COMPUTER MODELING FOR COMPLEX ENGINEERING DECISIONS

Traction Power System Study For Metro-North Railroad

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1 INTRODUCTION

In 2002, Metro-North Railroad (MNR), in conjunction with the State of Connecticut Department Of Transportation, commissioned SYSTRA Consulting, Inc. to carry out a system-wide study of its traction power system. This paper describes the activities of the study to date. The study work is ongoing.

The study is concerned with the electrified portion of the MNR system. The electrified tracks of the MNR system consist of three lines: Hudson Line, Harlem Line and New Haven Line. While Hudson and Harlem lines are in New York State only, the New Haven line serves both New York State and Connecticut State. A map of the system is shown in Figure A1 of the Appendix.

All three lines originate north of New York City and converge to reach Grand Central Terminal in the heart of Manhattan. In addition, AMTRAK operates on a portion of the New Haven Line as part of the North-East Corridor services. The traction power system is a key element of the railroad's operations.

Due to historical reasons, the MNR Traction power system comes in two forms: DC and AC.

The DC system uses rectifiers in line-side substations to convert commercial power at 3-phase 13kV AC into 700V DC, which is distributed by conductor rails to power the trains. The DC system serves both Hudson Line (34 miles of route) and Harlem Line (48 miles of route), plus a small section of the New Haven Line (3 miles of route). There are about 250 miles of tracks in the DC territory.

The AC system uses transformers in supply-substations to transform commercial power at 3 phase 138kV (or 115kV) AC into 26kV AC. Autotransformers in line-side substations further transform the 26kV voltage into +13kV/-13kV voltages. These voltages are distributed along the tracks by the overhead catenary system and line-side feeder wires. Trains are powered at 13kV voltage level. The majority of the New Haven Line (between Pelham and New Haven) plus a branch between Stamford and New Canaan is served by AC power. There are about 250 miles of tracks in the AC territory.

2 DC SYSTEM STUDY

2.1 Load flow model

The software package that is used to develop the load flow model is the RAILSIM® Load Flow Analyzer (DC version). The entire DC system is modeled as a single entity, in the same way that the system is configured electrically. The input data for the load flow model is described below briefly.

Track data. To start with, the track data is "mapped" into the model. Due to the complexity of the track layout, the tracks are divided into segments. These segments are then pieced together to reflect the real connections of the system. Engineering stationing is used to describe the locations of all entities that are associated with the tracks, in the same way as it is used in engineering drawings.

This approach makes the model extremely flexible. There is no limitation on the track topology that can be modeled. For example, the Grand Central Terminal has two levels with dozens of tracks, which form part of the integral model.

There are many instances when discontinuities in engineering stationing occur. This may be caused by previous line changes, or different conventions in different lines that make up the system. Such discontinuities can be accommodated easily.

Train operations. The Year 2002 operating timetable is used as the baseline. Due to the nature of the commuter railroad, most trains are unique, since they differ in either train consists and/or station stop patterns. This demands that each train must be modeled individually. There are over 600 trains dispatched from across the system in a typical weekday. Weekends and holidays have different timetables from weekdays.

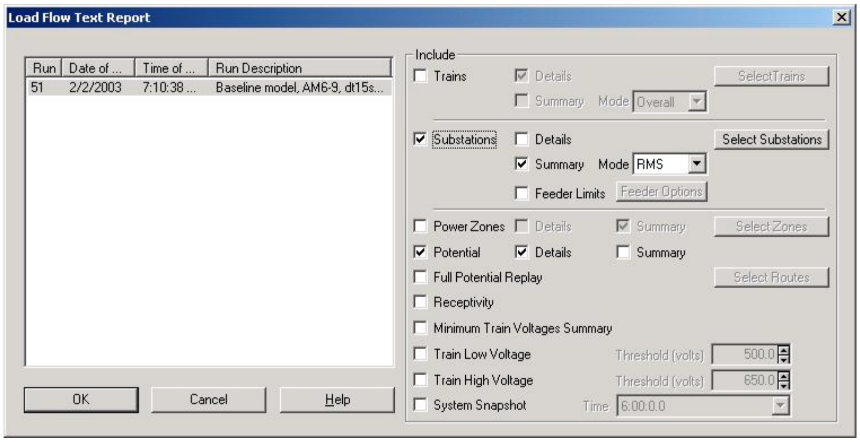
Yard load. MNR has four yards for train storage, inspection and maintenance for DC powered trains. Trains in the yards take a lesser amount of power as they draw “hotel” power to provide heating or air conditioning, and to operate compressors, etc. Based on the operating timetable, each train that enters a particular yard was assigned a power demand figure and time duration for its stay in the yard. A final load table for each yard was derived over a typical 24-hour cycle, including background load in workshop areas that are part of the yard facilities. Saturday, Sunday and holidays were treated separately from weekdays.

Vehicle characteristics. Seven types of electric vehicles currently run on the DC system. Six of which are electric multiple units (EMU) with the type designations of M1a, M3a, ACMU, M2, M4, M6, while one is a dual-mode powered diesel electric-electric locomotive known as the “Genesis”. Between Grand Central and 125th Street, the Genesis locomotive takes power from the 3rd rail electrical supply. North of 125th Street, it runs on diesel. A rolling stock database was established, with each type of vehicle having its own characteristics.

Electrical Network. For the electrical network data input, the start point is the electrical single line diagram. A full diagram was developed for the whole DC system. Individual components of the network include: substations and circuit breaker houses, 3rd rail conductors, running rails; feeder connections (both positive and negative), negative reactors, cross-track bonding connections, etc. A database for all these components was established for inputting into the load flow model.

2.2 Organization of Simulation Results

The simulation results are stored in binary data files. A dedicated report generator was developed to present the results in both graphical form and numerical form. Both forms of output can be exported to electronic files. These files can be used for report writing and further analysis. The report and plot wizards of the report generator are shown in Figure 1 and Figure 2 respectively.



Load Flow Text Report

Run	Date of ...	Time of ...	Run Description
51	2/2/2003	7:10:38 ...	Baseline model, AM6-9, dt15s...

