This paper describes a method used to estimate the electrical power required for a computer system and the heat generated by it. The method is a program that serves as an installation planning tool accessed principally by Installation Planning Representatives through communication terminals.

The Power Profile—An installation management tool

by J. A. Laird

As part of setting up a computer installation, the physical requirements for the operation of the computer equipment must be determined. Among such items are the amounts of electrical power and air-conditioning needed. In this paper, a tool, called the Power Profile, is described that enables a more accurate estimate of these requirements to be obtained.

The Power Profile is a program[1] used to estimate electrical power and heat data characterized by particular computer systems. The present program can be used by any IBM personnel concerned with the facility engineering aspects of computer installations. In particular, however, the majority of the users are currently IBM Installation Planning Representatives (IPRS), who are working with customer technical representatives or consultants on site preparation for new or expanded systems. It can be used to provide data to customers who are planning to buy an uninterruptible power supply (UPS) to buffer the computer system from power line transients or short-term outages. The usual static inverter UPS can maintain power from five minutes to one hour following a utility failure, depending upon the storage batteries supplied.

The data from the profile is also of value in non-UPS installations where sizing of transformers, circuit breaker capacities, or power requirements are being studied.

The profile can be accessed using a communication terminal and data communication system. The IPRS commonly use the IBM Field Support System telephone network as the communication media. Access can also be made using commercial telephone.

APL was chosen as the programming language for this use because of its terminal-oriented characteristic. This feature allows the program to be used at a large number of locations (presently anywhere in the United States and Canada). In addition, the *time-shared operation* used at the APL center allows the results to be printed out at any particular terminal in a relatively short time. Composition of the usual profile takes from 15 to 30 minutes depending upon the system list and the parameters that the user wishes to calculate.

Measurement

Before development of the profile, a conventional method of estimating computer system electrical parameters was to make a simple addition of unit electrical apparent power (kilovolt amperes, kVA) and heat parameters (kilo-BTUs per hour), both given in Installation Planning Manuals. This method of estimating has certain drawbacks because heat is a scalar quantity and thus can be directly added, whereas electrical apparent power (kVA) is a vector quantity. A direct addition of the unit apparent power results in a total value larger than the vector magnitude.

An improved estimate of electrical parameters using a vector approach can be made with the summation of the real power (kilowatts) and the summation of the reactive power (kilovars kVAR), together with the rule of vector resolution for right-angle components to provide apparent power (kVA). This type of estimate assumes, however, that the electrical load being estimated uses sinusoidal voltage and current. Many loads for IBM equipment draw nonsinusoidal currents with varying waveforms for different units of equipment.

Because of the above problems, an analysis was made to determine how the system estimate could be improved. An objective of the analysis was to increase the estimate accuracy by including the effects of:

- The variation in phase between voltage and current of the various system units. This variation directly relates to the real power (kilowatts, kW), and reactive power (kVAR) being drawn by each unit.
- The nonsinusoidal current being drawn by various units from the power source. Here a knowledge of the voltage and current waveforms of each unit, together with a Fourier series analysis, is implied.

The magnitude of the analysis effort for each unit, together with the system calculation, required the use of computer programs.

