AN ENERGY STORAGE SYSTEM

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AN INTRODUCTION TO THE PROBLEM

Part of Oklahoma State University's program of energy storage research in the School of Electrical Engineering involves the use of unconventional energy sources such as wind and sunlight.[1] This energy must be used when available or stored until needed. Since the energy supply and demand are usually independent, some type of storage is needed to act as a buffer to match the two. [2] The storage system currently under study uses an electrolysis cell to convert electrical energy into hydrogen and oxygen under high pressure and stores them until they are used either in a fuel cell or in an internal combustion engine or steam turbogenerator.[5,6,7]

Two slightly different power system configurations are prominent in our research efforts. For small systems the design is kept simple; for the larger systems the efficiency of operation becomes important enough to warrant additional switching and control devices. The two situations to be modeled using GPSS are the simple case shown in Figure 1-(A) wherein all energy passes through storage and the more complex situation shown in Figure 1-(B) wherein a direct path exists between the generator and the load in parallel with the storage system. The objective of the simulation is both to provide design information and to provide information for the economic optimization of the systems.

PHYSICAL COMPONENTS OF THE SYSTEM

A description of the system's physical components will aid in understanding the simulation diagrams.

Wind

GPSS is ideal for dealing with wind or solar phenomena because of their obvious statistical nature. This is indicated by Figure 2 which is a plot of the hourly readings of wind velocity at Will Rogers Airport in Oklahoma City for January of 1962. According to a report from Stanford University the gustiness of the wind depends upon the surrounding obstructions.[3] Thus, a random number generator and an error function curve, the distribution function for the normal curve, with the properly chosen standard deviation are all that are needed to simulate the variations about the average (hourly) readings.[4]

Component Transfer Characteristics

The wide range of input power causes the actual generator efficiency to vary because of varying speeds and fixed losses. The efficiency also varies because of the finite time needed for the wind-intercept device and generator to respond to gusts. The GPSS functions are readily adapted to simulate these two effects by two different functions. Figure 3 is an example of a function showing generator efficiency versus power input and Figure 4 shows percent effective wind velocity versus wind gust percent.

Transmission efficiency from the generator to its loads can be a constant or it can be represented by a function. A GPSS function is well suited to characterize the nonlinear electrolysis cell action when it acts as a load.

Storage

After electrolysis the gases are stored in high-pressure tanks. The GPSS entity of storage is ideally suited to this simulation. Energy leakage from the tanks is simulated by removing units periodically from storage. The number of units removed is a function of the total storage, i.e., the pressure in the tank.

Reconversion Device Characteristics

At this point the physical problems diverge but the simulation techniques do not. The reconversion characteristic functions for a fuel cell and a steam turbogenerator will differ but the result in each case will be electrical energy for some electrical load. The simulation pattern for the two cases is the same.

ATTRIBUTES OF GPSS USED

While this simulation may not use the strongest feature of GPSS, i.e., queueing theory, it does find other attributes of GPSS to be highly desirable. The gathering of tabular data, the optional printout of savevalue data as desired, and the use of list functions are among these highly useful characteristics of GPSS. Also, the fact that component efficiencies may be functions rather than constants adds much realism to the simulation.

The simpler system is simulated by the program diagrammed in Figure 5, and the more comprehensive system is diagrammed in Figure 6. The inputs necessary are functions describing available energy versus time, load demand versus time, system efficiencies and definitions of variables. See Figure 7. (Function 1 is given for only one day because of space limitations but the other listings are presented as actually used in one of the simulation runs.)

OBJECTIVES OF PARTICULAR PROGRAM TECHNIQUES USED

Tabulating Data

In choosing generator ratings, wind-intercept areas, electrolysis cell or fuel cell ratings, and storage capacities, the designer needs to know as much as is practical about the utilization of each of these components. Thus power flow through each element is tabulated for study by the designer. The GPSS tables are ideally suited for providing the answers to such questions as: Is it economically sound to attempt to extract the peak energy from the wind gusts or will it be more economical to build a larger propeller and a smaller generator and thereby discard the peak energies?

