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SIMULATION MODELS FOR THE ELECTRIC POWER REQUIREMENTS IN AN AUTOMATED GUIDEWAY TRANSIT SYSTEM

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16. Abstract

This report describes a computer simulation model developed at the Transportation Systems Center to study the electrical power distribution characteristics of Automated Guideway Transit (AGT) systems. The objective of this simulation effort is to provide a means for determining the power distribution requirements of AGT systems and for evaluating their performances under varied operating conditions. Typical systems which could be modeled include the Morgantown Personal Rapid Transit System, the Dallas-Fort Worth Airtrans System, or one of the proposed Downtown People Movers.

This work was conducted under sponsorship of the Advanced Group Rapid Transit (AGRT) Program of the Office of New Systems and Automation of the Urban Mass Transportation Administration. The purpose of the AGRT program is the development, evaluation, and verification of a second generation AGT technology which is capable of providing transit service in urban areas. The purpose of this report is to provide the reader with a working knowledge of the multi-vehicle AGT simulation model and its application to urban transit systems.

This report specifically describes a Fortran computer program which models the electric power requirements of a typical AGT system. The inputs are: 1) the vehicle propulsion system characteristics; 2) the guideway deployment; and 3) the mission profile for each vehicle. The output is a series of tables which show the voltages, power, and harmonic currents in the electric power distribution system. Also included in this report is a complete listing of the Fortran program and an illustrativ example of its application to multi-vehicle AGT systems is provided.

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AGT; Automated Guideway Transit; Computer Models; Downtown People Movers; Electric Power; Models and Modeling; Simulation Program

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PREFACE

This report describes a computer model developed at the Transportation Systems Center, Cambridge, Massachusetts, for the simulation of electrical power distribution characteristics of Automated Guideway Transit (AGT) systems. This work was conducted under the sponsorship of the Office of New Systems and Automation of the Urban Mass Transportation Administration (UMTA). The objective of this simulation effort is to provide the necessary software for rapid evaluation and assessment of AGT power system distribution requirements.

The author wishes to acknowledge the assistance of Mr. Roger Flanders of the Systems Development Corporation, Cambridge, Massachusetts for his valuable contributions in the development of certain elements of the computer model.

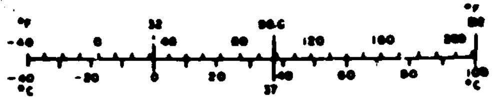
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

This report describes a simulation model developed to study the electrical power distribution characteristics of Automated Guideway Transit (ACT) systems. This work was conducted under sponsorship of the Advanced Group Rapid Transit (AGRT) Program of the Office of New Systems and Automation, Urban Mass Transportation Administration (UMTA). The purpose of the AGRT program is the development, evaluation, and verification of a second generation AGT technology which is capable of providing transit service in urban areas. The computer simulation model developed at the Transportation Systems Center provides the required software for rapid evaluation of the complex power distribution of multi-vehicle AGT systems. The application of the computer model provides the system designers with important information on the anticipated power consumption characteristics of AGT systems. Such information is extremely valuable in both the initial design stage of system development as well as in later system evaluation studies aimed at assessing the overall system performance.

The purpose of this report is to provide the reader with a working knowledge of the multi-vehicle AGT simulation model and its application to urban transit systems. Basically the model is comprised of two separate elements which describe (1) the time-varying spatial characteristics of the power distribution network, and (2) the complex power

characteristics of the active (vehicle) loads. These elements are integrated into a comprehensive simulation model which accepts as prescribed input data the vehicle mission profile and computes as output data (in graphical or tabular format) the power consumption characteristics of the vehicle system network. The report includes a complete listing of the FORTRAN program and provides an illustrative example of its application to multi-vehicle AGT systems.

1. INTRODUCTION

This document describes a FORTRAN computer program which models the electric power requirements of a guideway transit system. Typical systems which could be modeled include: Morgantown Personal Rapid Transit System, Dallas-Fort Worth Airtrans, or one of the proposed Downtown People-Movers. All of these are Automated Guideway Transit (AGT) systems. The model is designed for studies which examine the impact on power consumption of the following:

1) Changing the vehicle propulsion system
2) Changing the power distribution system by moving/adding/deleting power substations
3) Incorporating regenerative braking
4) Altering the vehicles' mission profiles.

The model is general enough so that different AGT systems can be studied. The model is a modular one so that AGT system modifications are made either by changing modules (FORTRAN subroutines) or by changing parameters within a module (FORTRAN statements).

The important features of this model are: (1) the equivalent circuit for the electric power distribution system is automatically updated as the vehicles move, (2) the power flow problem is solved using the efficient Newton-Raphson algorithm, (3) harmonic currents (which are important in sizing power distribution equipment) are included.

The remainder of this document is structured to serve as both a users' manual and a programmers' reference manual. Section 2 is an overview of the model and it contains a functional description of the model and its component parts. Section 3 contains the analysis used in the model. The simulation output is discussed in Section 4. Section 5 shows the conclusions of a model validation study using the AIRTRANS system.

Finally the procedure for preparing input data, and using the model are included in Section 6.

2. MODEL OVERVIEW

The power flow in an AGT system is a complex process. In a simplified form, three-phase electric power enters the AGT system via an electric utility connection. It flows through cables to power substations located along the guideway. At the substation, a step-down transformer converts it to a lower voltage, current is fed to the power rail on the guideway, and current may be fed to other buildings for housekeeping use (heating, cooling, lighting, etc.)

The power rail carries the current to the AGT vehicles on the guideway. Once the electric power reaches the vehicles, most of it is converted into thrust by the propulsion system, but some is used for vehicle housekeeping.

The thrust produced by the propulsion system is a function of time. The vehicle's control system will vary the thrust as it adjusts the velocity of the vehicle. As a result each vehicle's power demand varies with time, and the AGT system's power demand may also vary.

In effect the AGT is a power distribution network with (1) generators (the electric utility connection), (2) transmission lines (cables and power rail), and (3) loads (the AGT vehicles).

The solution to the power demand problem is to model the AGT system as a power distribution network and solve the load-flow problem repeatedly as the time-varying loads change and as the transmission lines change. One point that needs to be made is that in simplifying the AGT system, we neglected regenerative braking. Regenerative braking means that during braking operations, the AGT vehicles can generate power and feed it back into the power distribution system. Thus our power distribution network has loads which vary in magnitude and sign (negative loads are generators). A block diagram of the AGT power distribution model is shown in Figure 2-1.

Note that the three quantities: (1) the vehicle's position, (2) the vehicle's power demand, and (3) the housekeeping power demand, are the independent variables. Together they determine the systems aggregate power demand.

Each vehicle in the AGT fleet is following a route along the guideway. The characteristics of this route (i.e. the grades, the expected vehicle velocity, and average headwinds encountered) and the characteristics of the vehicle's propulsion system (thrust or tractive force at the wheels vs. electric power into the motor) both determine the vehicle's time-varying power demand. Figure 2-2 shows a block diagram of the AGT vehicle model.

The inputs to the vehicle model, which relate to the guideway route, are functions of time. This set of functions (expected velocity, guideway grade, and headwind encountered) form part of a vehicle's mission profile.

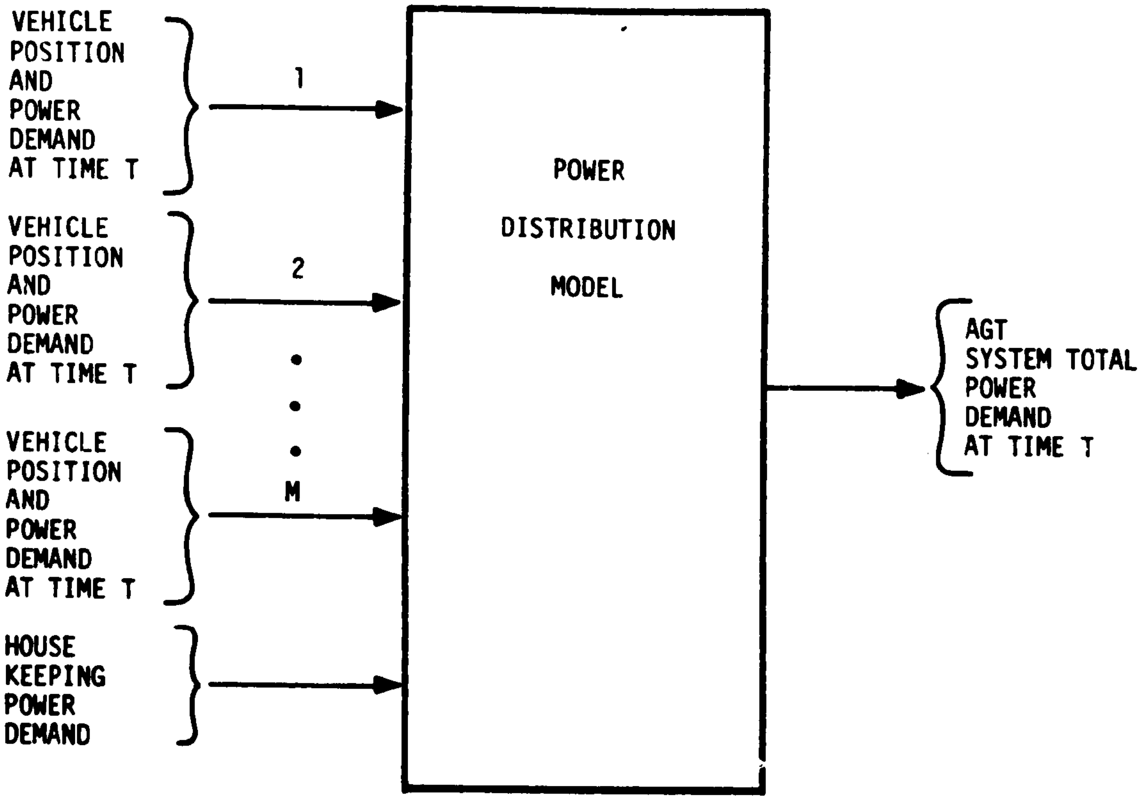


FIGURE 2-1. FUNCTIONAL VIEW OF THE POWER DISTRIBUTION MODEL

So far the propulsion system model has described how much power each vehicle is demanding, but not where in the power distribution network the demand is. After all, some of the AGT vehicles are moving along the power rail somewhere between stations. So we augment the mission profile to include a location code as a function of time. The code has two parts: (1) a prefix part to identify a guideway segment, and (2) a footage part to identify the distance from the segment reference end point.

By using the location code for vehicles and power substations, together with information on the spatial arrangement of guideway segments into the guideway network, the physical length of the power rail which separates vehicles and power substations can be found. (See Figure 2-3 for an example.) This physical length can be converted into the power rail's transmission line admittance for use in the power distribution model.

The transformation from substation and vehicle location codes into power-rail admittances is summarized by the guideway network model. That model is shown functionally in Figure 4.

In summary, the model has three parts:

1. AGT vehicle propulsion system model--it calculates the individual vehicle's power demand versus time.

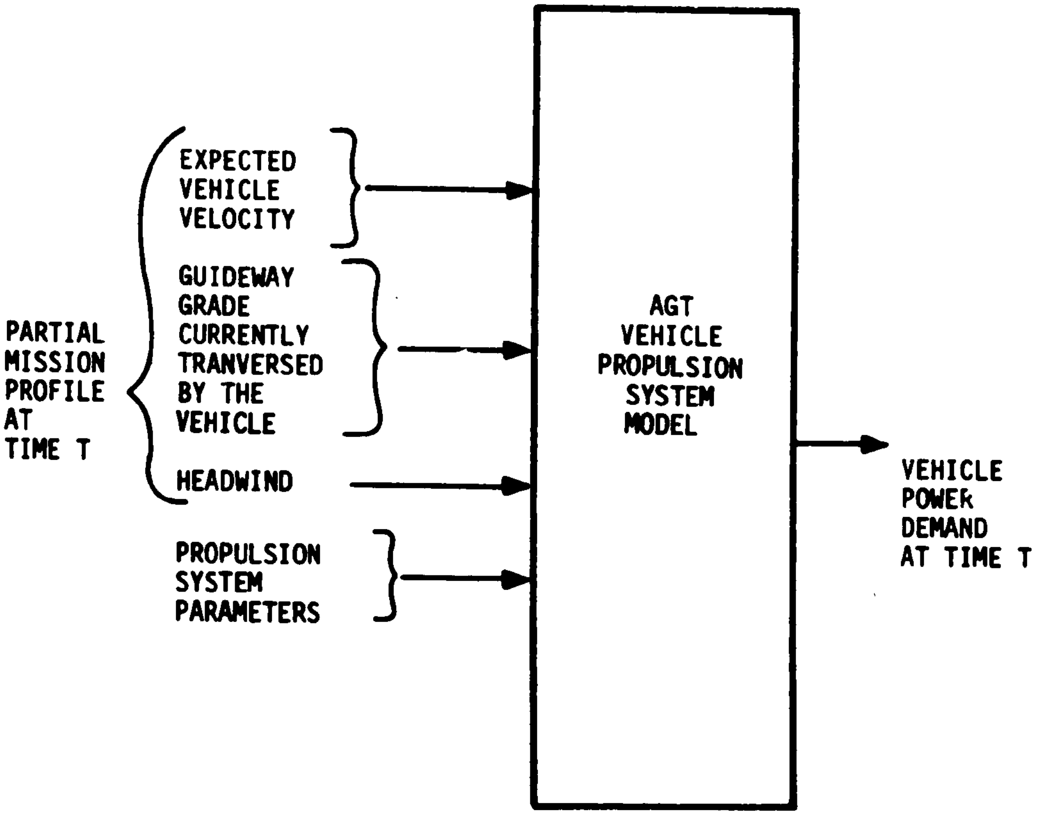
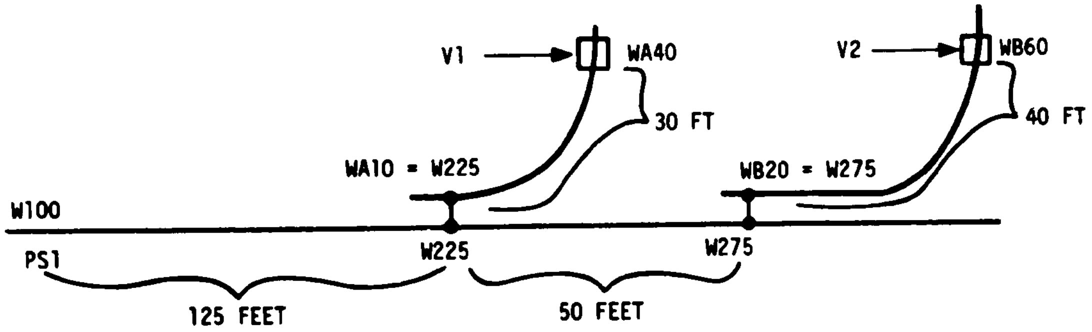


FIGURE 2-2. FUNCTIONAL VIEW OF A SINGLE AGT VEHICLE

KEY

V1	VEHICLE #1
V2	VEHICLE #2
W100	100 FOOT ON THE W GUIDEWAY
PS1	POWER SUBSTATION #1



DISTANCE

PS1 to V1	125 + 30 = 155
PS1 to V2	125 + 50 + 40 = 215
V1 to V2	30 + 50 + 40 = 120

FIGURE 2-3. THE USE OF LOCATION CODES TO FIND THE LENGTHS OF POWER RAIL AMONG VEHICLES AND POWER SUBSTATIONS

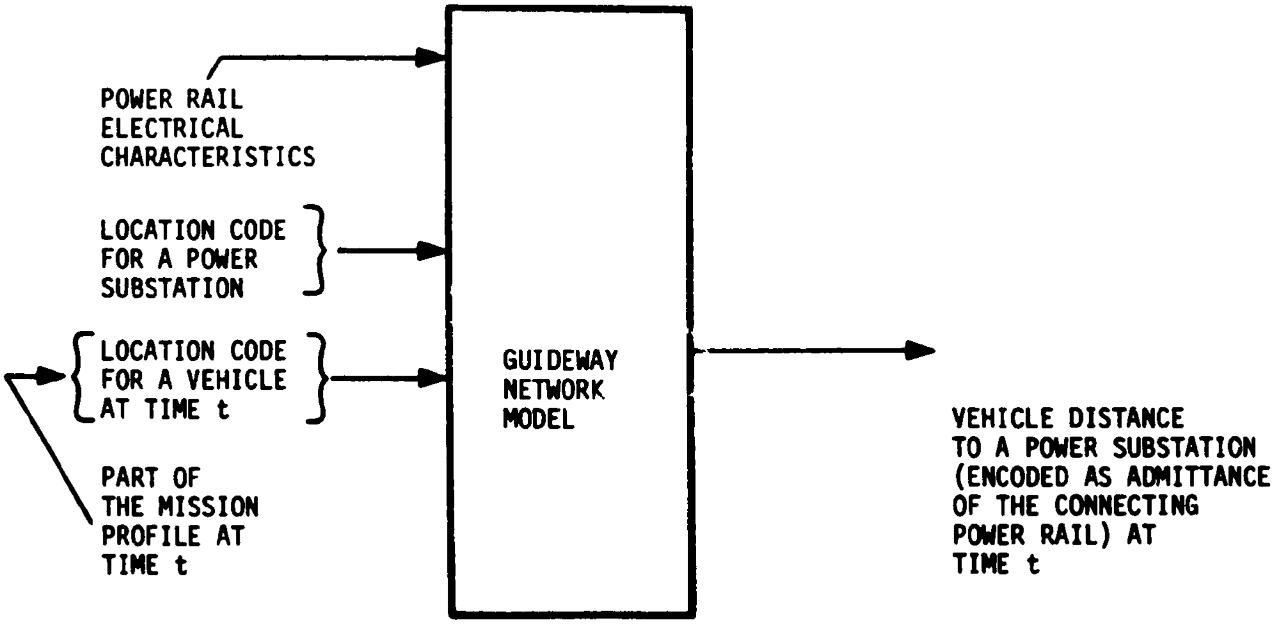


FIGURE 2-4. A FUNCTIONAL DIAGRAM FOR THE GUIDEWAY NETWORK MODEL

2. Guideway Network Model - It calculates the position of the individual vehicle versus time.
3. Power Distribution Model - It combines the individual power demands, based on their magnitude and their location, into a system power demand versus time.

2.1 OUTPUT

The model calculates a number of values in addition to the systems' electric power demand at each sample time. In general, the output data will depend on whether the power rail carries ac or dc. A general list of data follows:

1. Active power (P) at the power rail/vehicle interface. P, which is either dc or 60 Hz ac, is the real power used for the vehicles' propulsion system and its auxiliary loads (i.e. heating, lighting, cooling and control systems).
2. Reactive power (Q) at the power rail/vehicle interface. Q, which is present in the ac power rail case, is the quadrature component of the 60 Hz real power.
3. The power rail voltage. This is the voltage present at the power rail/vehicle interface. It is either dc or 60 Hz ac.
4. Distortion current (IO) at the vehicle. It is the RMS value of the harmonic currents which flow across the power rail/vehicle interface.

5. Distortion current at the utility. The RMS value of the harmonic currents which flow from the utility to the AGT system.
6. The active power (P) and reactive power (Q) at the utility.

Assuming that the utility is a "stiff" source and therefore its voltage (E1) is sinusoidal, then the apparent power (U) at the utility is given by Equation 2.1-1 (where ** indicates exponentiation).

U = SQRT (P ** 2 + Q ** 2 + E1 ** 2 * ID ** 2) (2.1-1)

The above values are summarized in a table printed by the model at each sample time.

2.2 INPUT

The simulation involves data from two input files. The first is the guideway deployment data file. It contains information about the guideway which is relevant to the power distribution circuit. Each record in the file describes a branch in the power distribution circuit. The following list shows the type of information in the file:

1. Power feed point locations
2. Power cross-under locations. These are the points at which the two power rails are connected together at a merge or diverge structures.
3. Length of power rail segments between feed point locations and cross-under locations. These are used to calculate the impedance of the branches in the power distribution circuit.

4. Step-down transformer leakage impedance. If the branch between the utility and power feed point contains a step-down transformer, then its impedance plus any cable impedance may be included.

In summary, the guideway deployment data file describes the nodes and branches (in the power distribution circuit) which are geographically fixed.

The second is the mission profile file. It contains information about the vehicles' locations and operating conditions. Each record describes a point on an ideal mission profile. The following list shows the type of information in the file:

1. A time increment. This is the time interval which normally ellapses before the next mission profile point describes the vehicle (i.e., station dwell time).
2. A commanded velocity. This is the velocity which is an ideal velocity, and the vehicle accelerates or decelerates towards it.
3. Encountered grade. This measures the rise or descent in the guideway encountered by the vehicle. Note that if superelevation is present, then it can be combined with the grade to produce a compensated grade.
4. Encountered headwind.

5. Vehicle location. This is the position of the vehicle on the guideway where the mission profile point data becomes effective.

It should be noted that the mission profile is an ideal one from which a vehicle may deviate. For example, if the vehicle's propulsion system cannot provide the necessary tractive effort or if it is jerk-limited, then the current velocity differs from the commanded velocity.

2.3 SUBMODELS

This section considers the three submodels and their interfaces. The model can be considered a framework into which modules are inserted. The user creates these modules for a particular vehicle and a particular guideway deployment. Figure 2-5 shows the three models and their interfaces. A functional description for each submodel follows.

2.3.1 Vehicle Propulsion Submodel

This model calculates the electrical power load which the vehicle produces at the power rail. This load is a function of the vehicle dynamics, motor, the power conditioning unit, and the auxiliary loads. The computation of the load rises from the following five steps:

1. Data on a vehicle's commanded mission profile (velocity, acceleration, encountered grade) and data on the vehicle's current state (actual velocity and position) are retrieved from tables.

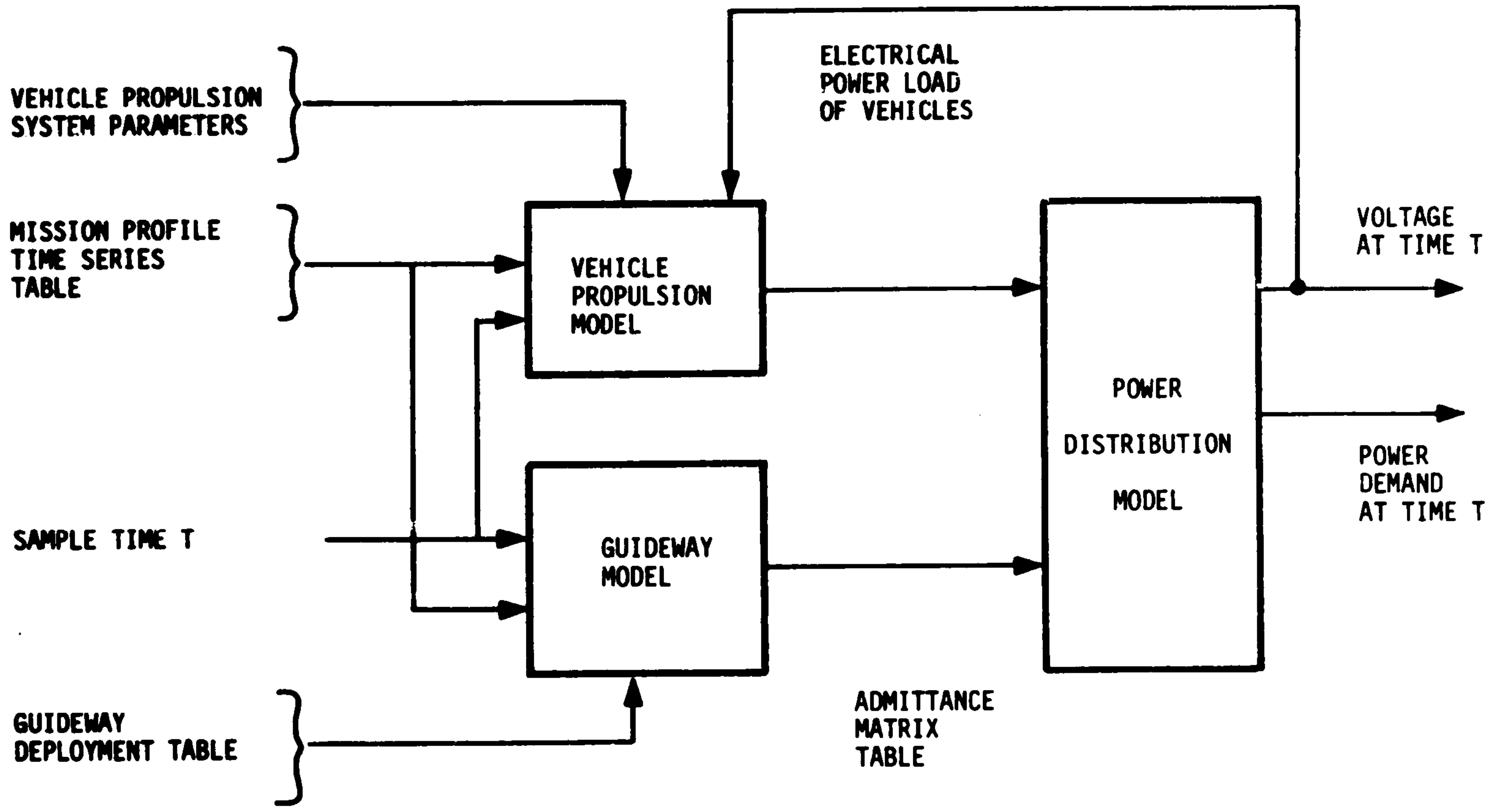


FIGURE 2-5. THREE SUBMODELS AND THEIR INTERFACES

2. The equations of motion for the vehicle (which include a quadratic polynominal in velocity to model tractive resistance) are solved for the mechanical power of the motor.
3. The equations for the motor are solved for the electric power into the motor terminals.
4. The equations for the power conditioning unit are solved for the electric power load at the power rail. These equations use as input the power at the motor terminals.
5. Data on the vehicles' load at the power rail/ vehicle interface and at the motor terminals is entered into tables which are accessible to the other submodels.

It should be noted that steps 1 and 5 are bookkeeping operations required to keep track of a fleet of vehicles. The user is only concerned with providing information about the dynamics, the motor system, and the power conditioning system of a single vehicle. The computations are automatically extended to the fleet of vehicles and tables are used to store the fleet data.

2.3.2 Guideway Deployment Submodel

This model is used for bookeeping. In general, it is a table of power rail segments. The data recorded for each segment includes its length and its adjoining segments. The computation done by this submodel entails updating a queue of the vehicles on each power rail segment. This is done using the current position of each vehicle.

2.3.3 Power Flow Submodel

This model solves the equivalent circuit for the power distribution network. It is an iterative computation, similar to the algorithm used by electric utility companies to simulate their power transmission networks. The difference here is that the loads are dynamic. That is, they vary with the voltage at the vehicle/power rail interface. The power flow submodel involves the following computational steps: (in this model, we use the name "node" where nodes are power feed points, power rail connections, or vehicle/power rail interface points).

1. Using the data from the guideway deployment table (which also specifies the vehicles located on each segment at a given time), calculate the node admittance matrix.
2. Assume initial node voltage values. Calculate the real and reactive power at the vehicle/power rail interface. This is the power needed at each vehicle. Call it the scheduled power.
3. Set an iteration counter to zero.
4. Calculate the power flowing in the power rail. From this the power delivered at each vehicle is determined.

5. Find the largest discrepancy between the power scheduled and power delivered.
6. If the discrepancy is small enough (less than one percent, say), then end the process with step 7. Otherwise go on to step 8.
7. Print-out the voltages and power values. The power distribution computation ends here.
8. Calculate a Jacobian matrix (its elements are partial derivatives of power with respect to voltage).
9. Invert the Jacobian matrix.
10. Use it to calculate the updated node voltages.
11. Recalculate the scheduled power at the power rail/ vehicle interfaces. Continue at step 4.

In Section 3, the details and analysis used for these models are presented.

3. ANALYSIS FOR THE MODELS

In this section, the data and analysis for a test case are discussed. The program listings in Appendix A have been set up for this same test case. In general, the vehicle is externally similar to the Morgantown vehicle, but with a 120 horsepower dc motor supplied by three-phase power rail through a variable-voltage rectifier. The guideway is a loop which is based on the Morgantown system. Two vehicles are moving around the loop following a mission profile which approximates the Morgantown operation (but with only two vehicles out of the usual fifteen vehicle fleet running). The analysis is divided into seven parts - one for each major subroutine.

3.1 VEHICLE DYNAMICS

In this section the dissipative and conserved forces acting on the vehicle are used to calculate the real power at the wheels. When positive, this power must be supplied by the propulsion system. When negative, this power must be absorbed by friction brakes or some power source (regenerative braking).

Rolling friction force arises because of the roughness of the contact between the moving vehicle and the guideway. It is linearly proportional to the vehicle weight with an experimentally determined proportionality constant.

VM = 12,000 vehicle weight (lb)
A = 0.025 coefficient of rolling friction (n.d.)
GRADE = encountered grade in percent
FR = VM * COS (GRADE/100.) * A where FR is the rolling friction force (lb)

Coulombic friction forces arise because of wheel/guideway deformation and wheel bearing resistance. It is proportional to the vehicle weight and speed.

VV = vehicle velocity (mph)
VM = 12,000 vehicle weight (lb)
B = 0.00005 coulombic friction coefficient (n.d.)
FC = VM * VV * B where FC is the coulombic friction force (lb)

Aerodynamic drag forces arise because of vehicle motion relative to the air mass. It is proportional to frontal area and the vehicle's relative velocity squared.

C = 0.85 drag coefficient for leading vehicle, use 0.19 for trailing vehicles
RHO = 0.002331 air density (slugs/ft ** 3)
CON1 = 1.46667 ft/sec per mph, conversion factor
VV = vehicle velocity (mph)
HW = encountered headwind (mph)
FD = 0.5 * RHO * C * (VV+HW) ** 2* CON 1 ** 2 where FD is aerodynamic drag force (lb)

The total dissipative force can be found as RFORCE.

RFORCE = FR + FC + FD

The gravitational force arises because of a component of the vehicle's weight retards its uphill motion and advances its downhill motion. It is calculated as the component of weight tangent to the guideway.

VM = 12,000 vehicle weight (lb)
GRADE = encountered grade (%)
FG = VM * SIN (ATAN (GRADE/100)) where FG is the gravitational force (lb)

Inertial force arises when the vehicle must change velocity and overcome inertia. It is proportional to the vehicle's mass and acceleration.

