```
C****   Definition of some constant values
      S1=A1/NREF**2
      S2=B1
      S5=E1
      S6=F1*NREF
      S7=G1*NREF**2
      S8=H1*NREF**3

C****   Initial guess for speed (X1) and flowrate (X2)
C****   the initial speed is taken to be the speed where
C****   HEADpump=HEADsystem at zero flowrate
      NINIT=NREF*(S3/A1)**.5
        IF(NINIT.GE.NMAX)THEN
          FAIL=4
      ENDIF
C****   the initial flowrate is taken to be the flowrate
C****   at maximum permitted speed where HEADpump=HEADsystem
       QINIT=((S3-S1*NMAX**2)/(S2-S4))**.5
      X(1)=NINIT
      X(2)=QINIT

C****   The following part evaluates the torque required to
C****   provide flow.
C****   Evaluation of Q and H at shutoff condition
C****   QOFF is choosen to be very small, i.e. QNOM per second
C****   divided by 100
      QOFF=QNOM/3.6E5
      HOFF=A1-B1*QOFF**2
C****   Computation of torque at shutoff condition at reference
C****   speed
      IF(POFF.LT.0)THEN
       ETAOFF=E1+F1*QOFF+G1*QOFF**2+H1*QOFF**3
         TOFF=CONST*QOFF*HOFF/ETAOFF/NREF
        ELSE
       TOFF=POFF/(2.*PI*NREF)
      ENDIF

      TREQ=TOFF*(NINIT/NREF)**2
        FAIL=0
C-----------------------------------------------------------------
    ELSE
C****   First and following calls in timestep
        FAIL=0
C****   Set inputs
      TL=XIN(1)

        X(1)=S(ISTORE)
        X(2)=S(ISTORE+1)

C****   to avoid division by zero, i.e. if torque=0
```

```
   IF(TL.GT.TREQ)THEN
    LOOP=0

C****************************************************
50      CONTINUE
     COUNTER=1
C****     Iterative process to find the solution of the system of
C****     nonlinear equations, using Newton's method
100    CONTINUE
C****     set up the objective functions
     CALL SYSTEM(F,X,TL)
C****     set up of the Jacobian matrix
      CALL JACOBIAN(J,X,TL)

C****    To inverse the matrix a direct method via the adjuncte is used
C****     Evaluation of the determinant of the Jacobian
       DET=J(1,1)*J(2,2)-J(2,1)*J(1,2)

C****     Evaluation of the inverse of the Jacobian
      JINV(1,1)=J(2,2)/DET
      JINV(1,2)=-J(1,2)/DET
      JINV(2,1)=-J(2,1)/DET
      JINV(2,2)=J(1,1)/DET

C****     Basic algorithm
      XNEW(1)=X(1)-(JINV(1,1)*F(1)+JINV(1,2)*F(2))
      XNEW(2)=X(2)-(JINV(2,1)*F(1)+JINV(2,2)*F(2))

C****     Check on the infinity norm of the solution vector
C****     i.e. the maximum value of xnew-xold (=max. error)
C****     about convergence
      DELTA1=ABS(XNEW(1)-X(1))
      DELTA2=ABS(XNEW(2)-X(2))
      IF (MAX(DELTA1,DELTA2).GT.EPS) THEN
       IF (COUNTER.LT.MAXIT) THEN
        COUNTER=COUNTER+1
        X(1)=XNEW(1)
            X(2)=XNEW(2)
        GOTO 100
       ELSE
C****          Convergence was not attained after maxit iterations
          FAIL=3
       ENDIF
      ENDIF
C****************************************************
      X(1)=XNEW(1)
      X(2)=XNEW(2)
      N=XNEW(1)
      Q=XNEW(2)
C****     Check if Q is in the negative range, i.e. the wrong solution
```

```
C****    is found
      IF ((Q.LT.0.).OR.(N.LT.0)) THEN
C****       to protect an endless loop situation the following
C****       control function is introduced
         IF(LOOP.EQ.0)THEN
       X(1)=NMAX
       X(2)=5.*QINIT
          LOOP=1
          GOTO 50
         ELSEIF(LOOP.EQ.1)THEN
C****        try again with higher limits
          X(1)=2.*NMAX
          X(2)=2.*QNOM
          LOOP=2
          GOTO 50
         ELSE
C****        Newton could not find proper soluion
C****        go ahead
          FAIL=2
         ENDIF
      ENDIF

C****    Evaluation of total head and efficiency
       H=S3+S4*Q**2
      ETA=CONST*Q*H/TL/N
C****    Check if speed exceeds maximum speed
      IF(N.GT.NMAX)THEN
C****       Flowrate is taken to be the flowrate at maximum
C****       permitted speed
       Q=QINIT
         FAIL=1
C****       Evaluation of total head
        H=S3+S4*Q**2
C****      Efficiency is evaluated at NMAX and QINIT
        ETA=S5+S6*Q/NMAX+S7*Q**2/NMAX**2+S8*Q**3/NMAX**3
C****       Correction of inital guess
       X(1)=NMAX
       X(2)=QINIT
        ENDIF
     ELSE
C****    In this case the affinity laws are valid. The torque
C****    or the speed follows a parabolic function
      N=NREF*(TL/TOFF)**.5
      Q=0.