Print Routines

In order to maintain a time relationship along with the statistical data, some very versatile print routines have been devised. The desired data are stored in savevalue locations and printed out at predetermined times. The routines allow such variations as printing the hourly data for every Friday (or Monday, etc.), printing data for only the month of July, or perhaps printing the data at 6:00 a.m. at the beginning of each day instead of having to print all the data for each .1 hour. Figure 8 is a plot of the total energy stored at 6:00 a.m. of each day for 3 months.

List Functions

Because of the nature of the look-up routines for continuous or discrete functions, their use becomes prohibitively time consuming for large amounts of data. Thus, list functions which simply use the data points in order are used whenever large amounts of data are needed.

CONCLUSIONS

Figure 9 is a composite plot of the tabulated data for the instantaneous wind power, the instantaneous generator output, and the excess power sent to storage during a 3-month simulation. Similar data are tabulated for power transmitted directly to the load and power demand from storage systems.

The next step is the using of this tool in developing design criteria for optimizing various variables of the system. Current projects in our laboratories include wind interupt devices, electrolysis and fuel cells operating in stacks, and high pressure gas storage.[4,6] From these projects should come the appropriate transfer functions needed by this program. This program will then be coupled with an optimization program for use in designing actual systems.

REFERENCE

1. Proceedings of the United Nations Conference on New Sources of Energy, Seven Volumes, (Conference held in Rome in 1961), United Nations, New York, 1964.

2. Energy Storage - Key to Our Economic Future, Brochure presented by the Office of Engineering Research, Oklahoma State University, Stillwater, Oklahoma, 1963.

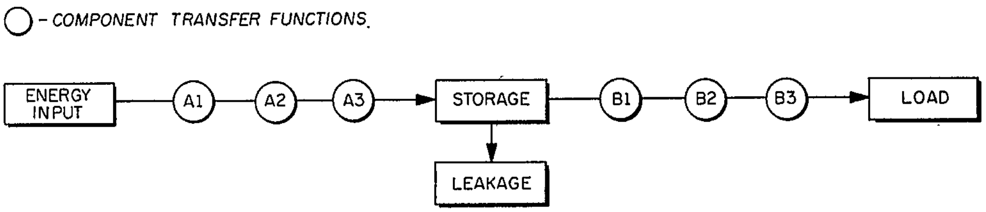
3. Merchant, David H., Stochastic Model of Wind Gusts, Ph.D. Thesis, Stanford University, 1965.

4. Gibson, LeRoy A., Wind Analysis in Relation to the Development of Wind Power, Ph.D. Thesis, Oklahoma State University, 1968.

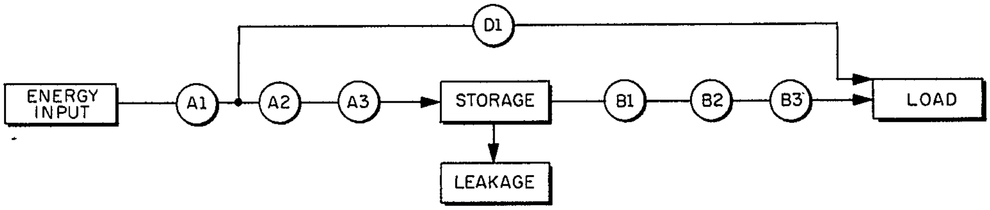
5. Bruckner, Arthur II, A System for the Economic Analysis of Balanced Energy Conversion and Storage Systems, Ph.D. Thesis, Oklahoma State University, 1967.

6. Energy Conversion and Storage Research, Annual Report, School of Electrical Engineering, Oklahoma State University, 1968.

7. Bruckner, Arthur II, Fabrycky, W. J., and Shamblin, James E., "Economic Optimization of Energy Conversion with Storage", IEEE Spectrum, April, 1968.