Include

☐ Trains ☑ Details ☐ Summary Mode Overall

☑ Substations ☐ Details ☑ Summary Mode RMS ☐ Feeder Limits

☐ Power Zones ☐ Details ☑ Summary

☑ Potential ☑ Details ☐ Summary

☐ Full Potential Replay

☐ Receptivity

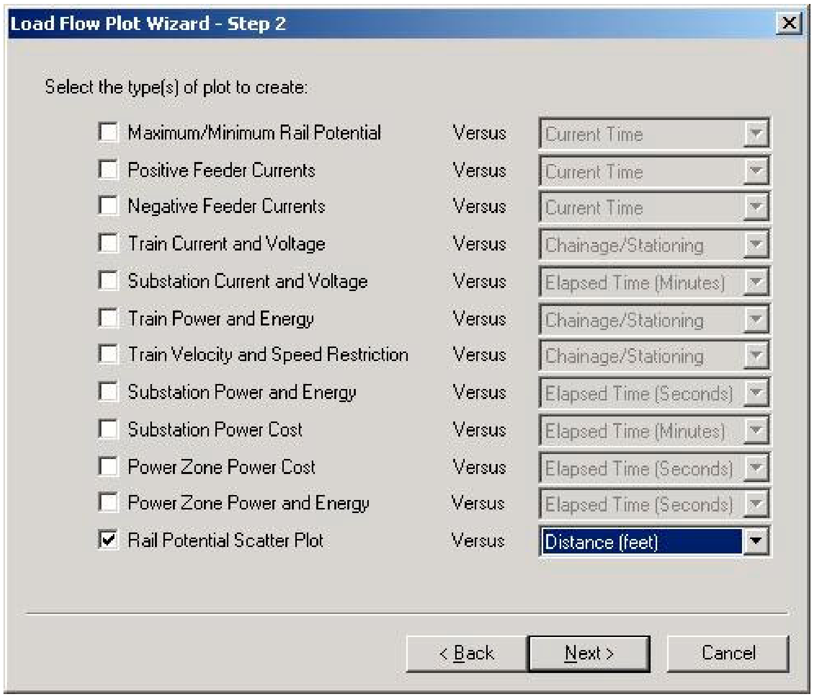
☐ Minimum Train Voltages Summary

☐ Train Low Voltage Threshold (volts) 500.0

☐ Train High Voltage Threshold (volts) 650.0

☐ System Snapshot Time 6:00:0.0

Figure 1. Report generator text report wizard



Load Flow Plot Wizard - Step 2

Select the type(s) of plot to create:

☐ Maximum/Minimum Rail Potential Versus Current Time
☐ Positive Feeder Currents Versus Current Time
☐ Negative Feeder Currents Versus Current Time
☐ Train Current and Voltage Versus Chainage/Stationing
☐ Substation Current and Voltage Versus Elapsed Time (Minutes)
☐ Train Power and Energy Versus Chainage/Stationing
☐ Train Velocity and Speed Restriction Versus Chainage/Stationing
☐ Substation Power and Energy Versus Elapsed Time (Seconds)
☐ Substation Power Cost Versus Elapsed Time (Minutes)
☐ Power Zone Power Cost Versus Elapsed Time (Seconds)
☐ Power Zone Power and Energy Versus Elapsed Time (Seconds)
☑ Rail Potential Scatter Plot Versus Distance (feet)

Figure 2. Report generator plot wizard

3 FIELD DATA GATHERING

MNR recognized that the simulation results could only be as good as the input data. From the very beginning, the project management team insisted on collecting good-quality data from field test where possible. As a result, an extensive field data gathering program is a salient feature and an important element of this study. This section describes some of the field tests taken to acquire the necessary input data.

3.1 Measurement for substation data

Substations are a major component of the electric traction power system. There are 47 substations and 3 circuit breaker houses (CBH) in the DC system. (A circuit breaker house makes electrical connections between different tracks to reduce voltage drops to the trains. It is similar to a substation but has no rectifier equipment). A typical substation diagram is shown in Figure 3.

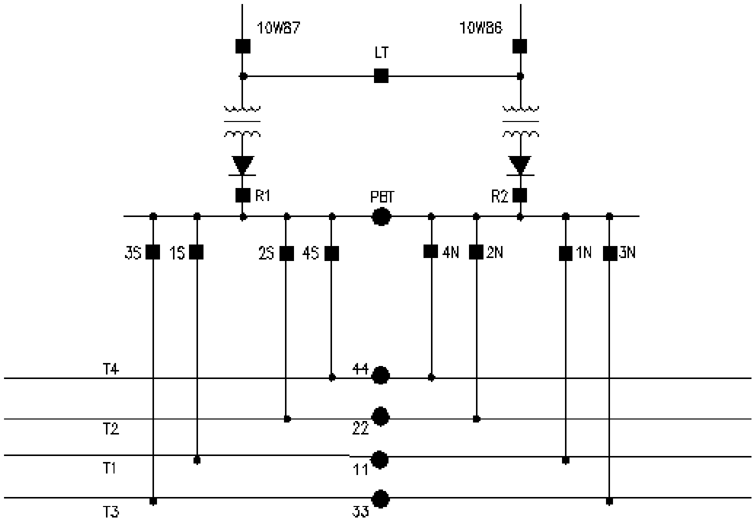


Figure 3. Typical DC substation diagram

In order to model the DC substations, the rectifier's voltage regulation characteristics must be established. Typically the desired regulation is specified in the technical requirements before the rectifiers are built. The parameters of the transformers and rectifiers determine the inherent regulation of the equipment. There are two additional factors that affect the overall regulation of the substation. These are the tap positions of the rectifier transformers and the AC supply conditions. The AC supply conditions are affected by two parameters: short circuit capacity and supply voltage variations. Although typical figures can be assumed, field measured data is superior as it can better reflect the real system conditions.

Due to the large number of substations in the system, it was not practical to record the data in each substation. Eight substations were chosen across the system as representative sites. An example from the recorded data is shown in Figure 4.

