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Mine Power System Analysis-Design Computer Programs

By Dean H. Ambrose

UNITED STATES DEPARTMENT OF THE INTERIOR

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TABLE

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere
ft	foot
hp	horsepower
kbyte	kilobyte
kV	kilovolt
kvar	kilovar (thousand volt-ampere-reactive)
kW	kilowatt
Mbyte	megabyte
Mvar	megavar (million volt-ampere-reactive)
MW	megawatt
V	volt
var	volt-ampere-reactive

MINE POWER SYSTEM ANALYSIS-DESIGN COMPUTER PROGRAMS

By Dean H. Ambrose [1]

ABSTRACT

Computer programs are presented that provide mine electrical systems based on computer modeling for design and safety analysis suitable for large or small computer systems and handheld calculators. Bureau of Mines research has resulted in load-flow, fault, grounding, reliability, short-circuit, transient, and cable ampacity computer models that enable mine power system engineers to analyze their system or to design a system. This report describes the capabilities of the program.

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INTRODUCTION

Bureau research has resulted in several computer models that enable mine power system engineers to perform analyses of their systems. The programs are suitable for large and small computer systems. (Several programs are suitable for handheld programmable calculators.) Computer programs have been constructed for batch processing (FORTRAN IV or APL) as well as interactive processing (FORTRAN IV, BASIC, or APL).

The planning, design, and operation of mine power systems require several studies to evaluate the current system performance, reliability, safety, and ability to grow with production requirements. Studies of transients, reliability, grounding, harmonics, load-flow, short-circuit, and stability are most likely needed. The electrical engineer in charge of system design must decide which studies are needed to ensure that the system will operate safely, economically, and efficiently over the expected life of the system.

The complexity of modern mine industry power systems has made manual performance of power system studies difficult and time consuming, if not impossible. However, through the use of digital computers, these studies can be made with relative ease. Answers to many perplexing questions regarding impact of expansion on the system, short-circuit capacity, stability, load distribution., etc., can be intelligently obtained.

It is important for those concerned with assembling and preparing data for input to a power system analysis computer program and those interpreting and applying results generated by such a program to understand the development of the program and of basic analytical solutions that apply. The following section will briefly discuss the purpose of each computer program (table 1). Details of program development and analytical solutions that apply program listings, and program run procedures, are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161. A reference is given at the end of each discussion.

TABLE 1. - Computer program models

Program	Language	Processing[1]	Application
Fuse coordination.................	([2])	HP-97, TI-58/59.....	Design.
Ground bed design.................	([2])	...do...............	Do.
Ground bed resistance.............	([2])	...do...............	Analysis.
Intermittent duty ampacities......	BASIC.........	Interactive.........	Do.
Do............................	([2])	HP-41C..............	Do.
Load-flow and fault analysis......	FORTRAN IV....	Interactive-batch...	Do.
Do............................	APL...........	...do...............	Do.
Do............................	BASIC.........	Interactive.........	Do.
NEMA size contactor...............	([2])	HP-97, TI-58/59.....	Design.
Power factor correction...........	([2])	...do...............	Do.
Relay setting selection...........	([2])	...do...............	Do.
Reliability evaluation............	FORTRAN IV....	Batch...............	Do.
Snubber circuit...................	([2])	HP-97, TI-58/59.....	Do.
Transient voltages................	([2])	...do...............	Analysis.
3-phase short circuit.............	([2])	...do...............	Design.
Trip settings for cables..........	([2])	...do...............	Do.

HP Hewlett-Packard. TI Texas Instruments. NEMA National Electrical Manufacturers Association.

[1]Use of brand names is for identification only and does not imply endorsement by the Bureau of Mines.

[2]Program written for handheld calculator listed under "Processing."

COMPUTER PROGRAM MODELS

FUSE COORDINATION

Three programs were developed to perform fuse coordination design. To properly apply fuse overload and fault protection, it is necessary that fuses be applied such that they can carry the continuous current of the system they are protecting. The use of the program is somewhat complicated because the fuse data is so voluminous. The input data required for each fuse location includes full-load and maximum-fault currents. The program performs calculations on each fuse location. These calculations provide a fuse size for each location resulting in a fuse coordination scheme (1).[2]

PREDICTION OF GROUND-BED RESISTANCE

The program was developed to compute the ground-bed resistance by merely supplying a description of the ground bed. The use of the program is straightforward. Regardless of the type of ground bed configuration, the following quantities are entered: earth resistivity, rod length, rod radius, and the number of rods. Also, enter bed diameter if the ground bed configuration is a circle, or enter spacing between adjacent rods if the ground bed configuration is a straight line. The program calculates the ground bed resistance and outputs the results (1).

CALCULATING INTERMITTENT-DUTY AMPACITIES

The program was developed to determine trailing cable ampacities under cyclic loading. The program resolves technical issues on how to incorporate the variables (insulation type, ambient temperature, cable size, and cable temperature variation) in a meaningful yet manageable relationship for rating cables. The program required input values include cable cycle time, cable percentage on time, cable size, and cable 30CFR18 rating. The output prints the allowable current a given cable can safely carry under cyclic loads (2).

LOAD-FLOW FAULT ANALYSIS

Two programs were developed to perform analysis on coal mine electrical power systems under either normal operating conditions or fault situations. Both programs provide options for choosing a solution technique. The programs have the capability for analyzing of systems having 100 buses and 300 elements, although these numbers could be changed, if desired.

