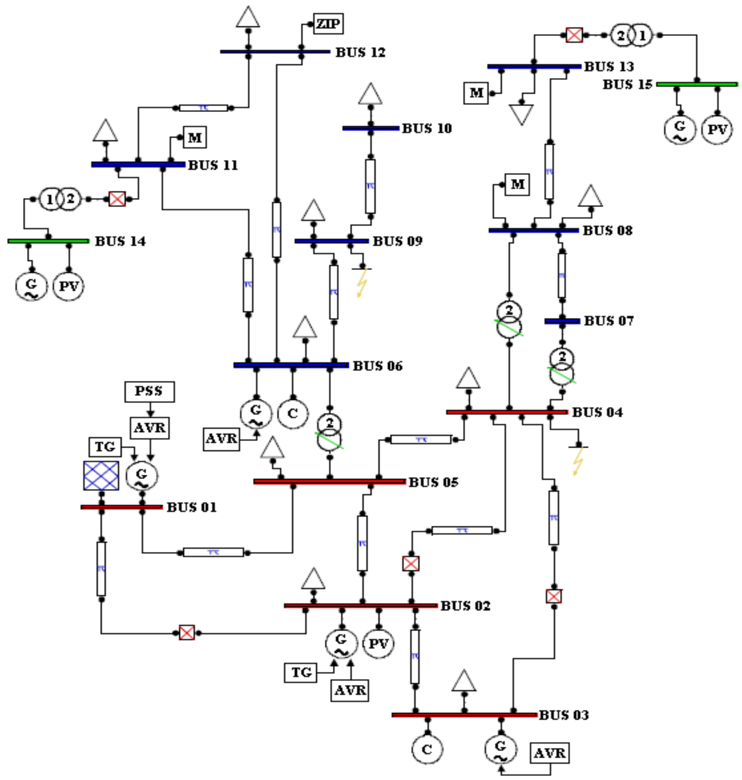

Fig. 1. Reduced 16 buses section from Marmara region electrical power system map

Existing operation voltage in Marmara region electrical power system is 170 kV and 420 kV. There are 13 buses with 420 kV and 105 buses with 170 kV in this region. Among these 118 buses, 20 buses are for production and 98 buses are for load bus. In this system there are 7 auto producer power plants, 4 special power plants, 7 thermal power plants and 2 hydraulic power plants. All 420 and 170 kV transmission line rates in the system were conversed the PU (per unit) system to adapt [9].
In PSAT 2.1.9 program, characteristic rate of autotransformers were used. Numbers were given from 1 to 118 for all buses. Auto producer and free production power plants which are connected to the electrical power system from medium voltage level did not exist but existing power plants which have special 170 kV switchyard (Enerjisa, Entek) were considered however produced at medium voltage level. 380 kV Ada DGKCS-1 transformer center was selected as slack bus thereby writing bus voltage rate for each bus. Power flow analysis was made thereby accepting the transmission loss provided from this bus. Indeed, this bus already is a high generator bus. Table 1 codes are defined for the buses from 1 to 16 in the Marmara region electrical power transmission network and each bar code is used in later studies. Impedances of reduced 16 buses section from Marmara region electrical power system are given in table 2. Angles and load status information in the reduced 16 buses electrical power system are given in table 3.

Table 4. Buses names and codes for given 16 buses

Bus Number	Bus Name	Bus Number	Bus Name
1	420 Ada DGKCS-1	9	420 Adapazarı
2	Köseköy	10	Karasu
3	Arslanbey	11	Sakarya
4	Izmit Gis	12	Kaynarca
5	Hyundai	13	Hendek
6	Toyota	14	Kuzuluk

7	Yarımca-1	15	Goksu Hes
8	Yarımca-2	16	Adapazarı

Table 2. Impedances of reduced 16 buses section from Marmara region electrical power system