VM = 12,000 vehicle weight (lb)
KG = 32.174 gravity (lb/slug)
ACC = vehicle acceleration (mph/sec)
CON1 = 1.46667 ft/sec per mph Conversion
FI = VM/G * ACC * CON1 where FI is inertial force (lbs)

The total tractive force, FT, can be calculated. It is the thrust required at the wheels in order to maintain a given velocity and acceleration with an encountered guideway grade and headwind.

FT = RFORCE + FG + FI where FT is the tractive force (lb)

The power, PW, required to develop the necessary tractive force at the vehicle wheels is the product of that force and vehicle velocity.

FT = tractive force at wheels (lb)
VV = vehicle velocity (mph)
CON1 = 1.46667 ft/sec per mph Conversion Factor
CON2 = 1.356 watt per ft lb/sec Conversion factor
PW = FT*VV*CON1 CON2 where PW is the power at the wheels (watts)

In summary the variable PW is calculated as a function of VV, ACC, HW and GRADE. Subroutine VEHDYN does this computation.

3.2 VEHICLE MOTOR

In this section, the real power at the wheels is used to calculate the voltage and current at the motor terminals. These calculations model the motor and drive train components in the propulsion system.

The motor is a separately-excited dc machine rated at 120 horsepower and 600 volts dc. It is connected to the wheels via a gearbox and differential whose efficiency is assumed constant.

Four different modes of operation are considered:

1. Motoring with voltage control,
2. Motoring with field-weakening,
3. Regenerative braking,
4. Friction braking

Modes 2 and 3 are used at higher speeds - those above a 30 mph threshold. Modes 1 and 2 are used if the power at the wheels is positive. More precisely the table below shows the operating conditions for each mode (VV is velocity (mph), PW is power at the wheels (watts)).

MODE	VELOCITY	POWER
1	$VV<30$	$PW>0$
2	$VV\geq 30$	$PW>0$
3	$VV>30$	$PW<0$
4	$VV\leq 30$	$PW\leq 0$

The power output at the dc machine shaft is a function of the drive train efficiency and the power at the wheels.

PW = power at wheels (watts)

GREFF = 0.92 gearbox efficiency (n.d.)

PMS = PW/GBEFF power at machine shaft (watts) if mode 1 or 2

PMS = PW*GBEFF power at machine shaft (watts) if mode 3 or 4

Power losses in the dc machine are either stray load losses or windage losses.

PMS = power at machine shaft (watts)

PL3 = 0.01 ABS(PMS) where PL3 are the stray load loss (watts) computed as one percent of the absolute value of the power at the machine shaft.

VV = vehicle velocity (mph)

PL4 = 1461.2*(VV/30.)**2.5 where PL4 are the windage losses (watts)

Note PL4 is modeled as a single term with the vehicle velocity raised to the 2.5 power. For mode 1, the terminal voltage and current are calculated as follows:

CF = 10 where CF is the rated field current (amp)

CON3 = 1.92 where CON3 is a motor constant (volts per mph per amp)

VV = vehicle velocity (mph)

EA = CON3*V*CF where EA is the armature back EMF (volt)

PL3 = stray load losses (watt)

PL4 = windage losses (watt)

VBD = 2.0 the comutator brush drop (volts)

PMS = power at motor shaft (watts)

EA = armature back EMF (volts)

CA = (PMS + PL3 + PL4) / (EA - VBD)

The terminal voltage can then be found

RA = 0.15 armature resistance (ohms)

VT = EA+RA*CA where VT is the terminal voltage (volts)

For MODE 2, which is field weakening, the terminal voltage is held relatively constant at its 30 mph value, while the field current is reduced for speed control above 30.

Writing first an equation for power-in equals power-out plus losses,

CA = armature current

VT = 576 rated terminal voltage (volts)

VBD = 2.0 brush drop (volts)

PMS = power at machine shaft (watts)

PL3 = strong load loss (watts)

PL4 = windage loss (watts)

RA = armature resistance (ohms)

CA*VT = PMS + CA* VBD + CA** 2 * RA + PL3 + PL4

then we can solve it for the armature current.

CA = ((VT - VBD) + SQRT ((VT - VBD)** 2 + 4* RA* (PMS+PL3+PL4)
/(2*RA)

The MODE 3, which is regenerative braking, the dc machine acts as a generator. In this case the armature voltage is greater than the machine terminal voltage, so that reverse armature current flows. Figure 3-1 shows this.

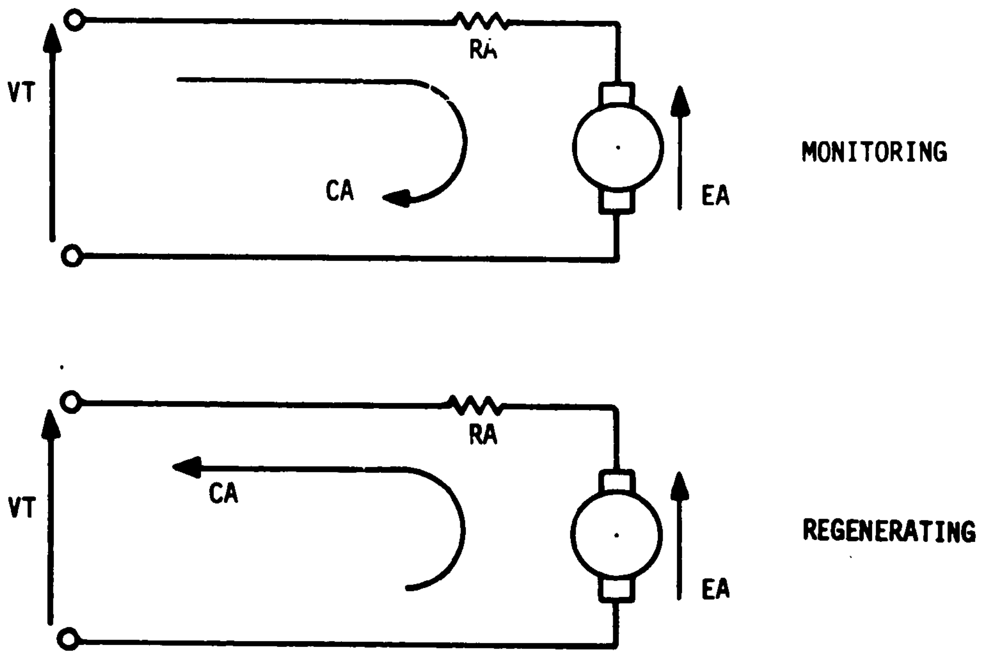


FIGURE 3-1. THE DC MACHINE'S ARMATURE EQUIVALENT CIRCUIT DURING MOTORING AND REGENERATION.

In this case the armature voltage and current are calculated as shown:

CF = 10 rated field current (amp)

CON3 = 1.92 motor constant (volts per mph per amp)

VV = vehicle velocity (mph)

EA = CON3*VV*CF armature back EMF (volts)

PMS = power output at machine shaft (watts) - note PMS=0.

PL3 = stray load loss (watts)

PL4 = windage loss (watts)

CA = (PMS + PL3 + PL4) / (EA + VBD)

RA = Armature resistance (ohms)

VT = EA + CA*RA

For MODE 4, which is friction braking, the motor is disconnected and mechanical brakes dissipate the energy. The voltage and current are set essentially to zero.

VT = 0.01 machine terminal voltage (volts)

CA = 0.01 machine terminal current (amps)

These computations are carried out by subroutine MOTOR. The final step in MOTOR is to calculate the magnitude of VT and CA.

VMTR = ABS (VT)

IMTR = ABS (CA)

TMTR = 0 IF $CA \geq 0$

TMTR = 180 IF $CA < 0$

In summary the function of the motor simulation is to calculate VMTR, IMTR, and TMTR using PW (the power at the wheels) and VV (the vehicle velocity).

3.3 VEHICLE POWER - CONDITIONING UNIT

In this section, the equations used to model the power-conditioning unit (PCU) are discussed. The PCU is a 3-phase fully-controlled bridge rectifier, which interfaces the 3-phase power rail with the dc machine terminals. When real power flows from the power rail to the machine terminals (Mode 1 or 2), the PCU provides a positive terminal voltage as current flows against the machine's back-EMF.

When real power flows from the machine terminals to the power rail (Mode 3), the machine's back-EMF is in the opposite direction from above. The machine's field current is reversed to produce this back EMF change. The machine's back-EMF is larger than the PCU output (which changes size as the firing angle is increased), so the armature current flows in the same direction. Figure 3-3 shows the principle components of the rectifier. It is a six-pulse, bridge circuit with an isolation transformer.

The analysis here follows one used by Schaefer (Schaefer, 1965). The SCR's in the rectifier have a commutation time in which the current flowing through one SCR is switched to another. A voltage drop, EX, is associated with this commutation. It is a function of the leakage reactance (on the secondary) of the transformer and the output current.

CA = output current (amps)

XC = 0.057 transformer leakage reactance on secondary (ohms)

EX = 3 XC *CA/3.1416 voltage drop due to commutation (volts)

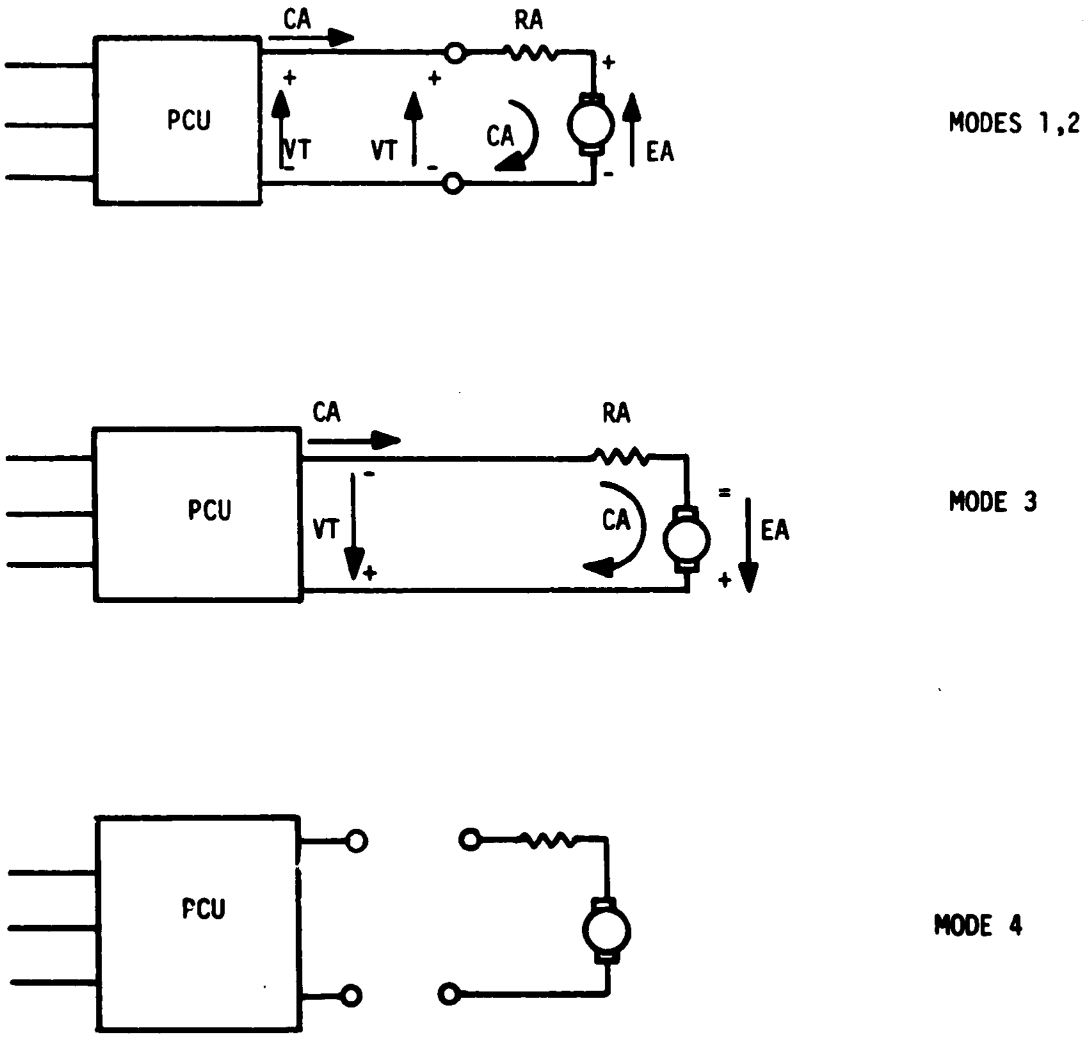


FIGURE 3-2. THE PCU AND DC MACHINE OPERATION

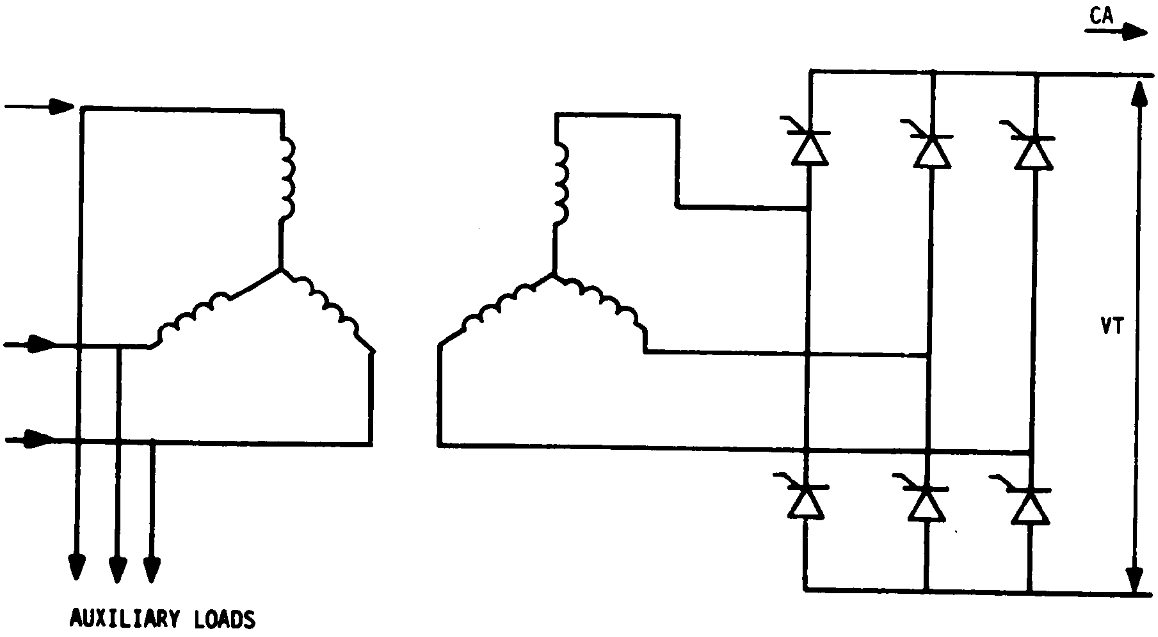


FIGURE 3-3. PCU RECTIFIER

The phase delay angle or thyristor firing angle controls the output voltage. The following equation calculates this angle, ALPHA, as a function of the commutation voltage drop, the desired output voltage, and the uncontrolled output voltage.

EX = commutation voltage drop

VRAIL = complex phase voltage at the power rail (p.u.)

VBASE = base phase voltage (volts)

EDO = 3 SQRT (6.)/3.1416 CABS (VRAIL) VBASE the uncontrolled output dc voltage (volts)

Note SQRT(X) is square root of X, CABS(X) is the absolute value of the complex quantity X

ED = VT the desired output dc voltage

ALPHA = ACOS ((EX + ED)/EDO) the SCR firing angle (radians)

Note ACOS(X) is arc cosine of X

Using this firing angle, we proceed to calculate the power into the PCU. The calculation involves a correction factor to account for the effects of commutation. For this factor, the commutation voltage drop is converted into a commutation angle.

ED = PCU output dc voltage (volts)

EX = commutation voltage drop (volts)

EDO = uncontrolled output voltage (volts)

ALPHA = firing angle (radians)

AMU = ACOS((ED-EX)/EDO) - ALPHA the commutation angle (radians)

Note ACOS(X) is arc cosine of X

The correction factor is calculated in three steps:

ALPHA = firing angle (radians)
AMU = commutation angle (radians)
CF1 = .5 * (COS(ALPHA) + COS(ALPHA + AMU))
CF2 = (2.*AMU + SIN(2*ALPHA) - SIN(2*ALPHA + AMU))/ (2.*(COS(ALPHA) - COS(ALPHA + AMU))
CFF = 1./SQRT(CF1**2 + CF2**2)) the final correction factor for commutation

The power factor is next calculated.

ALPHA = firing angle (radians)
CFF = commutation correction factor
PF = COS(ALPHA)*CFF the power factor at the PCU input

The real power into the PCU is equal to the real power, assuming negligible losses.

VT = PCU output voltage (volts)
CA = PCU output current (amps)
REF = VT*CA real power input to the PCU (watts) in all three phases.

The reactive power into the PCU is calculated below.

EDO = uncontrolled output voltage (volts)
CF2 = correction failure for ratio of fundamental reactive power to uncontrolled dc power
CA = output current
AIMP = EDO*CA*CF2 the reactive power (VA) in all three phases.

The final equations are concerned with adding in the auxiliary loads and then normalizing the power values to per unit.

PAUX = 11,520 the real power for the auxiliary load (watts) in all 3 phases.

QAUX = 8,640 the reactive power for the auxiliary loads (VA) in all 3 phases.

PBASE = 333,000 BASE POWER (VA) for one phase

BP = (REF + PAUX)/PBASE/3 per unit real power at the power rail/vehicle interface.

BQ = (AIMP + QAUX)/PBASE/3. per unit reactive power at the power rail/vehicle interface.

3.4 ADMITTANCE MATRIX

The power rail segments and power cables each have an impedance which affects the power flow from the utility connection to the vehicles. This impedance is modeled as a linear function of the guideway segment length or as a constant for the power cables (and step-down transformers). The impedance values are calculated as per unit impedances, converted to per unit admittances, and stored in a sparse admittance matrix. The admittance computation is summarized below.

CASE 1. A POWER RAIL BETWEEN NODE I AND J

ZGY = complex power rail impedance (per unit ohms per ft per phase)

D = distance along the power rail (ft) from node I to node J

YD = 1./(D*ZGY)

YD = complex power rail admittance (per unit mhos per phase) between nodes I and J

CASE 2. A CABLE OR TRANSFORMER BETWEEN NODE I AND J.

GWAY(II,4) = real part of the complex fixed impedance. between nodes I and J (see Section 6. using the model.)

GWAY(II,5) = imaginary part of the complex fixed impedance between nodes I and J. (See Section 6. using the model.)

YD = 1./CMPLX(GWAY(II,4), GWAY(II,5)

YD = complex power rail admittance (per unit mhos per phase) between nodes I and J.

The admittance computation involves nodes in the guideway network. A numbering convention is adopted for these electrical nodes. Node 1 is the electric utility connection. Nodes 2, 3, ..., NCAR+1 are vehicles.

In summary, the function of the PCU simulation is to calculate:

1) BP - per unit real power into PCU at power rail/vehicle interface

2) BQ - per unit reactive power into PCU at the power rail/vehicle interface

3) ALPHA - SCR firing angle (radians), given as inputs.

1) UMTR - magnitude of the motor terminal voltage (volts)

2) IMTR - magnitude of the motor terminal current (amps)

3) TMTR - has value 0 if motor terminal voltage is greater than 0, has value 180 otherwise

4) VRAIL - complex power rail voltage (volts)

This simulation is carried out by the subroutine PCU. These nodes are usually moving and have a current associated position (a guideway segment and displacement from the segment beginning). Nodes NCAR+2, NCAR+3,...,SZ-1-1,SZ1 are fixed nodes along the guideway. These nodes include power feed points, diverge or merge power rail connections and power tie points between parallel segments. There are SZ1 nodes in total where SZ1 is a user-supplied parameter.

The admittance matrix is stored in several tables, but only nonzero values are stored in order to save space. The tables are shown in Figure 3-4 and their entries are described below. Note that in the two-dimensional admittance row I and column I are devoted to node number I. The entry Y(I,I) is the driving point admittance at node I. The entry Y(I,J), where I ≠ J,is the transfer admittance. Finally since Y(I,J) equals Y(J,I), the tables of Figure 3-4 have only one entry for those pairs. Again, this is done to save space.

3.5 LOAD FLOW ALGORITHM

The equivalent circuit for the power distribution network is described by a set of simultaneous equations. They relate a)

	1	2	3	4
1	A	0	B	C
2	0	D	0	0
3	B	0	E	F
4	C	0	F	G

b)

	Y	YP	YQ	MATCOL
1	A	1	1	5
2	D	2	2	0
3	E	3	3	7
4	G	4	4	0
5	B	1	3	6
6	C	1	4	0
7	F	3	4	0

FIGURE 3-4. a) AN ADMITTANCE MATRIX AND, b) ITS TABULAR REPRESENTATION

the voltages, current, and power at each node in the network. The load flow algorithm is just the iterative solution technique used on the equations. Many variations exist (Stott, 1974), but the one used here is a power-mismatch version in which a generalized Newton-Raphson method is used. The basic equations are given below. All quantities are fundamental (60HZ) values.

$$DP(k) - jDQ(k) = CONJG(E(k))*I(k)$$

DP(k) = real power (per unit) delivered into the network at node k

DQ(k) = reactive power (per unit) delivered into the network at node k

E(k) = line to neutral voltage (per unit) at node k

1(k) = phase current (per unit) into the network at node k.

CONJG(E(k)) = complex conjugate of E(k)

The admittance values are brought into the analysis with the following network performance equation:

$$I(k) = \sum_{n=1}^{SZ1} y(k,n)*E(n)$$

I(k) = phase current (per unit) into the network at node k

y(k,n) = admittance (per unit) value from the admittance matrix. It is either a driving point admittance (if k=n) or a transfer admittance (if k≠n).

E(n) = line to neutral voltage (per unit) at node n.

SZ1 = number of network nodes

By combining these two equations the following set of nonlinear equations results:

$$DP(k) - jDQ(k) = CONJG(E(k)) \sum_{n=1}^{SZ1} y(k,n)*E(n)$$

The solution involves the following steps:

1. Find the admittance matrix so that y(k,n) values are known.
2. Assume initial voltages (E(k)) at each node.
3. Find the P(k) and Q(k) values at each node in the network where a vehicle needs electric power. Note that the real power could be positive to model a regenerating vehicle or negative to model a power absorbing vehicle. These values are the <u>scheduled</u> power. They are functions of the vehicle's propulsion system, its current mission profile demand, and the node voltage E(n) at the power rail/vehicle interface.
4. Using the nonlinear system of network equations, with the admittance values y(k,n) and node voltages E(n), find the <u>delivered</u> power. Any mismatch between the scheduled and delivered power can be corrected by revising the voltages E(n) at each node. Succeeding steps perform this correction.
5. Calculate the differences between scheduled and delivered power,

DELTAP (k) = P(k) - DP(k)

DELTAQ (k) = Q(k) - DQ(k)

P(k) = real power scheduled (per unit) into the network at node k

DP(k) = real power delivered (per unit) into the network at node k

Q(k) = reactive power delivered (per unit) into the network at node k

DQ(k) = reactive power delivered (per unit) into the network at node k

DELTAP(k) = real power (per unit) mismatch at node k

DELTAQ(k) = reactive power (per unit) mismatch at node k

6. The iteration may stop if the maximum DELTAP(k) and DELTAQ(k) are below some cutoff, EPSIL (Typically 0.10) If the maximum mismatch is too large, then the following steps revise the node voltages.
7. Calculate the current into the network at each node I(k).

   I(k) = (P(k) - jQ(k))/CONJG(E(k))
8. Solve a set of linear equations for the change in node voltages. These equations are shown in Figure 3-5. The Jacobian matrix, J, is a sparse matrix, so only the nonzero elements are stored in a table. Figure 3-6 depicts these tables. The standard Gauss-Jordan reduction algorithm is used to find the updated E(k) values.

$$\begin{bmatrix} \text{DELTAP(k)} \\ \hdashline \text{DELTAQ(k)} \end{bmatrix} = \underbrace{\left[\begin{array}{c:c} J_1 & J_2 \\ \hdashline J_3 & J_4 \end{array}\right]}_{\text{JACOBIAN}} \begin{bmatrix} \text{REAL (DELTAE(k))} \\ \hdashline \text{IMAG (DELTAE(k))} \end{bmatrix}$$

J_1 TERMS: $\frac{\partial\ p(k)}{\partial\ \text{REAL}(E(k))}$

J_2 TERMS: $\frac{\partial\ p(k)}{\partial\ \text{IMAG}(E(k))}$

J_3 TERMS: $\frac{\partial\ Q(k)}{\partial\ \text{REAL}\ (E(k))}$

J_4 TERMS: $\frac{\partial\ Q(k)}{\partial\ \text{IMAG}(E(k))}$

FIGURE 3-5. VOLTAGE CORRECTION EQUATIONS USING THE JACOBIAN MATRIX

a) JACOBIAN MATRIX

	1	2	3	4
1	A	0	E	0
2	0	B	0	F
3	G	0	C	0
4	0	H	0	D

b) TABLES FOR THE JACOBIAN

	JCOB	JCR	JCC	JNC
1	A	1	1	5
2	B	2	2	6
3	C	3	3	0
4	D	4	4	0
5	E	1	3	0
6	F	2	4	0
7	G	3	1	3
8	H	4	2	4

FIGURE 3-6. JACOBIAN MATRIX AS A SPARSE ARRAY.
(a) THE MATRIX, (b) THE TABLES

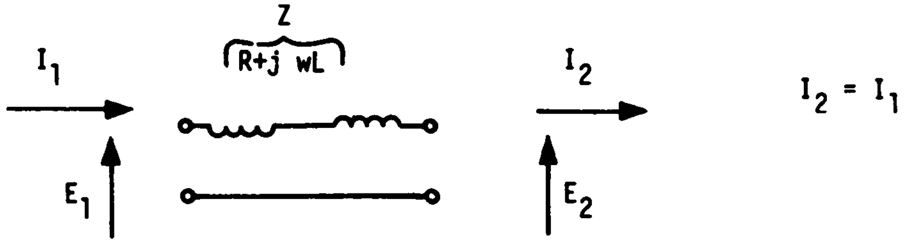


FIGURE 3-7. EQUIVALENT CIRCUIT FOR ONE PHASE OF A POWER RAIL SEGMENT. THE IMPEDENCE Z IS A FUNCTION OF LENGTH

9. The computation continues at step 3.

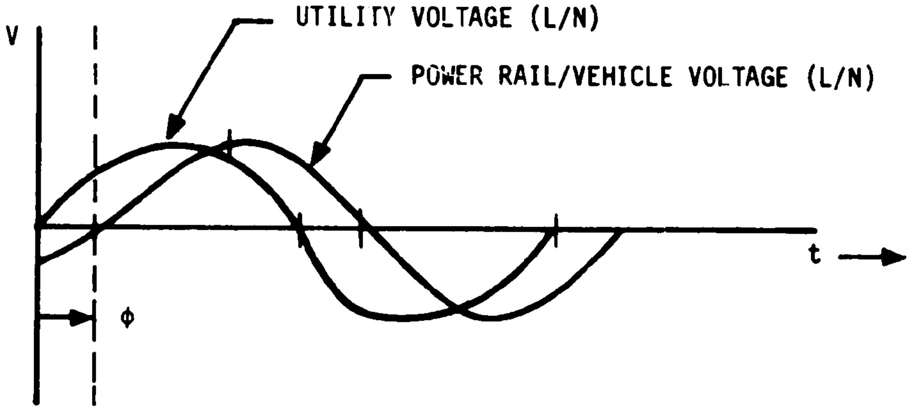
This computation is carried out by the subroutine named NR. In addition the subroutine FORMY is used for the admittance matrix formation and subroutines GETJ and PUTJ handle the Jacobian matrix manipulation.

3.6 DISTORTION POWER

In this section the high frequency currents are used to calculate the power components which are not included in the fundamental real and reactive power. The analysis of the high frequency currents is concerned with two types of locations in the power distribution network. One is the power rail/vehicle interface where the nonlinear PCU generates the harmonic currents. Second is the utility connection where the currents impact the supply network and where the metering is located.

In order to simplify the analysis, two assumptions are made: (1) the voltage waveform at the utility connection is sinusoidal (i.e., it is a stiff source), and (2) the power rail is a short transmission line (i.e., it is a constant series impedance dependent on rail length). The equivalent circuit for a power rail segment is shown in Figure 3-7.

This analysis involves two steps. First the harmonic currents at each power rail/vehicle interface are calculated. Second these currents are combined into the current at the utility connection.



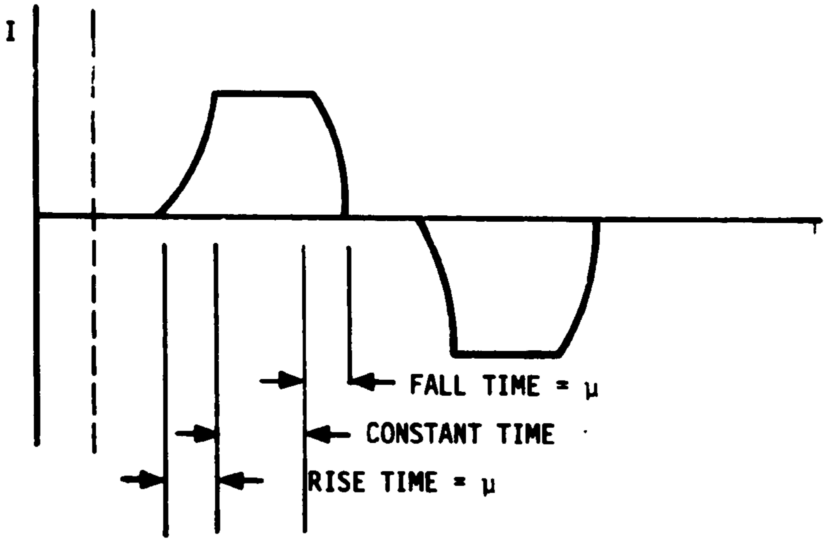


FIGURE 3-8. LINE TO NEUTRAL VOLTAGE AT THE UTILITY AND AT POWER RAIL/VEHICLE INTERFACE

FIGURE 3-9. LINE CURRENT AT THE POWER RAIL/VEHICLE INTERFACE

The harmonic currents are calculated by Fourier analysis on the wave forms. The current wave form used is shown in Figure 3-8. This wave form is discussed in the literature (Schaefer, 1965, p 327-334). It represents the line current for one phase when two effects are present: (1) a delay due to the SCR firing angle α, and (2) a rise (fall) which is not instantaneous commutation.

