POWER DISTRIBUTION SYSTEM ANALYSIS OF URBAN ELECTRIFIED RAILWAYS

Farhad Shahnia — *farhadshahnia@yahoo.com*
Saeed Tizghadam — *s_tizghadam@yahoo.com*
Seyed Hossein Hosseini — *hosseini@tabrizu.ac.ir*
Electrical and Computer Engineering Faculty, University of Tabriz, Tabriz, Iran

Key words: Electrified railway, load flow, power distribution system, simulation

ABSTRACT

Load flow of power distribution system of Tabriz urban railway is analyzed in this paper. Dynamic load flow behavior of electrified train sets and fault analysis is considered in selecting the appropriate ratings of the electrical equipments in the railway electrification system through the study. The simulation and analysis of the power distribution system is done with PowerWorld simulator software.

I. INTRODUCTION

The Electrified urban railways play an important role for metropolitan public transportation because of high efficiency, heavy ridership and fast transportation. To serve such a mass public transportation, the reliability of the whole power network is significant for the full performance of the urban railway system.

An electrified railway line resembles a typical power distribution system but the major difference is the changes in the positions of the trains called as the frequently moving loads. To solve the power consumption of the trains operation on the track, it is also necessary to investigate the dynamic load behavior of the train along the route. The dynamic behavior of the train loads mostly includes starting and stopping time intervals near the stations. Power demand varies over a wide range and a load may even become a power source when regenerative braking is allowed. Other factors such as train speed, traffic and service schedule and track layout have also great influence on the power demand of the electrified railway system.

The electrical power system feeding the railway should be designed so the voltages at the train sets are in the admissible range and the conductor currents and transformer powers are smaller that their rated values. The over design problems of the railway power system during the planning stage should be solved through load flow analysis which can lead to appropriate selection of the ratings of the transformers and feeder cables and enhancing the operation efficiency of the power system. The power substations have to be designed so that sufficient capacity can be provided for the normal operation and the scheme of load transfer can be implemented for the emergency condition when one of the substations is outaged. It is necessary to find the substation loading according to the ridership and operation time table of the traction system [1,2].

In this paper, the power distribution system of Tabriz urban railway is studied. The simulation is done with PowerWorld Simulator software which has a high analytical and graphical capability in power system simulation [3,4]. The loading factor of distribution feeders is studied through the results, not exceeding the limits.

II. ELECTRICAL POWER SUPPLY SYSTEM

Tabriz urban railway is 18.5 kilometers long with 20 stations which is fed through four 132/20 kV substations that feed 10 traction substations. In traction substations, the 20 kV AC power is stepped down to 592 volts AC and converted through 12 pulse rectifiers to 750 volts DC and is delivered along the track with overhead contact system. The total active power demand of Tabriz urban railway is about 25 MW which is supplied form *Yagchian*- 7 MW, *Roshanayi*- 6 MW, *Golestan*- 5 MW, *Mashinsazi*- 7 MW substations respectively. The traction substations are located at stations 1, 2, 4, 6, 8, 10, 14, 16, 19 and 20 which have been connected in parallel. By this way, the power source of each traction substation can be switched from one bulk substation to the other in the case of emergency outage of the related bulk substation, resulting in increasing the reliability of the traction power distribution system [5].

The whole traction system would be utilized in a few years but the first 6 kilometers of the traction system is going to start operation in 2006. The single line diagram of the AC power distribution system feeding this part of the traction system is shown in Fig. 1. The rest of the system has a resembling structure.

track layout can be shown in Fig. 3 from the first station to the last one.