Figure 1 Typical profile input

```
      START
DO YOU WANT THE SHORT QUESTION LIST? ENTER 'Y' OR 'N'.
N
IS THIS PROFILE BEING MADE FOR AN IBM SYSTEM
THAT WILL HAVE (OR HAS) AN UPS (UNINTERRUPTIBLE POWER SYSTEM)?
ENTER 'Y' OR 'N'.
Y
SPECIFY THE POWER FREQUENCY OF THE SYSTEM: ENTER '50' OR '60'.
⎕:
      60
WHEN PROMPTED FOR THE SYSTEM COMPONENTS,
ENTER THE QUANTITY, TYPE, AND MODEL OF EACH COMPONENT,
UNTIL YOU HAVE EXHAUSTED THE LIST.
THEN ENTER THE WORD 'END'.IF YOU WISH TO EXIT FROM THE PROGRAM
BEFORE YOU HAVE ENTERED 'END',ENTER THE WORD 'STOP'.

EACH COMPONENT ENTRY IS TO BE IN THE FORMAT:

           QQ TTTT MMM

WHERE QQ IS THE QUANTITY OF SUCH COMPONENTS,
      TTTT IS THE TYPE NUMBER
      MMM IS THE MODEL IDENTIFIER.

QQ MAY BE 1 OR MORE DIGITS, AND THE ITEMS ARE SEPARATED BY 1 OR MORE BLANKS.
WHEN ENTERING THE MODEL,DO NOT USE BURIED OR LEADING ZEROES.
FOR EXAMPLE: 2 1052 N01 SHOULD BE ENTERED AS 2 1052 N1
             3 1052 001 SHOULD BE ENTERED AS 3 1052 1

SPECIFY LIST OF COMPONENTS IN THE SYSTEM:
1 3155 K
4 3360 3
2 2314 1
1 2250 1
END

DO YOU WISH THE PEAK CURRENT TO BE CALCULATED? THIS VALUE IS REQD. FOR A SYSTEM WITH UPS.
THE CALCULATION NORMALLY TAKES FROM 3 TO 10 MINUTES.ENTER 'Y' OR 'N'.
Y
DO YOU WISH TO ADD A KVA VALUE FOR AN OEM UNIT THAT IS NOT
ON THE ABOVE SYSTEM LIST? ENTER 'Y' OR 'N'.
N
DO YOU WANT THE TRUNCATED OR FULL LISTING? ENTER'T' OR 'F'.
F
ENTER THE INSTALLATION NAME
IBM KINGSTON,S/370-155
PLEASE ROLL THE PAPER UP UNTIL YOU ARE AT THE TOP OF
THE NEXT PAGE. WHEN YOU ARE DONE,ENTER 'D'.
```

In 1970, a mathematical model based upon the Fourier series was derived taking these factors into account (see Reference 2). The model was programmed in FORTRAN. Measurement, waveform data analysis, and storage in a data bank were undertaken for a sample of IBM system units. Several tests were made of the computed system power using the mathematical model versus the system electrical input measurement. Correlation between the two methods was good. In 1972, the FORTRAN profile program was translated into APL to provide the capability for use in the field.

Voltage and current analog waveforms have since been measured on a number of individual units using commercially available test equipment. The line-to-neutral voltage and phase current are measured using a true RMS (root-mean-square) meter. A picture is then taken of the two waveforms presented on a two-channel oscilloscope. The picture is enlarged and used as a pattern while the waveforms are digitized into punched cards. These cards provide an input to a FORTRAN program that calculates Fourier coefficients through the sixtieth harmonic. A set of Fourier coefficients for voltage and current together with an identification format define the single electrical phase parameters for a unique type/model. This data is stored on a disk at IBM facilities in Kingston, N.Y. At discrete intervals, selected data is transferred via magnetic tape to the APL data bank.

The data stored in the data bank is in the form of records. Each record defines one electrical phase for a particular type/model. A single record contains:

- Identification data defining the type/model, electrical phase, peak value of the inrush current, and its duration.
- Four 60-element vectors. ("Vector" as shown here is in the APL usage, that is, a one-dimensional array of numbers.) Two of the vectors define the A and B Fourier coefficients for the voltage waveforms, while the other two define them for the current waveform. The use of the A and B coefficients specifies the electrical phase relationship between voltage and current.

The measurement process is a continuing program. Data is provided on new units by power systems or product assurance groups at the various development laboratories. Where measured data is not available, the Installation Planning Manual data is used and the waveforms are sine-wave simulated for storage in the data bank until measured data is available.

Profile input-output

The profile program is designed for user-program interaction. The user of the program must:

1. Have a system list showing the quantity and type/model of each unit.
2. Determine the power frequency (i.e., 50 or 60 Hz).
3. Determine whether the system is for a UPS or not.

The user can request calculation of the peak value of the current waveform and a printout of the 10 highest inrush currents of the system units. These options are usually required for a UPS system,[3-5] but may not be required on non-UPS systems.

The program uses prompting-type inputs where the user must select one of two options on each question or enter data (see Figure 1). At the conclusion of the input selection sequence, the profile program prints the results of the system calculation.

A typical profile printout is shown in Figure 2. The list in this printout shows the system used for calculation. The user is expected to compare the printout with his original list to check for entry mistakes.

