ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2010. No. 8(104)
ELEKTRONIKA IR ELEKTROTECHNIKA

ELECTRICAL ENGINEERING
T 190
ELEKTROS INŽINERIJA

Analysis of the Power Blackout in the Marmara Earthquake

B. Oral, F. Dönmez
Department of Electrical Education, Marmara University,
Goztepe Campus, Kadikoy, Istanbul, Turkey, phone: +90 216 3365770, e-mail: boral@marmara.edu.tr

Introduction

Blackouts are the most serious disruptions of power system operation without a doubt and any system can collapse under certain conditions of uncommon strain. Blackouts are composed by the effects of various types of disturbance or fault on the power systems. Large blackouts are initiated by a single event that gradually leads to cascading outages and eventual collapse of the entire system [1]. Whatever the cause, the power system is effected by a natural environmental phenomena. The result of phenomena can be either overvoltage or undervoltage. Overvoltage and undervoltage generally are not the result of system faults, but are caused by load variations on the system and system switching operations [2].

The power frequency overvoltages occur in large power systems and they are of much concern in extra high voltage power systems, i.e. systems of 400 kV and above. The main causes for power frequency and its harmonic overvoltages are sudden loss of loads, disconnection of inductive loads or connection of capacitive loads, Ferranti effect, unsymmetrical faults and saturation in transformer, etc [3].

When a large power system is subjected to disturbances, according to type of the disturbances, different effects can be formed on the power system. Simultaneously, components of the power system can be affected; therefore, it can cause cascading failures [4].

Sudden disturbances on power systems may result from factors external to the system itself such as weather, environment and natural disasters [5]. The impacts of natural disasters are often greatly prolonged and exacerbated by disruptions to critical infrastructure systems. Critical infrastructure includes electric power system, water, transportation and other systems [6]. The potential and effects of earthquake and other natural disaster on the power system will be system faults [5]. The faults are not only limited with physical damages on power systems but also power quality disturbances may take place. They may cause severe power outages and blackouts.

Since 1990, it has been many significant blackouts. One of them is the Marmara Earthquake Blackout, which is the largest power blackout in last twenty years, in Turkey. Turkey is geographically located at one of the most earthquake-prone areas of the world. The earthquake struck northwestern Turkey at 3:02 a.m. on August 17, 1999. The duration of shaking registered 45 seconds, a long period of seismic movement. The earthquake is called “The Marmara Earthquake” in literature. The earthquake caused heavy damage in the cities of the Marmara Region. The Marmara Region, where the major impact of the earthquake occurred, is very important to the Turkish Economy both in terms of production and consumption capacities. In 1999, the earthquake region was the residential area where 23.43% of population of Turkey lived. Industrial foundations in the earthquake region present a structure using advanced technology and that foreign capital had more portion than other regions of the country. The portion of the seven cities, which were Izmit, Adapazari, Istanbul, Bolu, Bursa, Eskisehir and Yalova, affected by the earthquake in gross domestic product (GDP) was 33.4% [7,8]. The region had an important role regarding electricity consumption. At the end of the year 1999, the region used 32.2% of the electricity consumption of Turkey with 28 Billion kWh [9].

In this study, It is examined the Marmara Earthquake Blackout. Turkish power system was modeled with generation stations, substations, power transmission lines and load outputs by 1999. Analysis of the Marmara Earthquake Blackout is simulated by MATLAB.

The Blackout Anatomy

In 1999, Turkish Electric Generation Transmission CO. (TEAS) was responsible for the generation and transmission of electricity throughout the country. The system was observed and managed by five regional operation divisions of National Load Dispatch Department. These were Northeast Anatolia (NEA), Northwest Anatolia (NWA), West Anatolia (WA), Mid Anatolia (MA), and Southeast Anatolia (SEA).

The Marmara Earthquake occurred on 17th August at local time 03:02. After the first shock, Turkish Power System was badly affected and the system except some regions, which were WA and isolated region from national grid that supplied by international connections (Bulgaria, Georgia, and Iran), was blackout [10]. Therefore, the thermal and hydroelectric power plants were out of service except WA.

The time range of the minimum load drawn at Turkish power system is usually between 02:00 and 07:00 hours. Therefore, at the earthquake time, the load of Turkish power system was at minimum. The NWA earthquake region was the highest region generation-consumption of electricity, industry and population density in Turkey.

Generation-consumption of the regions on the day before the earthquake is given Table 1 [10]. The view is expressed that both generation and consumption of NWA was the highest and WA, the second most consuming region, was balanced roughly in generation–consumption.