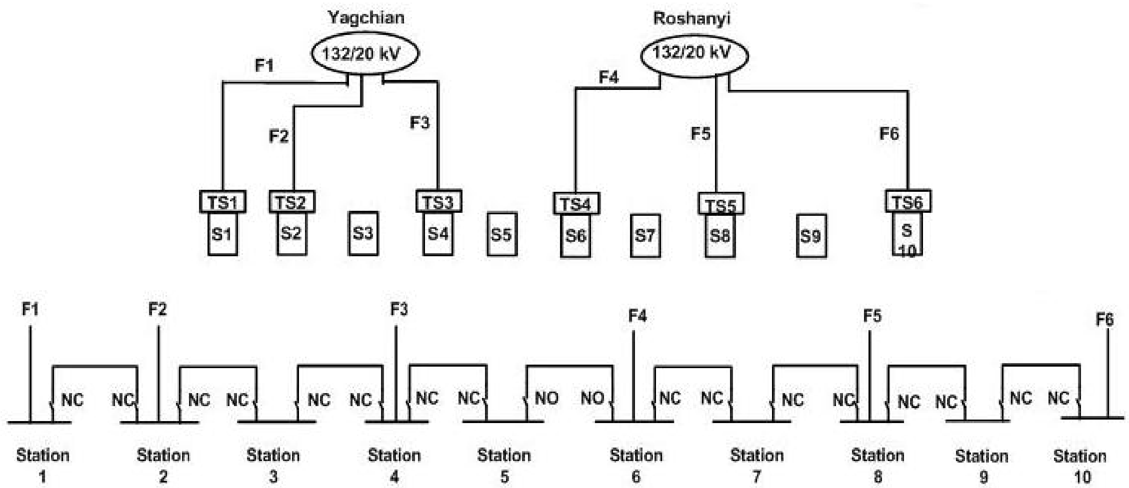


Fig. 1. Single line diagram of power distribution system for Tabriz urban

III. DYNAMIC TRAIN LOAD

For studying the load flow analysis of the traction power distribution systems, the power consumption of the train operation is necessary to be investigated and the dynamical behavior of the traction system loads along the route to be studied. Fig. 2 shows the typical speed profile of a train set between two stations [6]. When the train starts from the first station, it operates in constant acceleration mode, shown in region I. As the speed reaches 22 km/hour, the operation mode is changed to constant power, shown in region II. When the speed is above 37 km/hour, the train set is operated with the constant slip where the traction effort is inversely proportional to the square of the train speed, shown in region III. After the speed reaches the cruising speed, the train operates with coasting mode without applying any input propulsion power, shown in region IV. When the train approaches the next station, the electric regeneration braking is applied by operating the induction motors as induction generators so that the kinetic energy of the train set can be converted into electricity to achieve the energy conservation, shown in region V. For each operation mode, the power demand of the train set can be solved based on the acceleration and various types of train resistance. The track layout including route gradient and curvatures of the traction system, the distance between the adjacent stations and also the headway time of the trains for different traffic and service schedules have also a great effect on the dynamic load behavior of the traction systems. So the power demand of the train sets of Tabriz urban railway in accordance with their speed profiles and

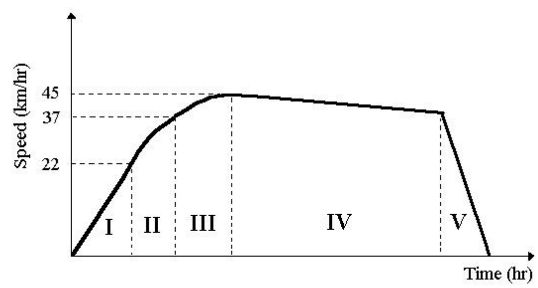


Fig. 2. Speed characteristics of the train sets with time and place variations.

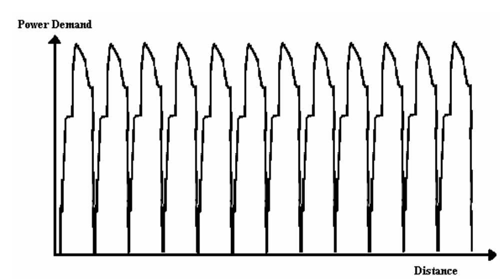


Fig. 3. Power demand characteristics of the Tabriz urban railway train sets form the first station to the last.