From Bus	To Bus	R (pu)	X (pu)	Y (pu)
420 Ada DGKCS-1	420 Adapazarı	0.000469	0.004334	0.096258
Adapazarı	Köseköy	0.011959	0.056119	0.024037
Köseköy	Arslanbey	0.001546	0.006486	0.084544
Köseköy	Izmit Gis	0.012467	0.037456	0.014778
Adapazarı	Hyundai	0.024641	0.079038	0.027088
Hyundai	Toyota	0.002675	0.014587	0.005368
Adapazarı	Yarımca-1	0.017758	0.083332	0.035693
Adapazarı	Yarımca-2	0.017512	0.081327	0.033411
Adapazarı	Sakarya	0.011660	0.057846	0.012442
Kuzuluk	Goksu Hes	0.005476	0.040663	0.025366
Adapazarı	Karasu	0.036744	0.074525	0.063533
Adapazarı	Hendek	0.032256	0.103462	0.035458
Adapazarı	Kaynarca	0.019411	0.062263	0.021339
Hyundai	Izmit Gis	0.015363	0.065836	0.045664

Table 3. Load angles and load status of reduced 16 buses section from Marmara region electrical power system at date 30.08.2015

Buses	Active Power	Reactive Power	Apparent Power	Angle
420 Ada DGKCS-1	1632.000	435.000	1703.645	13.675
420 Adapazarı	1921.230	565.470	1995.435	14.096
Köseköy	100.360	64.600	127.890	34.676
Karasu	14.300	3.900	14.854	17.564
Arslanbey	74.500	21.500	78.445	12.431
Sakarya	52.360	11.425	56.261	13.539
Izmit Gis	95.320	62.580	110.243	31.365
Kaynarca	12.800	4.230	13.576	19.245
Hyundai	64.700	9.545	67.320	7.418
Hendek	39.670	9.230	42.023	26.452
Toyota	66.300	21.500	69.328	15.219
Kuzuluk	23.240	5.670	24.025	9.254
Yarımca-1	44.600	15.750	48.238	20.583
Göksu Hes	12.100	4.400	12.927	13.496
Yarımca-2	41.680	21.650	45.325	17.439
Adapazarı	336.680	193.620	371.395	29.329

Only power production bus of the Marmara region electrical power system (as well as the slack bus) is 420 kV Ada DGKCS-1. The production of active power is 1672 MW and reactive power is 193 MVAr in this slack bus.

Roles of Marmara region electrical power system;

1. Provision of electricity production and transmission, according to consumer needs. 2. System voltage and frequency to be kept within certain limits, and load shedding. 3. Conduct of the business, the coordination of maneuvers and get the work done.

3. Critical Fault Condition Analyses

The critical fault condition analyses are investigated into three different scales.

- Short circuit analysis,
- Outage series capacitor unit analysis,
- Outage shunts capacitor unit analysis.

The critical fault condition analyses are handled into three different cases.

Case 1: The electrical power system with normal load in all the load buses is considered as normal condition and the Newton-Raphson load flow is carried out with loading factor value equal to 1.

Case 2: The electrical power system with 50% increased load in all the load buses is considered as a critical condition. Loading of the electrical power system went beyond this level and results in poor voltage profile in the load buses and unacceptable real power loss level.

Case 3: Contingency is imposed by considering the most critical line outage in the electrical power system. This is the most suitable condition for voltage stability analysis of a power system as voltage stability is usually triggered by line outages.

The critical fault condition cases one line diagram is given in figure 2.