The "System Data" portion of the printout relates to the steady state electrical conditions after power is completely sequenced on all units of the system. The "Inrush Data" relates to the tran-

Figure 2 Typical profile output

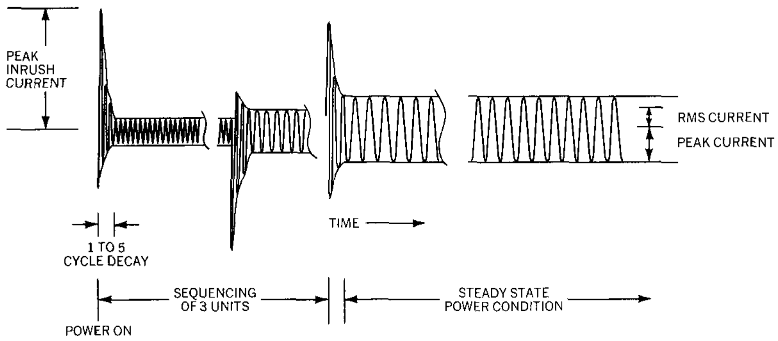
```
D

SYSTEM POWER PROFILE

IBM KINGSTON,S/370-155
12/17/74     11:28

60 HERTZ SYSTEM

EQUIPMENT LIST
  QTY     UNIT-MOD       REMARKS
    1     3155-  K
    4     3360-  3
    2     2314-  1      INCLUDES 9 DISKS
    1     2250-  1
           SYSTEM DATA
SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =115.9  AMPS
AVG. STEADY STATE PEAK CURRENT PER LINE=163.8  AMPS
POWER FACTOR...........................=0.928
REAL POWER.............................=38.721 KW
REACTIVE POWER.........................=¯15.545 KVARS
APPARENT POWER.........................=41.725 KVA
HEAT DISSIPATION PER HOUR..............=132.154 KBTU/HR

           SYSTEM NOTES
1) POWER FACTOR = SYSTEM KW ÷ SYSTEM KVA; IT IS
   NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR
   MOST WAVEFORMS.  IT IS EQUAL TO COSINE PHASE
   SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.

           INRUSH DATA
THE 10 HIGHEST (PEAK) INRUSH CURRENTS ARE:

(3155-  K)=700 AMPS  DCAY IN 5 CYCLS       (2314-  1)=150 AMPS
(3360-  3)=85 AMPS                         (2250-  1)=30 AMPS
(0000-000)=0 AMPS                          (0000-000)=0 AMPS
(0000-000)=0 AMPS                          (0000-000)=0 AMPS
(0000-000)=0 AMPS                          (0000-000)=0 AMPS

           INRUSH NOTES
1) INRUSH VALUE GIVEN IS MAXIMUM INSTANTANEOUS VALUE
   FOR 1 UNIT OF THE TYPE SHOWN.
2) INRUSH CURRENTS FOR VARIOUS UNITS DO NOT OCCUR
   SIMULTANEOUSLY, SINCE UNITS ARE NORMALLY SEQUENCED ON.
3) ALL INRUSH CURRENTS (EXCEPT AS SHOWN IN NOTE 4)
   ARE FOR A HALF CYCLE OR LESS, UNLESS OTHERWISE INDICATED.
4) TYPICAL INRUSH FOR A DISK FILE LASTS 20 SECONDS
   OR LESS PER FRAME; TYPICAL INRUSH FOR A DRUM LASTS
   15 SECONDS OR LESS.

THANK YOU
```

sient current that occurs as each system unit is sequenced on and becomes part of the total load.

Figure 3 shows a typical current representation from initial unit sequencing to steady state full load. Initially turning on each unit causes an inrush current that typically has a high peak on the first half cycle, and then decays to steady state current in one to five cycles. The inrush current in most units is due to the power transformer(s) in the unit. The inrush current peak is not a constant value nor necessarily in the same direction each time a unit is turned on, since the peak value will depend upon the instantaneous applied voltage magnitude/phase and the magnetization state of the transformer core when the unit is turned off. A worst-case inrush condition on any individual unit can be expected to occur within approximately 30 on-off cycles, however. Motors, such as in motor-generator sets, have characteristics similar to transformers in that there is a half cycle peak effect. In addition though, they draw a current higher than the steady state value for some seconds of time as the motor comes up to speed. The exact amount of time will depend upon the motor design.