(a) BLOCK DIAGRAM OF SIMPLE SYSTEM



(b) BLOCK DIAGRAM OF COMPLEX SYSTEM

Figure 1. Block Diagrams of Systems.

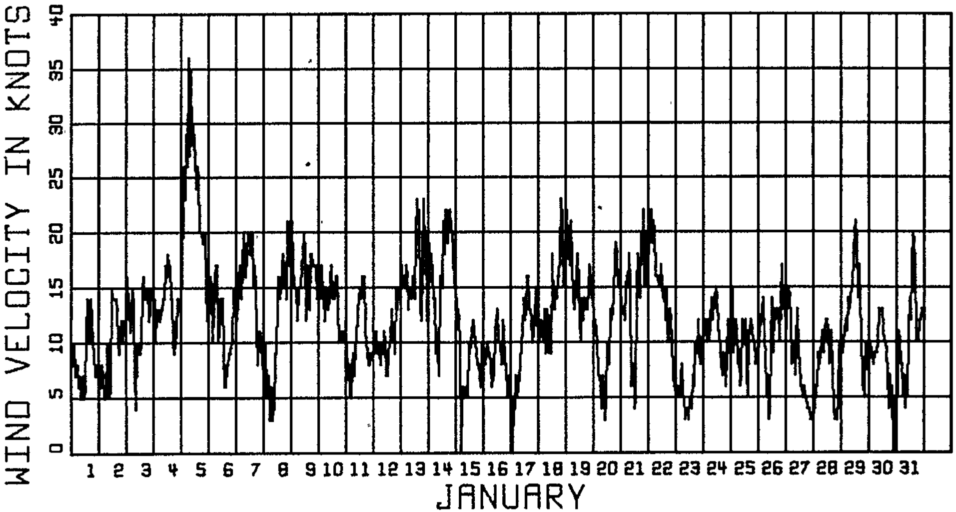


Figure 2. Wind Velocity for January of 1962 at Will Rogers Airport in Oklahoma City.

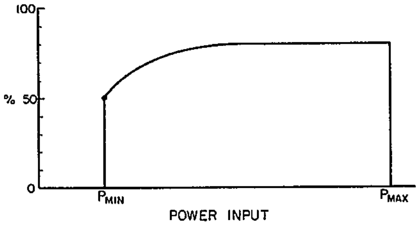


Figure 3. Generator Efficiency versus Power Input.