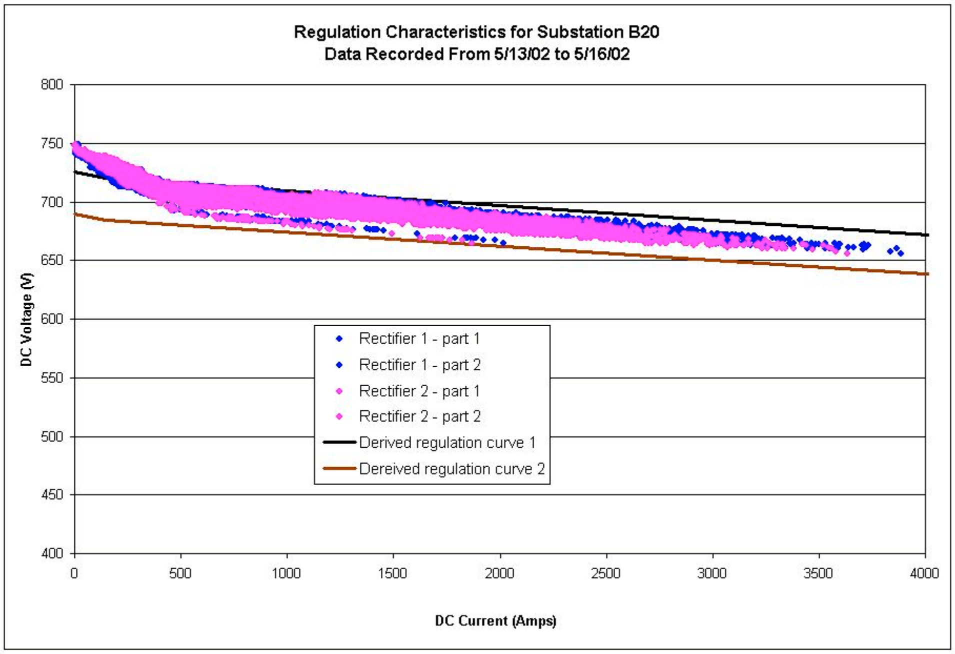


Figure 4. Derivation of rectifier regulation characteristics from measured data

This figure illustrates that the voltage regulation forms a band rather than a single line. This reflects the instantaneous changes in AC supply side conditions. The two solid-lines in the figure represent the derived upper and lower limits of the regulation. Usually the average regulation characteristic is chosen for the load flow model. In some cases, either the upper or the lower limit may be more desirable. This is dependent on the particular application that is undertaken.

3.2 Measurement for train data

All types of trains that run on the DC system were field-tested. Test-trains were run on a section of track on the Hudson line. Data was gathered by electronic data recorders and transferred to computers for analysis. At the same time, line-side substation data was also recorded in three substations that supply the test track. The test track was electrically isolated from the rest of the system during the tests. The data recorder setup in one of the tests is shown in Figure 5.

Figure 5. Recorder setup for the measurement of train data

From each test, the test data was analyzed to obtain the calibrated characteristics of these trains. Figure 6 is an example, which shows the derivation of tractive effort curve from the test data.

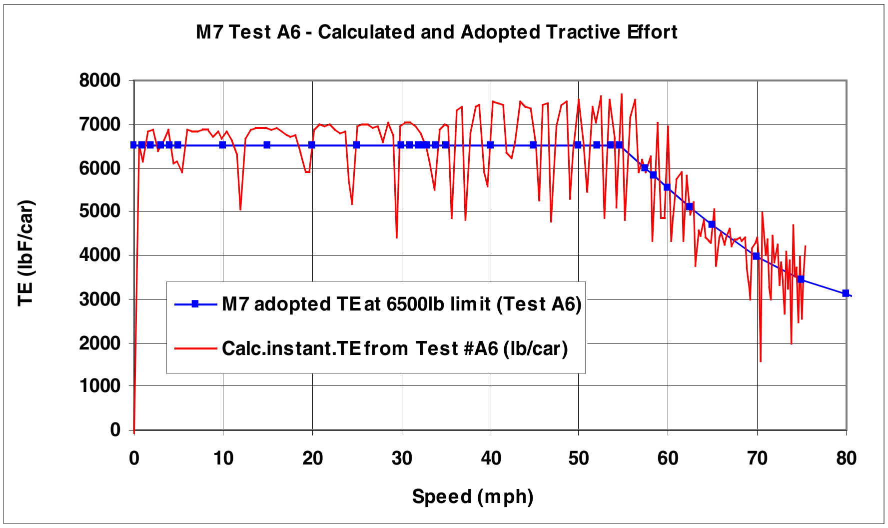


Figure 6. Calibration of tractive effort from test data

3.3 The Benefit of Field Test

The field tests were not only used to derive the various parameters that are required by the simulator. They have also been used as a tool for evaluating current system conditions and for system improvement. There were occasions when unforeseen benefits that can be brought by such tests. This section describes one such example.

Modification of M3a propulsion characteristics

One of the main indicators for traction power system performance is the train voltage. If a train's voltage level is healthy, its power demand can be fully met by the traction power system. If a train's voltage is too low, its power demand cannot be fully met. As a result, the train cannot accelerate at the desired acceleration rate, which will cause journey time delays.

The M3a vehicle was field-tested, based on its existing conditions. Its electric current demand characteristics were then graphed, which is shown by the thin line in Figure 7 (blue color). MNR equipment engineers studied it and recognized that the peak current demand by this type of vehicle was excessive under existing settings. Such high current demand has the tendency to pull train voltage down. A new setting was proposed by reconfiguring the control circuitry. The new setting was then field-tested again. Figure 7 shows the comparison between the new characteristic (shown by the thick line in red color) and the old one.

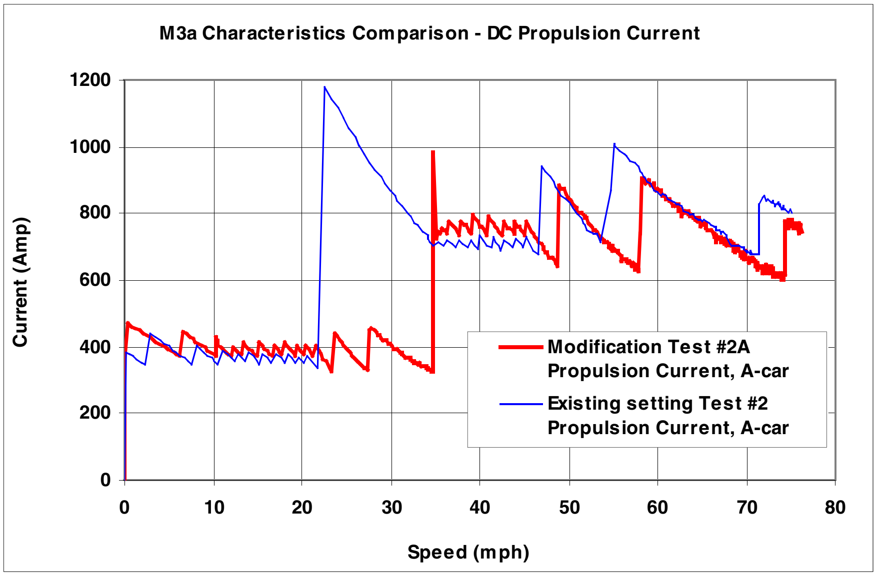


Figure 7. Modification of the power control regime for M3a vehicle to limit excessive peak current demand

As a result of the modification, the peak current demand is reduced from 1180 Amps per car to 980 Amps per car, a 17% reduction. The load flow model was used to assess the overall effect of this modification on the traction power system performance. With the same electric network in service, the modified fleet would result in a reduction of low voltage occurrences by 28% in the morning peak hours.

