Power Quality Concerns of Unit Commitment of Main Transformers for DC electrified Urban Railway Systems

Mehrdad Tarafdar Haque, Farhad Shahnia, Mitra Sarhangzadeh

Abstract—**The power quality problems of DC electrified urban railway systems are discussed for the unit commitment situations on the main transformers of the traction substations. Utilizing unit commitment and the transformer planning procedure for an electrified traction system which is applied to derive the optimal transformer capacity to meet the annual peak demand and provide reserve for service reliability, minimizes the overall cost of main transformers over the life cycle. On the other hand, some power quality problems are caused or even emphasized due to the natural characteristics of the traction system. The dynamic programming method of unit commitment is done in MATLAB where its results are the input data for the rest of our power quality investigation procedure. The power quality characteristics of the traction system are then studied and verified through the simulation results done with PSCAD/EMTDC software.**

Index Terms—**Unit commitment, Electrified railway, Power quality, Loading factor, load forecast**

I. INTRODUCTION

THE DC electrified railway systems provide a great means of public transportation in the metropolitan areas because of high efficiency, higher transportation speed and lower pollution. For maintaining higher service quality of such systems, it is necessary that their power distribution system be designed in such a way that no block out would happen. The fully back up capability of the system, prevents the electricity outage due to failure of any of the network components. It is the conventional practice to design and install the main transformers in the traction substations with the initial capacity to cover all the power loading, i.e. provide 100% capacity reserve for the peak operation of the system. In this case, the loading factors of the main transformers are less than 50% even for the peak operation for the traction system. Since the ridership of the traction systems is often very small during the initial operation years which increases over the next years, the main transformers are very lightly loaded most of the time and the operation efficiency of traction power system is deteriorated over the life cycle.

To achieve the high operation efficiency of an MRT power system, the proper capacity planning of the main transformers should be performed according to the increase of annual ridership of the system. Furthermore, the service reliability of the power system can be improved by executing the load transfer among transformers with switching operation in case of system emergency for example at the times when an outage happens at one of the main transformers. In this way, the transformer units are installed with proper capacity to meet the whole power demand of the traction system and very significant saving of transformer investment can be obtained for the successful operation of the traction system. Because the power demand is increased with the annual ridership, the transformer capacity planning can be treated as a dynamic programming problem. The unit commitment of main transformers is then determined so that the overall cost of transformer loss and investment over the period from the first year to the target year can be minimized.

II. POWER SUPPLY SYSTEM DESCRIPTION

The power distribution system of DC electrified railways include traction substations for stepping down and converting the AC voltage to DC and also lightning substations for each station. The schematic diagram of the power distribution system of a DC electrified railway is shown in Fig. 1.

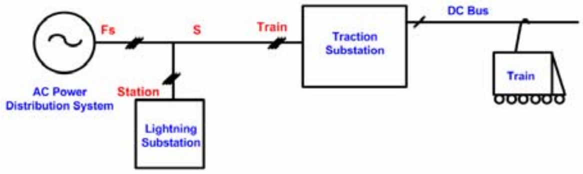

Fig. 1. Schematic of the power distribution system of DC electrified railways.

The traction substation has one or two 20 kV /0.592 kV/ 0.592 kV three winding transformers with Y/Y/Δ connections which step downs the 20 kV AC grid voltage to 592 volts AC. Two six-pulse rectifier units are connected in parallel to the outputs of the transformer which convert the 592 volts AC to 750 volts DC. Therefore, a 12 pulse rectifier is utilized in the traction substation for reducing the amount of harmonics in the system. The DC voltage is then transmitted along the track through overhead contact or third rail systems. The schematic diagram of the traction substations is shown in Fig. 2. The lighting substation that is used to consumption of lighting,

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ventilation and lifts in the stations utilize a 20 kV/400 V transformer with Y/Δ connection.