The expression to describe the current curve is given below for the three segments (rise, constant, fall).

α = SCR Firing Angle (radians)

$\gamma = 2\pi/3$ Length of current pulse with instantaneous commutation (radians)

μ = commutation angle (radians)

ID = output dc current from PCU (amp)

IB = per unit base Current (amp)

IR = PCU input line current during Rise Time as a function of ωt (per unit amp)

$IR(\omega t) = ID*(\cos(\alpha) - \cos(\omega t+\gamma/2))/(\cos(\alpha) - \cos(\alpha+\mu))/IB$

$IC(\omega t) = ID/IB$ PCU input line current during constant time as a function of ωt (per unit amp)

IF = PCU input line current during fall time as a function of ωt(per unit amp)

$IF(\omega t) = ID*(1-(\cos(\alpha) - \cos(\omega t-\gamma/2))/(\cos(\alpha) - \cos(\alpha+\mu)))/IB$

The Fourier analysis, which yields the harmonic currents, is performed next. Because of the positive/negative symmetry in the current wave form, the integral is evaluated over a half period.

ID = output dc current from PCU(amp)

α = SCR firing angle (radians)

μ = commutation angle (radians)

IR(ωt) = PCU input line current during rise time (per unit amp)

IC(ωt) = PCU input line current during constant time (per unit amp)

IF(ωt) = PCU input line current during fall time (per unit amp)

A(N) = (SQRT(2))/π*

$$\left(\int_{\alpha-\gamma/2}^{\alpha+\mu-\gamma/2} \mathrm{IR}(\omega t)*\sin(N\omega t)\, d\omega t \right.$$

$$+ \int_{\alpha+\mu-\gamma/2}^{\alpha+\gamma/2} \mathrm{IC}(\omega t)*\sin(N\omega t)\, d\omega t$$

$$\left. + \int_{\alpha+\gamma/2}^{\alpha+\mu-\gamma/2} \mathrm{IF}(\omega t)*\sin(N\omega t)\, d\omega t \right)$$

A(N) = RMS value of the N-th line current harmonic - the quadrature component (per unit amp).

B(N) = (SQRT(2))/π*

$$\int_{\alpha-\gamma/2}^{\alpha+\mu-\gamma/2} IR(\omega t)*\cos(N\omega t)\, d\omega t$$

$$+ \int_{\alpha+\mu-\gamma/2}^{\alpha+\gamma/2} IC(\omega t)*\cos(N\omega t)\, d\omega t$$

$$+ \int_{\alpha+\gamma/2}^{\alpha+\mu+\gamma/2} IF(\omega t)*\cos(N\omega t)\, d\omega t$$

(B/N) = RMS value of the N-th line current harmonic-in phase component (per unit AMP). Appendix C shows the result of evaluating these integrals.

The final step in the analysis is the combining of the harmonic current components at the power rail/vehicle interface into harmonic currents at the utility connection. For this, each N^{th} order harmonic is considered separately. So in the discussion that follows the fifth harmonic (N=5) is used but N could be 5,7,11,13,...,6N-1,6N+1. Figure 3-9 shows a small power rail distribution system.

By using superposition, the N^{th} harmonic current at the utility connection, I_1, can be found. Each current source corresponding to a vehicle is treated separately as the others are replaced by their infinite internal impedance. Since Z_1, Z_2, and Z_3 are series impedances for the short transmission line model, the current I_1 is $I_2 + I_3$. In general the N^{th} harmonic current flowing from the utility into the power rail

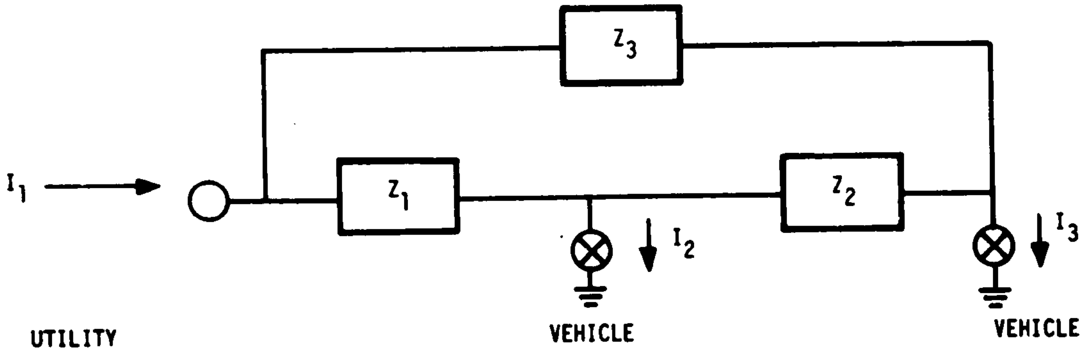


FIGURE 3-10. A SMALL POWER RAIL DISTRIBUTION SYSTEM

network is the sum of the N^{th} harmonic currents flowing into the power rail/vehicle nodes. The sum is a vector sum taking into account the phase angles. To illustrate, Figure 3-10 is presented.

Each fifth harmonic at a vehicle has a phase angle shown in Figure 3-10 as ϕ, which is the number of degrees by which it lags the fundamental voltage at the utility (our reference). The angle ϕ is calculated by the following equation:

N = harmonic number (n.d.)

$B(N)$ = RMS value of the N^{th} line current harmonic-in phase component (per unit amp).

$A(N)$ = RMS value of the N^{th} line current harmonic-quadrature component (per unit amp)

$\phi 2 = \mathrm{ATAN}(A(N)/B(N))$

$\phi 2$ = angle by which N^{th} harmonic current at vehicle lags fundamental voltage at vehicle (radians)

$\phi 1$ = angle by which fundamental voltage at the vehicle lags fundamental voltage at the utility (radians)

$\phi = N * \phi 1 + \phi 2$

ϕ = angle by which the N^{th} harmonic current at the power rail/vehicle interface lags the fundamental voltage at the utility (radians)

The fifth harmonic at the electric utility is only one of several harmonics which may be present. The RMS values of all these harmonics can be found from the sum of the squares.

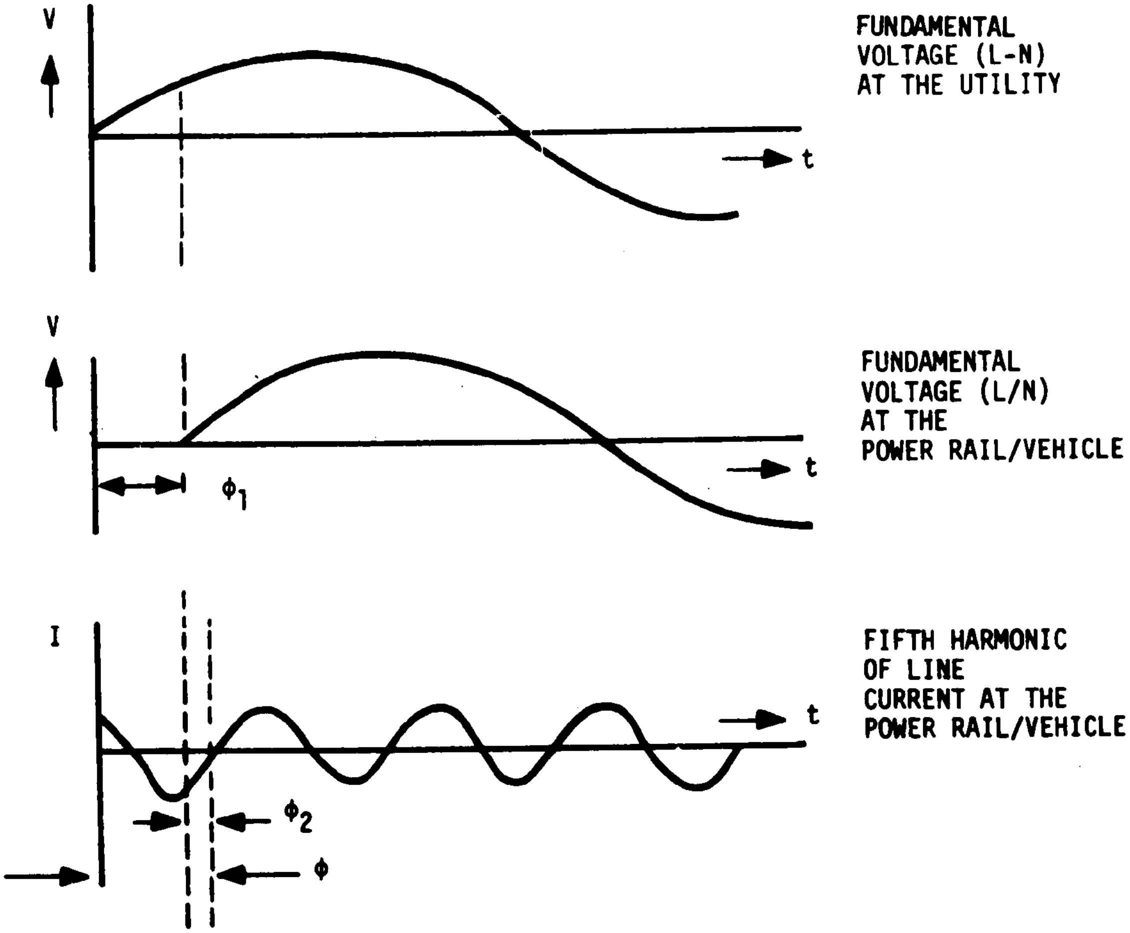


FIGURE 3-11. HARMONIC CURRENT AT THE POWER RAIL/VEHICLES WITH VOLTAGE WAVEFORMS FOR REFERENCE

I_N = RMS value of the N^{th} harmonic current at the utility node

$$DC(1) = SQRT\ (\sum_N I(N)**2\ )$$

DC(1) = RMS value of the distortion current at the utility node (per unit amp).

The distortion power can be calculated as the product of the utility voltage and distortion current.

DC(1) = RMS distortion current (p.u.)
E(1) = utility voltage (L-N) (p.u.)
DKVA = E(1) * DC(1)
DKVA = distortion power at the utility (p.u.)

The total apparent KVA may also be calculated.

P(1) = active power at the utility (p.u.)
Q(1) = reactive power at the utility (p.u.)
DKVA = distortion power at the utility (p.u.)
TKVA = SQRT(P(1)**2+Q(1)**2+DKVA**2)
TKVA = total apparent KVA at the utility (p.u.)

The distortion power is calculated from a Fourier analysis of the current wave shape. The parameters of the waveshape are α (SCR firing angle) and μ (commutation angle). The outputs are the distortion power and total apparent KVA at the electric utility connection node. This modeling is done by routine DISTOR.

3.7 VEHICLE POSITION UPDATES

Periodically during the simulation, the vehicle positions are updated. This section presents the analysis used to calculate these updated positions. The analysis involves data for each vehicle from three sources:

1. The commanded mission profile point, which is a requested velocity, and encountered grade, encountered headwind, a position on the guideway and a time interval before the next profile point should be attained.

2. The current vehicle state, which is like the commanded mission profile point but with actual rather than commanded values used.

3. The propulsion system limitations for the maximum acceleration, jerk, thrust and power at the wheels.

The strategy for using this data is illustrated in Figure 3-11. Three commanded mission profile velocity points (CV(t), (CV(t+1), CV(t+2)) are shown, together with the actual velocity (AV(t+1)). Each commanded velocity is treated as a speed limit (which the vehicle accelerates or brakes to achieve). These limits change in two ways. First, if a vehicle passes the guideway position associated with a commanded velocity profile point, the commanded velocity changes. That is, referring to Figure 3-12, each point in time has a position (P(t), P(t+2)). It is assumed that the guideway conditions (grade, headwind, speed limit) which are recorded at a time such as t+1 for position P(t+1) remain constant until position P(t+2). A problem arises when a vehicle is dwelling (velocity is zero). In this case it will never pass the next guideway position and

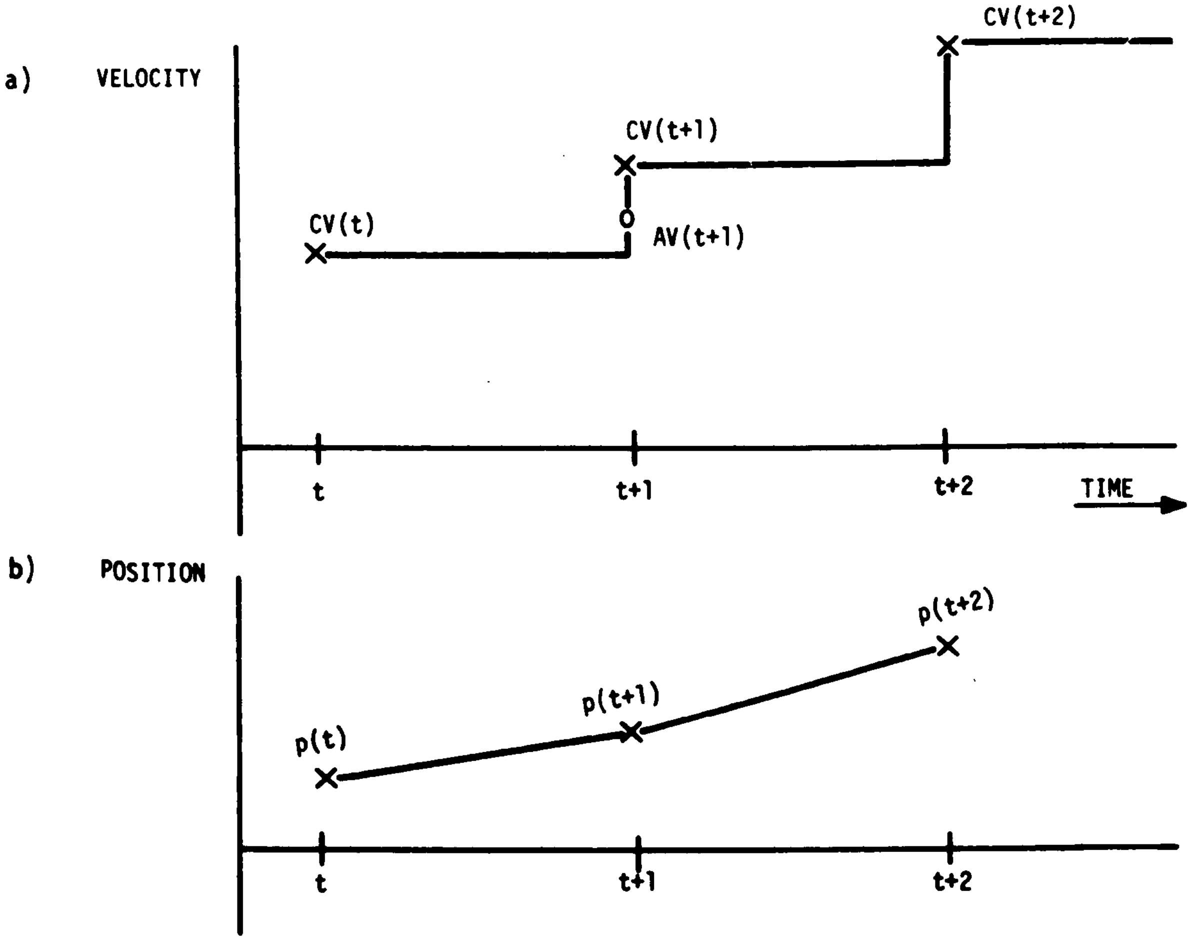


FIGURE 3-12. (a) COMMAND AND ACTUAL VELOCITY PROFILE.
(b) POSITION PROFILE POINTS.

"move" to a new commanded mission profile point. To correct for this a second method is employed to change mission profile points. This one says if the velocity is zero and the time interval is exceeded, then use the next profile point. The next point should have a nonzero velocity, which is used to calculate an acceleration to move the vehicle. The position of each vehicle is calculated by the following formula:

DT = time interval (sec)

POS = vehicle displacement (ft) from last guideway reference point. (Its position at some previous time t.)

VVEL = vehicle velocity (mph) at time t (actual velocity achieved)

VACC = vehicle acceleration (mph/sec) during interval DT

C1 = 1.4667 conversion factor to change mph into feet/sec.

NEWPOS = POS + VVEL + DT * C1 + 0.5 *VACC * C1 * DT & DT

NEWPOS = vehicle displacement (feet) from last guideway reference point. (Its position at time t + DT)

It should be noted that the acceleration VACC takes into account jerk acceleration and thrust limitations. The new velocity can also be found.

DLEVEL = vehicle velocity (mph) at time t

VACC = vehicle acceleration (mph/sec) during interval DT

DT = time interval (sec)

VVEL = vehicle velocity (mph) at time t + DT

This simulation is done by subroutine NUPNT which uses the mission profile data, current vehicle state information, and subroutine VEHDYN to calculate a new position and velocity for the entire vehicle fleet.

4. SAMPLE OUTPUT - AGRT

In this section, a sample run is described. From this run the reader can see the type of output data produced by the simulation. This data, together with the mission profile input data (Appendix A), provides a complete check case for the program.

The output consists of three parts: (1) a record of the guideway data used for input, (2) a record of the mission profile data used for input (it is a partial listing of only the first 15 lines of the table), (3) output tables showing the vehicles' positions, the power flow from the utility connection, the network node voltages , and the state of the propulsion system for each vehicle. The latter group (3) of output tables are repeated for each sample time.

Table 4-1 is the complete output for two vehicles running along a loop (similar to the Morgantown system). The power rail is pictured in Figure 4-1. In this case the two vehicles become electrical nodes (buses) numbered 2 and 3. The reader should note that the vehicles are identified as vehicle number 1,2,...,NCAR, but once they are included in the equivalent electric circuit, they are node (bus) number 2,3,...,NCAR+1.

The list below describes the output data:

1. Guideway segments at time-n sec. This table displays the guideway input data but appends the node

number for any vehicle on that segment.

2. Power flow summary. This table displays the power flow along each individual cable which is connected to the electric utility connection. It is fundamental P and Q in per unit.
3. Total apparent KVA. This is the apparent power supplied by the utility in per unit.
4. Bus voltages.
   This table lists the bus voltage in per unit, the fundamental power into the network in per unit (loads are negative, generators are positive) and the distortion current in per unit.
5. State of the vehicles
   For each vehicle number (1 to NCAR) this table lists a vehicle position (a guideway identifier and a footage displacement), current velocity (in MPH), acceleration (in MPH/s) ideal or commanded velocity (in MPH), encountered grade (in percent), encountered headwind (in MPH), motor terminal voltage (volts), motor terminal current (amps) number of passengers, number of cars coupled together, a mode (1-voltage controlled speed, 2-field-weakening controlled speed, 3-regenerative-braking, 4-friction braking), the power conditioning units firing angle (alpha-in radians).

These tables are written by the subroutines named: RITE or VEHSUM. The labels, formats and variables are described there.

TABLE 4-1.

```
     MORGANTOWN GUIDEWAY DATA - THREE LINES

       GUIDEWAY DATA
      FROM  TO SEGMENT    START     END
        6.  4.  E      11650.000 12285.000
        6.  5.  M3     12285.000 17160.000
        5.  4.  M4     17160.000 21903.000
        4.  4.  W          1.000  2050.000
        4.  5.  M1      2050.000  6785.000
        5.  6.  M2      6785.000 11650.000
        1.  4.  TT         0.000     0.025
        1.  5.  TT         0.000     0.025
        1.  6.  TT         0.000     0.025
      AGT 2
         0  746   73  224    0
         0  385  435  584    0
         2    2
         1  413
         0    0
        3.0000    0.0000    0.0000    0.0000W     903.11
        1.0000    1.0200    0.0000    0.0000W     905.35
        1.0000    2.0400    0.0000    0.0000W     908.44
        1.0000    2.1760    0.0000    0.0000W     911.73
        1.0000    2.3120    0.0000    0.0000W     915.23
        1.0000    2.4480    0.0000    0.0000W     918.92
        1.0000    2.5840    0.0000    0.0000W     922.81
        1.0000    2.7200    0.0000    0.0000W     927.79
        1.0000    4.0800    0.0000    0.0000W     934.77
        1.0000    5.4400    0.0000    0.0000W     942.75
        1.0000    5.4400    0.0000    0.0000W     950.73
        1.0000    5.4400    0.0000    0.0000W     958.71
        1.0000    5.4400    0.0000    0.0000W     966.69
        1.0000    5.4400    0.0000    0.0000W     974.67
        1.0000    5.4400    0.0000    0.0000W     982.65
       GUIDEWAY SEGMENTS AT TIME =    0 SEC
        6. 4.E     11650.000    12285.000  3.  0.  0.  0.  0.
        6. 5.M3    12285.000    17160.000  0.  0.  0.  0.  0.
        5. 4.M4    17160.000    21903.000  0.  0.  0.  0.  0.
        4. 4.W         1.000     2050.000  2.  0.  C.  0.  0.
        4. 5.M1     2050.000     6785.000  0.  0.  0.  0.  0.
        5. 6.M2     6785.000    11650.000  0.  0.  0.  0.  0.
        1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
        1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
        1. 6.TT        0.000        0.025  0.  C.  C.  0.  0.


       POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF    0 SEC :

       POWER FLOW FROM NCDE 1 TO NODE    4 IS   0.0108 -0.0086
       POWER FLOW FROM NODE 1 TO NUDF    5 IS   0.0044 -0.0030
       POWER FLOW FROM NODE 1 TO NODE    6 IS   0.0148 -0.0540

       THE TOTAL APPARENT KVA IS   0.073040 IN PER UNIT

         BUS         VOLTAGE           POWER SCHEDULED       POWER DELIVERED      DISTORTION CURRENT
          1     1.0000    0.0000    0.0300    0.0655    0.0300    0.0655       0.0119
          2     0.9990   -0.0005   -0.0115   -0.0087   -0.0115   -0.0087       J.0000
          3     0.9981   -0.0001   -0.0184   -0.0570   -0.0184   -0.0570       0.0119
          4     0.9990   -0.0003    J.0000    0.0000    0.0000    0.J000       0.0000
          5     0.9999   -0.0001    J.0000    0.0000   -0.0000    0.000U       0.00C0
```

TABLE 4-1 (CONT'D)

```
    6   0.9987  -0.0004    0.0000    0.0000    0.0001    0.0002      0.0000

 STATE OF THE VEHICLES AT   0 SEC :
   NO.      POSITION       VEL      ACC   IDEAL VEL    GRADE  WIND  MOTOR VOLT  CURRENT   ANGLE      PASS      CARS    MODE    ALPHA    NO.
    1    W       903.11   0.00    -0.68        0.00     0.00  0.00        0.0      0.0     0.00        10         1      4.     1.57     1
    2    E     11760.60   5.10     0.34        5.10     0.00  0.00      109.0     63.0     0.00        10         1      1.     1.43     2


 GUIDEWAY SEGMENTS AT TIME =    1 SEC
   6. 6.E     11650.000     12285.000  3.  0.  0.  0.  0.
   6. 5.M3    12285.000     17160.000  0.  0.  0.  0.  0.
   5. 4.M4    17160.000     21903.000  0.  0.  0.  0.  0.
   4. 4.W         1.000      2050.000  2.  0.  0.  0.  0.
   4. 5.M1     2050.000      6785.000  0.  0.  0.  0.  0.
   5. 6.M2     6785.000     11650.000  0.  0.  0.  0.  0.
   1. 4.TT        0.000         0.025  0.  0.  0.  0.  0.
   1. 5.TT        0.000         0.025  0.  0.  0.  0.  0.
   1. 6.TT        0.000         0.025  0.  0.  0.  0.  0.
 GUIDEWAY SEGMENTS AT TIME =    2 SEC
   6. 6.E     11650.000     12285.000  3.  0.  0.  0.  0.
   6. 5.M3    12285.000     17160.000  0.  0.  0.  C.  0.
   5. 4.M4    17160.000     21903.000  0.  0.  0.  0.  0.
   4. 4.W         1.000      2050.000  2   0.  C.  0.  0.
   4. 5.M1     2050.000      6785.000  0.  0.  0.  0.  0.
   5. 6.M2     6785.000     11650.000  0.  0.  0.  0.  0.
   1. 4.TT        0.000         0.025  0.  0.  0.  0.  0.
   1. 5.TT        0.000         0.025  0.  0.  0.  0.  0.
   1. 6.TT        0.000         0.025  0.  0.  0.  0.  0.


 POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF    2 SEC :

 POWER FLOW FROM NODE 1 TO NODE    4 IS    0.0106 -0.0086
 POWER FLOW FROM NODE 1 TO NODE    5 IS    0.0035 -0.0019
 POWER FLOW FROM NODE 1 TO NODE    6 IS    0.0130 -0.0368

 THE TOTAL APPARENT KVA IS   0.055108 IN PER UNIT

   BUS         VOLTAGE            POWER SCHEDULED       POWER DELIVERED       DISTORTION CURRENT
    1      1.0000    0.0000      0.0272    0.0474     0.0272    0.0474       0.0074
    2      0.9990   -0.0005     -0.0115   -0.0087    -0.0115   -0.0087       0.0000
    3      0.9986   -0.0002     -0.0157   -0.0387    -0.0157   -0.0387       0.0074
    4      0.9990   -0.0003      0.0000    0.0000    -0.0000   -0.0000       0.0000
    5      1.0000   -0.0001      0.0000    0.0000     0.0000    0.0000       0.0000
    6      0.9991   -0.0003      0.0000    0.0000     0.0000    0.0000       0.0000

 STATE OF THE VEHICLES AT   2 SEC :
   NO.      POSITION       VEL      ACC   IDEAL VEL    GRADE  WIND  MOTOR VOLT  CURRENT   ANGLE      PASS      CARS    MODE    ALPHA    NO.
    1    W       903.11   0.00     0.00        0.00     0.00  0.00        0.0      0.0     0.00        10         1      4.     1.57     1
    2    E     11775.56   5.10     0.00        5.44     0.00  0.00      105.4     39.1     0.00        10         1      1.     1.43     2


 GUIDEWAY SEGMENTS AT TIME =    3 SEC
   6. 6.E     11650.000     12285.000  3.  0.  0.  0.  0.
   6. 5.M3    12285.000     17160.000  0.  0.  0.  0.  0.
   5. 4.M4    17160.000     21903.000  0.  0.  0.  0.  0.
   4. 4.W         1.000      2050.000  2.  0.  C.  0.  0.
   4. 5.M1     2050.000      6785.000  0.  0.  0.  0.  0.
   5. 6.M2     6785.000     11650.000  0.  0.  0.  0.  0.
```

TABLE 4-1 (CONT'D)

```
  1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000        0.025  0.  0.  0.  0.  0.
 GUIDEWAY SEGMENTS AT TIME =    4 SEC
  6. 6.E     11650.000    12285.000  3.  0.  0.  0.  0.
  6. 5.M3    12285.000    17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000    21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000     2050.000  2.  0.  0.  0.  0.
  4. 5.M1     2050.000     6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000    11650.000  0.  0.  0.  0.  0.
  1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000        0.025  0.  0.  0.  0.  0.


 POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF    4 SEC :

 POWER FLOW FROM NODE 1 TO NODE   4 IS   0.0100 -0.0086
 POWER FLOW FROM NODE 1 TO NODF   5 IS   0.0058 -0.0055
 POWER FLOW FROM NODE 1 TO NJDE   6 IS   0.0110 -0.0086

 THE TOTAL APPARENT KVA IS   0.100370 IN PER UNIT

   BUS        VOLTAGE          POWER SCHEDULED      POWER DELIVERED      DISTORTION CURRENT
     1    1.0000    0.0000    0.0275    0.1027    0.0275    0.1027      0.0208
     2    0.9930    0.0025   -0.0157   -0.0936   -0.0157   -0.0937      0.0208
     3    0.9996   -0.0003   -0.0115   -0.0087   -0.0115   -0.0087      0.0000
     4    0.9978   -0.0003    0.0000    0.0000    0.0001    0.0001      0.0000
     5    0.9999   -0.0001    0.0000    0.0000    0.0000    0.0000      0.0000
     6    0.9998   -0.0003    0.0000    0.0000    0.0000    0.0002      0.0000

 STATE OF THE VEHICLES AT    4 SEC :
   NO.     POSITION     VEL     ACC  IDEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS    CARS  MODE  ALPHA  NO.
    1    W     905.35  1.02    1.02       1.02    0.00  0.00        38.1   110.2   0.00     10       1    1.   1.51   1
    2    E   11791.77  5.44    0.00       5.44   -7.90  0.00         0.0     0.0   0.00     10       1    4.   1.57   2


 GUIDEWAY SEGMENTS AT TIME =    5 SEC
  6. 6.E     11650.000    12285.000  3.  0.  0.  0.  0.
  6. 5.M3    12285.000    17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000    21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000     2050.000  2.  0.  0.  0.  0.
  4. 5.M1     2050.000     6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000    11650.000  0.  0.  0.  0.  0.
  1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000        0.025  0.  0.  0.  0.  0.
 GUIDEWAY SEGMENTS AT TIME =    6 SEC
  6. 6.E     11650.000    12285.000  3.  0.  0.  0.  0.
  6. 5.M3    12285.000    17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000    21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000     2050.000  2.  0.  0.  0.  0.
  4. 5.M1     2050.000     6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000    11650.000  0.  0.  0.  0.  0.
  1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000        0.025  0.  0.  0.  0.  0.


 POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF    6 SEC :
```