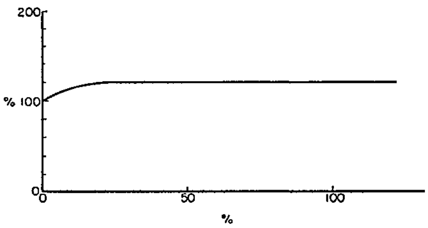
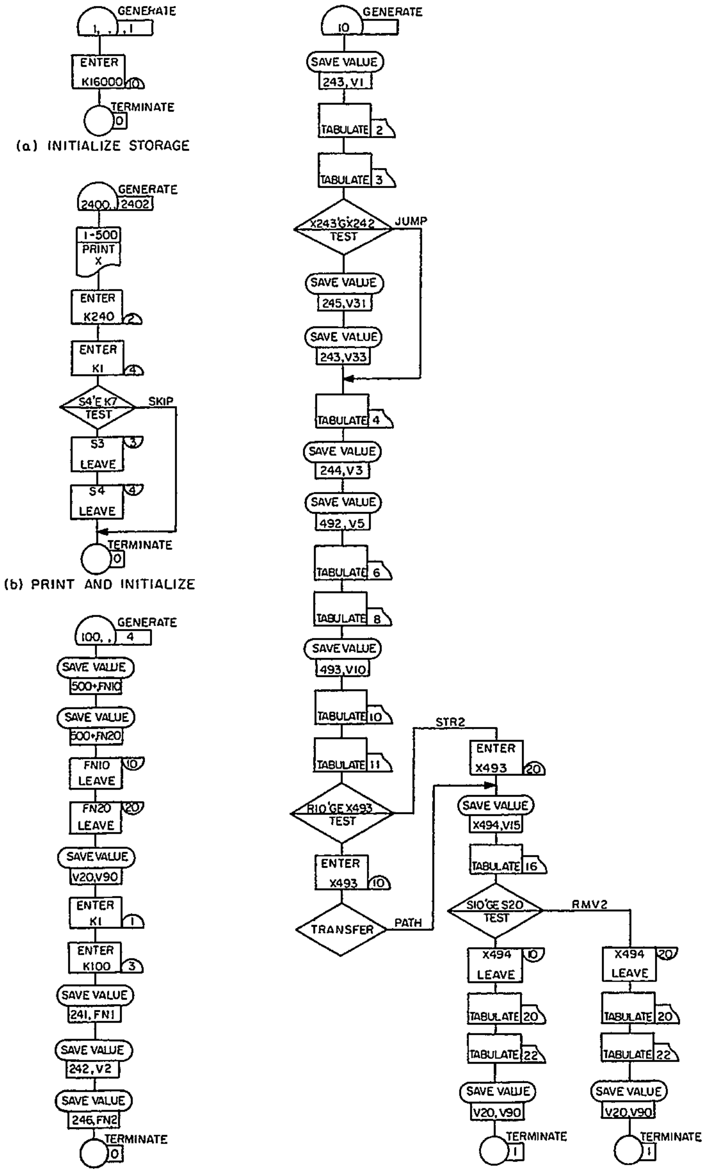


Figure 4. Percent Effective Wind Velocity versus Wind Gust Percent.