      H=HOFF*(N/NREF)**2
      ETA=0.
     ENDIF
    ENDIF
C------------------------------------------------------------
```

```
      IF((X(1).GT.0).AND.(X(2).GT.0.))THEN
       S(ISTORE)=X(1)
       S(ISTORE+1)=X(2)
      ENDIF

      PHYD=RHOG*Q*H
      PMECH=2*PI*TL*N

C**** Set outputs
      OUT(1)=N
      OUT(2)=TL
      OUT(3)=Q
      OUT(4)=H
      OUT(5)=ETA
      OUT(6)=PHYD
      OUT(7)=PMECH
      OUT(8)=FAIL

      END

C*****************************************************************
      SUBROUTINE SYSTEM(F,X,TL)
C**** Subroutine provides the objective function of the system
C     of nonlinear equations
C     TL,X1,X2  in
C     F         out

      REAL F(2),X(2)
       REAL TL,S1,S2,S3,S4,S5,S6,S7,S8,CONST

       COMMON /COEF/ S1,S2,S3,S4,S5,S6,S7,S8,CONST

       F(1)=S1*X(1)**2+S2*X(2)**2-S3-S4*X(2)**2
       F(2)=CONST/TL*(S1*X(1)**4*X(2)+S2*X(1)**2*X(2)**3)
     &     -S5*X(1)**3-S6*X(1)**2*X(2)-S7*X(1)*X(2)**2-S8*
     &     X(2)**3
      END
C*******************************************************************
      SUBROUTINE JACOBIAN(J,X,TL)
C**** Subroutine provides all the derivatives for the Jacobian matrix
C     X1,X2,TL  in
C     J         out

      REAL J(2,2),X(2)
       REAL TL,S1,S2,S3,S4,S5,S6,S7,S8,CONST

       COMMON /COEF/ S1,S2,S3,S4,S5,S6,S7,S8,CONST

       J(1,1)=2.*S1*X(1)
```

```
      J(1,2)=2.*S2*X(2)-2.*S4*X(2)
      J(2,1)=CONST/TL*(4.*S1*X(1)**3*X(2)+2.*S2*X(1)*X(2)**3)
     &      -3.*S5*X(1)**2-2.*S6*X(1)*X(2)-S7*X(2)**2
      J(2,2)=CONST/TL*(S1*X(1)**4+3.*S2*X(1)**2*X(2)**2)-
     &      S6*X(1)**2-2.*S7*X(1)*X(2)-3.*S8*X(2)**2
      END

C****************************************************************
      SUBROUTINE HEADPOLYNOMIAL (A1,B1)

C**** Program fits a polynomial through a given number of data
C**** points using least squares method
C**** the polynmial has the form  y=a+bx^2

C**** HEAD -- head of the pump [m]
C**** CAP -- Capacity (volumetric flowrate) [m^3/sec]
C**** A1,B1 -- Coefficients of thr constructed polynomial
C**** MEAN -- Average over the head values
C**** RSQUARES -- R^2 measure of curve fit
C**** SUM1-SUM6 -- Summation terms occuring in the normal equations
C**** Y -- Array containing the fitted values

      REAL SUM1,SUM2,SUM3,SUM4,SUM5,SUM6,A1,B1
      REAL MEAN,RSQUARE
      REAL HEAD(50),CAP(50),Y(50)
      INTEGER M

C**** Input file contains the data
      OPEN (12,FILE='HEAD.DAT',STATUS='OLD')
      REWIND(12)

C**** Read in number of data pairs
      READ(12,*) M
C**** Read in the data pairs
      DO 100 I=1,M