TABLE 4-1 (CONT'D)

```
POWER FLOW FROM NODE 1 TO NODE    4 IS    0.0101 -0.0366
POWER FLOW FROM NODE 1 TO NODE    5 IS    0.0034 -0.0021
POWER FLOW FROM NODE 1 TO NODE    6 IS    0.0107 -0.0086

THE TOTAL APPARENT KVA IS   0.0[illegible]12 IN PER UNIT

  BUS          VOLTAGE          POWER SCHEDULED       POWER DELIVERED      DISTORTION CURRENT
    1     1.0000    0.0000    0.0242    0.0473    0.0242    0.0473        0.0073
    2     0.9969    0.0006   -0.0126   -0.0385   -0.0126   -0.0386        0.0073
    3     0.9996   -0.0003   -0.0115   -0.0087   -0.0115   -0.0087        0.0000
    4     0.9991   -0.0003    0.0000    0.0000    0.0000    0.0000        0.0000
    5     0.9999   -0.0001    0.0000    0.0000    0.0000    0.0000        0.0000
    6     0.9998   -0.0003    0.0000    0.0000    0.0000    0.0000        0.0000

STATE OF THE VEHICLES AT    6 SEC :
   NO.       POSITION     VEL      ACC  IDEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE     PASS     CARS   MODE   ALPHA   NO.
    1    W       900.35  1.02     0.00       1.02    0.00  0.00        27.3    38.6   0.00      10        1     1.     1.53     1
    2    E     11807.72  5.44     0.00       0.74   -7.90  0.00         0.0     0.0   0.00      10        1     4.     1.57     2


GUIDEWAY SEGMENTS AT TIME =    7 SEC
  6. 6.E     11650.000    12285.000  3.  0.  0.  0.  0.
  6. 5.M3    12285.000    17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000    21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000     2050.000  2.  0.  0.  0.  0.
  4. 5.M1     2050.000     6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000    11650.000  0.  0.  0.  0.  0.
  1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000        0.025  0.  0.  0.  0.  0.
GUIDEWAY SEGMENTS AT TIME =    8 SEC
  6. 6.E     11650.000    12285.000  3.  0.  0.  0.  0.
  6. 5.M3    12285.000    17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000    21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000     2050.000  2.  0.  0.  0.  0.
  4. 5.M1     2050.000     6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000    11650.000  0.  0.  0.  0.  0.
  1. 4.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000        0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000        0.025  0.  0.  0.  0.  0.

POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF    8 SEC :

POWER FLOW FROM NODE 1 TO NODE    4 IS    0.0137 -0.0883
POWER FLOW FROM NODE 1 TO NODE    5 IS    0.0125 -0.0107
POWER FLOW FROM NODE 1 TO NODE    6 IS    0.0421 -0.1128

THE TOTAL APPARENT KVA IS   0.225045 IN PER UNIT

  BUS          VOLTAGE          POWER SCHEDULED       POWER DELIVERED      DISTORTION CURRENT
    1     1.0000    0.0000    0.0683    0.2117    0.0683    0.2117        0.0335
    2     0.9929    0.0023   -0.0179   -0.0935   -0.0179   -0.0934        0.0208
    3     0.9953   -0.0005   -0.0499   -0.1181   -0.0500   -0.1181        0.0283
    4     0.9978   -0.0003    0.0000    0.0000   -0.0001    0.0003        0.0000
    5     0.9997   -0.0003    0.0000    0.0000   -0.0000    0.0002        0.0000
    6     0.9972   -0.0011    0.0000    0.0000    0.0002    0.0005        0.0000

STATE OF THE VEHICLES AT    8 SEC :
```

TABLE 4-1 (CONT'D)

```
   NO.     POSITICN      VEL     ACC  ICEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS   CARS  MODE  ALPHA  NO.
    1   W     913.90  2.04     1.02       2.18    0.00  0.00       57.6   110.3    0.00     10      1    1.   1.49    1
    2   E   11843.04 12.04     3.30      13.16   -7.90  0.00      254.9   150.4    0.00     10      1    4.   1.22    2


 GUIDEWAY SEGMENTS AT TIME =   9 SEC
   6. 6.E     11650.000   12285.000  3.  0.  C.  0.  0.
   6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
   5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
   4. 4.W         1.000    2050.000  2.  0.  C.  0.  0.
   4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
   5. 6.M2     6785.000   11650.000  0.  0.  C.  0.  0.
   1. 4.TT        0.000       0.025  0.  0.  0.  0.  0.
   1. 5.TT        0.000       0.025  0.  C.  C.  0.  0.
   1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.
 GUIDEWAY SEGMENTS AT TIME =  10 SEC
   6. 6.E     11650.000   12285.000  3.  0.  C.  0.  0.
   6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
   5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
   4. 4.W         1.000    2050.000  2.  0.  C.  0.  0.
   4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
   5. 6.M2     6785.000   11650.000  0.  0.  0.  0.  0.
   1. 4.TT        0.000       0.025  0.  0.  C.  0.  0.
   1. 5.TT        0.000       0.025  0.  0.  0.  0.  0.
   1. 6.TT        0.000       0.025  0.  0.  0.  C.  0.

 POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF  10 SEC :

 POWER FLOW FROM NODE 1 TO NODE   4 IS   0.0113 -0.0436
 POWER FLOW FROM NODE 1 TO NODE   5 IS   0.0030 -0.0025
 POWER FLOW FROM NODE 1 TO NODE   6 IS   0.0107 -0.0084

 THE TOTAL APPARENT KVA IS   0.040987 IN PER UNIT

   BUS       VOLTAGE          POWER SCHEDULED      POWER DELIVERED     DISTORTION CURRENT
    1     1.0000   0.0000    0.0258   0.0545    0.0258   0.0545      0.0091
    2     0.9963   0.0000   -0.0141  -0.0460   -0.0141  -0.0459      0.0051
    3     0.9996  -0.0003   -0.0115  -0.0087   -0.0115  -0.0086      0.0000
    4     0.9989  -0.0003    0.0000   0.0000   -0.0000  -0.0000      0.0000
    5     0.9999  -0.0001    0.0000   0.0000   -0.0000   0.0000      0.0000
    6     0.9998  -0.0003    0.0000   0.0000   -0.0000   0.0007      0.0000

 STATE OF THE VEHICLES AT  10 SEC :
   NO.        POSITION      VEL     ACC  IDEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS   CARS  MODE  ALPHA  NO.
    1   W       920.36  2.31     0.14       2.45    0.00  0.00       53.5    48.3    0.00     10      1    1.   1.50    1
    2   E     11882.47 13.16     0.00      14.28   -7.90  0.00        0.0     0.0    0.00     10      1    4.   1.57    2


 GUIDEWAY SEGMENTS AT TIME =  11 SEC
   6. 6.E     11650.000   12285.000  3.  0.  C.  C.  0.
   6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
   5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
   4. 4.W         1.000    2050.000  2.  0.  C.  0.  0.
   4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
   5. 6.M2     6785.000   11650.000  0.  0.  0.  0.  0.
   1. 4.TT        0.000       0.025  0.  0.  C.  0.  0.
   1. 5.TT        0.000       0.025  0.  C.  0.  0.  0.
   1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.
```

TABLE 4-1 (CONT'D)

```
GUIDEWAY SEGMENTS AT TIME =  12 SEC
  6. 6.E     11650.000   12285.000  3.  0.  0.  0.  0.
  6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000    2050.000  2.  0.  C.  0.  0.
  4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000   11650.000  0.  0.  C.  0.  0.
  1. 4.TT        0.000       0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000       0.025  0.  C.  0.  0.  0.
  1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.

POWER FLOW SUMMARY AT SIMULATED CLOCK TIME UF  12 SEC :

POWER FLOW FROM NODE 1 TO NODE    4 IS   0.0121 -0.0435
POWER FLOW FROM NODE 1 TO NODE    5 IS   0.C097 -0.0063
POWER FLOW FROM NODE 1 TO NODE    6 IS   0.0458 -0.0921

THE TOTAL APPARENT KVA IS   0.158603 IN PER UNIT

  BUS        VOLTAGE           PCWER SCHEDULED       POWER DELIVERED      DISTORTION CURRENT
   1     1.0000    0.0000     0.0675    0.1419     0.0675    0.1419        0.0215
   2     0.9963    0.0000    -0.0144   -0.0460    -0.0144   -0.0460        0.0051
   3     0.9950   -0.0008    -0.0511   -0.0954    -0.0530   -0.0955        0.0235
   4     0.9989   -0.0003     0.0000    0.0000     0.0001    0.0002        0.0000
   5     0.9990   -0.0002     0.0000    0.0000    -0.0000    0.0000        0.0000
   6     0.9977   -0.0011     0.0000    0.0000     0.0000   -0.0001        0.0000

STATE OF THE VEHICLES AT  12 SEC :
 NO.     POSITION     VEL     ACC  IDEAL VEL  GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS    CARS  MODE  ALPHA  NO.
  1   W    927.94   2.58    0.14      2.72   0.00  0.00       58.7    48.3   0.00     10      1     1.   1.49   1
  2   E  11929.66  16.32    2.04     18.36  -3.85  0.00      333.0   124.8   0.00     10      1     1.   1.12   2


GUIDEWAY SEGMENTS AT TIME =  13 SEC
  6. 6.E     11650.000   12285.000  3.  0.  C.  0.  0.
  6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
  5. 4.M4    17160.000   21903.000  0.  0.  C.  0.  0.
  4. 4.W         1.000    2050.000  2.  0.  0.  0.  0.
  4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000   11650.000  0.  0.  0.  0.  0.
  1. 4.TT        0.000       0.025  0.  0.  C.  0.  0.
  1. 5.TT        0.000       0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.
GUIDEWAY SEGMENTS AT TIME =  14 SEC
  6. 6.E     11650.000   12285.000  3.  0.  C.  0.  0.
  6. 5.M3    12285.000   17160.000  0.  0.  C.  0.  0.
  5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
  4. 4.W         1.000    2050.000  2.  0.  C.  0.  0.
  4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
  5. 6.M2     6785.000   11650.000  0.  0.  C.  0.  0.
  1. 4.TT        0.000       0.025  0.  0.  0.  0.  0.
  1. 5.TT        0.000       0.025  0.  0.  0.  0.  0.
  1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.

POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF  14 SEC :

POWER FLOW FROM NODE 1 TC NCDE    4 IS   0.0119 -0.0364
POWER FLOW FROM NODE 1 TO NODE    5 IS   0.0074 -0.0039
```

TABLE 4-1 (CONT'D)

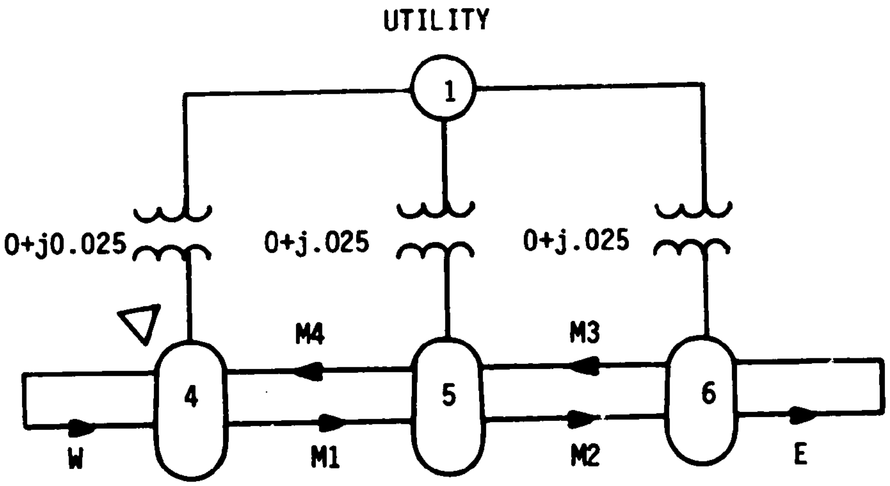
```
POWER FLOW FROM NODE 1 TO NODE    6 IS   0.0371 -0.0583

THE TOTAL APPARENT KVA IS   0.114250 IN PER UNIT

  BUS        VOLTAGE            POWER SCHEDULED        POWER DELIVERED       DISTORTION CURRENT
   1     1.0000    0.0000     0.0563    0.0986     0.0563    0.0986          0.0123
   2     0.9968    0.0005    -0.0139   -0.0386    -0.0138   -0.0384          0.0073
   3     0.9972   -0.0008    -0.0419   -0.0604    -0.0419   -0.0601          0.0146
   4     0.9991   -0.0003     0.0000    0.0000    -0.0003    0.0000          0.0000
   5     0.9990   -0.0002     0.0000    0.0000    -0.0000    0.0002          0.0000
   6     0.9992   -0.0009     0.0000    0.0000    -0.0003   -0.0000          0.0000

STATE OF THE VEHICLES AT  14 SEC :
   NO.       POSITION      VEL      ACC   ICEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS    CARS  MCDE   ALPHA   NO.
    1    W       936.02  2.72     0.00        4.00    0.00  0.00        59.9    38.8    0.00     10       1    1.     1.49    1
    2    E     11988.01 19.72     1.36       21.00   -3.85  0.00       391.0    77.7    0.00     10       1    1.     1.04    2


GUIDEWAY SEGMENTS AT TIME =  15 SEC
   6. 6.E      11650.000    12285.000  3.  0.  C.  C.  0.
   6. 5.M3     12285.000    17160.000  0.  0.  0.  0.  0.
   5. 4.M4     17160.000    21903.000  0.  0.  C.  0.  0.
   4. 4.W          1.000     2050.000  2.  0.  C.  0.  0.
   4. 5.M1      2050.000     6705.000  0.  0.  0.  0.  0.
   5. 6.M2      6705.000    11650.000  0.  0.  0.  0.  0.
   1. 4.TT         0.000        0.025  0.  0.  0.  0.  0.
   1. 5.TT         0.000        0.025  0.  0.  C.  C.  0.
   1. 6.TT         0.000        0.025  0.  0.  0.  0.  0.
GUIDEWAY SEGMENTS AT TIME =  16 SEC
   6. 6.E      11650.000    12285.000  3.  0.  0.  0.  0.
   6. 5.M3     12285.000    17160.000  0.  0.  0.  0.  0.
   5. 4.M4     17160.000    21903.000  0.  0.  0.  0.  0.
   4. 4.W          1.000     2050.000  2.  0.  C.  0.  0.
   4. 5.M1      2050.000     6705.000  0.  0.  0.  0.  0.
   5. 6.M2      6705.000    11650.000  0.  0.  0.  0.  0.
   1. 4.TT         0.000        0.025  0.  0.  0.  0.  0.
   1. 5.TT         0.000        0.025  0.  0.  0.  0.  0.
   1. 6.TT         0.000        0.025  0.  0.  0.  0.  0.


POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF  16 SEC :

POWER FLOW FROM NODE 1 TO NODE    4 IS   0.0227 -0.1045
POWER FLOW FROM NODE 1 TO NODE    5 IS   C.C089 -0.0068
POWER FLOW FROM NODE 1 TO NODE    6 IS   0.0229 -0.0272

THE TOTAL APPARENT KVA IS   0.150626 IN PER UNIT

  BUS        VOLTAGE            POWER SCHEDULED        POWER DELIVERED       DISTORTION CURRENT
   1     1.0000    0.0000     0.0545    0.1305     0.0545    0.1305          0.0230
   2     0.9913    0.0023    -0.0286   -0.1108    -0.0286   -0.1104          0.0254
   3     0.9987   -0.0006    -0.0251   -0.0286    -0.0252   -0.0285          0.0059
   4     0.9974   -0.0006     0.0000    0.0000    -0.0004    0.0007          0.0000
   5     0.9990   -0.0002     0.0000    0.0000    -0.0001   -0.0001          0.0000
   6     0.9993   -0.0006     0.0000    0.0000     0.0001    0.0008          0.0000

STATE OF THE VEHICLES AT  16 SEC :
   NO.       POSITION      VEL      ACC   ICEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS    CARS  MCDE   ALPHA   NO.
    1    W       951.98  5.44     1.36        5.44    0.00  0.00       126.3   134.6    0.00     10       1    1.     1.40    1
    2    E     12053.03 22.44     1.36       22.44   -6.92  0.00       436.0    31.1    0.00     10       1    1.     0.97    2
```

TABLE 4-1 (CONT'D)

```
GUIDEWAY SEGMENTS AT TIME =  17 SEC
 6. 6.E     11650.000   12285.000  3.  0.  0.  0.  0.
 6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
 5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
 4. 4.W         1.000    2050.000  2.  0.  0.  0.  0.
 4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
 5. 6.M2     6785.000   11650.000  0.  0.  0.  0.  0.
 1. 4.TT        0.000       0.025  0.  0.  0.  0.  0.
 1. 5.TT        0.000       0.025  0.  0.  0.  0.  0.
 1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.
GUIDEWAY SEGMENTS AT TIME =  18 SEC
 6. 6.E     11650.000   12285.000  3.  0.  0.  0.  0.
 6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
 5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
 4. 4.W         1.000    2050.000  2.  0.  0.  0.  0.
 4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
 5. 6.M2     6785.000   11650.000  0.  0.  0.  0.  0.
 1. 4.TT        0.000       0.025  0.  0.  0.  0.  0.
 1. 5.TT        0.000       0.025  0.  0.  0.  0.  0.
 1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.

POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF  18 SEC :

POWER FLOW FROM NODE 1 TO NODE   4 IS   0.0133 -0.0368
POWER FLOW FROM NODE 1 TO NODE   5 IS   0.0036 -0.0019
POWER FLOW FROM NODE 1 TO NODE   6 IS   0.0107 -0.0085

THE TOTAL APPARENT KVA IS   0.055243 IN PER UNIT

  BUS        VOLTAGE           POWER SCHEDULED       POWER DELIVERED      DISTORTION CURRENT
   1     1.0000    0.0000    0.0275    0.0473     0.0275    0.0473       0.0074
   2     0.9967    0.0004   -0.0159   -0.0386    -0.0159   -0.0386       0.0074
   3     0.9996   -0.0003   -0.0115   -0.0087    -0.0115   -0.0087       0.0000
   4     0.9991   -0.0003    0.0000    0.0000    -0.0000   -0.0000       0.0000
   5     1.0000   -0.0001    0.0000    0.0000    -0.0000    0.0000       0.0000
   6     0.9998   -0.0003    0.0000    0.0000     0.0000    0.0001       0.0000

STATE OF THE VEHICLES AT  18 SEC :
  NO.     POSITION        VEL     ACC   IDEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS    CARS  MODE  ALPHA  NO.
   1    W      967.94   5.44    0.00       5.44    0.00  0.00     112.0     39.1    0.00     10      1     1.    1.42   1
   2    E    12119.66  22.44    0.00      22.44  -10.00  0.00       0.0      0.0    0.00     10      1     4.    1.57   2

GUIDEWAY SEGMENTS AT TIME =  19 SEC
 6. 6.E     11650.000   12285.000  3.  0.  0.  0.  0.
 6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
 5. 4.M4    17160.000   21903.000  0.  0.  0.  0.  0.
 4. 4.W         1.000    2050.000  2.  0.  0.  0.  0.
 4. 5.M1     2050.000    6785.000  0.  0.  0.  0.  0.
 5. 6.M2     6785.000   11650.000  0.  0.  0.  0.  0.
 1. 4.TT        0.000       0.025  0.  0.  0.  0.  0.
 1. 5.TT        0.000       0.025  0.  0.  0.  0.  0.
 1. 6.TT        0.000       0.025  0.  0.  0.  0.  0.
GUIDEWAY SEGMENTS AT TIME =  20 SEC
 6. 6.E     11650.000   12285.000  3.  0.  0.  0.  0.
 6. 5.M3    12285.000   17160.000  0.  0.  0.  0.  0.
```

TABLE 4-1 (CONT'D)

```
 5. 4.M4   17160.000   21903.000  0.  0.  0.  0.  0.
 4. 4.W        1.000    2050.000  2.  0.  0.  0.  0.
 4. 5.M1    2050.000    6785.000  0.  0.  0.  0.  0.
 5. 6.M2    6785.000   11650.000  0.  0.  0.  0.  0.
 1. 4.TT       0.000       0.025  0.  0.  0.  0.  0.
 1. 5.TT       0.000       0.025  0.  0.  0.  0.  0.
 1. 6.TT       0.000       0.025  0.  0.  0.  0.  0.

POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF  20 SEC :

POWER FLOW FROM NODE 1 TO NODE   4 IS   0.0133 -0.0368
POWER FLOW FROM NODE 1 TO NODE   5 IS   0.0036 -0.0020
POWER FLOW FROM NODE 1 TO NODE   6 IS   0.0107 -0.0086

THE TOTAL APPARENT KVA IS   0.055310 IN PER UNIT

  BUS        VOLTAGE          POWER SCHEDULED      POWER DELIVERED      DISTORTION CURRENT
   1     1.0000   0.0000    0.0275    0.0474    0.0275    0.0474      0.0074
   2     0.9967   0.0004   -0.0159   -0.0306   -0.0159   -0.0306      0.0074
   3     0.9997  -0.0003   -0.0115   -0.0087   -0.0115   -0.0087      0.0000
   4     0.9991  -0.0003    0.0000    0.0000    0.0000    0.0000      0.0000
   5     1.0000  -0.0001    0.0000    0.0000    0.0000    0.0000      0.0000
   6     0.9990  -0.0003    0.0000    0.0000   -0.0000    0.0000      0.0000

STATE OF THE VEHICLES AT  20 SEC :
  NO.      POSITION      VEL     ACC  IDEAL VEL   GRADE  WIND  MOTOR VOLT CURRENT  ANGLE    PASS     CARS   MODE   ALPHA   NO.
   1    W     983.89  5.44    0.00       5.44    0.00  0.00       112.0    39.1    0.00     10        1     1.     1.42    1
   2    E   12185.48 22.44    0.00      22.44  -10.00  0.00         0.0     0.0    0.00     10        1     4.     1.57    2
```



KEY:

① ELECTRICAL NODE

0+j0.025 STEPDOWN TRANSFORMER WITH 0+j0.025 PER UNIT IMPEDANCE

——▶—— POWER RAIL SEGMENT W

▽ MILEPOST FROM WHICH ALL VEHICLE POSITIONS ARE MEASURED, AS DISPLACEMENT IN FEET.

FIGURE 4-1 THE TEST CASE POWER RAIL SEGMENTS

5. VALIDATION STUDIES

In order to validate the model, two tests were performed. The first compared the program's output to other simulations, while the second compared it to an operating system.

For the first test, we used a model of the Dallas-Fort Worth Airport AIRTRANS system developed by Vought Corporation. Several simulation studies had been done using this model. In essence, the AIRTRANS system consisted of fifteen (one or two car) trains running over fourteen miles of guideway. Four check cases were chosen, and the results of the Vought simulation and our simulation were compared for each case. The results show the electric power values to be similar. Any differences are accounted for by truncation errors (Typically 1%).

For the second test, the four check cases were compared with values measured at the Dallas Fort-Worth Airport. Our check cases are within 10 percent of the typical average real power.

6. USING THE MODEL

Three steps are involved in using the model: (1) set up the propulsion system subroutines, (2) create a data file for the guideway, and (3) create a data file for the mission profile.

Step one requires the user to modify the analysis presented in section 3 and then change the subroutines which embed that analysis in the simulation.

Steps two and three involve input data preparation.

Two data files are used by the model. The first contains guideway information; the second contains mission profile information. The size of these data files is recorded in compile-time parameters.

First - consider the guideway file. It is a series of records which are read sequentially into the array GWAY. The parameter GWAYRO specifies the number of records or lines. Each record is read into a row of the array GWAY at columns 1 to 5. The record describes one segment of guideway which connects two points or nodes on the guideway. The following naming convention is used for the guideway: Guideway nodes are integers Node one is the utility connection. Nodes two and higher are the power cross-unders and power feed points in any order.

The following list describes the record fields:

1. FN - the node number at the beginning of the segment. Vehicles enter the segment at this node.
2. TN - the node number at the end of the segment. Vehicles leave the segment at this node.
3. SI - the two-character segment identifier. This is a unique name for each segment.
4. SD - a distance mark for the FN node. Other points along the guideway are measured with respect to this reference. The units are in feet.
5. ED - a distance mark for the TN node. The length (feet) of the segment is ED-SD.

By convention ED>SD.

The subrouting SETGW reads in these records and stores them in array GWAY. The compile-time parameter, GWAYRO, defines the number of rows in array GWAY so that the number of rows equals the number of records.

The number of columns in the array GWAY is usually 10. The first five columns are used for the guideway records and the remaining are used for storing the node number of any vehicle which is currently positioned on that guideway segment.

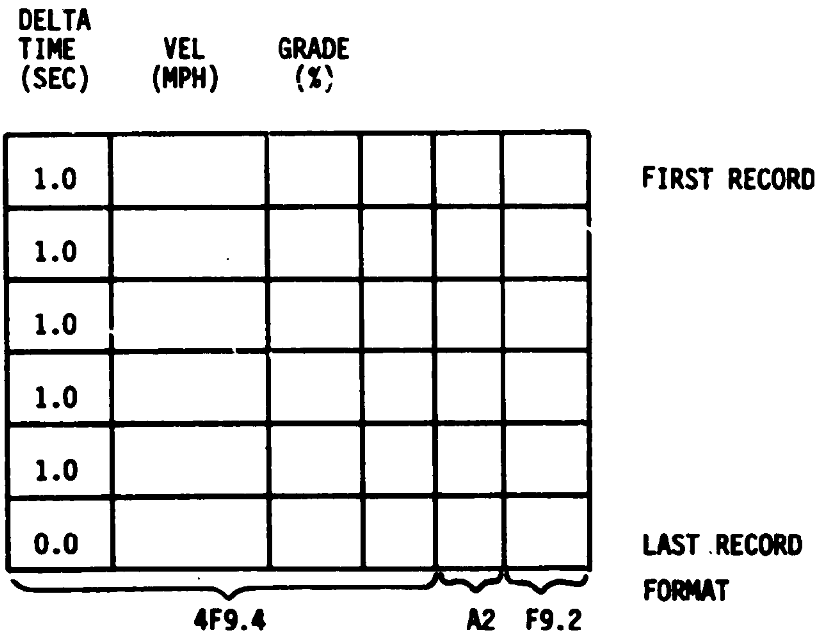
One exception for the guideway data file occurs for the case in which a step-down transformer and/or cables (rather

	FN	TN	SI	SD	ED
2X	3.0	F3.0	A2	F6.0	F6.0

FIGURE 6-1 GUIDEWAY RECORD AND FORMAT

than a power rail) connect two nodes. In that case, the SI field has a special value, "TT". The transformer impedance (R+jX in per unit) is stored in the SD and ED fields for R and X respectively.

The second data file contains mission profile information. It is a series of records which are read sequentially into the array PFILE. The parameter PFILER specifies the number of records. Each record is read into a row of the array. The record describes one point of the mission profile. An arbitrary number of records are collected together and called a route segment. Figure 6-2 shows this. The data at each mission profile point is described in the following list:



A ROUTE SEGMENT IN ARRAY PFILE

FIGURE 6-2 CONTIGUOUS ROWS IN ARRAY PFILE WHICH FORM A ROUTE SEGMENT.

1. DELTA TIME - A NORMAL TIME interval (seconds, between this point and the succeeding profile point. The last record in a route segment has DELTA TIME as 0.
2. VELOCITY - The COMMANDED SPEED UNIT (MPH)
3. GRADE - The encountered grade (%)
4. HEADWIND - The encountered headwind (MPH)
5. LOCATION CODE - A segment identifier (two unique characters) and a distance (feet).

Each such route segment is identified by the row number in PFILE where the first record is. Figure 6-3 shows a collection of route segments in the array PFILE. A complete mission profile data file is contained in Appendix A.

A vehicle's mission is usually a sequence of route segments as Figure 6-4a indicates. So this sequence of route segments is part of a prefix which is included in the mission profile data. The following list describes those data items:

1. Title - a forty character heading which appears on the output
2. ICAR - an array with one column for each vehicle, and an arbitrary number of rows. Column j contains the route segments (by first row number) in the mission profile of vehicle j. The first and last segments are arbitrarily zero.
3, SROW1- a vector with one element for each vehicle.

Its use is as a pointer to ICAR (i.e., vehicle J is initially in route segment ICAR(SROW1(J),J).).

4. SROW2 - a vector with one element for each vehicle. Its use is as a pointer to PFILE (i.e., vehicle J is intially at mission profile point PFILE(SROW2(J), 1 to 6)).
5. TYM - a vector with one element for each vehicle. Its use is to record remaining station dwell times for the vehicles. It is initialized to 0 usually.

This completes the input data preparation. The program operates with the user providing interaction at a terminal (FORTRAN device TTY). The user is prompted to type in at the terminal the following file names:

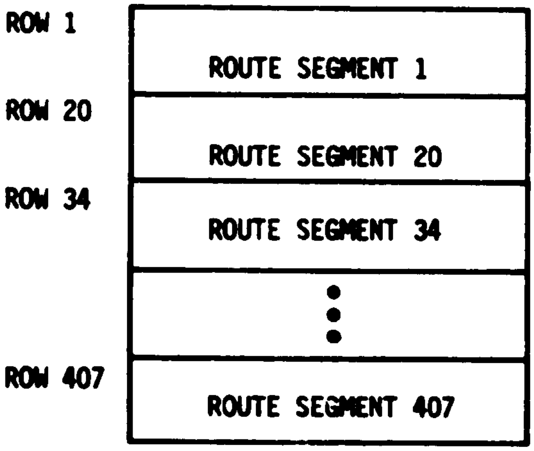
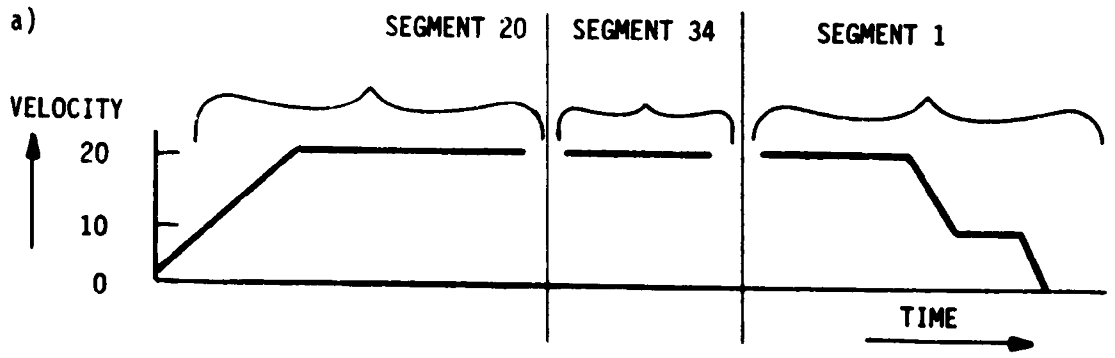


FIGURE 6-3 A COLLECTION OF ROUTE SEGMENTS IN ARRAY PFILE



b)

ICAR

	COLUMN J	
	0	
	20	
	34	
	1	
	0	

FIGURE 6-4 THE SEQUENCE OF ROUTES FOR VEHICLE NUMBER j GRAPHICALLY IN (a) AND AS TABLE ICAR IN (b).