Subsequently, MNR decided to modify the control circuits of the whole M3a fleet. The cost of reconfiguring the vehicle's control circuits is insignificant compared with upgrading the traction power system that can achieve the same performance. The cost saving is apparent.

3.4 Model Validation

The study underwent a process of verifying the load flow results against utility billing records. A large volume of data was provided by the utility company in the form of recorded power demand (kW) for each substation. The utility company billed these by time of day, for 24 hours each day. Altogether, 13 months' data was made available from January 2002 to January 2003.

A number of load flow simulation runs were then carried out. The results from the load flow model were compared against the billed data. Two items of data were compared. These are:

- 30 minute interval peak power demand (in kW) for both summer and winter
- Energy consumption (in kWh) for summer months, winter months and a whole year

Both items showed very good agreement between simulated results and the billed data.

The load flow results for peak power demands for both summer months and winter months were within five percent (5%) of the billed data. This is shown in Table 1.

Table 1. Comparison between load flow results
and the billed data (weekday kW power demand)

Time	**30 Minute Interval Peak Power Demand Difference %**
Summer Months	103.5%
Winter Months	100.9%

The load flow results for energy consumption were within five percent (5%) of the billed data. This is shown in Table 2.

Table 2. Comparison between load flow results
and the billed data (kWh energy consumption)

Time		**Energy Consumption Difference %**
Weekday	Summer Months	104.7%
	Winter Months	103.9%
	Annual Average	104.5%
Saturday	Summer Months	98.4%
	Winter Months	98.4%
	Annual Average	98.4%
Sunday	Summer Months	95.9%
	Winter Months	96.9%
	Annual Average	96.2%

This process was an excellent opportunity to verify the validity of the load flow model. It is apparent that good-quality input data that was gathered from field test was instrumental in achieving this type of accuracy.

4 A TOOL FOR DECISION MAKING

With close agreement between simulation results and real data, a high degree of confidence can be placed on the model. MNR engineers have made full use of it as a tool for decision making.

These decisions include assessment of the current condition of the traction power system and prediction of future requirements. This section describes some aspects of the applications.

4.1 Upgrading And Renewal of The Electrical Network

Between now and year 2020, the passenger traffic volume in the system is predicted to grow. As a result, the system load will increase. The load flow model has been used to study various scenarios of system improvement to meet the increased demand.

The upgrading and renewal include but are not limited to the following items:

- **Substation Rectifier Capacity Increases.** Where a substation is found to be loaded near to its long term rating, its capacity needs to be increased. This may be in the form of extra transformer-rectifier units, or replacement units with higher ratings on the same site. It could also be an additional substation nearby.
- **New Circuit Breaker House or Substation.** If a feeding section is found to cause excessive voltage drops to the trains that affect the train's performance, an intermediate circuit breaker house may be considered. If a circuit breaker house is not sufficient to solve the problem, a new substation needs to be considered.
- **Low Resistance Aluminum/Stainless Steel Contact Rail.** In place of a new circuit breaker house or a new substation for a weak feeding section, low resistance aluminum/stainless steel contact rail may be considered for replacement of existing higher resistance all-steel contact rails. Similarly, when a heavier running rail replaces a lighter running rail, the resistance in the return circuit is reduced. For a particularly weak section, a combination of contact rail replacement, running rail replacement and new circuit breaker houses or substations may be considered.
- **Protection Settings of Substation Feeder Breakers.** When the current through a feeder circuit breaker increases, it may exceed the settings of certain over-current protection devices. If this is the case, the protection settings need to be adjusted. If there is no room for such adjustment, new forms of protection need to be considered in order to avoid nuisance trips but still to provide the intended protection function.
- **Feeder Cables, Negative Return Reactors And Negative Bonds.** The simulated currents through these circuits are compared against their current-carrying capacities. Where a weak spot is identified, upgrading or replacement of the component is recommended.

4.2 Substation Capacity Assessment

Substations are the sources of the traction power system. They must deliver the power that is required to run an effective service. Two questions are often asked. (a). How is the substation performing under current service condition? (b). Is there sufficient capacity to run a future service?

Figure 8 shows a sample plot of substation voltage and current vs. time that was obtained from the simulation results.

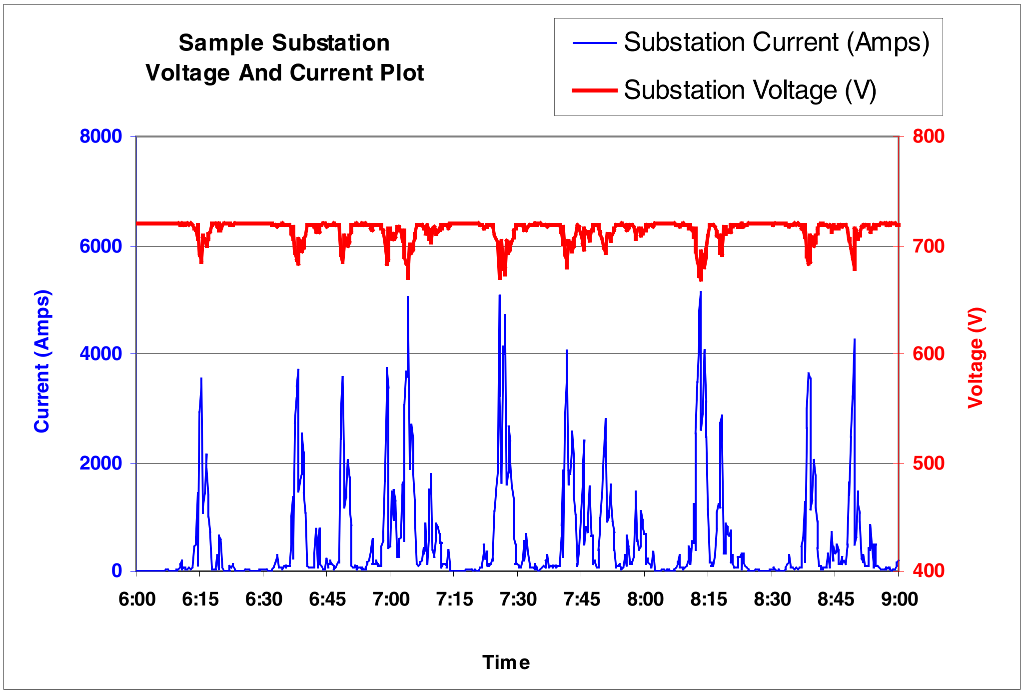


Figure 8. Substation load cycle

The load cycle plot gives a clear indication of how much the substation is loaded, and in what manner the substation is loaded. At a higher level, the ratios of substation load currents (root-mean-square values) over their long-term ratings are summarized across the system. A sample is shown in Table 3.