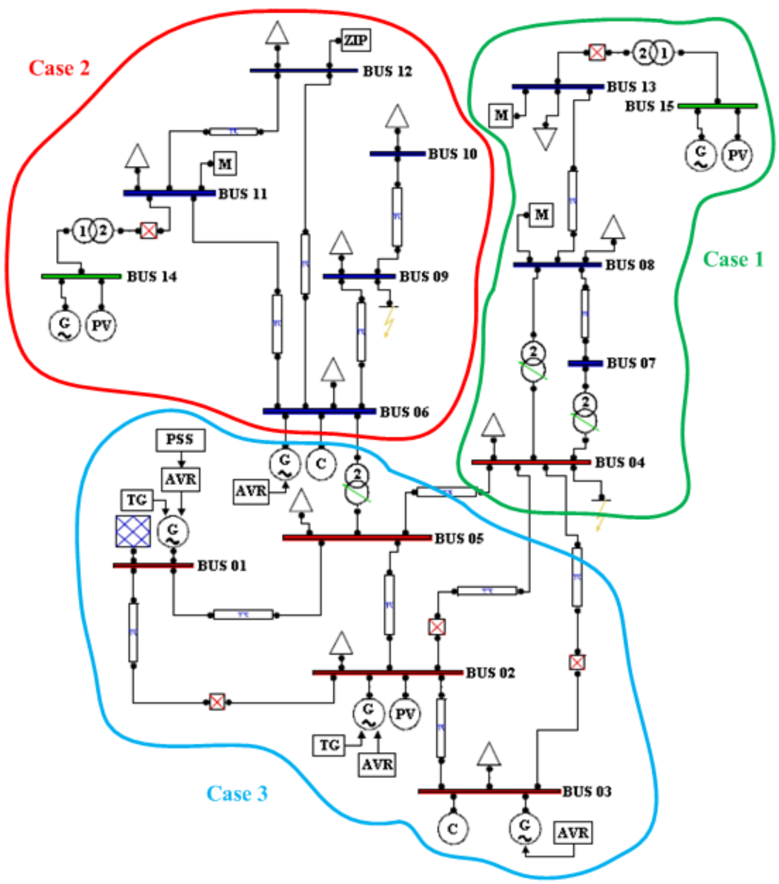

Fig. 2. The critical fault condition cases one line diagram

3.1 Short Circuit Analysis

Electric current carrying circuits, especially in power systems containing high voltage, short circuit is common situation. In such a situation are of very great dangers. Short circuit calculations, the worst possibility that the three phase short circuit state is considered. The short circuit analysis one line diagram for case 1 is given in figure 3. The short circuit calculation PSAT 2.1.9 program screenshot is shown in figure 4. As an example, three phase short circuit was created in Izmit Gis bus and the results are given in table 4.

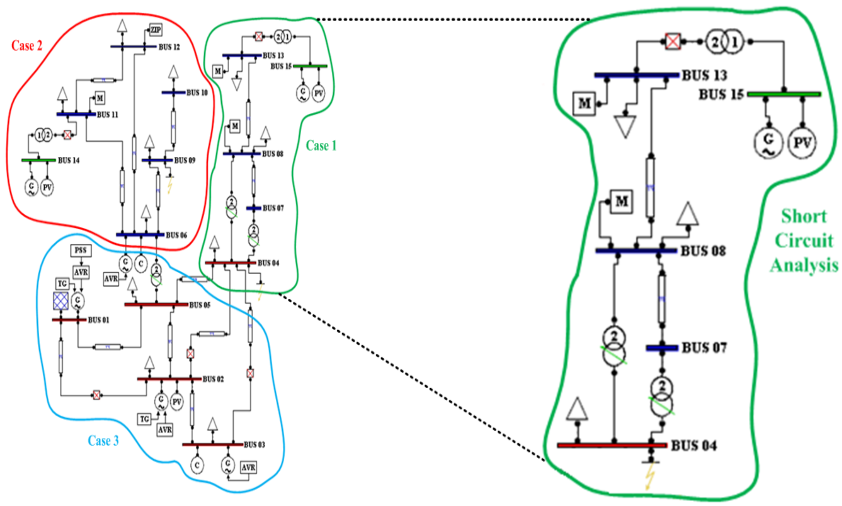

Fig. 3. The short circuit analysis one line diagram for case 1

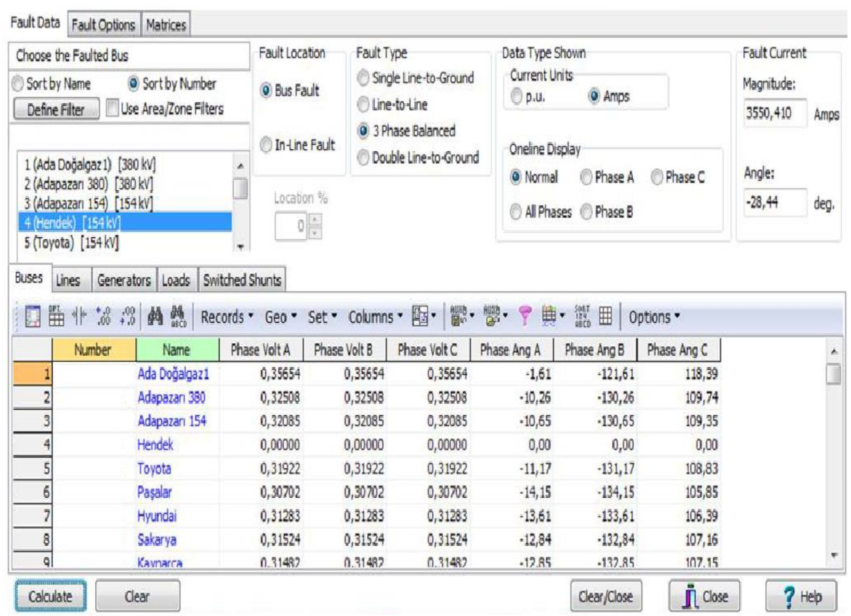

Fig. 4. The short circuit calculation PSAT 2.1.9 program screenshot

Table 4. Result of short circuit analysis in Izmit Gis bus for case 1 using PSAT 2.1.9 program