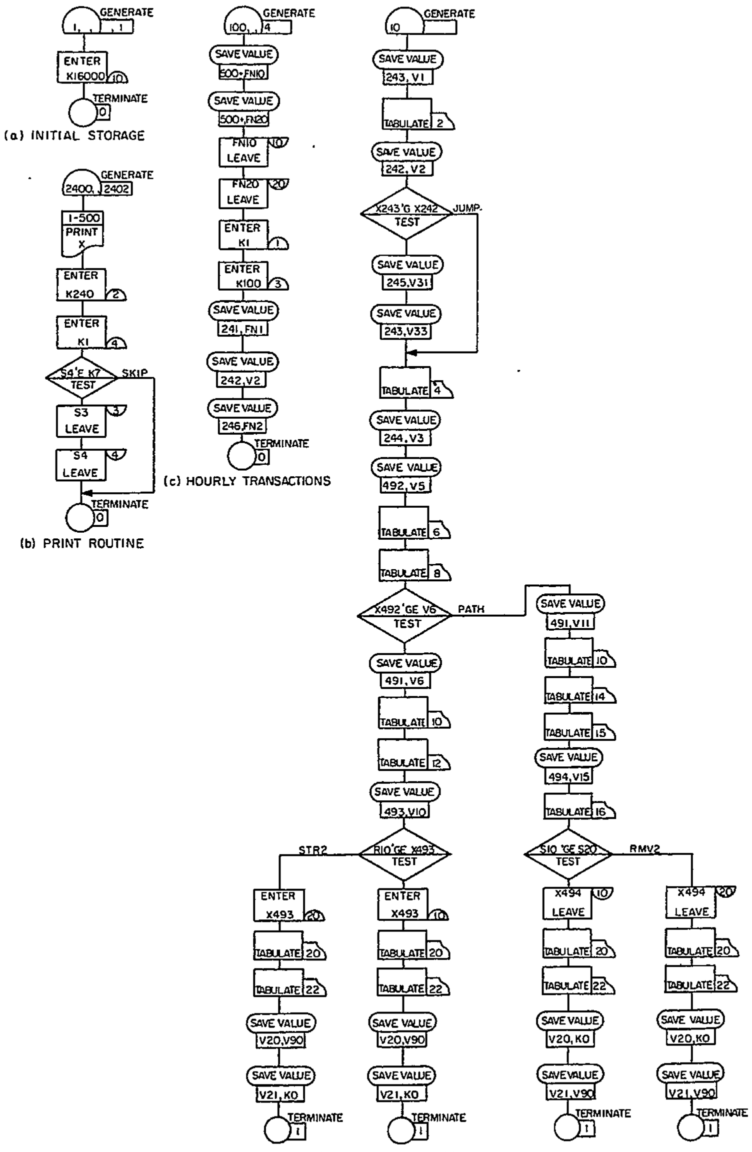
(a) INITIALIZE STORAGE

(b) PRINT AND INITIALIZE

(c) HOURLY OPERATIONS

(d) MAIN PROGRAM

Figure 5. GPSS Diagram for Simple System.



(a) INITIAL STORAGE

(b) PRINT ROUTINE

(c) HOURLY TRANSACTIONS

(d) OPERATING DIAGRAM

Figure 6. GPSS Diagram for Complex System.

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      1 FUNCTION    S1,L24         WIND VELOCITY DATA
         9.0         8.0          10.0          7.0          7.0         8.0
         6.0         7.0           5.0          5.0          7.0         5.0
         6.0        11.0          14.0         11.0         10.0        14.0
        12.0        10.0           9.0          7.0          8.0         7.0
      2 FUNCTION    S3,D23         ENERGY DEMAND CURVE
  700       0  1200    500  1300      0  1800   500  3100     0  3600   500
 3700       0  4200    500  5500      0  6000   500  6100     0  6600   500
 7900       0  8400    500  8500      0  9000   500 10300     0 10800   500
10900       0 11400    500 12700      0 13200   500 16800     0
     10 FUNCTION    S10,D18        ENERGY LEAKAGE FUNCTION
0      0      2000  1     4000  2     6000  3     8000  4     10000 5
12000 6      14000  7    16000  8    18000  9    20000 10     22000 11
24000 12     26000 13    28000 14    30000 15    32000 16     34000 17
     20 FUNCTION    S20,D18        ENERGY LEAKAGE FUNCTION
0      0      2000  1     4000  2     6000  3     8000  4     10000 5
12000 6      14000  7    16000  8    18000  9    20000 10     22000 11
24000 12     26000 13    28000 14    30000 15    32000 16     34000 17
     24 FUNCTION    RN1,C15        ERROR FUNCTION CURVE, SIGMA = 0.2
0      0      .001  40    .006  50    .023  60    .067  70    .159  80
.308   90     .500  100   .692  110   .841  120   .933  130   .977  140
.994   150    .999  160   1.0000200
     30 FUNCTION    X244,C6        GENERATOR EFFICIENCY CURVE
342    0      343   172   3000  1800  50000 35000 200000160000999999800000
     31 FUNCTION    X245,C6        GUST EXTRACTION EFFICIENCY CURVE
0      100    10    100   20    95    30    75    50    35    200   20
      1 VARIABLE    FN24*X241      SIMULATE GUST
      2 VARIABLE    X241*K100      SCALE AVERAGE VELOCITY
      3 VARIABLE    X243*X243/K1000*X243/K1000  CUBE EFFECTIVE INST VEL
      5 VARIABLE    FN30*15/100  GENERATOR EFFICIENCY AND SCALE FACTOR
      6 VARIABLE    X246*100/95   CALCULATE DIRECT LOAD DEMAND
      7 VARIABLE    X492-V6        CALC EXCESS ENERGY
      8 VARIABLE    V7*98/100      EXCESS ENERGY TRANSMITTED TO FUEL CELL
      9 VARIABLE    V8*65/100      EXCESS ENERGY CONVERTED TO GAS
     10 VARIABLE    V9/K10         DIVIDE BY 10
     11 VARIABLE    X492*95/100  CALC DIRECT ENERGY TO LOAD
     12 VARIABLE    X246-V11       CALCULATE EXCESS LOAD DEMAND
     13 VARIABLE    V12*100/100 B3 EFFICIENCY
     14 VARIABLE    V13*100/96   B2 EFFICIENCY
     15 VARIABLE    V14/K10        B1 EFFICIENCY AND DIVIDE BY 10
     20 VARIABLE    C1/10-S2       CALCULATE LOWER SAVEVALUE ADDRESS
     21 VARIABLE    C1/10-S2+K250  CALCULATE UPPER SAVEVALUE ADDRESS
     31 VARIABLE    X243/X241-K100  CALC GUST PERCENT
     32 VARIABLE    FN31*X245/K100+K100  CALC EFFECTIVE WIND VEL PERCENT
     33 VARIABLE    V32*X242/K100  CALC EFFECTIVE WIND VELOCITY
     90 VARIABLE    S10+S20        CALC TOTAL STORAGE
      2 TABLE       X243,0,100,102  INST WIND VEL IN TBL 2
      3 TABLE       V3,0,100,502   INST WIND PWR IN TBL 3
      4 TABLE       X243,0,100,72  INST USEABLE VEL IN TBL 4
      6 TABLE       X492,0,1000,402  GEN OUTPUT IN TBL 6
      8 TABLE       X492,0,100,102  GEN OUTPUT EXPANDED IN TBL 8
     10 TABLE       X491,0,100,22  DIRECT TRANS TO LOAD IN TBL 10
     12 TABLE       V7,0,20,502  EXCESS ENERGY IN TBL 12
     14 TABLE       V12,0,20,102  EXCESS LOAD DEMAND IN TBL 14
     15 TABLE       V14,0,10,202  STORAGE ENERGY OUTPUT IN TBL 15
     16 TABLE       X494,0,1,202  ENERGY FROM STORAGE IN TBL 16
     20 TABLE       S10,0,100,332   INSTANTANEOUS CONTENTS OF STORAGE
     22 TABLE       S20,0,100,332   INSTANTANEOUS CONTENTS OF STORAGE
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Figure 7. Listing of Functions and Definitions of Variables and Tables.