IV. POWER FLOW ANALYSIS

For performing power flow analysis of the power distribution system of DC electrified railways, input train information, route gradient and curvature, AC and DC network data, operation timetable, and the ridership of the traction system should be studied and analyzed for determining the accurate input information. Then, the power demand of the train performance according to the train speed, position and motion equation should be analyzed. The power demand at the secondary side of the traction transformers at traction substations should be done with DC load flow analysis. Then, the AC load flow analysis should be done for solving the loading of traction transformers at bulk substations for each snapshot. In this paper, PowerWorld Simulator software is used for power distribution system analysis of Tabriz urban railway. Power load flow and fault analysis of the AC distribution system feeding the traction system is done with this software. So the stability and the reliability of the traction system is investigated. With performing load flow analysis during design period, accurate ratings of electrical equipment can be achieved and tested through simulation cases [7-9]. Fig. 4 shows the active power load flow of the single line diagram for Tabriz urban railway, simulated with PowerWorld. In this simulation, buses 1 and 12 represent *Yagchian* and *Roshanayi* bulk substations which both of them energize the traction system with 3 feeders. The parameters of the buses including the active and reactive power consumption as the inputs of the simulation case which can be changed with 0.1 MW or MVar variations and voltage perunit and phase as the results of the load flow simulation are shown in Table 1. The parameters of the feeders between the different buses including active and reactive power and loading factors are also shown in Table 2 where the accuracy of the numbers are in 0.1.