       READ(12,*) CAP(I),HEAD(I)
100   CONTINUE

C**** Evaluation of the sum terms in the normal equations
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      DO 200 J=1,M
       SUM1=SUM1+CAP(J)**2
          SUM2=SUM2+HEAD(J)
       SUM3=SUM3+CAP(J)**4
       SUM4=SUM4+HEAD(J)*CAP(J)**2
200   CONTINUE
```

```
C**** Evaluation of the coefficients of the polynomial
    B1=(M*SUM4-SUM2*SUM1)/(M*SUM3-SUM1**2)
    A1=(SUM2-B1*SUM1)/M

    DO 300 L=1,M
     Y(L)=A1+B1*CAP(L)**2
300  CONTINUE

C**** Estimation of the curve fit precission
    MEAN=SUM2/M
    SUM5=0.
    SUM6=0.
    DO 400 LL=1,M
     SUM5=SUM5+(Y(LL)-MEAN)**2
        SUM6=SUM6+(HEAD(LL)-MEAN)**2
400  CONTINUE
C**** R^2 measures the proportion of total variation about the mean
C**** explained by the regression
    RSQUARE=SUM5/SUM6
    END

C******************************************************************
    SUBROUTINE EFFPOLYNOMIAL(E1,F1,G1,H1)

C**** Subroutine fits a polynomial through a given number of data
C**** points using least squares method
C**** the polynmial has the form  y=a+bx+cx^2+dx^3

C**** ETA -- pump efficiency
C**** CAP -- Capacity (volumetric flowrate)
C**** ESUM1-ESUM12 -- Summation terms occuring in the normal equations
C**** E1,F1,G1,H1 -- Coefficients of the constructed polynomial
C**** MEAN -- Average over the efficiency values
C**** RSQUARES -- R^2 measure of curve fit
C**** Y -- Array of dimension NN containing the fitted values
C**** A -- Array of dimension NN*NN containing the coefficients
C****      of the normal equations
C**** B -- Array of dimension NN (B-vector)
C**** SOL -- Array containing the solution, i.e. the coefficients
C****       E1,F1,G1,H1
C**** LINDEX -- index vector (Gaussian elimination)
C**** S -- scale vector (Gaussian elimination)

    INTEGER M,MM,NN
    PARAMETER (NN=4)
    REAL ESUM1,ESUM2,ESUM3,ESUM4,ESUM5,ESUM6,ESUM7,ESUM8
    REAL ESUM9,SUM10,ESUM11,ESUM12,E1,F1,G1,H1
    REAL MEAN,RSQUARE
    REAL ETA(50),CAP(50),Y(50),A(NN,NN),B(NN),SOL(NN)
    REAL LINDEX(NN),S(NN)
```

```
C**** Input file contains the data
      OPEN (14,FILE='EFF.DAT',STATUS='OLD')
      REWIND(14)

C**** Read in number of data pairs
      READ(14,*) M
      MM=M+4
C**** Read in the data pairs
      DO 100 I=1,M
       READ(14,*) CAP(I),ETA(I)
100   CONTINUE

C**** To force the fitted curve through the origin a couple
C**** of data pairs are set equal 0
      DO 120 II=M+1,MM
       CAP(II)=0.
       ETA(II)=0.
120   CONTINUE

C**** Evaluation of the sum terms in the normal equations
      ESUM1=0.