1. a file name for a disk file containing the guideway data.
2. a file name for a disk file containing the mission profile data.

Subsequent prompting occurs as the user is asked to supply a time interval before the next flow calculations. Entering a negative time terminates the simulation.

All output is written on FORTRAN device number 21.

7. CONCLUSIONS

The model described here is capable of simulating a fleet of electric vehicles moving over a guideway network. The output is a discrete and vehicle/power rail interface.

It has been in use for almost one year. It is a useful tool for predicting peak power demand, voltage droop, excessive harmonic currents.

Appendix A

A Program Listing (AUGUST 1979)

FILENAME - CONTENTS

MAIN2.F4 - the main program

P RANR.F4 - the common block and declarations used in each module

SETUP.F4 - subroutines SETPEL AND SETGW

VEHDYN.F4 - subroutine VEHDIN

MOTOR.F4 - subroutine MOTOR

TEFF.F4 - block data

NR2.F4 - subroutine NR

FORMY.F4 - subroutine FORMV

NEWPQ.F4 - subroutine NEWPQ

PCU.F4 - subroutine PCU

GPJ.F4 - subroutine GETJ,PUTJ

DISTOR.F4 - subroutine DISTOR

OUTPUT.F4 - subroutines RITE & VEHSUM

HEDWAY.F4 - subroutine HEDWAY

NUPNT.F4 - subroutine NUPNT

NUGWQ - subroutine NUGWQ

```
C       MAIN PROGRAM FOR VERSION 2
        INCLUDE 'PARAMR.F4'
        TTY=5
C       TTY IS THE LOGICAL DEVICE FOR USER I/O
        LOGFIL=21
C       LOGFIL IS THE LOGICAL DEVICE FOR A PERMANENT RECORD
C       READ IN THE GUIDEWAY SEGMENTS
        CALL SETGW
C       ARRAY GWAY IS SET UP
C       READ IN THE MISSION PROFILE ARRAYS
        CALL SETPFL
C       ARRAY ICAR,BROW1,BROW2, AND PFILE ARE SET UP
        DT=1
        DO 100 II=1,NCAR
C       II IS A VEHICLE NUMBER - ALL VEHICLES LESS THAN II ARE
C       FINISHED AS FAR AS THEIR STATE IS CONCERNED - VELOCITY,
C       POSITION, ACCELERATION, POWER ARE KNOWN -
C       STORE THE CURRENT VEHICLE NUMBER
        NUMVEH=II
C       ESTABLISH VEL, ACC, GRADE, AND HW FOR VEHICLE II -
C       THESE ARE INPUT FOR THE VEHICLE DYNAMICS ROUTINE -
C       VEHICLE II IS DESCRIBED BY PFILE ROW BROW2(II) -
C       LET J EQUAL THIS ROW
        J=BROW2(II)
        VEL=PFILE(J,2)
C       VEL IS THE VELOCITY COMMANDED IN MPH
        VVEL(II)=VEL
C       VVEL(II) IS THE ATTAINED VELOCITY OF VEHICLE II -
C       NEXT RECORD THE ACTUAL POSITION OF VEHICLE II
        POS(1,II)=PFILE(J,5)
C       POS(1,II) IS THE TWO LETTER LOCATION CODE FOR VEHICLE II
        POS(2,II)=PFILE(J,6)
C       POS(2,II) IS THE DISTANCE IN FEET ALONG THAT SEGMENT
C       FOR VEHICLE II
        TYM(II)=PFILE(J,1)
C       TYM(II) IS THE DWELL TIME OF VEHICLE II IN SEC
C       GET THE OLD VELOCITY FOR VEHICLE II
        JM1=J-1
        IF(JM1.LT.1)JM1=PFILER
        OLDVEL=PFILE(JM1,2)
C       COMPUTE THE ACCELERATION
        ACC=(VEL-OLDVEL)/DT
C       COMPUTE THE OLD ACCELERATION
        JM2=J-2
        IF(JM2.LT.1) JM2=PFILER
        OLDACC=(OLDVEL-PFILE(JM2,2))/DT
C       COMPUTE THE JERK
        JERK=(ACC-OLDACC)/DT
C       LIMIT JERK TO JERKM MPH/SEC**2
        IF(JERK.GT.JERKM) JERK=JERKM
        IF(JERK.LT.-JERKM) JERK=-JERKM
        ACC=JERK*DT+OLDACC
C       LIMIT ACC TO ACCM MPH/SEC
        IF(ACC.GT.ACCM) ACC=ACCM
        IF(ACC.LT.-ACCM) ACC=-ACCM
C       JERK AND ACC ARE WITHIN LIMITS -
C       SAVE ACTUAL VALUES OF VELOCITY, GRADE, AND HEADWIND
        VV=VEL
        GRADE=PFILE(J,3)
        HW=PFILE(J,4)
C       SOLVE FOR VEHICLE DYNAMICS TO GET FT THRUST
```

MAIN.F4

```
C       AND PW POWER AT WHEELS
        CALL VEHDYN
C       HAVE ACC, JERK, FT, AND PW APPROPRIATELY LIMITED
        VACC(II)=ACC
C       VACC(II) IS THE ATTAINED ACCELERATION OF VEHICLE II .
C       FIND THE MOTOR TERMINAL VALUES FOR VEHICLE II
        CALL MOTOR
C       HAVE VMTR, IMTR, AND TMTR .
C       SAVE THESE IN A TABLE FOR VEHICLE II
        TVM(II)=VMTR
        TIM(II)=IMTR
        TTM(II)=TMTR
C       VEHICLE II IS UPDATED
100     CONTINUE
C       HAVE ALL NCAR VEHICLES UPDATED
        CALL NUGWQ
C       HAVE THE GUIDEWAY SEGMENT QUEUES SET UP
120     CONTINUE
C       OUTPUT SIMULATED CLOCK TIME
        WRITE(LOGFIL,121) ITIME
121     FORMAT(//,2X,'POWER FLOW SUMMARY AT SIMULATED CLOCK TIME OF',
     1  I4,' SEC :',/)
C       SOLVE THE POWER FLOW PROBLEM
        CALL NR
C       OR FOR THE DC POWER RAIL CASE CHANGE
C       THE ABOVE TO CALL GSDC
C       CALL GSDC
C       FIND THE DISTORTION CURRENT AT THE BUSSES
        CALL DISTOR
        CALL RITE
C       PRINT OUT ON THE LOG FILE A SUMMARY OF THE VEHICLES
        CALL VEHSUM
        WRITE(TTY,130)
130     FORMAT(2X,'ENTER SECONDS TO NEXT SAMPLE, IN I3 :')
        READ(TTY,138)IT
138     FORMAT(I3)
        IF(IT.LE.0)STOP
        DT=1
140     CONTINUE
        CALL NUPWY
C       HAVE ADVANCED ALL VEHICLES BY DT SECONDS
C       SO WE HAVE A NEW PFILE R' : AND ACTUAL POSITION
        CALL NUGWQ
C       FINISHED UPDATING THE GUIDEWAY VEHICLE QUEUES
        IT=IT-DT
C       IT IS THE INTERVAL OF TIME BEFORE THE NEXT
C       SNAPSHOT OF THE LOAD FLOW .
C       VARIABLE IT IS IN SECONDS .
C       IF IT IS GREATER THAN 0 THEN ADVANCE THE VEHICLES
        IF(IT.GT.0) GOTO 140
C       FINISHED ADVANCE .
C       CHECK VEHICLE HEADWAYS
        CALL HEDWAY
        DO 150 II=1,NCAR
        NUMVEH=II
        VV=VVEL(II)
        ACC=VACC(II)
        GRADE=PFILE(SROW2(II),3)
        NW=PFILE(SROW2(II),4)
C       FIND THE MOTOR TERMINAL VALUES FOR VEHICLE II
        CALL MOTOR
```

```
C       HAVE VMTR, IMTR, AND TMTR -
C       SAVE THESE IN A TABLE FOR VEHICLE II
        TVM(II)=VMTR
        TIM(II)=IMTR
        TTM(II)=TMTR
150     CONTINUE
C       TAKE SNAPSHOT OF THE LOAD FLOW
        GOTO 120
        END
```

PARANR.F4

```
C     DECLARATIONS  6   10
      PARAMETER SZ1=16,SZ2=30,SZ3=50
C     SZ1 = THE NUMBER OF BUSSES
C     SZ2 = 2*(SZ1-1) THE JACOBIAN MATRIX SIZE
C     SZ3 = IT IS 1 + THE NUMBER OF BUSSES+
C             THE NUMBER OF NONZERO TERMS IN
C             THE ADMITTANCE MATRIX UPPER TRIANGLE
C             THE SIZE OF Y THE SPARSE ARRAY
C             REPRESENTING THE ADMITTANCE MATRIX
C
C     SZ4 IS THE SIZE OF THE ARRAY JCOB
C             USE 10*SZ1  OR MORE
      PARAMETER SZ4=300
C
C     ICARRO IS THE NUMBER OF ROWS IN ARRAY ICAR
C     WHICH IS 2 PLUS THE NUMBER OF MISSION PROFILE
C     SEGMENTS FOR THE LONGEST CAR ROUTE.
      PARAMETER ICARRO=8
      PARAMETER NCAR=10, PFILER=23)
C     NCAR IS THE NUMBER OF VEHICLES
C     PFILER IS THE NUMBER OF ROWS IN ARRAY PFILE
C     I.E. THE NUMBER OF MISSION PROFILE POINTS
      PARAMETER GWAYRO=6
      PARAMETER GWAYCO=10
C     GWAYRO IS THE NUMBER OF ROWS IN ARRAY GWAY
C     GWAYCO IS THE NUMBER OF COLUMNS IN GWAY
C     THE MAX QUEUE SPACE IS GWAYCO MINUS 5
C     THIS CONTROLS THE MAX NO OF VEHICLES
C     ON ONE GUIDEWAY SEGMENT
C
C     JACOBIAN DATA STRUCTURE FOR NEWTON RAPHSON
C     USE EITHER SPARSE ARRAY JCOB
C     OR USE TWO DIMENSIONAL ARRAY JCB
C
C     JCB IS THE JACOBIAN MATRIX OF SIZE 2*NO OF BUSES
C             MINUS 2
C     USE A SPARSE ARRAY JCOB FOR THE JACOBIAN
      REAL JCOB(SZ4)
C     JCOB(II) REPRESENTS JACOBIAN(JCR(II),JCC(II))
C     IE THE ROW IS JCR(II) AND THE COL IS JCC(II)
C     FOR ELEMENT JCOB(II)
      INTEGER JCR(SZ4),JCC(SZ4)
C     JNC(II) IS A POINTER INTO JCOB WHERE JCOB(JNC(II))
C     IS THE ELEMENT TO THE LEFT OF JCOB(II) AND IN
C     THE SAME ROW.
      INTEGER JNC(SZ4)
C     JRH(II) IS A ROW HEADER AND INDICATES THE
C     RIGHT MOST ELEMENT IN ROW II
      INTEGER JRH(SZ4)
C     AVAIL IS A POINTER TO THE AVAIL STACK
      INTEGER AVAIL
C     REAL JCB(SZ2,SZ2)
C     PUT THEM ALL IN COMMON
      COMMON JCOB,JCR,JCC,JNC,JRH,AVAIL
C     COMMON JCB
C
C
C     NEED TWO TEMPORARIES FOR THE INVERTER
      DIMENSION TINV(SZ2),UINV(SZ2)
      DIMENSION P(SZ1),Q(SZ1)
C     P(N) AND Q(N) ARE THE REAL AND REACTIVE POWER
C             AT NODE N (OR BUS NUMBER == N).
```

```
      COMPLEX E(521)
C     E(N) IS THE COMPLEX VOLTAGE (PER UNIT) AT BUS N
      INTEGER YP(521),YQ(521)
C     YP(N) AND YQ(N) ARE THE BUS NUMMBERS WHERE
C             ADMITTANCE Y(N) IS CONNECTED.
      COMPLEX Y(521)
C     Y(N) IS THE COMPLEX ADMITTANCE FROM BUS YP(N) TO
C             BUS YQ(N)
      COMPLEX I(521)
C     I(N) IS THE COMPLEX PHASE CURRENT (PER UNIT) INTO
C             THE SYSTEM AT BUS NUMBER N.
      COMPLEX YLC
C     YLC IS THE LINE CHARGING ADMITTANCE AT BUS 1
C     IT IS THE SUM OF ALL ADMITTANCES IN ROW 1
C     OF THE Y MATRIX
      REAL T,U,V,W
C     T,U,V,W ARE COEFFICIENTS IN THE EQUATIONS USED
C             FORMED FROM THE JACOBIAN.
      REAL IT1,IT2
C     IT1,IT2 ARE TEMPORARY VALUES OF CURRENT
C             (PER UNIT) AT THE BUS
      INTEGER NXTROW(521)
      INTEGER NXTCOL(521)
C     NXTCOL(I) IS A ROW OF ARRAYS Y,YP,YQ.  ITS VALUE
C             IS THE ROW WHERE ANOTHER Y(J,K) VALUE IS
C             IF NXTCOL(I) IS N,N .NE. 0 ,THEN
C             YP(I) .EQ. YP(N), THAT IS N IS THE ROW
C             FOR THE NEXT ADMITTANCE CONNECTED TO BUS
C             YP(I).
C             IF NXTCOL(I) IS 0, THEN NO MORE
C             ADMITTANCE TERMS EXIST IN THE EQUATION
C             FOR NODE YP(I).
      DIMENSION DP(521),DQ(521)
C     DP(N) AND DQ(N) ARE THE REAL POWER AND
C             REACTIVE POWER SUPPLIED AT BUS NUMBER N.
      DIMENSION DPOWER(522)
C     DPOWER IS A COMPOSITE
C     VECTOR WITH ELEMENTS
C     DP(2),DP(3),....,DP(521),DQ(2),DQ(3),....,DQ(521)
C     DPOWER IS USED IN THE NEWTON RAPHSON ROUTINE.
C

C     DC IS THE DISTORTION CURRENT IN ONE PHASE (PU)
C     DC(N) IS DC AT BUS NUMBER N.
      DIMENSION DC(521)
C
      INTEGER TTY
C     TTY IS THE LOGICAL OUTPUT DEVICE FOR USER INTERACTION
      INTEGER LOGFIL
C     LOGFIL IS THE DISK FILE FOR THE OUTPUT RECORDS
      COMPLEX S
C     S IS A TEMPORARY
      COMMON TINV,UINV,P,Q,E,YP,YQ,Y,I,YLC,T,U,V,W,IT1,IT2
      COMMON NXTROW,NXTCOL,DP,DQ,DPOWER,DC
      COMMON TTY,LOGFIL,S
C     PUT THEM ALL IN COMMON
C
C     THE MISSION PROFILE DATA STRUCTURE
C     ICAR(I,J) SUMMARIZES THE
C     ROUTE SEQUENCE FOR CAR J.
C     I=1 THE START TIME OF VEHICLE J
```

```
C     I=2,3,4,...ICARRO THE ROW IN PFILE WHERE
C     A ROUTE SEGMENT STARTS. THIS SEQUENCE OF ROUTE
C     SEGMENTS IS FOLLOWED BY CAR J
C     SROW1(I) IS THE POINTER TO THE RW IN ICAR COLUMN I WHERE
C     A POINTER TO PFILE EXISTS.  THE LATTER POINTER
C     IS TO THE BEGINNING OF VEHICLE I CURRENT ROUTE SEGMENT
C     SROW2(I) IS A POINTER TO PFILE ROW WHERE THE CURRENT
C     PROFILE POINT FOR VEHICLE I EXISTS.
C
C     TYM(I) IS THE NUMBER OF SECONDS LEFT FOR
C     CAR(I) TO REMAIN AT THE MISSION PROFILE
C     POINT INDICATED BY SROW2(I). TYM(I) IS USEFUL
C     FOR STATION STOPS AND ALLOWS MANY PROFIILE
C     POINTS TO BE COMBINED INTO ONE
C     SUSTAINED POINT.
C
C     EACH ROW OF PFILE IS A POINT ON THE MISSION
C     PROFILE -
C             COL 1 IS DELTA TIME
C             COL 2 IS VELOCITY (MPH)
C             COL 3 IS HEADNING (MPH)
C             COL 4 IS GUIDEWAY GRADE (PERCENT)
C             COL 5 IS LOCATION CODE PREFIX- TWO LETTERS
C             COL 6 IS LOCATION CODE FIVE DIGITS
C
C     ICARS(NCAR) SPECIFIES THE NUMBER OF CARS PER VEHICLE -
C     PI IS 3.1415926
C     DELX IS AN INCREMENTAL DISTANCE THAT ALLOWS THE VEHICLES TO
C     OVERSHOOT THE GUIDEWAY SEGMENT DISTANCES
      INTEGER ICAR(ICARRO,NCAR),SROW1(NCAR),SROW2(NCAR),TYM(NCAR)
      DIMENSION PFILE(PFILER,6),ICARS(NCAR)
      COMMON ICAR,SROW1,SROW2,TYM,PFILE,ICARS,PI,DELX
C     DT IS THE TIME INCREMENT IN SECONDS
C     IT IS THE TIME INTERVAL BEFORE NEXT LOAD FLOW SNAPSHOT
C     ITIME IS THE SIMULATED CLOCK TIME IN SEC.
      INTEGER DT,IT,ITIME
C
C
C     GWAY IS THE GUIDEWAY DATA STRUCTURE. EACH
C     ROW IS A LINK BETWEEN GUIDEWAY NODES. NODES ARE
C     GUIDEWAY MERGES, DIVERGES, OR POWER FEED POINTS.
C     VEHICLES ARE NOT INCLUDED AS GUIDEWAY NODES.
C
C     THE VEHICLE DATA STRUCTURES
C     VEL IS ITS COMMANDED VELOCITY (MPH)
C     VV IS THE ACTUAL VEHICLE VELOCITY IN MPH
C     ACC IS ITS ACCELERATION (MPH/SEC)
C     JERK IS ITS JERK (MPH/(SEC**2.0))
C     HW IS ITS ENCOUNTERED HEAD WIND (MPH)
C     GRADE IS ENCOUNTERED GRADE (PERCENT)
C     VM IS THE VEHICLE MASS IN POUNDS
      REAL JERK,JERKM
      COMMON DT,IT,ITIME,VEL,ACC,ACCM,JERK,JERKM,HW,GRADE,VV,VM
C
C     TABLES FOR THE VEHICLE FLEET STATE
C     EACH OF THE FIVE
C     VARIABLES BELOW IS SUBCRIPTED
C     BY II TO REFER TO VEHICLE NUMBER II.
C     VVEL(II) ACTUAL VELOCITY IN MPH
      REAL VVEL(NCAR)
C     VACC(II) ACCELERATION IN MPH PER SEC
```

```
      REAL VACC(NCAR)
C     POC(.,II) TWO LETTER LOCATION CODE
C     POS(2,II) FOOTAGE LOCATION CODE
      REAL POS(2,NCAR)
C     VMODE(II) MODE OF OPERATION OF VEHICLE
C              1 = VOLTAGE CONTROL;2 = FIELD WEAKENING; 3 =
C              REGENERATIVE BRAKING; 4 = FRICTION BRAKING
      REAL VMODE(NCAR)
C     NUMPAS(II) IS THE NUMBER OF PASSENGERS
      DIMENSION NUMPAS(NCAR)
C     NUMVEH IS THE NUMBER OF THE ONE VEHICLE UNDER SRUTINY
      REAL NUMVEH
C     COUPLE(NUMVEH) IS THE VEHICLE NUMBER TO WHICH NUMVEH IS COUPLED
      INTEGER COUPLE(NCAR)
C     PW IS THE PROPULSION POWER IN WATTS
C     FT IS THE TRACTIVE FORCE IN LBS
C     ALPH(II) IS THE PHASE DELAY AT VEHICLE II (RADIANS)
      DIMENSION ALPH(NCAR)
C     PUT THEM ALL IN COMMON
      COMMON VVEL,VACC,POS,VMODE,NUMPAS,NUMVEH,COUPLE,PW,FT,ALPH
C
C
C     VEHICLE DATA STRUCTURE
      COMMON DP,DQ,DDC
C     DP IS THE REAL POWER OF SOME VEHICLE (PU)
C     DQ IS THE REACTIVE POWER OF SOME VEHICLE(PU)
C     DDC IS THE DISTORTION CURRENT OF SOME VEHICLE(PU)
C     THE MOTOR DATA STRUCTURE
C     VMTR MAGNITUDE OF THE MOTOR TERMINAL VOLTAGE (VOLTS)
C     IMTR MAGNITUDE OF THE MOTOR TERMINAL CURRENT(AMPS)
C     TMTR ANGLE BY WHICH IMTR LEADS VMTR (DEGREES)
C     THESE THREE ARE FOR ONE PHASE - VMTR IS LINE TO NEUTRAL
C     IMTR IS PHASE CURRENT
      REAL VMTR,IMTR,TMTR
      COMMON VMTR,IMTR,TMTR
C
C     A TABLE OF VALUES AT THE MOTOR
C     TERMINALS ON EACH VEHICLE
C
      REAL TVM(NCAR),TIM(NCAR),TTM(NCAR)
      COMMON TVM,TIM,TTM
C     TVM(II) IS THE VOLTAGE AT MOTOR
C     TERMINALS ON VEHICLE NUMBER II
C     TIM(II) IS THE CURRENT AT THE MOTOR TERMINALS
C     ON VEHICLE NUMBER II (AMPS)
C     TTM(II) IS THE ANGLE BY WHICH
C     CURRENT LEADS VOLATGE AT VEHICLE II.
C
C     EACH ROW OF GWAY IS DEVOTED TO A LINK
C     THE COLUMNS ARE
C     1 FROM NODE ITS INTEGER IDENTIFICATION
C     2 TO NODE  ITS INTEGER IDENTIFIACATION
C              FROM AND TO DENOTE TRAVEL DIRECTION OVER THE LINK
C     3 LC.ATION CODE PREFIX ON ALL POINTS ALONG THE LINK
C     4 FROM NODE LOCATION CODE SUFFIX
C     5 TO NODE LOCATION CODE SUFFIX
C     6 TO 16 THESE COLUMNS ARE A QUEUE OF THE VEHICLES ON
C     THAT LINK EACH VEHICLE IDENTIFIED BY ITS BUSS NUMBER 2 TO NCAR
C     PLUS 1.
C
C     A SPECIAL CASE IF LOC CODE IS TT THEN IT IS NOT A
```

```
C     GUIDEWAY LINK BUT A TRANSFORMER OR CABLE LINK
C     THEN COL 4 AND 5 ARE ITS PER UNIT
C     IMPEDANCE REAL AND IMAGINARY PARTS.
      COMMON GWAY(GWAYNO,GWAYCO)
C
C     TITLE IS A TEN ELEMENT ARRAY FOR
C     TEMPORARY ALPHABETIC INFORMATION
      COMMON TITLE(10)
C
C     ZGY IS THE GUIDEWAY IMPEDANCE PER FOOT IN PER UNIT
      COMPLEX ZGY
C     YD IS THE GUIDEWAY ADMITTANCE FOR SOME
C     DISTANCE SEGMENT IN UNITS OF PER UNIT.
      COMPLEX YD
C     PUT THEM IN COMMON
      COMMON ZGY,YD
C
C     VRAIL IS THE COMPLEX PHASE VOLTAGE AT SOME VEHICLE
C     POSITION ALONG THE POWER RAIL
C     PER UNIT
      COMPLEX VRAIL
      COMMON VRAIL
```

SETUP.F4

```
      SUBROUTINE SETPFL
C     THIS ROUTINE SETS UP THE MISSION PROFILE INFORMATION .
C     ITS INPUT IS A SEQUENTIAL DATA FILE OF VALUES WHICH
C     ARE READ INTO ARRAYS ICAR, BROW1, BROW2, AND PFILE .
C     ITS OUTPUT IS AN INITIALIZED MISSION PROFILE DATA STRUCTURE .
C     A RECORD OF THE DATA IS KEPT IN THE  FILE CALLED LOGFIL .
C     DECLARATIONS :
      INCLUDE 'PARAMR.F4'
      WRITE(TTY,10)
10    FORMAT(2X,'ENTER THE FILE FOR MISSION PROFILE DATA IN A4 :')
      READ(TTY,11) IFIL
11    FORMAT(A4)
      CALL IFILE(23,IFIL)
      READ(23,12) (TITLE(II),II=1,10)
      WRITE(LOGFIL,12) (TITLE(II),II=1,10)
12    FORMAT(10A4)
      READ(23,15) ((ICAR(II,JJ),II=1,ICARRO),JJ=1,NCAR)
      WRITE(LOGFIL,15) ((ICAR(II,JJ),II=1,ICARRO),JJ=1,NCAR)
15    FORMAT(8I5)
      READ(23,16) (BROW1(II),II=1,NCAR)
      WRITE(LOGFIL,16) (BROW1(II),II=1,NCAR)
      READ(23,16) (BROW2(II),II=1,NCAR)
      WRITE(LOGFIL,16) (BROW2(II),II=1,NCAR)
      READ(23,16) (TYM(II),II=1,NCAR)
      WRITE(LOGFIL,16) (TYM(II),II=1,NCAR)
16    FORMAT(10I5)
      READ(23,20) ((PFILE(II,JJ),JJ=1,6),II=1,PFILER)
      WRITE(LOGFIL,20) ((PFILE(II,JJ),JJ=1,6),II=1,MIN0(PFILER,15))
20    FORMAT(4F9. ,A2,F9.2)
      RETURN
      END
```

```
      SUBROUTINE SETGW
C     THIS ROUTINE SETS UP THE GUIDEWAY DEPLO   NT DATA STRUCTURE .
C     ITS INPUT IS A SEQUENTIAL DATA FILE OF VA  ES WHICH
C     ARE READ INTO THE ARRAY GWAY .
C     ITS OUTPUT IS THE ARRAY GWAY FILLED WITH
C     ROWS CONTAINING GUIDEWAY SEGMENT INFORMATION .
C     A RECORD OF THE DATA IS KEPT IN THE  FILE CALLED LOGFIL .
C     DECLARATIONS :
      INCLUDE 'PARAMR.F4'
      WRITE (TTY,10)
10    FORMAT(2X,'ENTER THE FILE FOR GUIDEWAY DATA IN A4 :')
      READ(TTY,11)IFIL
11    FORMAT(A4)
      CALL IFILE(23,IFIL)
      READ(23,12) (TITLE(II),II=1,10)
      WRITE(LOGFIL,12) (TITLE(II),II=1,10)
12    FORMAT(10A4)
      WRITE(LOGFIL,13)
13    FORMAT(/2X,'GUIDEWAY DATA'/1X,'FROM  TO SEGMENT   START    END')
C     ONLY THE FIRST FIVE COLUMNS ARE READ IN .
C     THE QUEUES FOR THE VEHICLES ARE EMPTY
C     INITIALLY AND ROUTINE QUEUE SETS THEM UP .
C     NOW READ THE ARRAY GWAY ROW BY ROW .
      READ(23,15,END=900)((GWAY(II,JJ),JJ=1,5),II=1,GWAYRO)
15    FORMAT(2X,2F3.0,A2,2F6.0)
C     ADD AN OFFSET TO THE NODE NUMBERS OF THE GUIDEWAY SEGMENTS .
C     THE OFFSET IS NCAR SO THE NODES ARE :
```

```
C       1 = THE SWING BUS, 2 THRU NCAR+1 ARE THE VEHICLES,
C       AND NCAR+1 AND UP ARE GUIDEWAY MERGE AND DIVERGE
C       POINTS OR NODES CONNECTING GUIDEWAY SEGMENTS .
        IOFF=NCAR
        DO 100 II=1,GWAYRO
C       CORRECT THE FROM AND TO NODE NUMBERS ON GWAY ROW II
C       FOR ALL BUT NODE 1 THE SWING BUS .
        IF(GWAY(II,1).GT.1) GWAY(II,1)=GWAY(II,1)+IOFF
        IF(GWAY(II,2).GT.1) GWAY(II,2)=GWAY(II,2)+IOFF
100     CONTINUE
C       ALL NODE NUMBERS CORRECTED .
        WRITE(LOGFIL,200)((GWAY(II,JJ),JJ=1,5),II=1,GWAYRO)
200     FORMAT(2X,F3.0,1X,F3.0,2X,A2,2X,2F11.3)
        RETURN
1000    CONTINUE
C       TOO LITTLE DATA .
        WRITE(TTY,300)
300     FORMAT(/2X,'TOO LITTLE GUIDEWAY DATA')
        STOP
        END
```