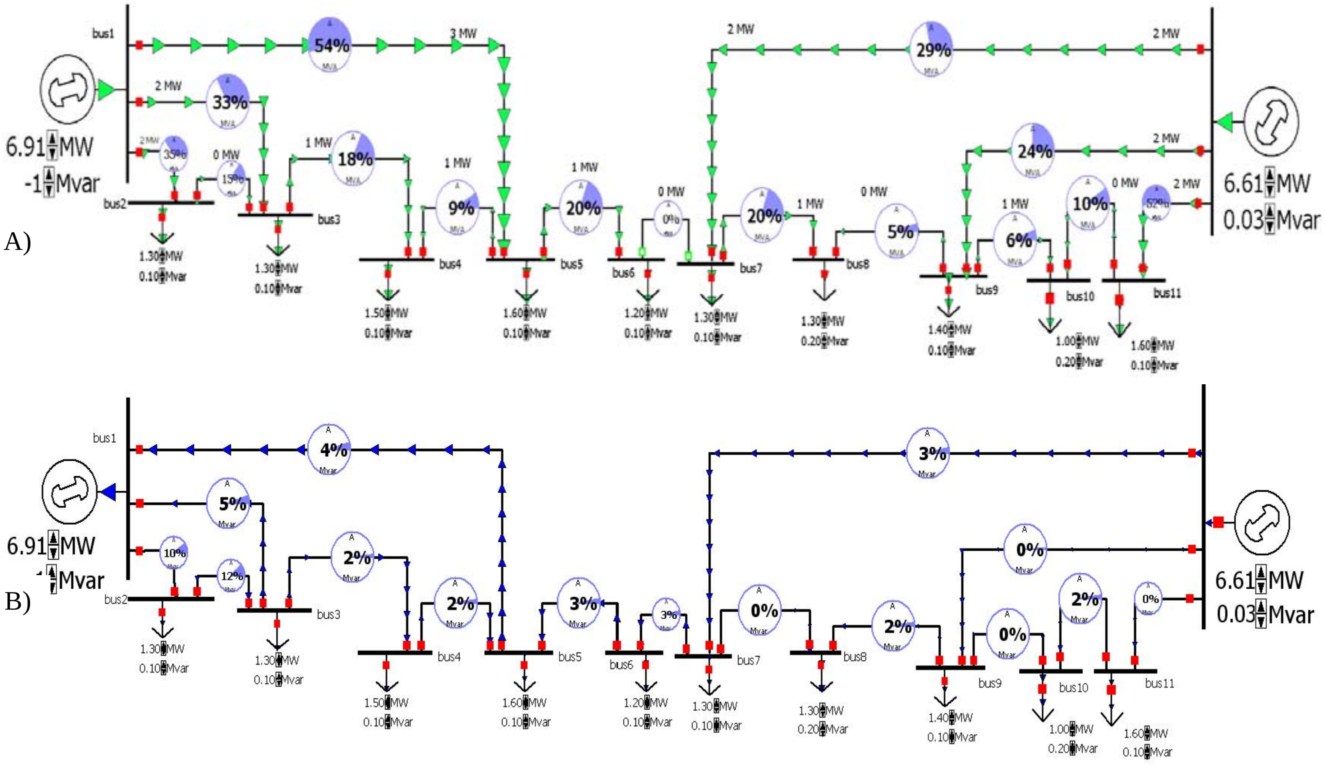


Fig. 4. Power load flow analysis of the AC distribution system, A)active power, B)reactive power.

For increasing the reliability of the traction electrical system, it is necessary to design the structure of the power distribution system in a way that it would be able to still be fed from other feeders when a disconnection occurs in a feeder. Also it must be able to feed the traction substations in peak load time without being outaged or overloading, resulting in increasing the reliability. For that reason, the electrical distribution system as shown in Fig. 1 is designed to be able to feed all of the traction substations without any problems such as overloading. Through the simulation results, it is proved that regenerative braking or heavy traffic schedule do not have any great effect on the overloading problems of the electrical equipment but feeder disconnection faults do have great impact. For that reason, the results of fault analysis done with PowerWorld Simulator are only shown below [10,11].

When the main feeders of the substations such as feeder 1-2 or 1-5 disconnects, the power system can be fed without any problems. Although, when the feeders between the traction substations such as feeder 3-4 disconnects, again the system can be fed with no problems because the ratings of the feeders are designed for fault conditions and also when a substation is outaged, the required power demand can be fed through the adjacent bulk substation with closing the circuit breakers of feeder 6-7. The results of the mentioned faults in loading factors are shown in Table 3 and Fig. 5. It is obvious that the ratings of the feeders should be designed for fault and peak times.

Table 1. Parameters of buses of the simulated study case

Bus No.	P (MW)	Q(MVar)	V(pu)	V (deg)
1	6.91 Gen.	1 Cons.	1	0
2	1.3	0.1	0.9997	-0.19
3	1.3	0.1	0.9994	-0.23
4	1.5	0.1	0.9985	-0.33
5	1.6	0.1	0.9984	-0.30
6	1.2	0.1	0.9977	-0.41
7	1.3	0.1	0.9990	-0.07
8	1.3	0.1	0.9983	-0.16
9	1.4	0.1	0.9987	-0.09
10	1	0.1	0.9983	-0.14
11	1.6	0.1	0.9987	-0.09
12	6.61 Gen.	0.03 Cons.	1	-0.12