      ESUM2=0.
      ESUM3=0.
      ESUM4=0.
      ESUM5=0.
      ESUM6=0.
      ESUM7=0.
      ESUM8=0.
      ESUM9=0.
      ESUM10=0.
      DO 200 J=1,M
       ESUM1=ESUM1+CAP(J)
       ESUM2=ESUM2+CAP(J)**2
       ESUM3=ESUM3+CAP(J)**3
       ESUM4=ESUM4+CAP(J)**4
       ESUM5=ESUM5+CAP(J)**5
       ESUM6=ESUM6+CAP(J)**6
       ESUM7=ESUM7+ETA(J)
           ESUM8=ESUM8+ETA(J)*CAP(J)
           ESUM9=ESUM9+ETA(J)*CAP(J)**2
           ESUM10=ESUM10+ETA(J)*CAP(J)**3
200   CONTINUE

C**** Set up the matrix containing the normal equations A(n,n)
C**** In this case it is a (4*4) matrix
      A(1,1)=REAL(MM)
      A(2,1)=ESUM1
      A(2,2)=ESUM2
      A(3,1)=ESUM2
      A(3,2)=ESUM3
```

```
      A(3,3)=ESUM4
      A(4,1)=ESUM3
      A(4,2)=ESUM4
      A(4,3)=ESUM5
      A(4,4)=ESUM6

C**** because of the symmetry of the matrix,it can be
C**** filled up by

      DO 250 I=1,4
       DO 250 J=1,4
        IF(I.NE.J)THEN
          A(I,J)=A(J,I)
        ENDIF
250   CONTINUE

C**** Set up B vector (dimension=4)
      B(1)=ESUM7
      B(2)=ESUM8
      B(3)=ESUM9
      B(4)=ESUM10

C**** The linear system of equations (normal equations) is solved
C**** using Gaussian elimination with partial pivoting
C**** LINDEX & S must occur in the calling sequence because they
C**** have a variable dimension. They are not used as output
      CALL GAUSS(A,B,SOL,LINDEX,S,NN)

C**** Output
      E1=SOL(1)
      F1=SOL(2)
      G1=SOL(3)
      H1=SOL(4)

      DO 300 L=1,MM
       Y(L)=E1+F1*CAP(L)+G1*CAP(L)**2+H1*CAP(L)**3
300   CONTINUE

C**** Estimation of the curve fit precission
      MEAN=ESUM7/REAL(MM)

      ESUM11=0.
      ESUM12=0.
      DO 400 LL=1,MM
       ESUM11=ESUM11+(Y(LL)-MEAN)**2
          ESUM12=ESUM12+(ETA(LL)-MEAN)**2
400   CONTINUE
C**** R^2 measures the proportion of total variation about the mean
C**** explained by the regression
      RSQUARE=ESUM11/ESUM12
```

```
      END

C*************************************************************************
C**** Subroutine Gauss with partial pivoting
      SUBROUTINE GAUSS(A,B,X,L,S,NN)

      REAL A(NN,NN),B(NN),L(NN),S(NN),X(NN)

C**** Scale factors(s) and pivot(l)
      DO 30 I=1,NN
       L(I)=I
          SMAX=0.
          DO 20 J=1,NN
        SMAX=AMAX1(SMAX,ABS(A(I,J)))
20        CONTINUE
       S(I)=SMAX
30    CONTINUE

C**** Look for largest ratio to select pivot row
      DO 70 K=1,NN-1
       RMAX=0.