VEHDYN.f-14

```
      SUBROUTINE VEHDYN
C     THIS ROUTINE HANDLES THE VEHICLE DYNAMICS -
C     IT COMPUTES DISSIPATIVE AND CONSERVED FORCES ON THE VEHICLE -
C     IT OUTPUTS TRACTIVE FORCE AND PROPULSION POWER -
C     THE INPUTS ARE VV, ACC, GRADE, HW, COUPLE, AND NUMVEH -
C     WHERE VV IS THE VELOCITY OF THE VEHICLE (MPH) -
C     ACC IS THE ACCELERATION (MPH/SEC) -
C     GRADE IS THE ENCOUNTERED GRADE (PERCENT) -
C     HW IS THE ENCOUNTERED HEADWIND (MPH) -
C     AND COUPLE(NUMVEH) IS THE VEHICLE NUMBER TO WHICH
C     THE VEHICLE UNDER SCRUTINY (NUMVEH) IS COUPLED -
C     NOTE : VEHICLE NUMVEH IS A LEADING VEHICLE
C     IF COUPLE(NUMVEH) IS  ZERO -
C     OTHERWISE VEHICLE NUMVEH IS A TRAILING VEHICLE -
C     DECLARATIONS :
      INCLUDE 'PARAMS.F4'
      DATA A/0.025/,B/0.00005/,RHO/0.002331/,CON1/1.466667/,
     0 CON2/1.356/,FTLIM/1300.0/,PWLIM/82340.0/
C     A IS THE COEFFICIENT OF ROLLING FRICTION -
C     B IS THE COULOMBIC FRICTION FORCE COEFFICIENT -
C     RHO IS THE AIR DENSITY (SLUGS/(FT**3.0)) -
C     CON1 IS THE FT/SEC PER MPH CONVERSION FACTOR -
C     CON2 IS THE WATT PER FT-LB/SEC CONVERSION FACTOR -
C     FTLIM IS THE TRACTIVE FORCE LIMIT FOR MOTORING (LBS) -
C     PWLIM IS THE PROPULSION POWER LIMIT FOR MOTORING (WATTS) -
      VW=12000.0+NUMPAS(NUMVEH)*150.0
C     VW IS THE VEHICLE GROSS WEIGHT IN LBS -
C     ADDED TO THE EMPTY WEIGHT IS THE PASSENGER WEIGHT
C     AT 150 LBS PER PASSENGER -
      FR=VW*COS(GRADE/100.)*A
C     FR IS THE ROLLING FRICTION FORCE IN LBS -
      FC=VW*VV*B
C     FC IS THE COULOMBIC FRICTION FORCE IN LBS -
      IF(COUPLE(NUMVEH).EQ.0) C=0.85
      IF(COUPLE(NUMVEH).NE.0) C=0.190
C     C IS THE DRAG COEFFICIENT (LEADING OR TRAILING VEHICLE) -
      FD=0.5*RHO*C*(VV+HW)**2*CON1**2
C     FD IS THE AERODYNAMIC DRAG FORCE IN LBS -
      DFORCE=FR+FC+FD
C     DFORCE IS THE TOTAL OF THE DISSIPPATIVE FORCES -
C     NOW CALCULATE THE CONSERVED FORCES -
      FG=VW*SIN(ATAN(GRADE/100.))
C     FG IS THE GRAVITATIONAL FORCE IN LBS -
      FI=(VW/32.174)*ACC*CON1
C     FI IS THE INERTIAL FORCE IN LBS -
C     NOW FT THE TRACTIVE FORCE IS FOUND -
      FT=DFORCE+FG+FI
C     LIMIT FT TO FTLIM LBS -
      IF(FT.GT.FTLIM) FT=FTLIM
C     FIND PW THE PROPULSION POWER IN WATTS -
      PW=FT*VV*CON1*CON2
C     LIMIT PW TO PWLIM WATTS -
      IF(PW.GT.PWLIM) PW=PWLIM
C     UPDATE FT IF POWER LIMIT ENCOUNTERED -
      IF(VV.GT.0.0) FT=PW/VV/CON1/CON2
C     UPDATE ACC IF THRUST OR POWER LIMIT ENCOUNTERED -
      ACC=(FT-DFORCE-FG)/(VW/32.174)/CON1
      IF(ABS(ACC).LT.0.0001) ACC=0.0
      RETURN
      END
```

motor.f4

```
      SUBROUTINE MOTOR
C     THIS SUBROUTINE HAS AS INPUT THE MISSION PROFILE DATA :
C             VV = ACTUAL VELOCITY (MPH)
C             ACC = VEHICLE ACCELERATION (MPH/SEC)
C             HW = ENCOUNTERED HEADWIND (MPH)
C             GRADE = GUIDEWAY GRADE (PERCENT)
C     THE OUTPUT IS THE MOTOR/GENERATOR CHARACTERISICS :
C             VMTR = MOTOR TERMINAL VOLTAGE (VOLTS)
C             IMTR = ARMATURE CURRENT (AMPS)
C             TMTR = PHASE ANGLE OF VMTR WITH RESPECT TO IMTR (DEG)
C                    (TMTR .LT. 0 MEANS I LAGS V)
C     THE DC MACHINE HAS THE FOLLOWING FEATURES :
C     4-POLE, SEPARATELY EXCITED, 120 HP MAX SHAFT POWER .
C     600 V MAX TERMINAL VOLTAGE, 160 A MAX ARMATURE CURRENT .
C     96092 W MAX POWER AT TERMINALS . 89500 W MAX POWER AT SHAFT .
C     1300 LB MAX TRACTIVE FORCE AT WHEELS AT 30 MPH .
C     0.15 OHM ARMATURE RESISTANCE . 574 V BACK EMF AT 30 MPH .
C     DECLARATIONS :
      INCLUDE 'PARAMS.F4'
      DATA DREFF/0.92/,CON3/1.0133/,CFRM/10.0/,CFRB/10.0/,VBD/2.0/,
     &  VTMAX/600.0/,RA/0.15/,PL40/1445.0/,PMSLIM/89500.0/
C     DREFF IS THE AVERAGE DRIVE TRAIN EFFICIENCY .
C     CON3 IS THE MOTOR EXCITATION CONSTANT (VOLTS/MPH/AMP) .
C     CFRM IS THE RATED FIELD CURRENT FOR MOTORING (AMPS) .
C     CFRB IS THE RATED FIELD CURRENT FOR BRAKING (AMPS) .
C     VBD IS THE COMMUTATOR BRUSH DROP (VOLTS) .
C     VTMAX IS THE MAXIMUM TERMINAL VOLTAGE FOR MOTORING (VOLTS) .
C     RA IS THE ARMATURE RESISTANCE (OHMS) .
C     PL40 IS THE FRICTION, WINDAGE, AND CORE LOSSES AT 30.0 MPH .
C     PMSLIM IS THE MACHINE SHAFT POWER LIMIT (WATTS) .
C     FIND FT TRACTIVE FORCE AND PW PROPULSION POWER
C             NEEDED BY THE VEHICLE .
      CALL VEHDYN
C     THE DIFFERENT MODES OF OPERATION ARE :
C             1 = MOTORING VOLTAGE CONTROL
C             2 = MOTORING FIELD WEAKENING
C             3 = REGENERATIVE BRAKING
C             4 = FRICTION BRAKING
C     FIND PMS = THE POWER AT THE MACHINE SHAFT IN WATTS .
      IF(PW.GT.0.0) PMS=PW/DREFF
      IF(PW.LE.0.0) PMS=PW*DREFF
C     LIMIT PMS TO PMSLIM WATTS .
      IF(PMS.GT.PMSLIM) PMS=PMSLIM
      IF(PMS.LT.-PMSLIM) PMS=-PMSLIM
C     COMPUTE SOME LOSS TERMS AND AIR-GAP POWER .
      PL3=0.01*ABS(PMS)          !STRAY LOAD LOSS
      PL4=PL40*(VV/30.0)**2.5    !FRICTION, WINDAGE, AND CORE LOSSES
      PAG=PMS+PL3+PL4            !AIR-GAP POWER
      IF(PW.LE.0.0) GOTO 100
C     MOTORING WITH VOLTAGE SPEED CONTROL .
      MODE=1
      CF=CFRM                    !FIELD CURRENT
      EA=CON3*VV*CF              !BACK EMF
      CA=PAG/EA                  !ARMATURE CURRENT
      VT=EA+VBD+RA*CA            !TERMINAL VOLTAGE
      IF(VT.LE.VTMAX) GOTO 500
C     MOTORING WITH FIELD WEAKENING SPEED CONTOL .
      MODE=2
      VT=VTMAX
C     COMPUTE EA (BACK EMF) AT VTMAX (MAXIMUM TERMINAL VOLTAGE) .
      EA=((VT-VBD)+SQRT((VT-VBD)**2.0-4.0*PAG*RA))/2.0
```

```
      CF=EA/(CON3*VV)    !FIELD CURRENT
      CA=PAC/EA          !ARMATURE CURRENT
      GOTO 500
100   CONTINUE
C     BRAKING MODES -
      IF(VV.LE.30.0) GOTO 300
C     REGENERATIVE BRAKING AT HIGH SPEED -
      MODE=3
      CF=CFMB            !FIELD CURRENT
      EA=CON3*VV*CF      !BACK EMF
      CA=PAC/EA          !ARMATURE CURRENT
      VT=EA+VBD+RA*CA    !TERMINAL VOLTAGE
      GOTO 500
300   CONTINUE
C     BRAKING USING FRICTION BRAKES -
      MODE=4
      PMS=0.0
      CF=0.0
      EA=0.0
      CA=0.01
      VT=0.01
500   CONTINUE
C     RECORD THE MODE -
      VMODE(NUMVEH)=MODE
C     TRANSFER TO OUTPUT VARIABLES -
      VNTR=VT
      INTR=CA
      TNTR=0.0
      IF(CA.LT.0.0) TNTR=90.0
C     RECORD THESE VALUES -
C     WRITE(LOGFIL,99)VV,ACC,NN,GRADE,VNTR,INTR,TNTR,MODE
C     WRITE(LOGFIL,99)PMS,EA
99    FORMAT(2X,4F8.1,2X,3F7.2,2X,I3)
      RETURN
      END
```

```
      BLOCK DATA
      INCLUDE 'PARAMR.F4'
      DATA PI/3.1415926/,DELX/5.0/,(ICARS(II),II=1,NCAR)/NCAR*1/,
     & (NUMPAS(II),II=1,NCAR)/NCAR*10/,JERKM/10.0/,ACCM/5.0/
      END
```

JEFF.F4

NR2.F4

```
      SUBROUTINE NR
      INCLUDE 'PARAMR.F4'
C     NEWTON RAPHSON SOLUTION
C     INPUT IS A MATRIX OF ADMITTANCE VALUES Y
C     OUTPUT IS THE VOLTAGE AND POWER AT EACH BUS
C     BUS ONE IS THE SWING BUS
C
      DATA EPSIL/.01/
C     EPSIL IS THE ACCURACY REQUIREMENT FOR
C             CONVERGENCE.
C
C      NR CALLS FORMY
C     IF FULL ARRAY IS USED FOR THE JACOBIAN
C           MINV80 (MATRIX INVERTER)
C          NEWPQ
C     NR IS CALLED BY MAIN
C     STEP 1 FORM THE BUS ADMITTANCE MATRIX Y,YP,YQ,MXTCOL
      CALL FORMY
C     STEP 2 ASSUME INITIAL BUS VOLTAGES IN ARRAY E.
      DO 10 II=1,NX1
      E(II)= CMPLX(1.,0.)
10    CONTINUE
      E(1)=(1.0,0.)
C     CALCULATE THE SCHEDULED P AND Q AT EACH NODE,
C             AS A FUNCTION OF BUS VOLTAGES
      CALL NEWPQ
      CALL SIZE
C     STEP 3 SET THE ITERATION COUNT K TO 0
      K=0
C     K TIMES THE BUS VOLTAGES HAVE BEEN UPDATED.
C
C     STEP 4 CALCULATE THE SUPPLIED REAL POWER AND REACTIVE
C             POWER INTO THE SYSTEM AT NODE N.
C             IS DP(N) AND DQ(N)
C
C     FIRST ZERO OUT DP AND DQ
18    CONTINUE
      DO 20 II=1,NX1
      DP(II)=0.
      DQ(II)=0.
20    CONTINUE
C NOW GO THROUGH EACH ADMITTANCE Y IN ANY ORDER
      DO 200 II=1,NZ1
      IF (YP(II).EQ.0 )GO TO 201
C     YP(II) .EQ. 0 MEANS ALL ROWS OF Y ARE DONE
C     IF NOT AT THE SENTINEL THEN WE HAVE
C     Y(II) CONNECTED FROM YP(II) TO YQ(II)
      IYP=YP(II)
      IYQ=YQ(II)
C     SAVE THE BUS NUMBERS
      B=-AIMAG(Y(II))
      G=REAL(Y(II))
C     SAVE THE REAL AND IMAG PART OF THE ADMITTANCE
      IT1=REAL(E(IYQ))*G+AIMAG(E(IYQ))*B
      IT2=AIMAG(E(IYQ))*G-REAL(E(IYQ))*B
      DP(IYP)=DP(IYP)+REAL(E(IYP))*IT1+AIMAG(E(IYP))*IT2
      DQ(IYP)=DQ(IYP)+AIMAG(E(IYP))*IT1-REAL(E(IYP))*IT2
C     NOW WE ALSO HAVE THE SAME ADMITTANCE Y(II) FROM
C             BUS YQ(II) TO YP(II)
C             UNLESS IYP EQUALS IYQ THAT IS
C             WE HAVE A DRIVING POINT ADMITTANCE
```

```
      IF (IYP .EQ. IYQ) GO TO 200
C     ARRIVE HERE IF WE HAVE A TRANSFER ADMITTANCE
      IYP=IU(II)
      IYQ=IP(II)
      IT1=REAL(E(IYQ))*G+AIMAG(E(IYQ))*B
      IT2=AIMAG(E(IYQ))*G-REAL(E(IYQ))*B
      DP(IYP)=DP(IYP)+REAL(E(IYP))*IT1+AIMAG(E(IYP))*IT2
      DQ(IYP)=DQ(IYP)+AIMAG(E(IYP))*IT1-REAL(E(IYP))*IT2
200   CONTINUE
C     FINISHED ADMITTANCE Y(II)
201   CONTINUE
C     FINISHED ALL ADMITTANCES
C     STEP 5 AND 6 FIND THE MAX DIFFERENCE IN POWER
C             SCHEDULED AND POWER DELIVERED
      DO 250 II=2,NB1
      IF(EPSIL .LT. ABS(P(II)-DP(II)))GO TO 270
      IF(EPSIL .LT. ABS(Q(II)-DQ(II)))GO TO 270
250   CONTINUE
C     STEP 7 ARRIVE HERE IF CONVERGENCE IS ACHIEVED
      GOTO 500
270   CONTINUE
C     NO CONVERGENCE YET
C     STEP 8 FIND THE CURRENT INTO EACH BUS
C     EXCEPT THE SWING BUS
      DO 60 II=2,NB1
      I(II)=CMPLX(DP(II),-DQ(II))/CONJG(E(II))
60    CONTINUE
C     STEP 9
C     FIND THE JACOBIAN MATRIX JCB
C     EACH TERM IS A CURRENT IS THE
C     PARTIAL DERIVATIVE OF
C     POWER WITH RESPECT TO VOLTAGE
C     SET UP THE EMPTY JACOBIAN
      DO 331  II=1,NZ2
      JCOB(II)=0.
      JRN(II)=II
      JCR(II)=II
      JCC(II)=II
      JNC(II)=0.
331   CONTINUE
C     LINK THE AVAIL STACK
C     AND ZERO OUT REST OF JCOB
      AVAIL=NZ2+1
      DO 332 II=AVAIL,NZ4
      JNC(II)=II+1
      JCOB(II)=0
      JCR(II)=0
      JRN(II)=0
      JCC(II)=0
332   CONTINUE
      JNC(NZ4)=0
C     AVAIL STACK IS INITIALIZED AND LINKED THRU
C     JNC ARRAY POINTERS.
      DO 360 II=2,NB1
C     JACOBIAN DOES NOT INVOLVE THE BUS 1
C     SO JCB(I,J) REFERS TO THE PARTIAL
C     DERIVATIVE OF POWER AT BUS I+1 WITH
C     RESPECT TO VOLTAGE AT BUS J+1
      IF(YP(II).EQ.1) GOTO 355
      IF(YP(II).EQ.0)GOTO 367
      G=REAL(Y(II))
```

```
      B=AIMAG(Y(II))
      IP=YP(II)-1
      IP1=YP(II)
      IQ=YQ(II)-1
      IQ1=YQ(II)
      IP2=IP+NSI-1
      IQ2=IQ+NSI-1
      AIMAGE=AIMAG(E(IP1))
      REALE=REAL(E(IP1))
      IF(IP1.NE.IQ1)GOTO 235
C     HAVE Y(II) A SELF ADMITTANCE
      G=REAL(Y(II))
      B=AIMAG(Y(II))
C     JCB(IP,IP)=REALE*G-AIMAGE*B+C
      IX=0
      CALL PUTJ(REALE*G-AIMAGE*B+C,IP,IP,IX)
C     JCB(IP,IP2)=REALE*B+AIMAGE*G+D
      IX=0
      CALL PUTJ(REALE*B+AIMAGE*G+D,IP,IP2,IX)
C     JCB(IP2,IP)=REALE*B+AIMAGE*G-D
      IX=0
      CALL PUTJ(REALE*B+AIMAGE*G-D,IP2,IP,IX)
C     JCB(IP2,IP2)=-REALE*G+AIMAGE*B+C
      IX=0
      CALL PUTJ(-REALE*G+AIMAGE*B+C,IP2,IP2,IX)
      GOTO 266
 235  CONTINUE
C     Y(II) IS A TRANSFER ADMITTANCE
C     FILL IN THE JACOBIAN WHICH IS  MADE OF
C     FOUR SUBMATRICES WHICH ARE SYMMETRIC
C
C     JCB(IP,IQ)=REALE*G-AIMAGE*B
      IX=0
      CALL PUTJ(REALE*G-AIMAGE*B,IP,IQ,IX)
C     JCB(IP,IQ2)=REALE*B+AIMAGE*G
      IX=0
      CALL PUTJ(REALE*B+AIMAGE*G,IP,IQ2,IX)
C     JCB( P2,IQ)=AIMAGE*G+REALE*B
      IX=0
      CALL PUTJ(AIMAGE*G+REALE*B,IP2,IQ,IX)
C     JCB(IP2,IQ2)=AIMAGE*B-REALE*G
      IX=0
      CALL PUTJ(AIMAGE*B-REALE*G,IP2,IQ2,IX)
C     JCB(IQ,IP)=JCB(IP,IQ)
      IX=0
      CALL PUTJ(REALE*G-AIMAGE*B,IQ,IP,IX)
C     JCB(IQ,IP2)=JCB(IP,IQ2)
      IX=0
      CALL PUTJ(REALE*B+AIMAGE*G,IQ,IP2,IX)
C     JCB(IQ2,IP)=JCB(IP2,IQ)
      IX=0
      CALL PUTJ(AIMAGE*G+REALE*B,IQ2,IP,IX)
C     JCB(IQ2,IP2)=JCB(IP2,IQ2)
      IX=0
      CALL PUTJ(AIMAGE*B-REALE*G,IQ2,IP2,IX)
 265  CONTINUE
 266  CONTINUE
 267  CONTINUE
C     FINISHED JACOBIAN
CC    FOR DEBUGGING WRITE OUT THE JACOBIAN
C     WRITE(LOGFIL,2670)AVAIL
```

```
2670    FORMAT(2X,'JACOBIAN WITH AVAIL ',I5)
C       WRITE(LOGFIL,272)((JCOB(II),JCR(II),JCC(II),JNC(II),
C     $  JNR(II)),II),II=1,MIN0(900,SZ4))
C       STOP
272     FORMAT(2X,F7.3,5I4)
C       WRITE(TTY,271)((JCB(II,JJ),JJ=1,SZ2),II=1,SZ2)
271     FORMAT(1X,8F9.4)
C       NOW INVERT THE JACOBIAN
C       C        SOLVE FOR DELTA E IN PLACE OF DP AND DQ ARRAYS
C       USE GAUSS-JORDAN REDUCTION ON THE JACOBIAN
C       MATRIX WITH ONE COLUMN VECTOR DP,DQ APPENDED
C       ON THE RIGHT
C       SETUP DPOWER VECTOR A COMPOSITE DP,DQ VECTOR
        DO 273 II =2,SZ1
        DPOWER(II-1)=P(II)-DP(II)
        DPOWER(II+SZ1-2)=Q(II)-DQ(II)
273     CONTINUE
C       DPOWER IS NOW DP(2),DP(3),...,DP(SZ1),DQ(2),DQ(3),...,DQ(SZ1)
C       SUBTRACTED FROM P(2),P(3),...,P(SZ1),Q(2),Q(3),...,Q(SZ1)
C       STEP 9.1 CHOOSE A PIVOT ROW KK
        DO 211 LK=1,SZ2
        KK=LK
C       GET PIVOT ELEMENT - JACOBIAN(KK,KK)
        PIVOT=JCOB(KK)
C       FOR A TRACE WE CAN . . .
C       WRITE(TTY,2110)PIVOT,KK
2110    FORMAT(2X,F10.3,I6)
        IF(JCC(KK).NE.KK.OR.JCR(KK).NE.KK)PIVOT=0.
C       CHECK THE SIZE OF THE PIVOT
C       IF TOO SMALL THEN ACCURACY OF COMPUTATION IS LOST
        IF(ABS(PIVOT).GT.1E-10) GOTO 215
C       PIVOT ELEMENT IS TOO SMALL
        WRITE(LOGFIL,213)PIVOT,KK
        WRITE(TTY,213 ) PIVOT,KK
213     FORMAT(2X,'JACOBIAN ELEMENT',F10.7,' AT ROW ',
     $ I6,' IS TOO SMALL')
2125    CONTINUE
C       DUMP JACOBIAN
        WRITE(LOGFIL,2130) PIVOT,KK,AVAIL
        WRITE(LOGFIL,2130)((JCOB(II),JCR(II),JCC(II),JNC(II),
     $  JNR(II)),II),II=1,MIN0(100,SZ4))
2130    FORMAT(2X,F10.6,5I4)
        STOP
215     CONTINUE
C       STEP 9.2 NORMALIZE THE PIVOT ROW
C       START AT THE ADDITIONAL COLUMN DP,DQ
C       WHICH IS IN ARRAY DPOWER
        DPOWER(KK)=DPOWER(KK)/PIVOT
C       NORMALIZE OTHER COLUMNS IN JACOBIAN
        ICOUNT=0
        JJ=JNR(KK)
C       START AT RIGHT END OF ROW JJ
217     IF(JCC(JJ).EQ.KK)GOTO 2160
C       NOT YET REACHED DIAGONAL IN ROW KK
        JCOB(JJ)=JCOB(JJ)/PIVOT
        ICOUNT=ICOUNT+1
        IF(ICOUNT.LT.SZ2)GOTO 218
        WRITE(TTY,2468)
        GOTO 2125
        STOP
218     CONTINUE
```

```
      IF(JJ.GT.0)JJ=JNC(JJ)
      GOTO 217
C     HAVE JCOB(JJ) A DIAGONAL ELEMENT
2100  CONTINUE
      JCOB(JJ)=1.0
C     FINISHED NORMALISING PIVOT ROW
C     STEP 2.3 ELIMINATE THE K TH COLUMN ELEMENTS IN ALL BUT
C     THE PIVOT ROW
      DO 219 LI=1,NNN
      II=LI
      IF(II.EQ.KK) GOTO 219
C     HAVE ROW II TO WORK ON
C     FIND JACOBIAN(II,KK)
      VJIK=0.
      CALL GETJ(VJIK,II,KK,IX)
C     IF JACOB(II,KK) IS 0 , THEN ELIMINATION IS DONE
      IF(ABS(VJIK).LT.1E-20)GOTO 219
C     DO THE EXTRA OP.ON COLUMN WHICH IS IN DPOWER
C     CHANGE ROW II WHERE II.NE.KK , KK THE PIVOT
      DPOWER(II)=DPOWER(II)-VJIK*DPOWER(KK)
C     NOW MOVE ONTO THE JACOBIAN IN JCOB.
C     PICK UP A COLUMN POINTER
C     JK MOVES LEFT ACROSS THE PIVOT ROW
C     JI MOVES LEFT ACROSS THE OTHER ROW II
C     JIOLD IS THE PREVIOUS VALUE OF JI
      JIOLD=0
C     ICOUNT IS THE NUMBER OF ELEMENTS IN THE ROW DONE.
      ICOUNT =0
      JK=JRN(KK)
      JI=JRN(II)
220   CONTINUE
      IF(JCC(JK)-JCC(JI)) 221,222,223
C     < 221, = 222, > 223,
221   CONTINUE
C     PIVOT ROW KK COLUMN JCC(JI) IS ZERO (JACOBIAN(KK,JCC(JI)))
C     SO DO NOT CHANGE JACOBIAN(II,JCC(JI))
C     MOVE LEFT IN ROW II
      IF(JI.GT.0)JIOLD=JI
      IF(JI.GT.0)JI=JNC(JI)
      GOTO 224
222   CONTINUE
C     CHANGE JACOBIAN(II,JCC(JK))
C      AT JCOB(JI), ITS NEW VALUE IS VALNU
      VALNU=JCOB(JI)-VJIK*JCOB(JK)
      IF(ABS(VALNU).LT.1E-20)GOTO 2220
C     PUT IN NON ZERO VALUE AT JCOB(JI)
      JCOB(JI)=VALNU
C     ADVANCE THE POINTERS ALONG THE ROWS
      IF(JK.GT.0)JK=JNC(JK)
      IF(JI.GT.0)JIOLD=JI
      IF(JI.GT.0)JI=JNC(JI)
      GOTO 224
2220  CONTINUE
C     PUT IN ZERO VALUE AT JCOB(JI)
      JIT=JNC(JI)
      JNC(JI)=AVAIL
      AVAIL=JI
      IF(JIOLD.GT.0)JNC(JIOLD)=JIT
      IF(JIOLD.EQ.0)JRN(II)=JIT
      JI=JIT
      IF(JK.GT.0)JK=JNC(JK)
```

```
      GOTO 224
223   CONTINUE
C     ROW I,COLUMN JCC(JK) IS ZERO
      CALL PUTJ(-VJIK*.COS(JK),II,JCC(JK),JIOLD)
      IF(JK.GT.0)JK=JNC(JK)
      GOTO 224
C
224   CONTINUE
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LE.NX2)GOTO 2244
C     DONE TOO MANY JACOBIAN ELEMENTS, BAD POINTERS.
      WRITE(TTY,2445)
2445  FORMAT(2X,'TROUBLE IN GAUSS-JORDAN REDUCTION')
      GOTO 2138
      STOP
2244  CONTINUE
      IF(JK.GT.0 .AND. JI.GT.0)GOTO 220
210   CONTINUE
C     FOR DEBUGGING WRITE OUT JACOBIAN
C     WRITE(LOGFIL,2443)II,KK,(DPOWER(LX),LX=1,8)
2443  FORMAT(1X,2I3,8F8.3)
C     WRITE(LOGFIL,2139)((JCOB(LX),JCR(LX),JCC(LX),JNC(LX),
C    &         JNR(LX),LX),LX=1,NX4)
211   CONTINUE
C     FOR JCB FORTRAN ARRAY TO REPRESENT JACOBIAN
C     HANDLE THAT CASE WITH INVERTER ROUTINE MINV20
C     CALL MINV20(JCB,NX2,1,TINV,UINV,NX2,TTY,0,DET,IEXP)
C     WRITE(TTY,271)((JCB(II,JJ),JJ=1,NX2),II=1,NX2)
C     STEP 10 UPDATE THE BUS VOLTAGES
C              AT ALL BUT THE SWING BUS
      DO 200 II=2,NX1
C     FIND A DELTA FOR E(II)
C     IF USING JCB ARRAY THEN MULTIPLY INVERSE JACOBIAN
C     BY DELTA POWER DP,DQ TO GET DELTA E.
C     T1=0.
C     T2=0.
C     IROW=NX1-1+II-1
C     DO 275 JJ=2,NX1
C     ICOL=NX1-1+JJ-1
CC    T1=T1+JCB(II-1,JJ-1)*(P(JJ)-DP(JJ))
C    1+JCB(II-1,ICOL)*(Q(JJ)-DQ(JJ))
C     T2=T2+JCB(IROW,JJ-1)*(P(JJ)-DP(JJ))
C    1+JCB(IROW,ICOL)*(Q(JJ)-DQ(JJ))
C275  CONTINUE
C     END OF MATRIX MULTIPLY, NOW T1,T2 IS DELTA E(II)
C     T1 AND T2 ARE THE REAL AND IMAGINARY PART
C     OF DELTA E SO FOR THE GAUSS-JORDAN REDUCTION
C     IF USING JCBS ARRAY, THEN
C     WE HAVE SIMPLY THE FOLLOWING
      T1=DPOWER(II-1)
      T2=DPOWER(II+NX1-2)
C     T1,T2 IS THE DELTA E(II)
      E(II)=E(II)+CMPLX(T1,T2)
200   CONTINUE
300   CONTINUE
C     UPDATE THE P AND Q SCHEDULED
C     BASED ON THE NEW BUS VOLTAGES
      CALL NEWPQ
C     STEP 12 UPDATE THE ITERATION COUNT
      K=K+1
C     CALL RITE
```

```
      IF(K.LE.5)GO TO 13
C     LOOP AROUND TO RECALCULATE THE SUPPLIED POWER
C     OTHERWISE NO CONVERGENCE
      WRITE(TTY,405)
405   FORMAT(' NO CONVERGENCE')
C     JUMP HERE IF CONVERGENCE OCCURS OR
C             IF NO CONVERGENCE AFTER
C             SEVERAL TRIES AND MESSAGE
C             PRINTED
500   CONTINUE
C     STEP 11 CALCULATE THE POWER AT THE
C             SLACK BUS , BUS 1
      I(1)=(0.,0.)
      II=1
C     YLC THE LINE CHARGING ADMITTANCE IS THE
C     SUM OF THE FIRST ROW IN Y MATRIX
      YLC=Y(II)
550   CONTINUE
      II=NEXTCOL(II)
      IF(II.EQ.0)GOTO 560
C     ADD TO I(1) THE FLOW IN LINE 1 TO YO(II)
      S=(E(1)-E(YO(II)))*(-Y(II))
C     S IS THE POWER AND THE CURRENT IN THE LINE
C     SINCE E(1) = 1.0 PER UNIT
      WRITE(LOGFIL,559)YO(II),S
559   FORMAT(3X,'POWER FLOW FROM NODE 1 TO NODE ',
     & I3,' IS ',2F8.4)
      I(1)=I(1)+S
      YLC=YLC+Y(II)
      GOTO 550
560   CONTINUE
      I(1)=I(1)+E(1)*YLC
C     FIND COMPLEX POWER AT SWING BUS
      S=E(1)*I(1)
      P(1)=REAL(S)
      Q(1)=-AIMAG(S)
C     CALL BITE
      RETURN
      END
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Fcem/44

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      SUBROUTINE FORMY
C     THIS ROUTINE CREATES THE SPARSE ARRAY FOR
C     THE ADMITTANCE MATRIX Y
C     ITS INPUT IS THE ARRAY GWAY WITH INFORMATION ON
C     GUIDEWAY SEGMENTS, AND INFORMATION ON CABLES
C     OR TRANSFORMERS IN THE POWER DISTRIBUTION NETWORK
C
C     ITS OTHER INPUT
C     IS THE MISSION PROFILE ARRAYS WITH INFORMATION
C     ON THE VEHICLE POSITION.
C
C     THE OUTPUT IS THE ARRAYS G,B,YP,YQ,NXTROW,NXTCOL
C     THE STRATEGY IS TO FILL IN G AND B FIRST AS
C     ZERO THEN TRAVERSE THE GWAY ARRAY TO PICK UP
C     EITHER A CABLE TRANSMISSION LINE/TRANSFORMER
C     IMPEDANCE (PER UNIT) OR TO PICK UP A POWER
C     RAIL  LENGTH (FEET). THE
C     LATER MULTIPLIED BY THE POWER RAIL
C     IMPEDANCE PER FOOT (ZPU WITH UNITS PER
C     UNIT OHMS PER FOOT).
C
C     EACH IMPEDANCE BECOMES AN ADMITTANCE WHICH IS ADDED
C     TO THE Y MATRIX. RECAL THE DIAGONAL TERMS OF Y
C     ARE THE SELF ADMITTANCE TERMS AND ARE THE SUM OF
C     ALL ADMITTANCES CONNECTED TO THAT NODE
C     RECALL THE OFF- DIAGONAL TERMS ARE THE MUTUAL
C     ADMITTANCES AND ARE THE NEGATIVE OF THE
C     INTERVENING ADMITTANCE.
C
C     Y IS G - JWB
C
C     FORMY DECLARATIONS
      INCLUDE 'PARAMS.F4'
      INTEGER FN,TN,YPTR
C     FN AND TN ARE 'FROM' NODES AND 'TO' NODES
C     ALONG A GUIDEWAY SEGMENT.
C     SN AND BN ARE TEMPORARIES FOR NODE NUMBERS
C     SMALL NODE AND LARGE NODE NUMBERS (SORTED )
      INTEGER SN,BN
C     SET A POINTER TO HELP IN ADDING TO THE ARRAYS G AND B
      YPTR=NS+1
C     SET THE POWER RAIL IMPEDANCE (OHMS PER FOOT
C     ZBASE=4.33
      ZBASE=4.760
C     ZSTB=CMPLX(33.E-6/ZBASE,60.E-6/ZBASE)
      ZSTB=(.000073,.000055)
C     ZSTB=CMPLX(18.E-6/ZBASE,39.E-6/ZBASE)
C     ZSTB=(.000004,.000117)
C     ZERO OUT THE G AND B ARRAYS
      DO 100 II=1,NS1
      Y(II)=(0.,0.)
      YP(II)=II
      YQ(II)=II
100   CONTINUE
      DO 101 II=NS1+1,NS3
      Y(II)=(0.,0.)
      YP(II)=0
      YQ(II)=0
101   CONTINUE
      DO 200 II=1,GWAYNO
C     GET FROM GWAY EITHER A TRANSFORMER (CABLE) IMPEDANCE
```

```
C      OR GET A GUIDEWAY LENGTH
       FLAG='TT'
       IF(GWAY(II,1).EQ.FLAG)GOTO 500
C      HAVE A GUIDEWAY SEGMENT
C      SET UP MAXIMUM VEHICLE QUEUE LENGTH FOR SEGMENT LQ
       LQ=5
C      GET THE FROM NODE NUMBER FN
       FN=INT(GWAY(II,1)+0.5)
       FNLOC=GWAY(II,4)
C      GET THE NEXT NODE ALONG THE GUIDEWAY SEGMENT
100    CONTINUE
       LQ=LQ+1
C      WRITE(TTY,77)II,LQ,GWAY(II,LQ),TN,FN,TNLOC,FNLOC
C77    FORMAT(1X,2I4,F6.1,2I4,2F6.1)
       IF(LQ.GT.GWAYCQ) GOTO 150
C      LQ POINTS TO AN ENTRY IN THE QUEUE
       TN=INT(GWAY(II,LQ)+0.5)
C      HAVE A SEGMENT BETWEEN TWO
C      DIFFERENT NODES
       IF(TN.EQ.0)GOTO 150
C      HAVE A VEHICLE AT THE END OF THE GUIDEWAY SEGMENT IMPEDANCE
C      FIND ITS POSITION FROM ARRAY POS
C      NOTE THAT ITS VEHNUM IS TN-1
       TNLOC=POS(2,TN-1)
110    D=TNLOC-FNLOC
       IF(D.LT.1.)D=1.
       IF(TNLOC.LT.FNLOC)GOTO 5500
       IF(TNLOC.GT.GWAY(II,5)+DELX) GOTO 5500
C      WRITE(TTY,70)II,LQ,D
C      FIND THE ADMITTANCE ASSOCIATED WITH THE DISTANCE D (FEETO
       YD= 1/(D*SGY)
120    CONTINUE
C      ADD THE ADMITTANCE YD TO THE SELF
C      ADMITTANCE AT EACH NODE , TN FN .
       Y(FN)=Y(FN)+YD
       Y(TN)=Y(TN)+YD
C      FILL IN THE MUTUAL ADMITTANCE
C
       SN=MINO(FN,TN)
       BN=MAXO(FN,TN)
       DO 135 JJ=NSJ+1,YPTR
       IF(YP(JJ).EQ.SN.AND.YQ(JJ).EQ.BN)GOTO 137
135    CONTINUE
C      ROW FOR MUTUAL ADMITTANCE NOT FOUND
C      USE NEW ROW JJ
       JJ=YPTR+1
C      JJ IS THE ROW OF Y,YP, AND YQ TO USE
C      FOR THIS MUTUAL ADMITTANCE
       YPTR=JJ
       IF(YPTR.LT.SZ3)GOTO 137
C      ERROR IN Y MATRIX
139    WRITE(TTY,99)
99     FORMAT(3X,'ADMITTANCE MATRIX TOO SMALL')
       DO 136 III=1,YPTR
       WRITE(LOGFIL,999)III,Y(III),YP(III),YQ(III)
999    FORMAT(3X,I3,2F9.2,2I4)
136    CONTINUE
       STOP
137    CONTINUE
C      NO ERROR
       Y(YPTR)=Y(YPTR)-YD
```

```
      YP(YPTR)=SN
      YQ(YPTR)=EN
C     ADVANCE ALONG THE QUEUE
C     UPDATE THE FROM NODE
      FN=TN
      FNLOC=TNLOC
C     GET NEXT TO NODE
      GOTO 105
100   CONTINUE
C     HAVE NO VEHICLE AT THE END OF THE GUIDEWAY SEGMENT
C     IMPEDANCE, THE VEHICLE QUEUE IDS EMPTY. ITS A GUIDEWAY NODE
      TN=INT(GWAY(II,2)+0.5)
      IF(TN.EQ.FN)GOTO 200
      TNLOC=GWAY(II,5)
      D=TNLOC-FNLOC
      IF(D.LT.1.0)D=1.0
      IF(TNLOC+DELX.LT.FNLOC) GOTO 8500
C     WRITE(TTY,79)II,LQ,D
      YD=1./(D*ZMX)
      GOTO 160
200   CONTINUE
C     HAVE A SEGMENT WHICH IS A TRANSFORMER OR A CABLE
C     A FIXED IMPEDANCE NOT A GUIDEWAY LENGTH.
      FN=INT(GWAY(II,1)+0.5)
      TN=INT(GWAY(II,2)+0.5)
C     WRITE(TTY,79)II,LQ,D
C79   FORMAT( 3X,2I10,F7.1)
      YD=1./CMPLX(1.*GWAY(II,4),1.*GWAY(II,5))
160   CONTINUE
C     ADD THE ADMITTANCE YD TO THE SELF
C     ADMITTANCE AT EACH NODE, TN,FN.
      Y(FN)=Y(FN)+YD
C
      Y(TN)=Y(TN)+YD
C     FILL IN THE MUTUAL ADMITTANCE
C
      SN=MIN0(FN,TN)
      EN=MAX0(FN,TN)
      DO 175 JJ=NSS1+1,YPTR
      IF(YP(JJ).EQ.SN.AND.YQ(JJ).EQ.EN)GOTO 177
175   CONTINUE
      JJ=YPTR+1
C     USE A NEW ROW SO UPDATE YPTR
      YPTR=JJ
      IF(YPTR.GE.NS3)GOTO 119
177   CONTINUE
C     JJ IS THE ROW OF Y,YP, AND YQ TO USE
C     FOR THIS MUTUAL ADMITTANCE
      Y(JJ)=Y(JJ)-YD
      YP(JJ)=SN
      YQ(JJ)=EN
300   CONTINUE
C     FINISHED WITH G,B YP,YQ
C
C
C     FILL IN THE NXTCOL ARRAY
      DO 700 II =1,NS1
      IOLD=II
      N1=II+1
      N2=NS3-1
      DO 750 JJ=N1,N2
      IF(YP(IOLD).NE.YP(JJ))GOTO 750
```

```
C       MAKE NXT COL ENTRY
        NXTCOL(IOLD)=JJ
        IOLD=JJ
 750    CONTINUE
        NXTCOL(IOLD)=0
 700    CONTINUE
C
C       FILL IN THE NXT ROW ARRAY
C
        DO 800 II =1,NS1
        IOLD=II
        N1=II+1
        N2=NS2-1
        DO 850 JJ=N1,N2
        IF(YO(IOLD).NE.YO(JJ))GOTO 850
        NXTROW(IOLD)=JJ
        IOLD=JJ
 850    CONTINUE
        NXTROW(IOLD)=0
 800    CONTINUE
C       WRITE(TTY,999)NPTN
C       DO 999 II=1,NPTN
C       WRITE(TTY,999)II,XP(II),YO(II),NXTCOL(II),NXTROW(II),
C     &  Y(II)
C999    FORMAT(1X,5I5,2F9.3)
C900    CONTINUE
        RETURN
 9000   CONTINUE
C       BAD MISSION PROFILE DATA
        WRITE(TTY,960)II,PN,PNLOC,TN,TNLOC,SROW2(TN-1),
     & GWAY(II,4),GWAY(II,5)
 960    FORMAT(2X,'BAD MISSION PROFILE DATA FOR'/
     & 2X,'GUIDEWAY SEGMENT ',I5,7F9.1)
        STOP
        END
```