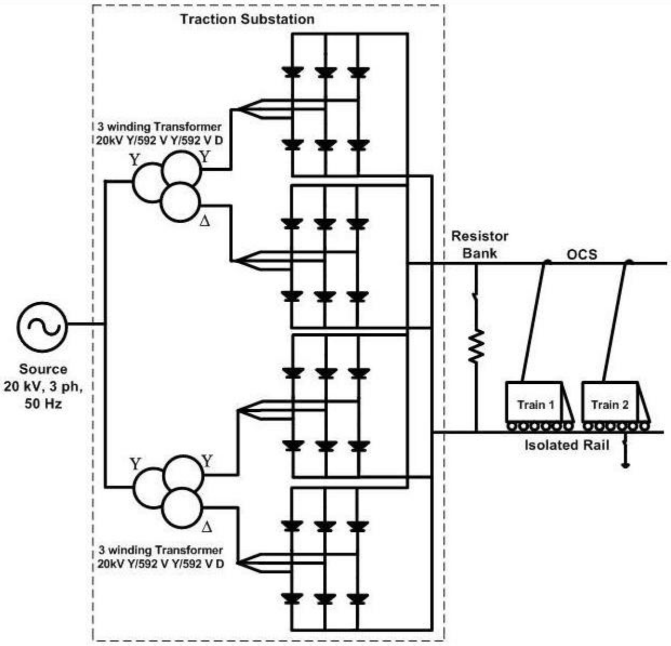

Fig. 2. Schematic of traction substations of DC electrified railway.

The single line diagram of the AC power distribution system feeding this first part of the railway system is shown in Fig. 3.

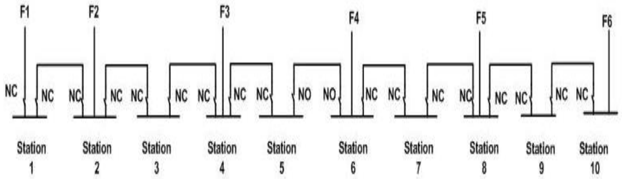

Fig. 3. Single line diagram of power distribution system for Tabriz urban railway.

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. The train sets running along the main lines pick up the DC power from the catenary and use their variable voltage variable frequency inverter fed three-phase induction motors for driving the train sets. The negative return DC current is collected and returned to the traction substations via special installed instruments for minimizing the stray current effects.

Fig. 4 shows the typical speed profile of a train set between two stations which consists of acceleration, constant speed and braking periods. When train is in the brake mode, the regenerative energy will be converted back into the DC line that can provide a part of the required power for the other running trains along the track. The PWM and quasi-six-step modes are applied to achieve the constant torque or constant acceleration when the train set leaves the station. The six-step is applied for the operation of both constant power and constant slip frequency.

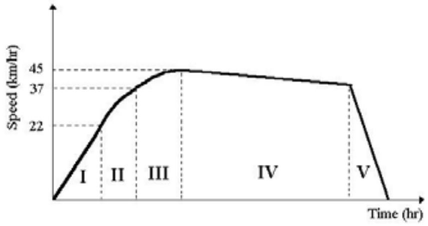

Fig. 4. Speed characteristics of the train sets with time variations.

III. DC AND LOAD FLOW ANALYSIS

The loading factor of the main transformers at the traction substation is scheduled to operate at the peak and off-peak periods according to the ridership forecast of the trains along the track. The peak and off-peak loading factors of the train sets in the first years of operation (2005) are 70% and 20% with the headway time of 6 and 12 minutes, respectively. However, this is increased to 100% and 40% with the headway time of 2 and 6 minutes, respectively for year 2015. The annual hourly ridership is then estimated by linear interpolation for each study year.

After determining the LF and headway of train sets during the peak and off-peak periods for each study year, the power demand of the traction substations should be studied carefully in accordance with the train traffic schedule. The power demand of a traction substation does have a very dramatic varying characteristic as shown in Fig. 5 due to the high number of start and stops of the trains with different time schedules.

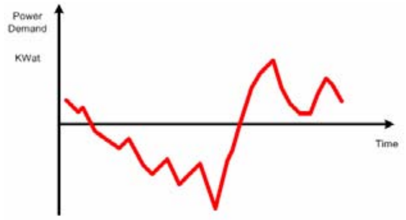

Fig. 5. Power demand characteristic of a traction substation.

It is necessary to study the DC load flow analysis at first where each train set represents a load bus with the power demand and location solved by considering the operation time table of the traction system. Then the AC load flow is necessary to be done for studying the power demand of main transformers in the traction substations where each traction substation is a load bus with the power demand result of DC load flow analysis. With the ridership forecast and the proposed headway, the total propulsion power demand of the whole traction system can be solved by load flow analysis for all main lines. A schematic diagram of the power demand of a traction substation at the peak and off-peak periods is shown in Fig. 6 while the main transformers are loaded very lightly.