          DO 40 I=K,NN
            R=ABS(A(L(I),K))/S(L(I))
        IF (R.GT.RMAX) THEN
         J=I
            RMAX=R
           ENDIF
40        CONTINUE

C****    Update pivot vector
       XK=L(J)
       L(J)=L(K)
       L(K)=XK

C****    Forward elimination
          DO 60 I=K+1,NN
        XMULT=A(L(I),K)/A(L(K),K)
           DO 50 J=K+1,NN
         A(L(I),J)=A(L(I),J)-XMULT*A(L(K),J)
50       CONTINUE
        A(L(I),K)=XMULT
60     CONTINUE
70    CONTINUE

C**** Backward substitution
      DO 100 K=1,NN-1
       DO 100 I=K+1,NN
           B(L(I))=B(L(I))-A(L(I),K)*B(L(K))
100   CONTINUE
```

```
      X(NN)=B(L(NN))/A(L(NN),NN)
      DO 150 I=NN-1,1,-1
       SUM=B(L(I))
          DO 140 J=I+1,NN
            SUM=SUM-A(L(I),J)*X(J)
140     CONTINUE
          X(I)=SUM/A(L(I),I)
150   CONTINUE

      END
```

Resistance

```
C*****************************************************************
      SUBROUTINE TYPE59(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C     Version from: 12/14/89
C-----------------------------------------------------------------
C     This subroutine represents a model of an ohmic resistance.
C     The value of the resistance has to be provided as a
C     parameter by the user. This component is designed to operate
C     in a photovoltaic powered energy system. It can operate on
C     two different modes: voltage or current mode. If the MODE
C     signal is set to be one, the current is signifant input and
C     voltage will be evaluated. Otherwise voltage is signifant
C     input and current will be evaluated corresponding to the
C     ohmic law.
C******************************************je**********************
C**** Definition of the variables:
C**** TRNSYS specific variables:
C     XIN == input array
C     OUT == output array
C     PAR == parameters
C     TIME == simulation time
C     T,DTDT == not used in this component
C     INFO == array to use TRNSYS internal information

C**** component specific variables:
C     I == current [amps]
C     V == voltage [volts]
C     P == power [watts]
C     R == resistance [ohms]
C     MODE == signal determining operating mode
C           MODE=1: current is significant input
C           MODE=2: voltage is signifianct input
C*****************************************************************
C**** declaration of variables:
      INTEGER INFO
      REAL R,V,I,TIME,XIN,OUT,T,DTDT,PAR,MODE
```

```
      DIMENSION XIN(3), OUT(3), PAR(1), INFO(10)
C*********************************************************************

      INFO(6)=3
      INFO(9)=0
C-------------------------------------------------------------------
C**** initial call of component
      IF(INFO(7).LT.0)THEN
           CALL TYPECK(1,INFO,3,1,0)
C****  set parameters
       R=PAR(1)
      ENDIF
C-------------------------------------------------------------------
C**** set inputs
      I=XIN(1)
      V=XIN(2)
      MODE=XIN(3)

      IF (MODE.EQ.1.)THEN
C****   current guess
       V=I*R+B
      ELSE
C****   voltage guess
       I=(V-B)/R
      ENDIF
      P=I*V

C**** set outputs
      OUT(1)=I
      OUT(2)=V
      OUT(3)=P

      END
```

Battery

```
C*****************************************************************
      SUBROUTINE TYPE70 (T,XIN,OUT,Q,DQDT,PAR,INFO)
C     version from 12/22/89
C*****************************************************************
C  THIS COMPONENT SIMULATES THE PERFORMANCE OF A LEAD-ACID
C  STORAGE BATTERY. IT IS DESIGNED TO OPERATE IN CONJUNCTION
C  WITH A SOLAR CELL ARRAY AND A REGULATOR.

C  Q = STATE OF CHARGE [AH]
C  QM = RATED CAPACITY OF CELL [AH]
C  QC,QD = CAPACITY PARAMETERS ON CHARGE, DISCHARGE
C  F = FRACTIONAL STATE OF CHARGE = Q/QM (1.0 IS FULL CHARGE)
C  CP,CS = NUMBER OF CELLS IN PARALLEL, SERIES
```

```
C  P = POWER [WATTS]
C  IQ = CURRENT [AMPS
C  IQMAX,IQMIN = MAXIMUM CURRENT (CHARGE), MINIMUM CURREN
C  (DISCHARGE)
C  V = VOLTAGE [VOLTS]
C  VC,IC = CUTOFF VOLTAGE ON CHARGE, CURRENT CORRESPONDING
C  TO VC
C  ICTOL = PARAMETER FOR ITERATIVE CALCULATIONS
C  VD = CUTOFF VOLTAGE ON DISCHARGE
C  ED,RD = DATA USED TO CALCULATE VD WHEN VCONTR .LT. 0.