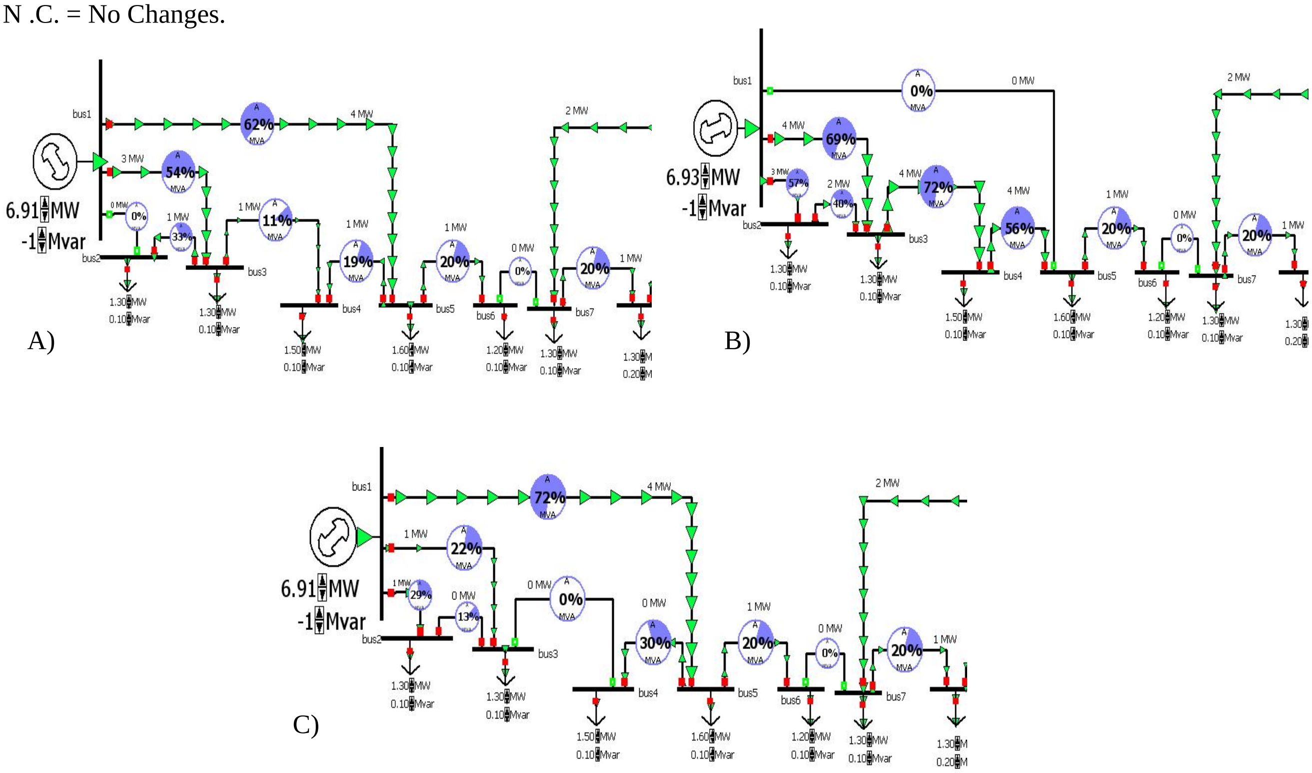
Table 2. Parameters of feeders of the simulated study case

From Bus No.	To Bus No.	P (MW)	Loading Factor %
1	2	2	35
1	3	2	33
1	5	3	54
2	3	0	15
3	4	1	18
4	5	1	9
5	6	1	20
6	7	1	0
7	8	1	20
8	9	0	5
9	10	1	16
10	11	0	10
12	7	2	29
12	9	2	24
12	11	2	52

Table 3. Results of loading factors of feeders between buses while a feeder has been disconnected

Feeder	1-2	1-3	1-5	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	12-7	12-9	12-11
Disconnect 1-2	0	54	62	33	11	19	20	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Disconnect 1-5	57	69	0	40	72	56	20	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Disconnect 3-4	29	22	72	13	0	30	20	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Disconnect B12	48	54	81	28	50	30	79	83	67	67	33	32	0	0	0

N .C. = No Changes.



A)

B)

C)