Table 3. Substation load summary

Substations Parameters					**RMS Load / Rating Ratio**	
Substation Code	**Stationing (ft) xxxx+xx**	**Miles**	**Installed Capacity (MW)**	**100% Rated current kA**	**Y2002-Current Baseline**	**Y2020A-Future Baseline**
B07	429+20.	8.13	4.0	5.8	75%	90%
M086	118+09.	2.24	3.3	4.8	56%	80%
B09	491+58.	9.31	4.0	5.8	57%	72%
B10	554+34.	10.50	4.0	5.8	63%	70%
B22	1172+28.	22.20	4.0	5.8	40%	68%
M126	225+00.	4.26	6.6	9.6	47%	62%
M042	13+20.	0.25	9.9	14.5	43%	58%
B13	690+20.	13.07	3.3	4.8	N/A	58%
M072	76+19.	1.44	6.0	8.8	40%	57%
M050	35+00.	0.66	9.9	14.5	42%	57%
B14	760+70.	14.41	4.0	5.8	52%	57%
B32	1706+40.	32.32	4.0	5.8	37%	56%

This table shows in descending order the most heavily loaded substations for a future service scenario. This type of summary gives a panoramic view of the predicted load conditions for all substations in the system.

Table 3 indicates that some of the substations will have high utilization ratios in the Y2020A scenario. Reinforcements for these areas are recommended.

Similar load summaries can be made for all current-carrying components, including feeder cables, negative reactors, conductor rails, etc. Short-term peak loads are summarized in a similar manner.

4.3 Power Delivery Ability

With adequate capacity established for the substations, the traction power system must have sufficient delivery ability to transmit the power to the trains. Power is transmitted through the 3rd rail and the running rails.

Figure 9 shows a sample plot of train voltage and current vs. location from simulation results, as the train moves along the track.

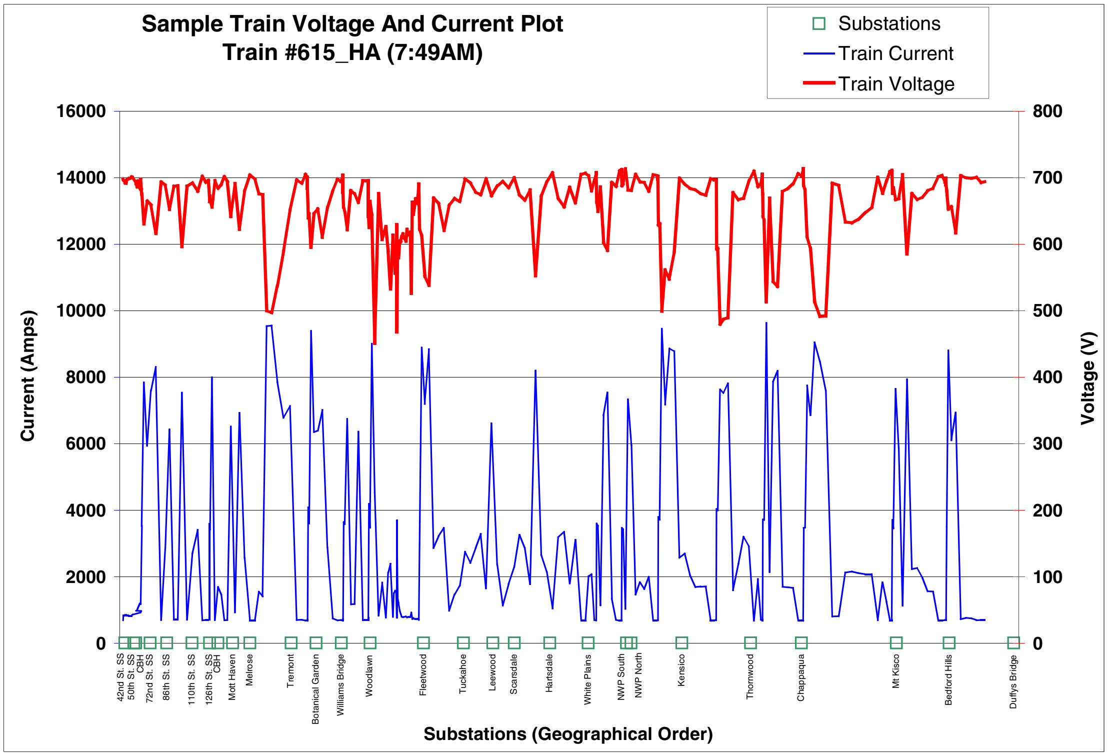


Figure 9. Train voltage and current plot

As this figure shows, the voltage at a train can drop significantly in some locations. This is an indication of weak spots in the power delivery network. All such weak spots need to be found out across the whole system.

At a higher level, a scattered plot of all train's low voltage occurrences was developed from the simulation results for this purpose. This type of plot serves as an indicator of the power delivery ability of the traction power system (or the inability to deliver power in certain weak areas).

Figure 10 shows an example. This is a scattered plot for all occurrences when train voltage falls below 500V on a section of the Harlem Line under a simulated operating scenario. Below 500V, train performance starts to degrade.