NEWPQF

```
      SUBROUTINE NEWPQ
C     SUBROUTINE TO FIND THE VEHICLE LOADS
C     INPUT THE VOLTAGE AT EACH NODE II, E(II)
C     ITS COMPLEX AND PER UNIT PHASE VOLTAGE
C     OUTPUT POWER P(II) Q(II) THE SCHEDULED
C     PER UNIT REAL AND REACTIVE VOLTAGE AT
C     NODE II.  IT IS THE POWER INTO THE
C     SYSTEM, SO LOADS ARE NEGATIVE, GENERATORS ARE
C     POSITIVE.
C
      INCLUDE 'PARAMS.F4'
C
      DO 100 II=1,NCAR
C     FOR EACH NODE EXCEPT THE SWING NODE
C     WHICH CORRESPONDS TO A VEHICLE
C     FIND THE POWER LOAD
C     NOTE NODE I IS VEHICLE NUMBER I
C     MINUS 1 WHERE I IS 2 UPTO NCAR+1
      NUMVEH=II
      INODE=II+1
      VRAIL=E(INODE)
      VMTROT=VM(NUMVEH)
      THTROT=TH(NUMVEH)
      INTROT=IN(NUMVEH)
      CALL PCU
      P(INODE)=-DP
      Q(INODE)=-DQ
  100 CONTINUE
      RETURN
      END
```

PCU.F4

```
      SUBROUTINE PCU
C     THIS ROUTINE HAS AS INPUT THE MOTOR
C     TERMINAL VOLTAGE VMTR , THE MOTOR CURRENT IMTR,
C     AND THE PHASE ANGLE THTR.
C
C     THE OUTPUT IS THE REAL POWER (PU) AND REACTIVE POWER (PU)
C     STORED IN P, AND RQ RESPECTIVELY
C     IT TAKES INTO ACCOUNT THE ISOLATION
C     TRANSFORMER, WHICH IS A DELTA-WYE
C     CONNECTION WITH A STEP DOWN RATIO A TO 1, AND
C     A LEAKAGE REACTANCE ON THE SECONDARY OF XC.
C     IT ALSO TAKES
C     INTO ACCOUNT THE 3 PHASE RECTIFIER - A FULLY
C     CONTOLED BRIDGE.
C
C     PCU DECLARATIONS
      INCLUDE 'PARAMS.F4'
C     THE BASE QUANTITIES ARE DEFINED
C     333000 VOLT-AMPS PER PHASE
      PBASE=333000 !BASE POWER IN VOLT-AMPS
C     0.333 BASE VOLTAGE, KV LINE TO NEUTRAL
      VBASE=333 !BASE VOLTAGE IN VOLTS LINE TO NEUTRAL
      CBASE =1000. !BASE CURRENT IN AMPS
C     GET INPUT VALUES
      VT=VMTR
      CA=IMTR
C     CORRECT FOR BRAKING WHEN CONVERTER 2 IS USED
      IF(ABS(THTR).GT.90)VT=-VT
      IF(ABS(THTR).GT.90) CA=-CA
C     THIS IS THE DC CASE FOR VMTR,IMTR AND THTR.
C
C     SET THE TURNS RATIO A
C     OF THE ISOLATION TRANSFORMER
      A=1
C     FIND THE VOLTAGE DROP DUE TO COMMUTATION OF SCR'S
C     AND STORE AS EX (VOLTS)
C     IT IS A FUNCTION OF THE LEAKAGE REACTANCE XC
C     OHMS PER PHASE
      XC=0.027
      EX=(3*XC*CA)/PI
C     FIND THE PHASE DELAY ANGLE ALPHA
C     ITS A FUNCTION OF THE UNCONTOLLED DC VOLTAGE EDO
      EDO=3*SQRT(6.)/PI*CABS(VRAIL)/A*VBASE
C     AND ITS A FUNCTION OF OF THE OUTPUT DC VOLTAGE ED
      ED=VT
      ALPHA=ACOS((EX+ED)/EDO)
C     SAVE THE PHASE DELAY ANGLE
      ALPH(NUMVEH)=ALPHA
C     FIND THE COMMUTATION ANGLE AMU
      AMU=ACOS((ED-EX)/EDO)-ALPHA
C     FIND THE POWER FACTOR PF AND THE PHASE ANGLE PHI
C     THEN FIND THE REACTIVE FACTOR SIN PHI
      CF1=.5*(COS(ALPHA)+COS(ALPHA+AMU))
C     CF2 IS THE RATIO OF THE FUNDAMENTAL REACTIVE POWER
C     TO THE UNCONTROLLED DC POWER PDO
      CF2=SIN(ALPHA)
      IF(ALPHA.GT.89.*PI/180.) GOTO 30
      IF(AMU.LT. 1.*PI/180) GOTO 30
      CF2=(2*AMU+SIN(2*ALPHA)-SIN(2*(ALPHA+AMU)))
     & /(2.*(COS(ALPHA)-COS(ALPHA+AMU)))
 30   CONTINUE
```

```
      PF=COS(ALPHA)*(1/SQRT(CF1**2+CF2**2))
      RF=SQRT(1-PF**2)
C     REAL POWER REP (WATTS) TOTAL IN ALL THREE PHASES
      REP=VT*CA
C     REACTIVE POWER  AIMP (VOLT-AMPS) TOTAL IN ALL THREE PHASES
      AIMP=REP*ABS(CA)*CF2
C
C     CONVERT TO OUTPUT VARIABLES IN PER UNIT
C     ADD IN THE AUXILIARY LOAD
C     PAUX REAL POWER (WATTS) TOTAL IN ALL THREE PHASES
C     QAUX IMAG POWER (VOLT AMPS) TOTAL IN ALL THREE PHASES
      PAUX=11530.
      QAUX=9640.
      RP=(REP+PAUX)/PBASE/3.
      QP=(AIMP+QAUX)/PBASE/3.
C     RECORD SOME VALUES ON THE LOG FILE.
C     WRITE(LOGFIL,99)ERO,ER,EI
C     TEMP=REP*CA*CF1
C     WRITE(LOGFIL,99)REP,TEMP
C     WRITE(LOGFIL,99)ALPHA,AMU,PF,RF
C  99 FORMAT(4X,5F10.1)
      RETURN
      END
```

GPJ.F4

```
      SUBROUTINE GETJ(VAL,II,J,K)
C     LOOK UP THE VALUE OF JACOBIAN (II,J)
C     THE RESULT GOES IN VAL
C     NOTE THE JACOBIAN ARRAY IS STORED IN
C     SPARSE ARRAY JCOB
C     K IS A STARTING POINT FOR THE SEARCH
C     K.EQ.0 SET K TO JRN(II)
C     K.NE.0 START LOOKING AT JCOB(K)
      INCLUDE 'PARAMS.F4'
C     CHECK INPUT PARAMETERS
      IF((II.GE.1 .AND. II.LE.NZZ
     & .AND. J.GE.1 .AND. J.LE.NZZ)GOTO 300
      WRITE(TTY,299)II,J
299   FORMAT(3X,'BAD JACOBIAN SUBSCRIPTS ',2I3)
      STOP
300   CONTINUE
C     II AND J ARE LEGAL JACOBIAN SUBSCRIPTS
      IF(K.EQ.0) K=JRN(II)
C     K IS NOW POINTING AT A LOCATION IN THE
C     SPARSE ARRAY.  USE IT TO START THE SEARCH.
C     LOOK AT JCOB(K), AN ELEMENT IN ROW I
10    CONTINUE
      IF(JCR(K).EQ.II .AND. JCC(K).EQ.J)GOTO 100
CC    NOT FOUND YET IN ROW I
      K=JNC(K)
      IF(K.EQ.0)GOTO 200
C     K POINTS TO AN ELEMENT IN ROW I
      GOTO 10
100   CONTINUE
C     FOUND IT
      VAL=JCOB(K)
      GOTO 210
200   CONTINUE
C     NOT FOUND
      VAL=0.
210   CONTINUE
C     HAVE FOUND VAL AND K
C     IF VAL IS ZERO THEN K IS ZERO
C     IF VAL IS NOT ZERO THEN VAL IS JCOB(K)
      RETURN
      END
      SUBROUTINE PUTJ(VAL,II,J,K)
C     GIVEN A VALUE VAL AND A POINTER WITH
C     WHICH TO START SEARCHING LOOK FOR
C     JACOBIAN(II,J) IN THE SPARSE ARRAY JCOB
C     STARTING AT JCOB(JNC(K)) IF K.NE.0
C     WHEN FOUND STORE VAL IN JACOBIAN(II,J).
CC    IF VAL .EQ. 0. THEN SPARSE ARRAY JCOB
C     DOES NOT STORE IT EXPLICITLY
      INCLUDE 'PARAMS.F4'
      IF(II.GE.1.AND.II.LE.NZZ
     & .AND.J.GE.1.AND.J.LE.NZZ)GOTO 500
      WRITE(TTY,499)II,J
499   FORMAT(3X,'BAD JACOB SUBSCRIPT ',2I3)
      STOP
500   CONTINUE
C
C     ICOUNT IS THE NUMBER OF ELEMENTS EXAMINED
      ICOUNT=0
C     SET UP POINTERS SO K1 PROCEEDS THRU
C     THRU ROW I, AND K FOLLOWS IT.
```

```
C
      IF(K.EQ.0)K1=JRN(II)
      IF(K.NE.0)K1=JNC(K)
C     CHECK THE K1 VALUE
      IF(K1.LE.0)GOTO 100
C     HAVE JCOB(K1) AS THE PLACE TO START THE SEARCH
C     CHECK THAT THIS IS THE CORRECT ROW
10    CONTINUE
C     TEST IF JACOBIAN(II,J) HAS BEEN FOUND
      IF(JCR(K1).EQ.II .AND. JCC(K1).EQ.J) GOTO 200
C     NOT FOUND ADVANCE LEFT ONE COLUMN
      IF(JCC(K1).LT.J) GOTO 100
      K=K1
      K1=JNC(K)
      IF(K1.EQ.0)GOTO 100
C     POINTER K1 LEADS K THRU ROW II
      IF(JCR(K1).NE.II)GOTO 17
C     WE HAVE A NEW PLACE JCOB(K1) WHICH IS PROMISING
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LE.822)GOTO 10
17    CONTINUE
      WRITE(TTY,19)II,J,K
      WRITE(TTY,18)JCOB(K1),K1
      WRITE(LOGFIL,18)((JCOB(II),JCR(II),JCC(II),
     &JNC(II),JRN(II),II),II=1,MIN0(824,1300))
18    FORMAT(2X,F8.4,5I4)
19    FORMAT(2X,'JACOBIAN TROUBLE SEARCHING FOR ',2I4,
     $'STARTING AT JCOB ',I4)
      STOP
100   CONTINUE
C     JACOBIAN(II,J) IS NOT IN THE ROW
C     ITS PREVIOUS VALUE IS ZERO
C     INSERT ITS NEW NONZERO VALUE INTO THE RIGHT OF
C     JCOB(K1)
      IF(ABS(VAL).LT.1E-20)RETURN
C     GET A NEW LOCATION FROM AVAIL
C     IF NONE AVAILABLE EXIT
      IF(AVAIL.EQ.0)GOTO 400
C     HAVE A LOCATION AT AVAIL
      JCOB(AVAIL)=VAL
      JCR(AVAIL)=II
      JCC(AVAIL)=J
      IF(K.EQ.0)JRN(II)=AVAIL
      IF(K.NE.0)JNC(K)=AVAIL
      K=AVAIL
      AVAIL=JNC(AVAIL)
      JNC(K)=K1
C     INSERTION AND AVAIL STACK BOOKKEEPING IS DONE
      RETURN
200   CONTINUE
C     FOUND THE JACOBIAN(II,J) AT JCOB(K1)
      IF(ABS(VAL).LT.1E-20.AND.JCC(K1).NE.JCR(K1))GOTO 300
C     UPDATE THE PREVIOUS NONZERO VALUE TO A NEW
C     NONZERO VALUE
      JCOB(K1)=VAL
      K=K1
      RETURN
300   CONTINUE
C     UPDATE THE PREVIOUS NONZERO VALUE TO A NEW VALUE = ZERO
      IF(K.EQ.0)JRN(II)=JNC(K1)
      IF(K.NE.0) JNC(K)=JNC(K1)
```

```
C       PUSH ONTO STACK
        JNC(K1)=AVAIL
        JCOD(K1)=0.
        JCC(K1)=0
        JCR(K1)=0
        AVAIL=K1
        RETURN
C       EMPTY STACK PROBLEM
400     CONTINUE
        WRITE(TTY,409)
409     FORMAT(2X,'AVAIL IS EMPTY')
        STOP
        END
```

0251-CR F4

```
      SUBROUTINE DISTOR
C     TO COMBINE CURRENTS INTO A DISTORTON
C     CURRENT AT THE BLACK BUS
C     DISTOR IS CALLED BY THE MAIN PROGRAM
C     DISTOR CALLS NO SUBROUTINES
C
C     INPUT TIN(II) MOTOR CURRENT FOR EACH VEHICLE
C     ALPH(I) FIRING ANGLE OF EACH VEHICLES
C     PCU IN RADIANS
C     PARAMETERS AND COMMUTATION ANGLE (RADIANS)
C     FOR THE EFFECT OF THE TRANSFORMER LEAKAGE
C     CBASE THE BASE CURRENT
C     REACTANCE AND POWER RAIL SYSTEM
C     PARAMETER MAXHAR HIGHEST HARMONIC TO INCLUDE
C     IN THE DISTORTION CURRENT - USUALLY 25
C     OUTPUT RHAR(II),AIHAR(II) WHERE II IS 1 TO 10C  SO RHAR(1) MAY
C     BE 5TH HARMONIC
C     RHAR(2) MAY BE 7TH HARMONIC
C     RHAR(3) MAY BE 11 TH HARMONIC
C     ETC UPTO 25TH IN RHAR(6)

C     RHAR(II) REAL COMPONENT OF THE  HARMONIC
C     WITH RESPECT TO THE BLACK BUS VOLTAGE REFERENCE
C     AIHAR(I) IS THE IMAGINARY COMPONENT OF THE
C     HARMONIC WITH RESPECT TO THE BLACK BUS VOLTAGE REFERENCE
C     BOTH RHAR AND AIHAR ARE CURRENT INTO THE SYSTEM AT THE BLACK BUS
C
      INCLUDE 'PARAMS.F4'
      REAL N
      DIMENSION RHAR(10),AIHAR(10),NHAR(10)
      DATA (NHAR(II),II=1,10)/5,7,11,13,17,19,23,25,29,31/
      DATA MAXHAR/25/
C     MAXHAR IS THE MAXIMUM HARMONIC NUMBER TO BE INCLUDED
      DATA CBASE/100./
C     CBASE IS THE BASE VALUE FOR PHASE CURRENT
C     CLEAR THE TABLE OF HARMONIC CURRENTS
      DO 400  II=1,10
      RHAR(II)=0.
      AIHAR(II)=0.
  400 CONTINUE
      DO 100 II=1,NCAR
C     CONSIDER THE VEHICLE NUMBER II (BUS NUMBER II+1)
C     SET DISTORTION CURRENT AT VEHICLE II TO 0.
      INODE=II+1
      DC(INODE)=0.0
      IF(ABS(TIN(II)).LT.0.1)GOTO 100
C     ARRIVE HERE WITH A CURRENT THAT WILL BE DECOMPOSED INTO
C     HARMONIC COMPONENTS WITH FOURIER COEFFICIENTS AN AND BN
      DO 90 JJ=1,10
C     JJ COUNTS THE NUMBER OF HARMONICS TO CONSIDER
C     N IS THE HARMONIC NUMBER
      N=NHAR(JJ)
C     N GOES 5,7,11,13,17,19,23,25 ETC
      IF(N.GT.MAXHAR)GOTO 95
C     SET THE COMMUTATION ANGLE ANU
      ANU=10./180.*PI
C     SET HALF GAMMA FOR SIX PULSE RECTIFIER
      HG=30./180.*PI
C     SET ALPHA FIRING ANGLE FOR VEHICLE II
      A=ALPH(II)
C     N IS THE HARMIONIC
```

```
C      WRITE(22,99)ANU,N,AL
C      FIGURE SOME ANGLES AND COEFFICIENTS
       A1=AL+ANU-NG
       A2=AL-NG
       A3=AL+ANU+NG
       A4=AL+NG
       C1=COS(AL)-COS(AL+ANU)
       C2=COS(AL)/C1
       C3=COS(NG)/C1
       C4=SIN(NG)/C1
       D1=(N-1)*A1
       D2=(N+1)*A1
       D3=(N-1)*A2
       D4=(N+1)*A2
       D5=(N-1)*A3
       D6=(N+1)*A3
       D7=(N-1)*A4
       D8=(N+1)*A4
       F1=2*(N-1)
       F2=2*(N+1)
C      FIND AN- THE FOURIER COEFFICIENT
       AN=C2/N*(COS(N*A3)-COS(N*A1))
C      WRITE(22,9)AN
       AN=AN-C3*(-COS(D1)/F1-COS(D2)/F2)
C      WRITE(22,9)AN
       AN=AN+C3*(-COS(D3)/F1-COS(D4)/F2)
C      WRITE(22,9)AN
       AN=AN+C4*(SIN(-D1)/(-F1)-SIN(D2)/F2)
C      WRITE(22,9)AN
       AN=AN-C4*(SIN(-D3)/(-F1)-SIN(D4)/F2)
C      WRITE(22,9)AN
       AN=AN+1/N*(COS(N*A1)-COS(N*A3))
C      WRITE(22,9)AN
       AN=AN-C3*(-COS(N*A3)/N+COS(N*A4)/N)
C      WRITE(22,9)AN
       AN=AN+C3*(-COS(D5)/F1-COS(D6)/F2)
C      WRITE(22,9)AN
       AN=AN-C3*(-COS(D7)/F1-COS(D8)/F2)
C      WRITE(22,9)AN
       AN=AN+C4*(SIN(D5)/F1-SIN(D6)/F2)
C      WRITE(22,9)AN
       AN=AN-C4*(SIN(D7)/F1-SIN(D8)/F2)
C      WRITE(22,9)AN
C      FIND BN - FOURIER COEFFICIENTS
       BN=C2*(SIN(N*A1)/N-SIN(N*A2)/N)
C      WRITE(22,9)BN
       BN=BN-C3*(SIN(-D1)/(-F1)+SIN(D2)/F2)
C      WRITE(22,9)BN
       BN=BN+C3*(SIN(-D3)/(-F1)+SIN(D4)/F2)
C      WRITE(22,9)BN
       BN=BN+C4*(-COS(-D1)/(-F1)-COS(D2)/F2)
C      WRITE(22,9)BN
       BN=BN-C4*(-COS(-D3)/(-F1)-COS(D4)/F2)
C      WRITE(22,9)BN
       BN=BN+(SIN(N*A3)/N-SIN(N*A1)/N)
C      WRITE(22,9)BN
       BN=BN-C2*(SIN(N*A3)/N-SIN(N*A4)/N)
C      WRITE(22,9)BN
       BN=BN+C3*(SIN(-D5)/(-F1)+SIN(D6)/F2)
C      WRITE(22,9)BN
       BN=BN-C3*(SIN(-D7)/(-F1)+SIN(D8)/F2)
```

```
C     WRITE(22,9)BN
      BN=BN+C4*(-COS(-B5)/(-F1)-COS(B6)/F2)
C     WRITE(22,9)BN
      BN=BN+C4*(-COS(-B7)/(-F1)-COS(B8)/F2)
C     WRITE(22,9)BN
      AID=TIN(II)/CBASE
      IF(TTH(II).GT.90)AID=-AID
      AN=2*AID/PI*AN
      BN=2*AID/PI*BN
C     AN AND BN ARE NOW HARMONIC CURRENT
C     COMPONENTS IN PER UNIT
      PHI=ATAN2(AIMAG(E(II)),REAL(E(II)))
C     PHI IS THE ANGLE BETWEEN THE BUS II VOLTAGE AND
C       THE REFERENCE E(1)
      PHI=PHI*N+ATAN2(BN,AN)
      HAR2=(AN*AN+BN*BN)/2.0
      HAR=SQRT(HAR2)
      RHAR(JJ)=RHAR(JJ)+COS(PHI)*HAR
      AIHAR(JJ)=AIHAR(JJ)+SIN(PHI)*HAR
      DC(INODE)=DC(INODE)+HAR2
 90   CONTINUE
 95   CONTINUE
      DC(INODE)=SQRT(DC(INODE))
C     FINISHED VEHICLE II HARMONICS
 100  CONTINUE
      DC(1)=0.0
C     FIND THE SLACK BUS HARMONIC RMS
C     CURRENT AS THE SUM OF THE SQUARES
C     PUT IN DC(1)
      DO 300 II=1,10
      DC(1)=DC(1)+AIHAR(II)**2+RHAR(II)**2
 300  CONTINUE
      DC(1)=SQRT(DC(1))
      DKVA=DC(1)*CABS(E(1))
      TKVA=SQRT(P(1)**2.0+Q(1)**2.0+DKVA**2.0)
      WRITE(LOGFIL,99) TKVA
 99   FORMAT(/,3X,'THE TOTAL APPARENT KVA IS ',F10.6,' IN PER UNIT')
      RETURN
      END
```