Table 1. Generation-Consumption of the regions at time of minimum load in 16th August, 1999 (GWh)

Region	Generation	Consumption
NWA	3,978	3,588
WA	2,234	2,574
SEA	2,622	1,420
MA	441	1,069
NEA	385	566
Total	**9,682**	**9,217**

At the earthquake time, Turkish power system was fed mostly by thermal plants. Fig. 1 shows the power flow between the regions [10]. The view is that the power flew toward to east from west. In general, power flow of Turkish power system is from east regions, which have important hydroelectric power plants, to west regions, which have wealthy industrial facilities. However, at the earthquake time, the power flow was not like that. The Marmara Earthquake occurred in the summer of 1999. The summer was draught, and water levels of hydroelectric power plants were low in minimum and the power plant used for irrigation. At the same time, buying guarantee had to be applied for natural gas power plants; therefore, the natural gas power plants had to be on the service at the earthquake time.

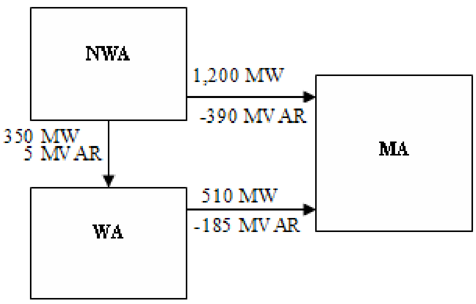

Fig. 1. Power flow between the regions at minimum time range on 17th August, 1999

When the earthquake occurred, load of the NWA suddenly was rejected. The region drew more than 35% totally load of Turkey. Excluding the isolated regions total drawn load of MA, NEA and SEA was roughly 4.0 GW. Load of WA was roughly 3.0 GW and 30% of total drawn load of Turkey. Fig. 2 shows change of the system load at the earthquake [11]. Therefore, load of Turkish power system suddenly reduced. In the result of disturbances on the power system, cascading failures in the system were formed.

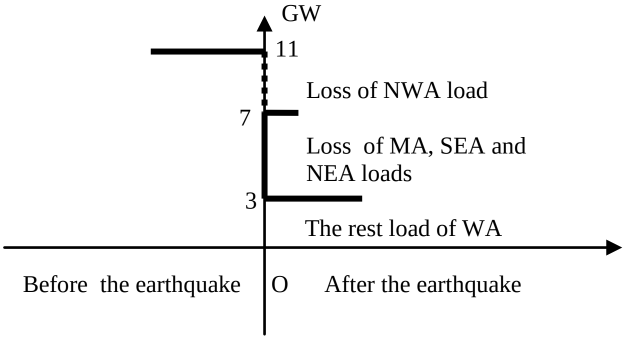

Fig. 2. Sudden load reduction of Turkish Power System in the Marmara Earthquake

Analysis of the Blackout

Disturbances on the Turkish power system are examined for the sudden load reduction after the damaged substations and the disconnected transmission lines as a consequence of an earthquake. Analysis of the blackout on Turkish power system on 17th August, 1999 is simulated by MATLAB. Turkish power system is modeled with generation stations, substations, power transmission lines and load outputs at the earthquake time.

In the earthquake, power demand of NWA was covered by Hamitabat, Ambarli, Unimar and Bursa natural gas power plants. At the same time, the region exported power to MA as generation. The power flow was roughly 1.2 GW [11]. The power connections were provided between NWA and MA by power transmission lines of 380 kV.

380 kV Osmanca and Adapazari transformer substations, which are located between NWA and MA regions, and power transmission lines of NWA region were affected by the earthquake. And then they damaged. Therefore, transformer substations of NWA were switched off, and load of the region suddenly lost.

Effect of a sudden loss of demand can develop following possible results on the power system:

- System frequency rise;
- System voltage rise;
- Transmission overload;
- Transient instability;
- System oscillations.

These actions affect power system for particular instants. These time intervals can be from 1/10 seconds to seconds for system frequency and voltage, however, they can be from seconds to minutes for transmission overload and system oscillations [5].

Fig. 3 shows power system of NWA region, which modeled by MATLAB. In fig. 3, you can only see NWA, but the Turkish power system was modeled completely in this study. In this context, at the earthquake time, transmission and distribution lines of NWA were faults, which were breaking and short circuits in lines, and substations, which were severe earthquake regions, were opened by buchholz relays. In addition, middle voltage and low voltage substations caused damage, so, immediately after the earthquake; the region load was rejected suddenly. At the same time, connection substations, between NWA and MA, suffered damage, when power was flowing from NWA to WA.