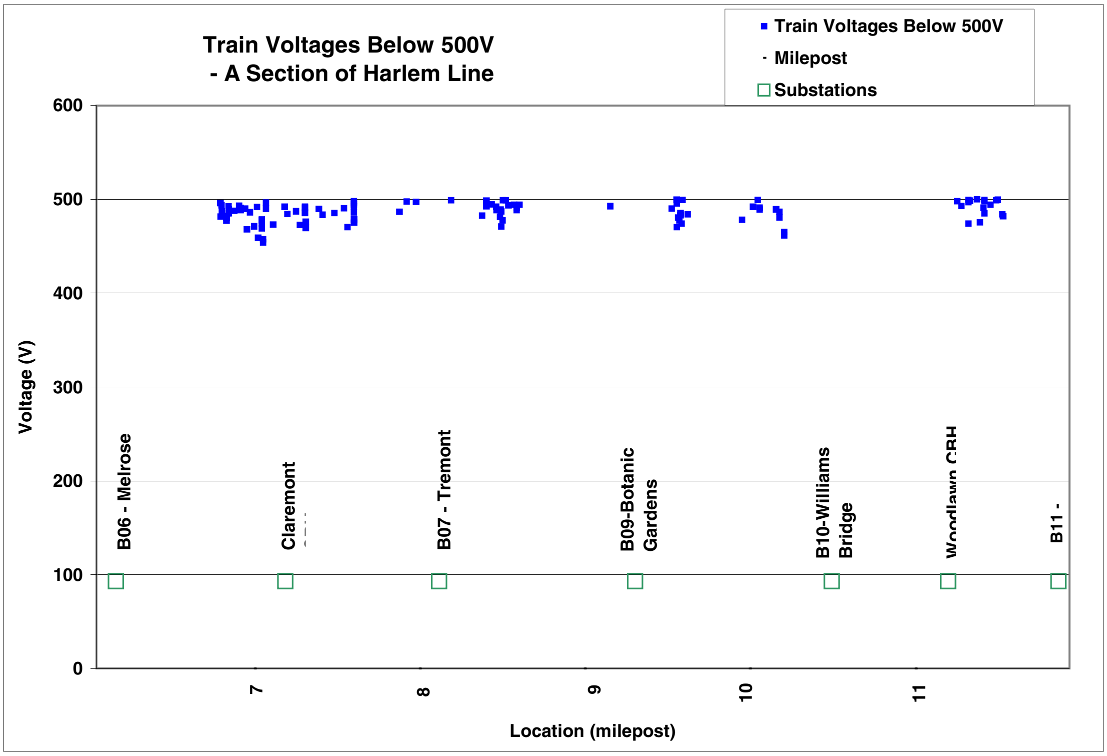


Figure 10. Scattered plot for train low voltage occurrences

The data shown in the scattered plots are then summarized. Table 4 gives a comparison of all occurrences when train voltages fall below 500V under several simulated scenarios.

Table 4. Summaries for the number of train voltage occurrences below 500V

Line	**Scenario A**	**Scenario B - With one Substation Outage**	**Scenario C**	**Scenario D**
Harlem line	655	790	178	51
Hudson line	348	348	137	30
New Haven line	2	2	2	2
Total	**1005**	**1140**	**317**	**83**

After the weak areas are identified, appropriate enhancement measures can be considered to mitigate or eliminate such weakness.

The primary factors that determine the power delivery ability of the electrical network are the no-load voltages in substations, spacing between substations and the resistivity of the 3rd rail and the running rails.

The example in Table 4 shows the effect of an envisaged capital improvement program. New electrical equipment in Scenario "C" over Scenario "A" includes some new substations and some 3rd rail replacement by aluminum composite rails that have lower resistivity than all-steel rails. Scenario "D" has more such equipment over Scenario "C". As more equipment is added, the numbers of low voltage occurrences are reduced.

4.4 Energy Consumption Estimation

Total system energy demands and losses are part of the output from the load flow model. These figures are useful for long term financial planing. A sample summary is shown in Table 5.

Table 5. Summary of system-wide energy consumption

Scenarios	Total Energy Delivered by Substations (kWh)	Total Energy Loss in System (kWh)	% Total Energy Loss in System
Scenario A	252055	22953	9.11%
Scenario B - With one substation Outage	252124	23911	9.48%
Scenario C	252584	17402	6.89%
Scenario D	249991	13307	5.32%

The scenarios listed in Table 5 are the same as those in Table 4. These figures show that as more equipment is added, the energy losses in the system are reduced, which will reduce the energy cost.

The other side of the equation is the cost of the envisaged new equipment. The technical and economical optimization process demands much iteration.

4.5 System Compatibility

MNR was in the process of introducing a replacement fleet of vehicles. The new vehicle, designated as M7, is heavier than the existing vehicles and can accelerate faster since it is equipped with modern traction drives of higher power ratings. As a result, it will demand more power from the electrical network.

Before the new vehicles enter into service, MNR engineers were anxious to have some lead-time in ensuring that the new vehicles are compatible with the existing traction power system.

Two questions were asked at the time for this new vehicle:

1. Will the traction power system be able to cope with the higher power demand of the new vehicle?
2. When substation's feeder circuit breakers have open and close operations, will the new vehicle affect such operations adversely?

Temporary performance limit

The first question was answered by simulation. The fleet replacement will happen in stages. For the first stage, the new vehicles will replace some of the existing vehicles. When this stage is reached, the traction power system is forecast to have certain upgrading work complete. Simulation results showed that the occurrences of train low voltages would increase to unacceptable levels if there were no limitation on the power demand of the new vehicles.

In order to run the services under the first stage fleet replacement conditions, some limits on the power demand need to be imposed. The power-demand limits on the new vehicles need to be done in such a way that the new vehicles should have at least a comparable or better performance against the performance of the vehicles that they are replacing.

The power control regime of the new vehicle is implemented by software. Its flexibility means that MNR engineers can experiment with the control of the vehicle's power demand without having to make any changes to the traction power circuitry. Several power-demand-limiting schemes were evaluated. These include:

- Limit of tractive effort
- Limit of propulsion current
- Limit of both tractive effort and propulsion current

For each scheme, simulations were carried out to compare the performance of the new vehicle against that of the existing vehicle. These were in turn fed into the load flow model to evaluate its impact on the traction power system. Many more such simulations were carries out until two acceptable power-demand-limit schemes emerged.

After MNR engineers were satisfied with the simulation results, a prototype train was brought onto the railroad for field tests. The test results showed that the selected power-demand-limiting schemes could be implemented as devised. The test data was used to calibrate the vehicle's characteristics under the proposed power-demand-limiting schemes, which form part of the rolling tock library for the study.

Figure 11 shows the comparison of the train's current demands between an existing vehicle and the new vehicle under two power-demand-limiting schemes.