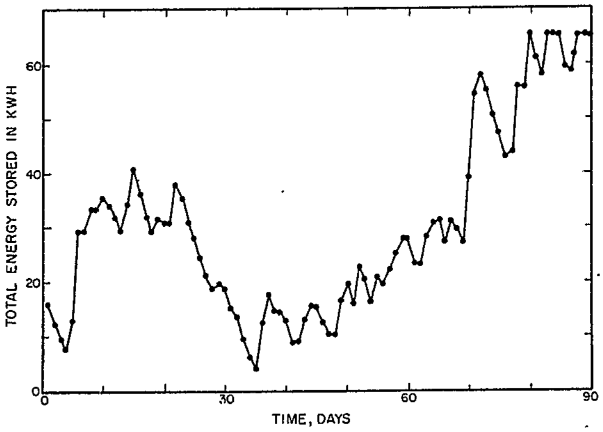

Figure 8.
Total Energy Stored at 6:00 a.m. of Each Day.

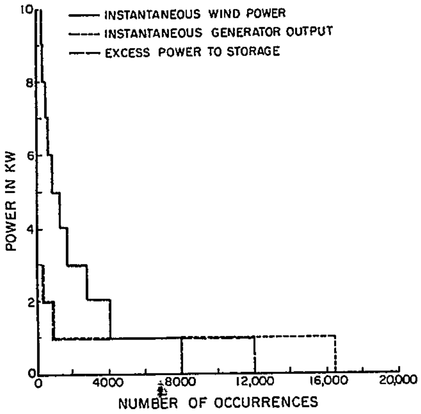

Figure 9. Composite Tabular Data.