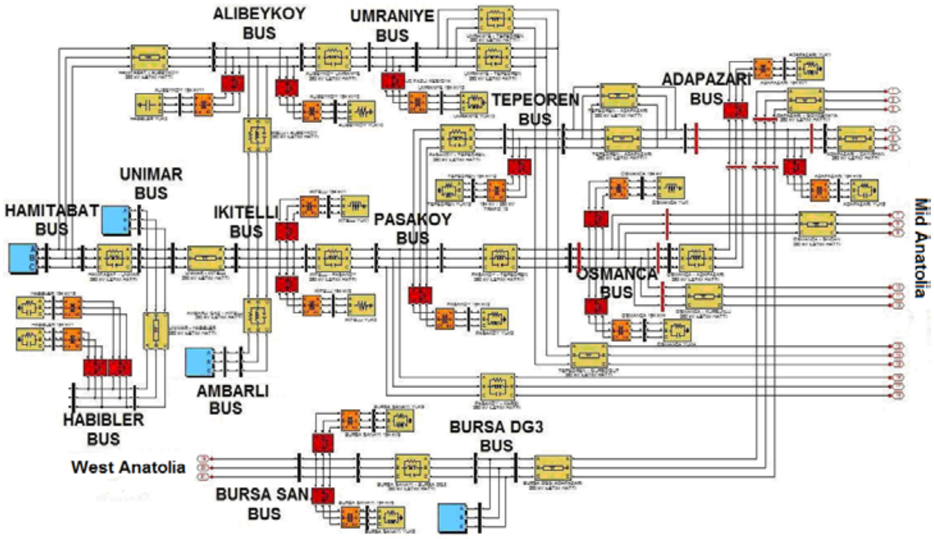

Fig. 3. MATLAB model of Northwest Anatolia Power System

Because of the earthquake, load rejection of NWA region and opening of connection between NWA and WA were expressed for t=1.0 s. and Turkish power system was simulated immediately after a transient process started.

Therefore, voltage and frequency profiles of buses, which were inside and outside of the region, were captured with graphics for the pre and post load rejection. Some of them are presented, in fig. 4-7.

Fig. 4 shows voltage of Umraniye Bus. It is substation of 380 kV and 154 kV in Anatolia side of Istanbul. This profile was captured at the bus of 380 kV and we can see that voltage sharply increased at t=1.0 s. The increase was roughly 1.5 per unit.

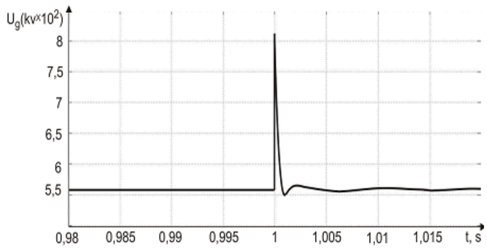

Fig. 4. Voltage of Umraniye Bus

Fig. 5 shows the voltage of Bursa San Bus. This substation is between WA and NWA regions. After the Marmara earthquake, cities of WA region did not experience power outages. Generation of this region was balanced the consumption and the region demand was supplied by their own power plants under 154 kV. The voltage of the bus increased 1.1 per unit.

Fig. 6 presents voltage of Golbasi Bus. Voltage of this bus also increased. But, the increasing was different from Bursa San Bus, especially. Since the bus was affected badly, voltage increasing was almost the same as Umraniye Bus.

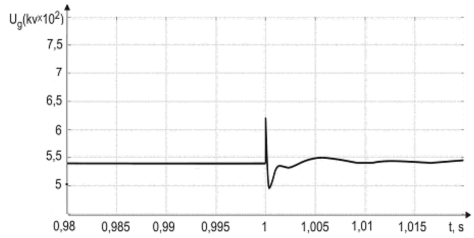

Fig. 5. Voltage of Bursa San Bus

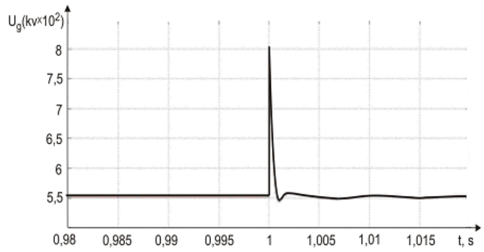

Fig. 6. Voltage of Golbasi Bus

At the instance of the load rejection, the breaker opens and the current rapidly goes zero. The voltage drop over the generator internal impendence becomes zero, as well, causing a sudden step change in generator output voltage amplitude and phase. When running as a generator connected to the grid, the electrical frequency of the generator is synchronized to the grid frequency [12].

Conclusions

An earthquake occurred on August 17, 1999 in Turkey and the Turkish Power System was adversely affected by the earthquake. Therefore, the power system collapsed. In this study, it was examined the power blackout on the system and technically analyzed by MATLAB simulation program.

The earthquake region was the most important industrial area in Turkey and also was in the front rank about the electricity consumption. At the earthquake time, there was a power flow from the earthquake region to other regions as generation. As the result of sudden loss of demand, there were disturbances in the power system. The system was affected badly and cascading failures were formed.

The analysis of MATLAB shows that voltages of buses increased between 1.2 and 1.5 per unit. When the load drops too low, there can be an overvoltage condition. This increase in voltage may go as high as 2.0 per unit value with 400 kV lines. At the Marmara Earthquake, the Turkish power system experienced overvoltage conditions.