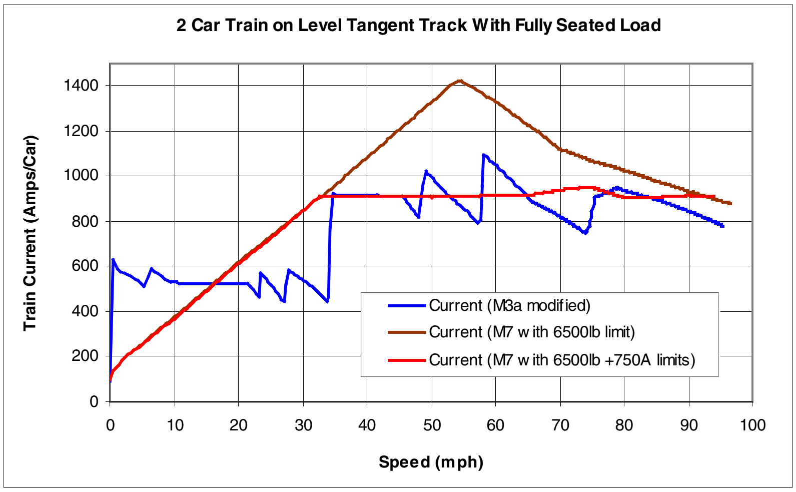


Figure 11. Simulated current demand from calibrated characteristics

Figure 12 shows the comparison of the train speeds under the same conditions as shown in Figure 11.

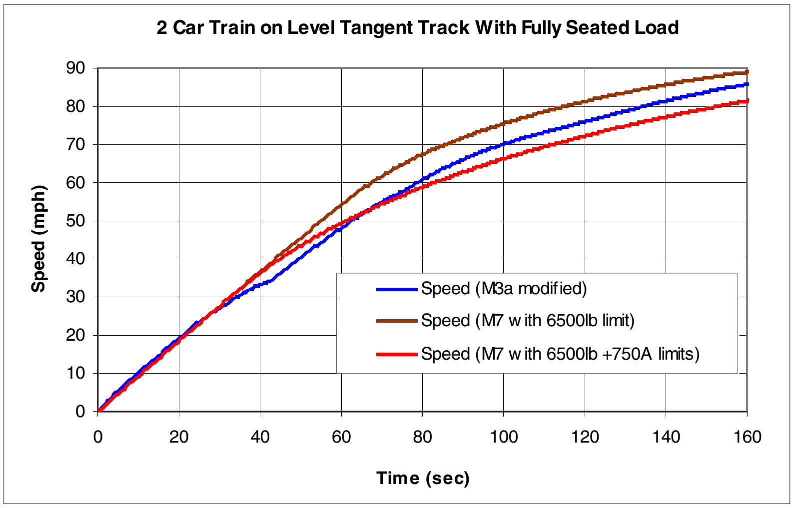


Figure 12. Simulated train speed from calibrated characteristics

With the help of the simulation results, MNR engineers were able to formulate a plan that will progressively upgrade the power supply system for each stage of the fleet replacement.

Substation circuit breaker reclosing

On the second question, MNR engineers devised a compatibility test scheme. The test was carried out at the same time when the power-demand-limiting test was carried out.

The test results showed that substation circuit breakers could not close if a dead train is in the feeding section. Subsequently, the manufacturer of the vehicle undertook to modify the electric circuitry to ensure that the vehicles are compatible with the existing power supply system. This is another example of the benefit that can be brought by field test.

4.6 Application of New Technology

When considering the future investment on their electrical system, MNR engineers looked at a range of options. As an example, a weak spot in the system was evaluated on whether it required a full rectifier substation or a flywheel substation to support the predicted service.

Flywheels are a type of energy storage device. With the use of new technology in the design and manufacture of these devices, their energy storage capacity is on the increase. The flywheel substation has two advantages over the rectifier substations. One - it takes less space. Two – it does not require high-power connections from outside electricity supplies. (Low power connection is still required for control and auxiliary supplies.)

With close cooperation with the manufacturer of the device, the RAILSIM® Load Flow Analyzer was enhanced to model the functions of this new device. Figure 13 shows the comparison of simulated power outputs between a rectifier substation and a flywheel substation of equal rating on the same site.

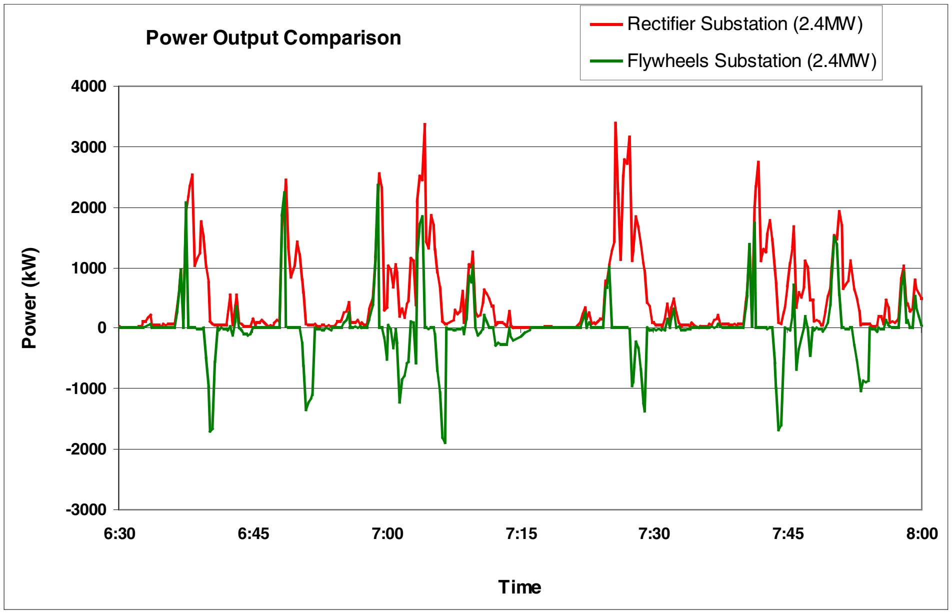


Figure 13. Comparison of power outputs by rectifiers and flywheels

When the flywheels are being charged, they take power from the traction power system. These are shown as negative values in Figure 13. When they are discharging power to the traction power system, the power output is positive. The power output from a rectifier substation is always positive, as the rectifier is a one-way device in terms of power output.

The specific conclusion drawn from this simulation was that a rectifier substation would be needed for this particular site due to heavy power demand in the area. A general conclusion is that each site should be simulated individually to assess the technical merits of this new device.

5 AC SYSTEM STUDY

The AC system model is currently under construction. The development for the AC model takes the same approach as the DC system model. At the time of publication of this paper, extensive field-testing has been carried out to gather the necessary data.

Substation Data Gathering. This includes all of the four supply substations (138kV or 115kV) and three of the intermediate autotransformer substations.