Any inrush effect due to a new load coming on-line occurs with the inrush effect being added algebraically to the existing steady

Figure 3 Typical power line current showing unit sequencing and steady state conditions



state load current. The sequencing of individual system units to a power-on condition is a choice of the operational personnel.

The profile program is not able to predict the system sequencing. Consequently, the inrush table provides the 10 worst-case peak values of inrush current for individual system units, assuming single loads. It can be noted from Figure 3 that the sequencing of system units does not occur simultaneously. The inrush peaks consequently occur one at a time.

The two current values shown under "System Data" in the profile provide information on the steady state condition of the system. The average RMS current per line is the current estimated as the arithmetic average of the current in each of the three power lines.

The current waveform in a computer system is often nonsinusoidal, since many units are nonlinear loads. The program must consequently calculate the peak value of the current waveform, if it is desired. This optional value is provided as the peak current per line.

The system calculation

The calculation for system power is based upon the system list entered by the user in conjunction with the stored Fourier coefficients in the data base. An example of a typical entry could be 1 3165 I (indicating one unit of Type 3165, Model I). The APL program uses an encoded value for the alphameric type/model as a comparison in searching the data bank for an identical type/model. If the search is successful, the inrush current data along with the four 60-element vectors (i.e., $\mathbf{A}_V$, $\mathbf{B}_V$, $\mathbf{A}_I$, and $\mathbf{B}_I$) is transferred to the user's workspace. If the search is not successful, an error message is typed out at the terminal notifying the user that he can stop or that the last entry will be ignored if he wishes to continue.

Following data transfer, the program multiplies the current coefficients by the unit quantity (individual units are parallel electrical loads). The four resultant 60-element vectors are then individually added to the existing four vectors in the workspace. Upon completion of unit entries, the two voltage vectors are divided by the number of entries in order to arrive at an average voltage for the system.

The program calculates the root mean square voltage and current values for the system using the four summed vectors previously described. The current that is derived from this calculation is the *total* current. Since practically all computer systems use a three-phase power source, this assumption is made in the program. The average current per phase is then one third of the total current. Total apparent power in kilovolt amperes is the product of the RMS voltage and current divided by 1000. The real power in kilowatts is derived from the summation of the products of voltage and current coefficients that represent the same phase and the same harmonic value, and the total value is divided by 1000. The reactive power in kilovars is derived from the vector relationship between the apparent power and real power. Power factor is calculated as the ratio of the real power to apparent power. The heat generated by the system bears a direct relationship to the real power. The calculation is a constant multiplying the real power value.

Several options are available on the calculations. If the peak value of the current waveform is required, the program uses the current coefficients to assemble the current waveform and make 120 slices through it. This action locates the peak value. The inrush data was previously stored in a table upon each unit entry. The program sorts the table and prints the values to be listed in descending order.

data monitor

The usage of the Power Profile is monitored through a program counter. Separate counts for UPS and total usage are stored in a data space at the APL center. The monitor data space also captures summary data on electrical power for UPS profiles.

Some uses of the profile

One of the primary uses of the profile has been to provide an electrical power estimate of a computer system for a proposed UPS installation. The electrical requirements are only one element of the required specifications for the proposal, but they provide the basis for an economic sizing of the UPS.

Another use has been to check transformer loading when additional equipment is being planned and overloading of the power transformer is in question.

Facility Engineering has used the Power Profile to estimate their total facility power load with an existing computer installation and to determine what a new power load would be with a different installation.

Conclusion

The Power Profile is a marked improvement over the previous method for estimating system electrical power parameters. The use of APL together with telephone networks and terminals has made the program available to a large number of users at various locations within IBM.

CITED REFERENCES AND FOOTNOTE

1. The program itself is not available for distribution outside of IBM.
2. G. W. Allen and Y. B. Chen, "Power computation for data processing systems," *IEEE Conference Record of IGA/1971 Sixth Annual Meeting of IEEE Industry and Applications Group* (October 18–21, 1971).
3. *A Guide to 60 Hertz UPS Selection*, Form No. GA27-2770, IBM Corporation, Data Processing Division, White Plains, New York.
4. *A Guide to 50 Hertz UPS Selection*, Form No. GA27-2771, IBM Corporation, Data Processing Division, White Plains, New York.
5. *UPS Installation Planning Guide*, Form No. GA27-2772, IBM Corporation, Data Processing Division, White Plains, New York.

Reprint Form No. G321-5014