Output.F4

```
      SUBROUTINE RITE
C     ROUTINE TO PRINT POWER AND VOLTAGE AT EACH NODE -
C     DECLARATIONS :
      INCLUDE 'PARAM.F4'
      WRITE(LOGFIL,10)
10    FORMAT(/4X,'BUS'8X,'VOLTAGE',9X,'POWER SCHEDULED',5X,
     &'POWER DELIVERED',8X,'DISTORTION CURRENT')
      DO 30 II=1,NB;
      REALE=REAL(E(II))
      AIMAGE=AIMAG(E(II))
      WRITE(LOGFIL,20) II,REALE,AIMAGE,P(II),Q(II),
     & DP(II),DQ(II),DC(II)
20    FORMAT(3X,I4,6F10.4,3X,F10.4)
30    CONTINUE
      WRITE(TTY,40)
40    FORMAT(3X,'TO CONTINUE')
      RETURN
      END

      SUBROUTINE VEHOUT
C     ROUTINE TO WRITE OUT THE TABLE
C     TO SUMMARIZE THE STATE OF THE VEHICLES -
C     DECLARATIONS :
      INCLUDE 'PARAM.F4'
C     WRITE A TITLE ON THE LOGFIL -
      WRITE(LOGFIL,10) ITIME
10    FORMAT(/3X,'STATE OF THE VEHICLES AT',I4,' SEC :')
      WRITE(LOGFIL,20)
20    FORMAT(3X,3X,'NO.',2X,4X,'POSI','TION',4X,2X,'VEL',3X,
     &3X,'ACC',2X,'IDEAL VEL',1X,2X,'GRADE',2X,'WIND',2X,
     &'MOTOR VOLT',1X,'CURRENT',2X,'ANGLE',4X,'PASS',5X,'CARS',
     &3X,'MODE',3X,'ALPHA',3X,'NO.')
      DO 40 II=1,NCAR
      WRITE(LOGFIL,30)II,POS(1,II),POS(2,II),VVEL(II),VACC(II),(PFILE
     &(AROW2(II),J),J=2,4),TVN(II),TIN(II),
     &TTH(II),NUMPAS(II),ICARS(II),VMODE(II),ALPH(II),II
30    FORMAT(3X,I5,3X,A3,F10.2,F6.2,F8.2,F11.2,F8.2,F6.2,F11.1,
     &F8.1,F8.2,I10,F8.0,F8.2,I5)
40    CONTINUE
      WRITE(LOGFIL,50)
50    FORMAT(//)
      RETURN
      END
```

HEDWAY-1

```
      SUBROUTINE HEDWAY
C     CHECK THE HEADWAY DISTANCES OF THE VEHICLE FLEET, SEARCH THE
C     GUIDEWAY VEHICLE QUEUES FOR A FIRST VIOLATION
C     PRINT IT OUT, AND THEN GIVE AN OPTION TU
C     CONTINUE THE SEARCH , STOP THE SIMULATION, OR
C     STOP THE SEARCH AND RESUME THE SIMULATION.
C     SROW2(II) GIVES THE POSTION OF CAR II IN PFILE .
C     POS(1,II) GIVES THE LOC CODE LETTER PPREFIX FOR CAR II .
C     POS(2,II) GIVES THE LOC CODE DISTANCE VALUE FOR CAR II .
C     OUTPUT A MESSAGE ON THE DEVICE TTY .
C     HEDWAY IS CALLED BY THE MAIN PROGRAM .
      INCLUDE 'PARAMS.F4'
C     CHOOSE A VEHICLE NUMBER II
      DO 500 II=1,NCAR
C     GET THE VELOCITY IN FEET PER SECOND
      VFPS=VEL(II)*1.46667
C     TAU IS THE REACTION TIME IN SECONDS
      TAU=0.5
C     EACCEL IS THE EMERGENCY DECELERATION IN FT PER SEC**2
      EACCEL=10.0
C     VLNGTH IS THE VEHICLE LENGTH IN FEET
      VLNGTH=11.0
C     HDWY IS THE HEADWAY DISTANCE IN FEET
      HDWY=VFPS*TAU+(VFPS*VFPS/2.0/EACCEL)+VLNGTH
C     GET THE POSITION OF VEHICLE II
      P1=POS(1,II)
      P2=POS(2,II)
C     FIND THE GUIDEWAY SEGMENT IN ARRAY GWAY WHERE VEHICLE II EXISTS
      DO 50 K=1,GWAYRO
      IF(GWAY(K,3).EQ.P1) GOTO 60
50    CONTINUE
      WRITE(TTY,80) II
80    FORMAT(/2X,'VEHICLE',I4,' HAS BAD POSITION FOR HEADWAY CHECK')
      STOP
60    CONTINUE
C     FOUND THE GUIDEWAY SEGMENT, ROW K, FOR VEHICLE II .
C     CHECK THAT VEHICLE II IS IN THE QUEUE FOR THAT GUIDEWAY SEGMENT
      DO 70 L=6,GWAYCO
      IF(GWAY(K,L).EQ.II+1) GOTO 90
70    CONTINUE
      WRITE(TTY,91) K
91    FORMAT(/2X,'BAD VEHICLE ARRANGEMENT ON GUIDEWAY ROW ',I3)
      STOP
90    CONTINUE
C     VEHICLE II IS IN GWAY(K,L) .
C     LOOK FOR THE VEHICLE AHEAD OF IT
      IF(L.LT.GWAYCO.AND.GWAY(K,L+1).NE.0) GOTO 190
C     THE VEHICLE AHEAD IS NOT ON THIS SEGMENT .
C     IS THERE ENOUGH HEADWAY DISTANCE JUST ON THIS SEGMENT ?
      DIST=GWAY(K,5)-P2
      IF(DIST.GT.HDWY) GOTO 500
C     IF YES, VEHICLE II DONE; IF NO, LOOK FARTHER ALONG THE ROUTE
      LOOK=ISCAR(SROW1(II)+1,II)
C     IF LOOK IS ZERO, VEHICLE II WILL FINISH ITS MISSION
C     AT THE END OF ITS CURRENT SEGMENT
      IF(LOOK.EQ.0) GOTO 500
C     FIND THE NEXT GUIDEWAY SEGMENT IN THE ARRAY GWAY
      P1NXT=PFILE(LOOK,3)
      DO 200 K=1,GWAYRO
      IF(GWAY(K,3).EQ.P1NXT) GOTO 260
200   CONTINUE
```

```
      WRITE(TTY,91) K
      STOP
200   CONTINUE
C     HAVE THE NEXT SEGMENT ALONG THE ROUTE OF VEHICLE II
      IF(QWAY(K,6).EQ.0) GOTO 500  ! NO VEHICLE ON NEXT SEGMENT
      NVAHD=QWAY(K,6)-1
C     NVAHD IS THE NUMBER OF THE FIRST VEHICLE ON NEXT SEGMENT +
C     COMPUTE DISTANCE TO NEXT VEHICLE
      DIST=DIST+POS(2,NVAHD)-QWAY(K,4)
      IF(DIST.GT.HDWY) GOTO 500
      GOTO 400
300   CONTINUE
      NVAHD=QWAY(K,L+1)-1
C     NVAHD IS THE NUMBER OF THE VEHICLE AHEAD ON SAME SEGMENT +
C     COMPUTE DISTANCE TO THE VEHICLE AHEAD
      DIST=POS(2,NVAHD)-P2
      IF(DIST.GT.HDWY) GOTO 500
400   CONTINUE
C     ARRIVE HERE IF INSUFFICIENT HEADWAY EXISTS
      WRITE(TTY,92) II,P1,P2,ITIME
92    FORMAT(/2X,'HEADWAY TROUBLE FOR VEHICLE',I3,
     &' AT POSITION ',A2,F10.2,'; TIME:',I3,' SEC',/,
     &2X,'INPUT 1 TO EXIT CHECK, 2 TO CONTINUE CHECK,
     &3 TO HALT ')
      READ(TTY,93)JJ
93    FORMAT(I)
      IF(JJ-2) 410,420,430
C     ARITHMETIC IF - 410; 0 420; + 430
410   RETURN
420   GOTO 500
430   STOP
500   CONTINUE
C     ALL VEHICLES DONE OR SEARCH WAS DISCONTINUED
      RETURN
      END
```

NUPNT.F4

```
      SUBROUTINE NUPNT
C     TO ADVANCE ALL THE VEHICLES BY DT
C     SECONDS IN THEIR MISSION PROFILE
      INCLUDE 'PARAMS.F4'
      REAL NEWPOS
C     CHOOSE A VEHICLE TO UPDATE
      DO 500 II=1,NCAR
C     STORE NUMBER OF VEHICLE TO BE UPDATED
      NUMVEH=II
C     THREE CASES EXIST:
C     1. THE VEHICLE II HAS NOT STARTED ITS MISSION
C     2. VEHICLE II IS IN A DWELL STATE WITH ZERO VELOCITY
C     3. VEHICLE II IS MOVING
C     DECIDE ON A CASE AND GO UPDATE
      IF(ITIME+DT.LT.ICAR(1,II))GOTO 500
C     WHERE ICAR(1,II) IS THE START TIME (SEC) FOR CAR II -
C     NOT CASE ONE
      J=SROW2(II)
      JP1=J+1
      IF(JP1.GT.PFILER)JP1=1
      JM1=J-1
      IF(JM1.LT.1)JM1=PFILER
C     CHECK THE COMMANDED VELOCITY FOR CAR II
      IF(PFILE(J,3).GT.0.0) GOTO 50
C     CASE 2 VEHICLE DWELLS
      VVEL(II)=0.0
      VACC(II)=0.0
      POS(1,II)=PFILE(J,5)
      POS(2,II)=PFILE(J,6)
C     TEST IF MISSION PROFILE POINT IS STILL
C     APPLICABLE AT TIME DT+TTM(II)
      IF(DT.GT.TTM(II)) GOTO 110
C     YES, CONTINUE DWELL ON THAT POINT
      TTM(II)=TTM(II)-DT
C     TTM(II) IS TIME LEFT FOR THAT POINT (SEC)
      GOTO 500
  110 CONTINUE
C     CURRENT POINT CANNOT BE SUSTAINED FOR ENTIRE DWELL SO
C     ADVANCE TO A NEW MISSION PROFILE POINT
      SROW2(II)=SROW2(II)+1
C     ALLOW PFILE ARRAY TO WRAP AROUND
      IF(SROW2(II).GT.PFILER) SROW2(II)=1
C     LOOK IN THE MISSION PROFILE ARRAY
      IF(PFILE(SROW2(II),1).NE.0.0) GOTO 120
C     PREVIOUS ROUTE SEGMENT IN PFILE ENDED -
C     TRY TO START A NEW SEGMENT
      SROW1(II)=SROW1(II)+1
C     SROW1(II) POINTS TO A NEW SEGMENT IN ICAR ARRAY
      IF(ICAR(SROW1(II),II).NE.0) GOTO 115
C     IF ICAR VALUE IS ZERO NO MORE ROUTE SEGMENTS
C     EXIST IN THE MISSION PROFILE FOR VEHICLE II -
C     VEHICLE II FINISHED ITS MISSION
      GOTO 310
  115 CONTINUE
C     HAVE A NEW ROUTE SEGMENT FOR VEHICLE II
      SROW2(II)=ICAR(SROW1(II),II)
  120 CONTINUE
C     HAVE A NEW MISSION PROFILE POINT -
C     RECORD POSITION FROM NEW PROFILE POINT
      J=SROW2(II)
      JP1=J+1
```

```
      IF(JP1.GT.PFILER) JP1=1
      JM1=J-1
      IF(JM1.LT.1) JM1=PFILER
      IF(PFILE(J,2).GT.0.0) GOTO 50
C     GET TTM(II) SO IT IS THE DURATION OF THIS POINT
      TTM(II)=PFILE(J,1)
C     REPEAT IF VEHICLE IS STILL IN DWELL
      GOTO 5
50    CONTINUE
C     CASE 3 - VEHICLE II HAS VELOCITY VVEL(II) (MPH) AND ACCEL.
C     VACC(II) (MPH/SEC) - VEHICLE II HAS NOT MOVED TO THE NEXT
C     COMMANDED MISSION PROFILE POINT -
C     SO PFILE(J+1,II) IS THE NEXT POINT -
C     AND PFILE(J,II) IS THE CURRENT POINT -
C     THE CURRENT STATE OF THE VEHICLE II IS
C     POS(5,II), VACC(II), VVEL(II) -
C     PFILE(J-1,*) IS THE LAST POINT -
C     SAVE THE CURRENT ACCELERATION AND JERK
      OLDVEL=VVEL(II)
      OLDACC=VACC(II)
      VEL=PFILE(J,2)
C     HAVE THE VEHICLE VELOCITY COMMANDED
      ACC=(VEL-OLDVEL)/DT
C     COMPUTE THE JERK
      JERK=(ACC-OLDACC)/DT
C     LIMIT JERK TO JERKM MPH/SEC**2
        ( R . T . R )   R O R
      IF(JERK.LT.-JERKM) JERK=-JERKM
      ACC=JERK*DT+OLDACC
C     LIMIT ACC TO ACCM MPH/SEC
      IF(ACC.GT.ACCM) ACC=ACCM
      IF(ACC.LT.-ACCM) ACC=-ACCM
C     JERK AND ACC ARE WITHIN LIMITS -
C     SAVE ACTUAL VALUES OF VELOCITY, GRADE, AND HEADING
      VVEL=OLDVEL+ACC*DT
      GRADE=PFILE(SROW2(II),3)
      HD=PFILE(SROW2(II),4)
C     SOLVE FOR VEHICLE DYNAMICS TO GET FT THRUST
C     AND PW POWER AT WHEELS
      CALL VEHDYN
C     HAVE ACC, JERK, FT, AND PW APPROPRIATELY LIMITED
      VACC(II)=ACC
C     VACC(II) IS THE ATTAINED ACCELERATION OF VEHICLE II -
C     FIND NEW VELOCITY OF VEHICLE II AND NEW POSITION IN FEET
      VVEL(II)=OLDVEL+ACC*DT
      NEWPOS=POS(5,II)+VVEL(II)*DT*1.46667+0.50
     1 VACC(II)*1.46667*DT*DT
      IF(NEWPOS.GE.PFILE(JP1,6)) GOTO 200
C     NOT MOVED TO NEXT PROFILE POINT
      POS(5,II)=NEWPOS
      GOTO 100
200   CONTINUE
C     VEHICLE II HAS MOVED TO NEXT PROFILE POINT
      DIS=NEWPOS-PFILE(JP1,6)
      SROW2(II)=SROW2(II)+1
      IF(SROW2(II).GT.PFILER) SROW2(II)=1
      IF(PFILE(SROW2(II),1).NE.0.0) GOTO 220
C     START NEW SEGMENT
      SROW1(II)=SROW1(II)+1
      IF(ICAR(SROW1(II),II).NE.0) GOTO 215
C     FINISHED PROFILE
```

```
210     WRITE(TTY,211) II
211     FORMAT(/,2X,'VEHICLE',I3,' HAS FINISHED PROFILE',//)
        STOP
215     CONTINUE
C       HAVE NEW ROUTE SEGMENT
        IROW2(II)=ICAR(IROW1(II),II)
        DIST=0
220     CONTINUE
C       HAVE NEW MISSION PROFILE POINT
        J=[illegible](II)
        JP1=J+1
        IF(JP1.GT.PFILEN)JP1=1
        JM1=J-1
        IF(JM1.LT.1)JM1=PFILEN
        POS(1,II)=PFILE(J,2)
        POS(2,II)=PFILE(J,3)+DX
        IF(POS(2,II).GT.PFILE(JP1,3)) GOTO 220
        TTM(II)=PFILE(J,1)
300     CONTINUE
C       ALL VEHICLE NUMBER LESS THN II UPDATED
400     CONTINUE
C       ALL VEHICLES DONE .
C       ADVANCE THE SIMULATED CLOCK TIME ITIME
        ITIME=ITIME+DT
C       NOW HAVE THE STATE OF ALL VEHICLES
C       AT TIME ITIME
        RETURN
        END
```

```
C     [illegible]
C     USE THE CURRENT MISSION PROFILE
C     DATA IN SROW1, SROW2,PFILE TO FILL
C     THE QUEUE OF VEHICLES ON EACH
C     GUIDEWAY SEGMENT IN THE ARRAY GWAY
C
C     USE COLUMNS 6 TO GWAYCO
C     LEFT JUSTIFY THE QUEUE, VEHICLES
C     ENTER AT 6 AND EXIT AT THE END NEAR GWAYCU
C
C     THE STRATEGY IS CHOOSE A VEHICLE
C     FIND ITS POSITION CODE, FIND WHICH
C     GUIDEWAY SEGMENT IT IS ON, SCAN THE
C     QUEUE OF VEHICLES ALREADY ON THAT SEGMENT
C     PUT IT IN ITS CORRECT SPOT IF ROOM EXISTS
C
C     DUMMY DECLARATIONS
      INCLUDE 'PARAMS.F4'
C     TEMPORARY LOCATION CODES HAVE PREFIX
C     PART PC AND SUFFIX PART SC
      REAL PC,SC
      INTEGER COL
C
C     EMPTY OUT ALL THE QUEUES
      DO 10 II=1,GWAYRO
      DO 5 JJ=6,GWAYCO
      GWAY(II,JJ)=0.
5     CONTINUE
10    CONTINUE
C
C     SELECT A VEHICLE
      DO 500 JJ=1,NCAR
C     PLACE VEHICLE JJ
C     FIND ITS LOCATION CODE FIRST
C     PC IS THE TWO LETTER PREFIX SC IS THE DISTANCE
      PC=PPOS(1,JJ)
      SC=PPOS(2,JJ)
C     FIND THE GUIDEWAY SEGMENT FOR VEHICLE JJ
      DO 20 II=1,GWAYRO
      IF(PC.NE.GWAY(II,3)) GOTO 20
      IF(SC.LT.GWAY(II,4).OR.SC.GT.GWAY(II,5)+DELX) GOTO 20
C     FOUND THE GUIDEWAY SEGMENT AT ROW II OF GWAY
      GOTO 30
20    CONTINUE
C     CANT FIND IT
      WRITE(TTY,99)JJ,[illegible](JJ)
99    FORMAT(' BAD PROFILE POINT FOR VEHICLE ',I3,
     &' AT ROW ',I5)
      CALL VEHOUT
      WRITE(LOGFIL,995) ITIME
      WRITE(LOGFIL,996)((GWAY(IR,JC),JC=1,GWAYCO),IR
     & =1,GWAYRO)
      STOP
30    CONTINUE
C     FOUND THE LOCATION CODE OF VEHICLE JJ
C     ON GUIDEWAY SEGMENT GWAY(II,0)
C     INSERT IN THE QUEUE
      COL=GWAYCO
      IF(GWAY(II,COL).NE.0.)GOTO 999
C     THERE IS ROOM TO INSERT
C     FIND THE RIGHT-MOST 0 COLUMN IN THE QUEUE
```

```
 32     CONTINUE
        COL=COL-1
        IF(COL.GT.5)GOTO 33
C       HAVE THE EMPTY QUEUE CASE
        COL=6
C       INSERT AT THE BEGINNING OF THE QUEUE
        GOTO 200
 33     CONTINUE
C       TEST THIS NEW COLUMN IN THE QUEUE
        IF(GWAY(II,COL).EQ.0)GOTO 32
C       HAVE COL AS THE LEFTMOST NONZERO COLUMN
C       AND COL IS 6,7,8,9 IN VALUE
        COL=COL+1
C       COL IS NOW THE LEFTMOST 0 ENTRY IN THE QUEUE
C               COL - 1 IS A NON ZERO ENTRY
 35     CONTINUE
C       INSERT, IN THE QUEUE AT COLUMN COL IN GWAY
C       TEST IF WE CAN INSERT VEHICLE NO JJ
C       IN THE QUEUE AFTER VEHICLE NO IVN
        IVN=INT(GWAY(II,COL-1)+0.5)
C       IVN IS LOCATED AT LOC CODE SUFFIX PFILE(6ROW2
C       (IVN-1),5)
        IF(LC.GT.POS(2,IVN-1))GOTO 200
C       DO NOT INSERT RATHER MOVE A QUEUE ELEMENT
        GWAY(II,COL)=GWAY(II,COL-1)
        COL=COL-1
        IF(COL.GT.6)GOTO 35
 200    CONTINUE
C       DO THE INSERT
        GWAY(II,COL)=JJ+1

C       END OF INSERT
 100    CONTINUE
        WRITE(LOGFIL,998) ITIME
        WRITE(LOGFIL,999)((GWAY(II,JJ),JJ=1,GWAYCO),
     & II=1,GWAYNO)
 999    FORMAT(3X,3F3.0,A2,3F12.3,5F4.0)
 998    FORMAT(3X,'GUIDEWAY SEGMENTS AT TIME =',I4,' SEC')
        RETURN
C
C       ERROR MESSAGES
C
 992    WRITE(TTY,997)
 997    FORMAT(' QUEUE FULL- TOO MANY VEHICLES',
     & ' ON A GUIDEWAY SEGMENT')
        WRITE(LOGFIL,998)
        WRITE(LOGFIL,999)((GWAY(II,JJ),JJ=1,GWAYCO),
     & II=1,GWAYNO)
        STOP
        END
```

Appendix B

A Program Concordance

The following table lists the important terms and variables used in the program which is listed in Appendix A:

1. Main program - it prompts the user for input data, sets up the state of the vehicles, initiates the load flow computation and updates the state of the vehicles. The latter two steps can be repeated. Main global symbols:

   VVEL(II) - vehicle II velocity (MPH)

   POS(1,II) - location of vehicle II in terms of a guideway segment identifier

   POS(2,II) - vehicle II position (FEET) from a reference

   TYM(II) - vehicle II dwell time (sec.)

   VACC(II) - vehicle II acceleration (MPH/sec)

   TVM(II) - motor terminal voltage at vehicle II (VOLTS)

   TIM(II) - motor terminal current at vehicle II (AMP)

   TTM - if POWER FLOW INTO MOTOR THEN 0, ELSE NONZERO.

2. SETPFL - a subroutine which prompts the user for a source (disk file name) of the mission profile input data.

   IFIL - mission profile data file name

3. SETGW - a subroutine which prompts the user for a source (disk file name) of the guideway input data.

   IFIL - guideway data file name

4. VEHDYN - a subroutine which handles the vehicle dynamics

5. MOTOR - a subroutine which models a separately excited dc motor
6. TEFF - the block data to initialize values in common
    - ICARS(II) - number of cars coupled together for vehicle II
    - NUMPAS(II) number of passengers on vehicle II
    - JERKM - Maximum jerk limit (MPH/s^2)
    - ACCM - maximum acceleration limit (MPH/s)
7. NR - the Newton-Raphson load flow subroutine. It will iterate 5 times or until the power mismatch is less than EPSIL
8. FORMY - a subroutine called by NR to calculate the admittance matrix Y
9. NEWPQ - a subroutine called by NR to calculate the scheduled P and Q values for each vehicle.
    - GLOBALS
        - P(II) - fundamental real power (per unit) at vehicle II.
        - Q(II) - fundamental reactive power (per unit) at vehicle II
10. PCU - a subroutine called by NEWPQ to model the power conditioning unit which converts 3 phase power into dc power for the motor
    - LOCAL
        - PRUX - constant auxiliary load real power at each vehicle (watts)
        - QUAX - constant auxiliary load reactive power at each vehicle (volt-amp)
        - AMU - constant commutation angle (radians)

GLOBAL

ALPHA - SCR firing angle (radians)

BP - fundamental real power (per unit) at vehicle under consideration

BQ - fundamental reactive power (per unit) at vehicle under consideration

11. GETJ(VAL,II,J,K) - a subroutine used by NR to look up Jacobian values. It assigns to VAL the Jacobian element at row II, column J. If K is zero then the search for the Jacobian element begins at the end of row. Otherwise the search begins at JCOB(K).

12. PUTJ(VAL,II,J,K) - a subroutine used by NR to update Jacobian values. It assigns to the Jacobian element at row II, column J the value VAL. If K is nonzero, then begin the search for Jacobian element at row II, column J at JCOB(JNC(K)) - otherwise at JCOB(JRH(K)).

13. DIST0R - a subroutine which evaluates the Fourier coefficients of the harmonic currents. Distortion currents at the vehicle/power rail interface and at the electric utility/network interface are calculated.

LOCA-NHAR(I) - a table of harmonics to consider

GLOBAL

DC(I) - RMS harmonic current (per unit) at node I.

14. RITE - a subroutine which prints out the power flow summary

15. VEHSUM - a subroutine which prints out the state (of the vehicles) summary

16. HEDWAY - a subroutine which calculates the distance between vehicles. Its output is a message that the mission profile and vehicle performance have caused some intervehicle distances to shrink below a limit (called HDWY).

LOCAL

HDWY - the limiting distance (feet) in front of a vehicle. It is the vehicle length (feet) plus vehicle velocity (feet per sec) times a reaction time (sec) plus emergency deceleration (feet/sec/sec) times velocity squared divided by 2.

TAU - vehicle reaction time (sec)

EACCEL - emergency deceleration rate (feet/sec/sec)

VLNGTH - vehicle length (feet)

17. NUPNT - a subroutine which advances the vehicle fleet to a new point on the mission profile

GLOBAL

DT - amount of time to advance (sec)

18. NUGWQ - a subroutine which updates all the vehicles' positions on the guideway segments. It changes the vehicle numbers stored in array GWAY columns 6 to 10.

Appendix C

The Fourier analysis integrals described in Section 3.6 yield the following expressions:

$$A(N) = \frac{\sqrt{2}\ I_d}{\pi} \Bigg($$

$$\frac{\cos\alpha}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{-\cos n(\alpha+\mu-\gamma/2)}{n} + \frac{\cos n(\alpha-\gamma/2)}{n} \right]$$

$$- \frac{\cos(\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{-\cos(n-1(\alpha+\mu-\gamma/2)}{2(n-1)} - \frac{\cos(n+1)(\alpha+\mu-\gamma/2)}{2(n+1)} \right]$$

$$+ \frac{\cos(\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\cos(n-1)(\alpha-\gamma/2)}{2(n-1)} - \frac{\cos(n+1)(\alpha-\gamma/2)}{2(n+1)} \right]$$

$$+ \frac{\sin(\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin(1-n)(\alpha+\mu-\gamma/2)}{2(1-n)} - \frac{\sin(1+n)(\alpha+\mu-\gamma/2)}{2(1+n)} \right]$$

$$+ \frac{\sin(\gamma/2)}{\cos\ \ - \cos(\ +\ )} \left[\frac{\sin(1-n)(\alpha-\gamma/2)}{2(1-n)} - \frac{\sin(1+n)(\alpha-\gamma/2)}{2(1+n)} \right]$$

$$- \frac{\cos n(\alpha+\mu+\gamma/2)}{n} + \frac{\cos(n(\alpha+\mu-\gamma/2)}{n}$$

$$- \frac{\cos\alpha}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{-\cos n(\alpha+\mu+\gamma/2)}{n} + \frac{\cos n(\alpha+\gamma/2)}{n} \right]$$

$$+ \frac{\cos(-\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[-\frac{\cos(n-1)(\alpha+\mu+\gamma/2)}{2(n-1)} - \frac{\cos(n+1)(\alpha+\mu+\gamma/2)}{2(n+1)} \right]$$

$$- \frac{\cos(-\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[-\frac{\cos(n-1)(\alpha+\gamma/2)}{1(n-1)} - \frac{\cos(n+1)(\alpha+\gamma/2)}{2(n+1)} \right]$$

$$+ \frac{\sin(-\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin(1-n)(\alpha+\mu+\gamma/2)}{2(1-n)} - \frac{\sin(1+n)(\alpha+\mu+\gamma/2)}{2(1+n)} \right]$$

$$+ \frac{\sin(-\gamma/2)}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin(1-n)(\alpha+\gamma/2)}{2(1-n)} - \frac{\sin(1+n)(\alpha+\gamma/2)}{2(1+n)} \right] \Bigg)$$

$$
\begin{aligned}
B(N) = \frac{\sqrt{2}\, I_d}{\pi} \Bigg(\\
& \frac{\cos\alpha}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin n(\alpha+\mu-\gamma/2)}{n} - \frac{\sin n(\alpha-\gamma/2)}{n} \right] \\
& + \frac{\cos\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin(1-n)(\alpha+\mu-\gamma/2)}{2(1-n)} + \frac{\sin(1+n)(\alpha+\mu-\gamma/2)}{2(1+n)} \right] \\
& + \frac{\cos\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin(1-n)(\alpha-\gamma/2)}{2(1-n)} + \frac{\sin(1+n)(\alpha-\gamma/2)}{2(1+n)} \right] \\
& + \frac{\sin\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[- \frac{\cos(1-n)(\alpha+\mu-\gamma/2)}{2(1-n)} - \frac{\cos(1+n)(\alpha+\mu-\gamma/2)}{2(1+n)} \right] \\
& - \frac{\sin\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[- \frac{\cos(1-n)(\alpha-\gamma/2)}{2(1-n)} - \frac{\cos(1+n)(\alpha-\gamma/2)}{2(1+n)} \right] \\
& + \frac{\sin n(\alpha+\mu+\gamma/2)}{n} - \frac{\sin n(\alpha+\mu-\gamma/2)}{n} \\
& - \frac{\cos\alpha}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin n(\alpha+\mu+\gamma/2)}{n} - \frac{\sin n(\alpha+\gamma/2)}{n} \right] \\
& + \frac{\cos\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[\frac{\sin(1-n)(\alpha+\mu+\gamma/2)}{2(1-n)} + \frac{\sin(1+n)(\alpha+\mu+\gamma/2)}{2(1+n)} \right] \\
& + \frac{\cos\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[+ \frac{\sin(1-n)(\alpha+\gamma/2)}{2(1-n)} + \frac{\sin(1+n)(\alpha+\gamma/2)}{2(1+n)} \right] \\
& + \frac{\cos\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[- \frac{\cos(1-n)(\alpha+\mu+\gamma/2)}{2(1-n)} - \frac{\cos(1+n)(\alpha+\mu+\gamma/2)}{2(1+n)} \right] \\
& - \frac{\sin\gamma/2}{\cos\alpha - \cos(\alpha+\mu)} \left[- \frac{\cos(1-n)(\alpha+\gamma/2)}{2(1-n)} - \frac{\cos(1+n)(\alpha+\gamma/2)}{2(1+n)} \right] \Bigg)
\end{aligned}
$$

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