After an earthquake, the sudden disturbances in the power system can occur. There is no warning of their onset, in other words, unpredictable disturbances. An interconnected power system is designed and operated such that uncontrolled, widespread interruptions are unlikely. However, building and operating a power system that is 100% reliable is not economical.

The voltage at sending end is affected by the line length, short circuit MVA at sending end bus, and reactive power generation of the line. Shunt reactors may reduce the voltage to 1.2 to 1.4 per unit. To minimize damage to loads, regulators employ a rapid runback control scheme that bypasses the normal time delay and runs the regulators back down as quickly as possible. This is typically 2 to 4 s per tab change.

Acknowledgements

The authors would like to thank Marmara University Scientific Research Projects Commission for its support in the form of a grant (FEN-YLS-290107-0041).

References

1. **Pourbeik P., Kundur P. S., Taylor C. W.** The anatomy of a power grid blackout–root causes and dynamics of recent major blackouts // IEEE Power and Energy Magazine. – Sept. Oct., 2006. – Vol. 4. – No. 54. – P. 22–29.
2. **Dugan R. C., McGranaghan M. F., Santosa S., Beaty H. W.** Electrical power system quality. – USA: McGraw–Hill, 2003. – 528 p.
3. **Naidu M. S., Kamaraju V.** High Voltage Engineering. – USA: McGraw–Hill, 1999. – 372 p.
4. **Gou B., Zheng H., Wu W., Yu X.** Probability Distribution of Blackouts in Complex Power Networks. // IEEE International Symposium on Circuits and Systems. – New Orleans, 2007. – P. 69–72.
5. **Knight U. G.** Power Systems in Emergencies From Contingency Planning to Crisis Management. – West Sussex: John Wiley& Sons Ltd., 2001. – 378p.
6. **Chen X., Deng C., Chen Y., Li C**. Blackout Prevention: Anatomy of the Blackout in Europe. // IEEE Power Engineering Conference. – Singapore, 2007. – P. 928–932.
7. **Ewing B. T., Kruse J. B., Ozdemir Ö.** Disaster Losses in the Developing World: Evidence from the August 1999 Earthquake in Turkey // Turkish Economic Association–Discussion Paper, 2004. – No.19. – 23 p.
8. **DIE (State Institute of Statistics).** 1999 Gross Domestic Product Results According to Provincials. – 2000. [in Turkish]
9. **Gokmen G., Tuncalp K.** The Design of a Hall Effect Current Transformer and Examination of The Linearity with Real Time Parameter Estimation // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 5(101). – P. 3–8.
10. **TEAS (Turkish Electric Generation Transmission Co.)**. – 1999 Operating Activities Report [in Turkish]. – Load Balancing Department. – Ankara, 2000.
11. **Batkauskas V., Kajackas A.** Quality of Heterogeneous Mobile Data Services: Capabilities and End-user Achievements // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 5(101). – P. 43–46.
12. **Terzija V. V., Akke M.** Synchronous and Asynchronous Generators Frequency and Harmonics Behaviour after a Sudden Load Rejection // IEEE Transactions on Power Systems. – May, 2003. – Vol. 18. – No. 2. – P. 730–736.

Received 2010 02 16

B. Oral, F. Dönmez. Analysis of the Power Blackout in the Marmara Earthquake // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 8(104). – P. 77–80.

An earthquake occurred on August 17, 1999 in Turkey and the Turkish Power System was adversely affected by the earthquake. Therefore, the power system collapsed. In this study, it was examined the power blackout on the system and technically analyzed by MATLAB simulation program. Voltage profiles of the region are shown in graphics. Ill. 6, bibl. 12, tabl. 1 (in English; abstracts in English, Russian and Lithuanian).

Б. Орал, Ф. Донмез. Исследование отказов передачи энергосетей после землятресения Мармара // Электроника и электротехника. – Каунас: Технология, 2010. – № 8(104). – С. 77–80.

Приведены обширные результаты отказов энергосетей после землятресения 17 августа 1999 года. Отказы проанализированы на основе пакета программ MATLAB. Полученные результаты иллюстрируются конкретными образцами для разных местностей землятресения. Ил. 6, библ. 12, табл. 1 (на английском языке; рефераты на английском, русском и литовском яз.).

B. Oral, F. Dönmez. Elektros energijos tiekimo sutrikimų analizė po Marmara žemės drebėjimo // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 77–80.

1999 m. rugpjūčio 17 d. įvykęs žemės drebėjimas padarė neigiamą poveikį elektros energijos tiekimo sistemoms. Buvusios sistemos buvo sunaikintos. Taikant MATLAB programų paketą, techniškai ištirtos buvusios elektros energijos tiekimo sistemos. Pateikti įtampų paveikslai atitinkamuose regionuose. Il. 6, bibl. 12, lent. 1 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).