The LOAD-FLOW program required input data include specification of mine power system topology, cable sizes and lengths, load horsepower, transformer ratings, and per unit impedances. The output includes convergence data, magnitude and angle of the voltage at each bus, power flows and line current flows between buses, and power and current flows to ground at each bus.

The FAULT program required input data includes mine power topology, cable sizes and lengths, transformer ratings and per unit impedances, and load horsepower. The output contains the fault current for the specified fault type for a fault at each system bus. For balanced faults, the voltages at all system buses and the line current flows between all buses are printed for a fault at each bus selected. For line-to-line faults, this information is printed for all buses connected to the faulted bus (3-4).

SELECTION OF NEMA SIZE CONTACTOR

The program was developed to compute the correct National Electrical Manufacturers Association (NEMA) size contactor for a particular size motor. The program is quite accurate for motor sizes between 2 and 600 hp. Outside this range, a table reference procedure is used. The program is easy to use: One needs only

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

to input the motor horsepower rating, assuming the voltage rating is 460 to 575 V. The program prints out the minimum size starter required (1).

SELECTION OF POWER-FACTOR CORRECTION CAPACITORS

The program was developed to compute the kilovars of capacitors required to increase the power factor of a known load to a higher value. This program uses an analytical approach equivalent to the table of multipliers. In order to use this program, input the original power factor, desired power factor, and real power load in watts, kilowatts, or megawatts. The program prints out the capacitor rating that is required in vars, kilovars, or megavars, depending upon the units for the real power (1).

RELAY-SETTING SELECTION

In order to be sure that the protecting relay causes its breaker to operate without the protected relay tripping its breaker, it is necessary that the relay times differ by a selective time margin.

This program was developed to compute time-dial settings of relays that normally use time-current plots to determine the settings. When relays of the same type are used, the time margin between breaker operating time and the factor of safety always decreases with increasing current. The selective time margin between two relays always exist at the maximum available fault current level to assure proper coordination for worst case conditions. This program allows the selection of time-dial settings that will achieve the desired selective time margins without drawing time-current coordination graphs. The program requires the values of 14 constants for each type of relay. These constants are available on any relay specification sheet. Because the program provides for storage of those values, they do not have to be keyed in each time they are used. The output prints the results of delay time when overcurrent is given, delay time when dial setting is given, or dial setting when delay time is given (1).

RELIABILITY EVALUATION

The program was developed to compute the failure rate and forced unavailability for any system configuration for a maximum of two redundancies. The program is fairly general so long as the elements of the system are symmetrical (i.e., cable, transformers, but not rectifiers). The failure rate data of molded-case circuit breakers, metal-clad drawout breakers, serial cables (15 kV at 1,000 ft), cable terminations, transformers, protective relays, disconnect switches, fuses, and insulated buses are already stored in the program. All one has to do is to number the various nodes of the system and enter the pertinent component data (node connections, component type, etc.) into the program. The program prints out the equivalent failure rate, downtime per failure, and the total downtime at each load point (5).

SNUBBER CIRCUIT DESIGN

The program was developed to design a low pass filter for transient suppression. The program provides an alternative to the nomogram technique normally used in the design of these filters. The input data required include the following: transformer rating, frequency, system series inductance, and allowable peak transient voltage. The program prints out four values to get the snubber design: capacitance, resistance, maximum power dissipated in the resistance, and working voltage of the capacitor (1).

PREDICTION OF TRANSIENT VOLTAGE

The program determines abnormal transient voltages on power systems. The program has three separate options (solutions): compute the value of a standard curve for a specific value of normalized time, compute the value on a specific standard curve (maximum voltage and current), and compute the damping factor for a given peak value of current or voltage. The program is dependent on reducing the transient problem to a configuration that can be represented by either a series or parallel RLC circuit (1).

THREE-PHASE SHORT CIRCUIT

The program was developed to compute the magnitude and phase angle of the fault current. When a three-phase short circuit occurs on a radial system, the fault current can be found by adding up all the contributions to the series impedance. The input data required include the following: system line-to-line voltage, the utility short circuit level, the transformer data [rating, percent reactance, percent resistance, and conductor data (operating voltage, reactance, and resistance)] (1).

TRIP SETTINGS (INSTANTANEOUS) FOR TRAILING CABLES

The program was developed to determine the instantaneous settings for circuit breakers based on the size of trailing cables. The program works for AWG sizes from No. 14 to 3/0, except No. 10 and 2/0. Settings for cable sizes 4/0 and larger are all equal to 2,500 A; the program handles this automatically. In order to use the program, one needs only to enter the wire size. Since there is no error checking, it is important that the wire sizes be properly entered (1).

CONCLUSIONS

The relatively low cost of minicomputers and microcomputers has contributed to their abundant use in the mine industry. The programs described in this report were written for use on a small computer having 256 kbytes of random access memory (RAM) and approximately 1/2 Mbyte of working disk storage. Also, several programs were written for use with a handheld calculator having magnetic-strip storage capability. Despite their limitations, the programs are capable of analyzing or designing the electrical power system for a mining operation in a reasonable amount of time.

The digital computer has already proven its value in other industries. The computational tasks involved in load-flow studies, short-circuit calculations, and transient analyses have been greatly simplified by the use of computers. Now, analyses and design of the electrical power system of a mine can also be effectively performed by computer.

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