Bus Number	Voltage			Angle		
	A Phase	B Phase	C Phase	A Phase	B Phase	C Phase
1	0.3462	0.3462	0.3462	-1.52	-121.43	119.28
2	0.3138	0.3138	0.3138	-11.38	-130.48	112.16
3	0.3265	0.3265	0.3265	-10.73	-129.35	110.76
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.3172	0.3172	0.3172	-13.46	-132.88	107.53
6	0.3092	0.3092	0.3092	-11.37	-131.47	109.37
7	0.3185	0.3185	0.3185	-10.54	-127.51	113.18
8	0.3129	0.3129	0.3129	-11.82	-130.89	111.45

9	0.3383	0.3383	0.3383	-10.55	-130.82	110.56
10	0.3165	0.3165	0.3165	-12.88	-128.25	109.65
11	0.3151	0.3151	0.3151	-11.47	-131.24	108.14
12	0.3148	0.3148	0.3148	-12.39	-130.37	107.98
13	0.3175	0.3175	0.3175	-10.46	-130.86	109.85
14	0.3205	0.3205	0.3205	-11.53	-128.73	110.81
15	0.3152	0.3152	0.3152	-10.38	-128.55	109.35
16	0.3169	0.3169	0.3169	-11.08	-130.67	111.64

3.2 Outage Series Capacitor Unit Analysis

Series capacitors are connected in series with the electrical power transmission line by the aim for compensating for inductive reactance (and also reducing the impedance of the transmission line). Series Capacitors also increases the maximum power and reduces loss of transmitted reactive power in transmission line [10]. The outage series capacitor unit analysis one line diagram for case 3 is given in figure 5.

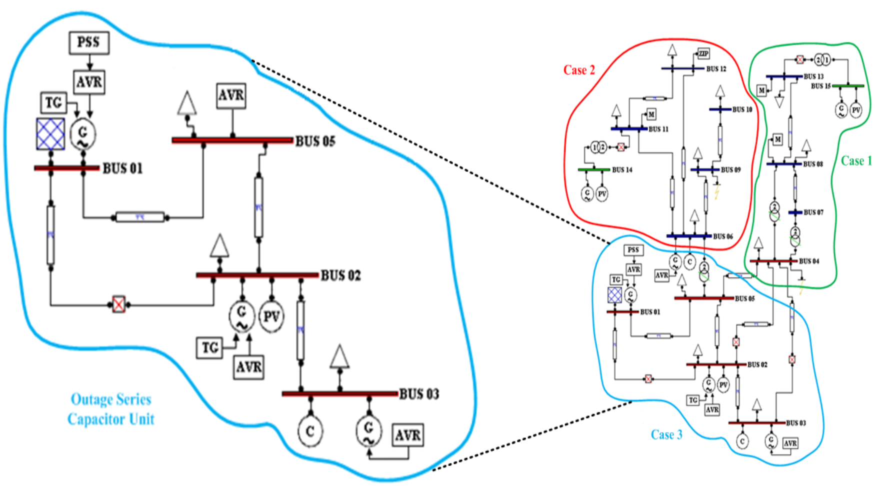

Fig. 5. The outage series capacitor unit analysis one line diagram for case 3

In the case of outage series capacitor unit, establishing different proportions of series compensation on electrical power system decreases the continuous load carrying capacity in power transmission lines. Marmara region electrical power transmission line PV curve status in the case of outage series capacitor unit is given in figure 6. As shown in figure 6, PV curves voltage collapse cases has been shifted from 1.45 pu (per-unit) voltage level to never collapse cases.