C  VCONTR =  SPECIFICATION OF VOLTAGE CONTROL ON DISCHARGE.
C  POSITIVE MEANS VD=VCONTR.  NEGATIVE MEANS VD=ED-ABS(IQ)*RD.
C  VDI = DIODE VOLTAGE FROM Z-P MODEL
C  VOC = OPEN CIRCUIT VOLTAGE AT FULL CHARGE
C  ESC,ESD = EXTRAPOLATED OPEN CIRCUIT VOLTAGES
C  GC,GD = COEFFICIENTS OF (1-F)IN V FORMULAS
C  RSC,RSD = INTERNAL RESISTANCES AT FULL CHARGE
C  MC,MD = CELL TYPE PARAMETERS WHICH DETERMINE THE SHAPES OF THE
C  I-V-Q CHARACTERISTICS
C  ICOUNT=COUNTS THE NUMBER OF ITERATIONS INVOLVED IN OBTAINING IC
C
C  THE BATTERY MODEL IS THE MODEL RECOMMENDED IN THE BEST
C  REPORT (THE HYMAN MODEL).  IT IS THE SHEPHERD MODEL MODIFIED BY
C  THE ADDITION OF A ZIMMERMAN-PETERSEN DIODE IN BOTH THE CHARGE AND
C  DISCHARGE EQUIVALENT CIRCUITS.
C*********************************************************************
      DIMENSION
     +  DQDT(1),    INFO(9),    OUT(9),     PAR(21),
     +  Q(1),       XIN(1)
      REAL
     +  I1,         IC,         IC1,        ICTOL,
     +  IDF,        IQ,         IQMAX,      IQMIN,
     +  K1,         MC,         MD
C*********************************************************************
      IF(INFO(7).GE.0)THEN
C****    set inputs
       IQ=XIN(1)
C****    current for one cell
       IQ=IQ/CP
      ENDIF

      IF(INFO(7).EQ.0)THEN
C****    computation of state of charge of battery from
C****    the previous time step
       F=OUT(2)
       H=1.-F
      ENDIF
C------------------------------------------------------
C**** Initialization--first call of component
      IF (INFO(7).LT.0) THEN
```

```
      INFO(9)=1
      INFO(6)=9
      CALL TYPECK (1,INFO,1,21,1)
      NDER=INFO(5)
      IF (NDER.NE.1) THEN
        CALL TYPECK (5,INFO,0,0,0)
       RETURN
      ENDIF
C****   Set parameters
      QM=PAR(1)
      CP=PAR(2)
      CS=PAR(3)
      EFF=PAR(4)
      VC=PAR(5)
      VCONTR=PAR(6)
      IF (VCONTR.GT.0) THEN
       VD=VCONTR
C****      Check on minimum discharge voltage
        IF (VD.GT.2.5.OR.VD.LT.1.5) CALL TYPECK (-4,INFO,0,0,0)
      ENDIF
      ICTOL=PAR(7)
          ESC=PAR(8)
          ESD=PAR(9)
          GC=PAR(10)
          GD=PAR(11)
          MC=PAR(12)
          MD=PAR(13)
          ED=PAR(14)
          RD=PAR(15)
          I1=PAR(16)
          K1=PAR(17)
      QC=PAR(18)
      QD=PAR(19)
      RSC=PAR(20)
      RSD=PAR(21)

C****   Check on maximum charge voltage
       IF (VC.GT.2.8.OR.VC.LT.1.8) CALL TYPECK (-4,INFO,0,0,0)
C-----------------------------------------------------------
C**** first and following calls in time step
     ELSE

C****   Modified Shepherd Model
      VOC=(ESC+ESD)/2.
      IF (IQ.GE.0.) THEN
C****      Charging
        VDI=1./K1*ALOG(IQ/I1+1.)
        V=VOC+VDI-GC*H+IQ*RSC*(1.+MC*H/(QC/QM-H))

       ICOUNT=0
```

```
      IC=50.