In this way, the operation efficiency of the traction power system will be enhanced by proper planning of main transformers according to the peak power demand growth of the traction system for each study year.

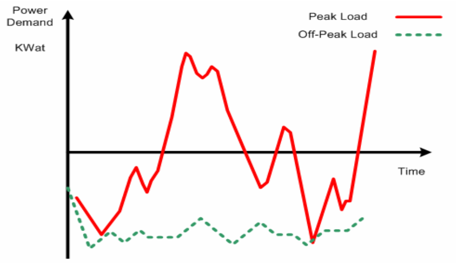

Fig. 6. Peak and off-peak power demand characteristic of a traction substation.

According to load flow analysis, the annual peak and off-peak power demand for the train set propulsion are calculated. The unit commitment strategy of main transformers is developed in this study so that the overall cost of capital investment and power loss can be minimized. Furthermore, the total transformer capacity for each study year should be sufficient to cover the annual peak demand and maintain the service reliability by providing proper reserve capacity.

III. SIMULATION RESULTS

The analysis of the dynamic programming of unit commitment for the traction system as the functions of train traffic schedule, load forecast, loading factor of the main transformers of the traction substation and unit commitment procedure are done with MATLAB software. For studying the power quality characteristics of electrified railway system, the DC urban railway traction system of Tabriz is simulated according to Figures 2 and 3 as shown in Fig. 7 with PSCAD/EMTDC software.

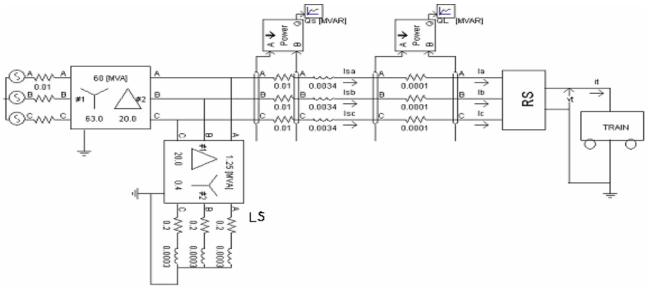

Fig. 7. PSCAD/EMTDC based traction power system simulation.

The current and voltage waveforms of the traction power supply system are shown in Fig. 8 while the harmonic spectrum of the source current is also shown in Fig. 9.

The three phase output voltage waveform of the inverter's of the induction motors with its RMS value are shown in Fig. 10. The DC current feeding the VSI of the first and second train sets as i_1 and i_2 is shown in Fig. 11. It is shown that during the accelerating time, the amplitude of i_1 and i_2 increases, it is almost constant in the constant speed mode and during regenerating braking mode, it will decrease and flow back from the inverter to the DC bus. If the conventional braking is happened instead of the regenerative, the current values decreases to constant value of zero. Therefore, the DC current of the overhead contact system as the sum of i_1 and i_2 is shown in Fig. 12.

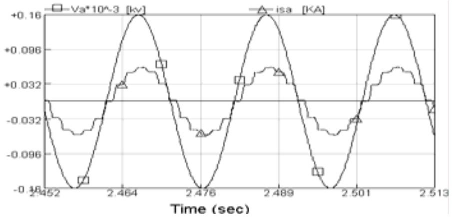

Fig. 8. Harmonic spectrum of the traction power system current.

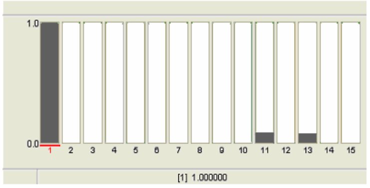

Fig. 9. Harmonic spectrum of the traction power system current.

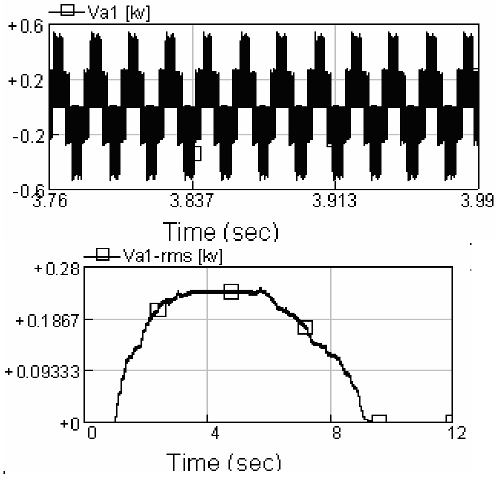

Fig. 10. The output voltage of the PWM controlled inverter feeding the induction motors.