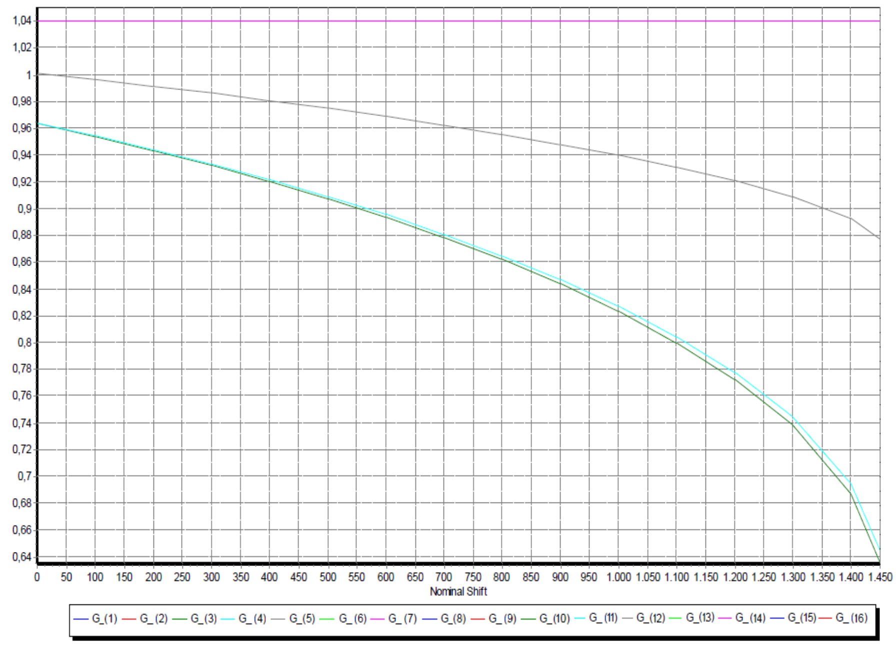

Fig. 6. Transmission line PV curve status in the case of outage series capacitor unit

3.3 Outage Shunts Capacitor Unit Analysis

Shunt capacitors group connected to power transmission line in parallel, increase bus voltage and generate reactive power. In general, they are used to produce reactive energy that consumers needed. Parallel capacitors provide reactive power and help to sustain voltages into acceptable limits [11]. The outage shunts capacitor unit analysis one line diagram for case 2 is given in figure 7.

In the case of outage shunts capacitor unit, establishing different proportions of shunts compensation on electrical power system decreases the continuous load carrying capacity in power transmission lines. Marmara region electrical power transmission line PV curve status in the case of outage shunts capacitor unit is given in figure 8. As shown in figure 8, PV curves voltage collapse cases has been shifted from 1.30 pu (per-unit) voltage level to never collapse cases. The amount of reactive power from slack bus decreases before the outage shunts capacitor unit.