Train Data Gathering. All EMUs operating on the AC portion of the railroad have been tested (M2, M4 and M6). All Amtrak rolling stock types have been tested (AEM7 DC Drives, AEM7 AC Drives, HHP, ACELA trainset).

AC Load Flow Model. The software package that is used to develop the load flow model is the RAILSIM® Load Flow Analyzer (AC version). The entire AC system will be modeled as a single entity, in the same way as the system is configured.

6 CONCLUSIONS

The RAILSIM® load flow model has proven to be a very useful tool in the traction power system study for Metro-North Railroad.

The usefulness of the load flow model has been greatly enhanced by using field test data, and the validation of the simulation results against real world data.

Close coordination with the Metro-North Railroad staff has made the study fruitful.

7 ACKNOWLEDGEMENT

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The viewpoints expressed in this paper are entirely the authors and are not those of either Metro-North Railroad or of SYSTRA Consulting, Inc. or the individuals mention above.

8 APPENDIX

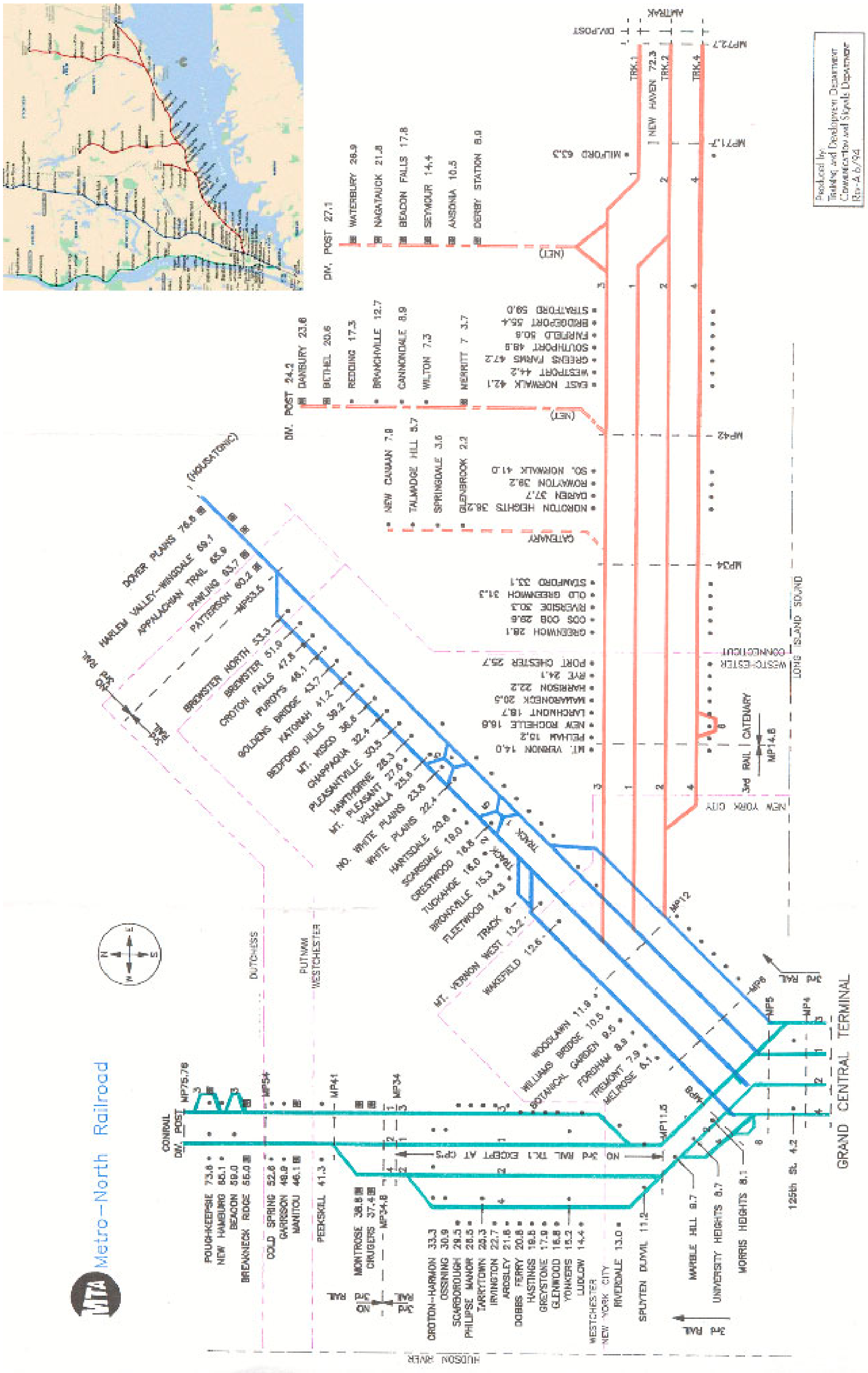

Figure A1. System Map of Metro-North Railroad

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Title of Paper: **"Traction Power System Study For Metro-North Railroad"**
Author: **J. Gordon Yu**

Author's Biographical Information

Gordon Yu graduated with a B.Sc. in Electrical Engineering from the Southwest Jiao-Tong University in China. After a few years of work in the railway industry both in China and in the UK, he went back to university and obtained his Ph.D. in Electrical Engineering from the University of Birmingham in the UK.

He has been working for SYSTRA Consulting, Inc. as a Senior Rail Operations Analyst over the last three and half years. His specialty field of work is in the traction power systems, which involves both simulation software development and applications.

In addition to his work on the Metro-North Railroad Traction Power Study project, he has also studied the NJ TRANSIT traction power systems for both the North Jersey Coast Line, and the Morris & Essex Line.

He has provided training courses for RAILSIM® users, including San Diego Metropolitan Transit Development Board (MTDB), Land Transport Authority (LTA) of Singapore and Washington Group International, New Jersey.

Before he joined SYSTRA, he had worked for WS Atkins Rail Ltd, ALSTOM Power Conversion Ltd and Balfour Beatty Rail Projects Ltd., all in the UK.

There he was involved in design and study of some major railway electrification projects, including:

- Mass Transit Railway Company (MTRC) of Hong Kong – for Lantau & Airport Railway project;
- Network Rail (Railtrack) – for west-coast mainline electrification upgrade;
- London Underground Ltd – for Jubilee Line Extension Project
- Ankara Metro,Turkey,
- Manchester Metrolink,UK
- British Columbia Transit Skytrain System, Canada

He has presented a dozen technical papers in conferences on the subject of traction power systems.