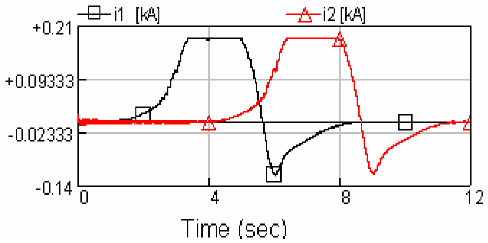

Fig. 11. DC current feeding the inverters of the first and second train sets.

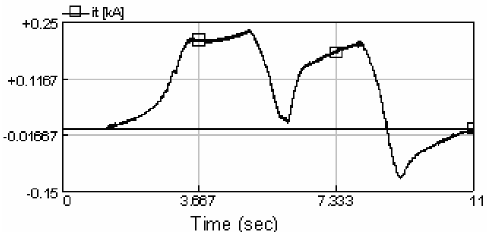

Fig. 12. DC bus current in the overhead contact system.

The RMS output current of the inverters of the first and second train set are shown in Fig. 13. It can be understood that at the accelerating time, the current increases but it reaches to its steady state value very fast and when regenerative braking happens, there is an overshoot in the decreasing waveform of the current because of the reactive part of the current because the induction machine consumes reactive power in generator mode. Providing conventional braking instead of regenerative, the current waveform would decrease to constant value of zero without a sudden overshoot.

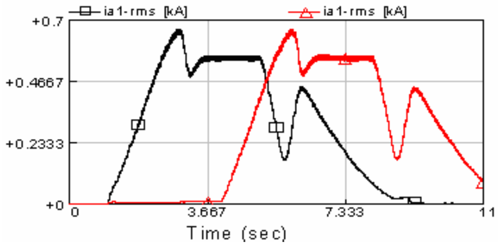

Fig. 13. RMS output current of the inverters of the first and second train sets.

The active and reactive power consumption of the first and second train sets are shown in Figures 14 and 15 respectively. The regenerated active power of the first train set is consumed by the second train but regenerated active power of the second train set is wasted in the resistor banks in the traction substation because of no active power demand in the system as shown in Fig. 16.

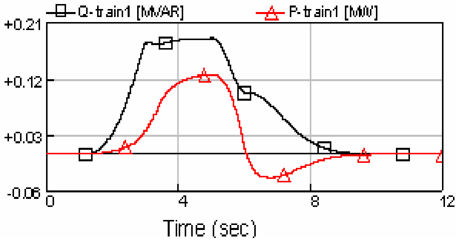

Fig. 14. Active and reactive power consumption of the induction motors on the first train set.

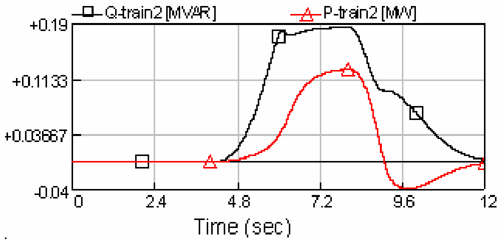

Fig. 15. Active and reactive power consumption of the induction motors on the second train set.

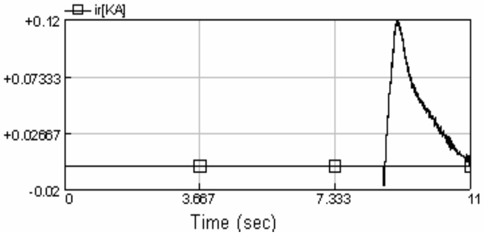

Fig. 16. DC current in the resistor bank in the traction substation.

IV. CONCLUSION

Utilizing unit commitment and transformer planning methods for an electrified urban railway system is applied to derive the optimal transformer capacity to meet the annual peak demand and provide reserve for service reliability, while minimizing the overall cost of main transformers over the life cycle. In this paper, the dynamic programming method of unit commitment is done in MATLAB where its results are the input data for the traction power system of our power quality investigation procedure. The power quality characteristics of the traction system are then studied and verified through the simulation results done with PSCAD/EMTDC software. The power quality problems of DC electrified urban railway systems are discussed for the unit commitment situations on the main transformers of the traction substations.

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