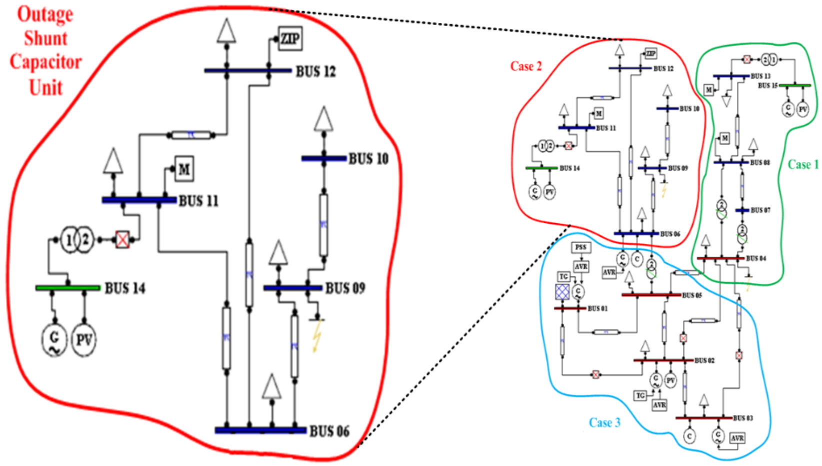

Fig. 7. The outage shunts capacitor unit analysis one line diagram for case 2

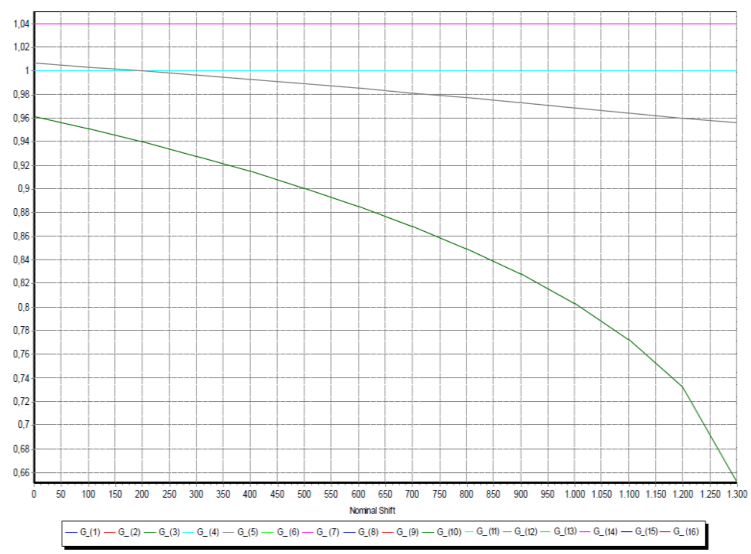

Fig. 8. Transmission line PV curve status in the case of outage shunts capacitor unit

Conclusions

Power flow, power system stability and critical fault condition analysis is an important criterion for operation of electrical power systems. Modern electrical power systems are planned for high level, multi-variable dynamic systems. Electrical power system planning, design and operation requires special attentions on careful evaluation and analysis schemes for providing high system performance, reliability, and healthy economic operability. Modern interconnected electrical power networks are composed of thousands of system elements and buses. Manual calculation may take great times. Today, Power analysis programs which run very short period of time are widely used for giving healthy outputs. Therefore, in this study, critical fault condition analysis of 16 buses sample of Marmara region electrical power system stability is investigated by using PSAT 2.1.9 program.

References

1. Reis, C., Barbosa F.P.M.: A Comparison of Voltage Stability Indices, IEEE Mediterraneen Electrotechnical Conference (MELECON), (2006) 1007-1010
2. Hotunluoglu, H., Karakaya, E.: Forecasting Turkey's Energy Demand Using Artificial Neural Networks: Three Scenario Applications, Ege Academic Review, vol. 11, special issue (2011) 87-94
3. Pamuk, N.: Multivariable Adaptive Hybrid Control Model for Interconnected Power Systems at the Inception of Voltage Collapse, Afyon Kocatepe University Journal of Science and Engineering, vol. 15, no. 2, (2015) 7-17
4. Abbasbandy, S.: Improving Newton - Raphson Method for Nonlinear Equations by Modified Adomian Decomposition Method, Applied Mathematics and Computation, vol. 145, no. 2-3, (2003) 887-893
5. Pamuk, N., Uyaroglu, Y.: Comparison the 154 and 380 kV Transmission System Network of Northwest Anatolia by Making Power Flow Emulation with Constraint Analysis in Turkey, Scientific Research and Essays, vol. 6, no. 2, (2011) 469-478
6. Abido, M.A.: Optimal Power Flow Using Particle Swarm Optimization, International Journal of Electrical Power & Energy Systems, vol. 24, no. 7, (2002) 563-571
7. Das, D., Kothari, D.P., Kalam, A.: Simple and Efficient Method for Load Flow Solution of Radial Distribution Networks, International Journal of Electrical Power & Energy Systems, vol. 17, no. 5, (1995) 335-346
8. Milano, F.: Power System Analysis Toolbox: Documentation for PSAT version 2.1.9 (2014) Available: http://faraday1.ucd.ie/psat.html
9. Pamuk, N.: Power Flow Simulation for 380 and 154 Kv Northwest Anatolia Network in Turkey, Master's Dissertation, University of Sakarya, Sakarya, Turkey (2009) (in Turkish)
10. Magaji, N., Mustafa, M.W.: Optimal Thyristor Control Series Capacitor Neuro - Controller for Damping Oscillations, Journal of Computer Science, vol. 5, no. 12, (2009) 980-987
11. Aman, M.M., Jasmon, G.B., Bakar, A.H.A., Mokhlis, H., Karimi, M.: Optimum Shunt Capacitor Placement in Distribution System - A Review and Comparative Study, Renewable and Sustainable Energy Reviews, vol. 30, (2014) 429-439