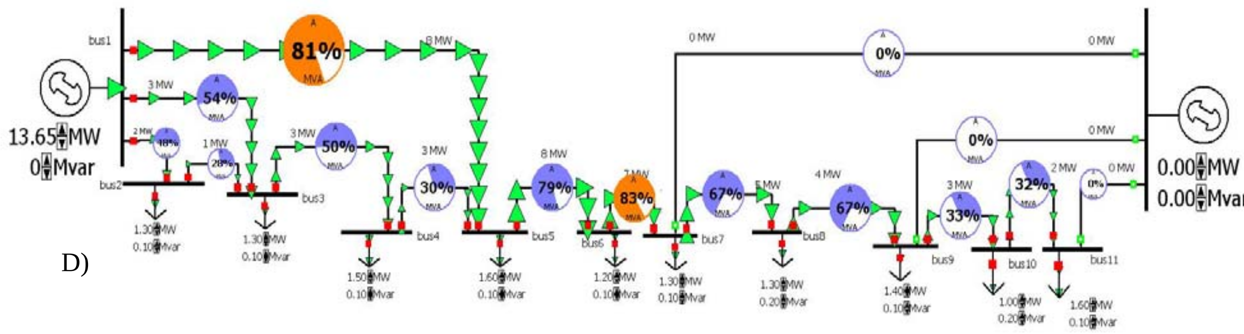


Fig. 5. Fault simulation of feeder disconnections for the study case, A)feeder 1-2, B)feeder 1-5, C)feeder 3-4, D)Bus 12.

V. CONCLUSION

For increasing the reliability of the power distribution system of urban railways, it is essential to investigate the power load flow analysis during designing. Therefore, it is essential to study the loading factor of the electric power distribution system in peak load time and also when a feeder disconnection fault occurs while the power demand of the train sets varies dramatically from time to time during the journey from one station to the other. In this paper, the power flow analysis for the DC urban railway and AC distribution network feeding the traction system of Tabriz was presented. The simulation was done with PowerWorld Simulator software considering a sample traffic schedule. Through the simulation results for peak load flow and fault analysis the accuracy of the selection of the feeder ratings can be proved.

REFERENCES

1. T.K. Ho, Y.L. Chi, J. Wang, K.K. Leung, "Load flow in electrified railway", *IEEE 2nd Int. Conf. on Power Electronics, Machines and Drives*, Vol. 2, Pages:498-503, April 2004.
2. T.K. Ho, J. Wang, K.K. Leung, C.T. Tse, L.K. Siu, "Probabilistic load flow calculation for ac traction supplies with AT feeding", *IEE 6th Int. Conf. on Advances in Power System Control, Operation and Management*, pp. 530-534, 2003.
3. User manual of PowerWorld Simulator Software, version 10, PowerWorld Corporation, 2004.
4. I. Dzafic, M. Glavic, S. Tesnjak, "An object oriented graphical package for power system simulation and analysis", *IEEE 12th Mediterranean Int. Conf. on Electrotechnical*, Vol. 3, pp. 835-839, May 2004.
5. Rail-Bandar Engineering Consultant Company, Tabriz Urban Railway Contract, Electrical studies results, February 2005.
6. C.S. Chen, H.J. Chaung, J.L. Chen, "Analysis and dynamic load behavior for electrified mass rapid transit systems", *IEEE 34th Int. Conf. Industry Applications*, Vol. 2, pp. 992-997, Oct. 1999.
7. E. Pilo, L. Rouco, A. Fernandez, A. Hernandez-Velilla, "A simulation tool for the design of the electrical supply system of high speed railway lines", *IEEE Power Engineering Society Summer Meeting*, Vol. 2, pp. 1053-1058, July 2000.
8. Y. Chai, M.R. Irving, S.H. Case, "*Iterative* techniques for the solution of complex DC rail traction systems including regenerative braking", *IEE Proc. on Generation, Transmission and Distribution*, Vol. 142, No. 5, pp. 445-452, September 1995.
9. M. Glavic, "The continuation power flow: A tool for parametric voltage stability and security analysis", *Proc. of 59th American Power Conf.*, pp. 1298-1304, USA, 1997.
10. S. Sagareli, "Traction power systems reliability concepts", *Proc. of ASME/IEEE Joint Rail Conf.*, pp. 35-39, 2004.
11. I. Zamora, E. Fernandez, E. Torres, A.J. Mazon, "Influence of faults in electric railway systems", *IEEE 2nd Int. Conf. on Power Electronics, Machines and Drives*, Vol. 2, pp. 504-509, April 2004.