C****   Iterative search for current
30      CONTINUE
      IC1=IC
      VDI=1./K1*ALOG(ABS(IC1)/I1+1.)
      IC=(VC-VOC-VDI-GC*H)/RSC/(1.+MC*H/(QC/QM-H))
      ICOUNT=ICOUNT+1

C****   100 iterations are permitted to find IC
      IF(ICOUNT.GT.100)THEN
       GOTO 50
      ELSE
       IF (ABS(IC1-IC).GT.ICTOL) GO TO 30
      ENDIF
50      CONTINUE

      DQDT(1)=IQ*EFF

     ELSE
C****   Discharging
      VDI=1./K1*ALOG(-IQ/I1+1.)
      V=VOC-VDI-GD*H+IQ*RSD*(1.+MD*H/(QD/QM-H))
      DQDT(1)=IQ
     ENDIF
    ENDIF
C--------------------------------------------------------------
    P=IQ*V

C**** Output
    OUT(1)=Q(1)
    OUT(2)=Q(1)/QM
    OUT(3)=P*CP*CS
    OUT(4)=0.
    IF (P.GT.0.) OUT(4)=(1.-EFF)*P*CP*CS
    OUT(5)=IQ*CP
    OUT(6)=V*CS
    IF (VCONTR.LT.0.) VD=ED-ABS(IQ)*RD
    OUT(7)=VD*CS
    OUT(8)=VC*CS
    OUT(9)=IC*CP
    RETURN
    END
```

Series Type Charge Controller

```
C************************************************************************
    SUBROUTINE TYPE73(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C     version from: 12/22/89
C************************************************************************
```

```
C**** Subroutine represents a charge controller for a system including
C**** PV-array, load and battery storage.
C**** The controler represents a series type controler.
C**** A blocking diode is included in the model. It prevents that the
C**** battery is being discharged through the cell. It is assumed that
C**** voltage drop at the diode is constant throughout the simulation
C**** and just depends on the diode material used in the system.
C**** The user has to provide this information as a parameter
C***********************************************************************
C    Variables:
C     VB -- battery voltage [volts]
C     VD -- low limit on voltage, when battery discharging
C     VC -- high limit on voltage, when battery charging: cutoff voltage
C     VDA -- limit on voltage, above battery can again begin to discharge
C          after being charged
C     VCA -- limit on voltage, above battery can again begin to charge
C          after being discharged
C    VDIODE -- voltage of diode
C    VCELL -- voltage send to cell
C    VLOAD -- voltage send to load
C     F -- fractional state of charge
C     FD -- discharge limit on F
C     FC -- charge limit on F
C     FDA -- limit on F above battery can be discharged again after
C          being charged
C     FCA -- limit on F below battery can be charged again after
C          being discharged
C     IBMIN,IBMAX -- min. and max. battery current permitted
C     IB -- battery current
C*****************************************************************

      IMPLICIT NONE
      INTEGER INFO
      INTEGER ISTORE,NSTORE,IAV
      REAL TIME,XIN,OUT,T,DTDT,PAR,S
      REAL VB,VC,VD,V,VDA,VCA,VDIODE,IB
      REAL F,FD,FC,FDA,FCA,IBMIN,IBMAX,FAIL
      REAL VCELL,VLOAD,DUMMY
      DIMENSION XIN(5), OUT(3), PAR(9), INFO(10)

      COMMON /STORE/ NSTORE,IAV,S(5000)
C**** store is used to store values from previous timestep
C*************************************************************
      INFO(6)=3
      INFO(9)=0

C-----------------------------------------------------
C**** Initial call of component
      IF(INFO(7).LT.0)THEN
```

```
C****   storage allocation
      INFO(10)=1
      CALL TYPECK(1,INFO,5,9,0)
      ISTORE=INFO(10)
C****   Initialization of auxiliary variables used in secant
C****   method
      S(ISTORE)=0.
C****   SET PARAMETERS
      FD=PAR(1)
          FC=PAR(2)
      FDA=PAR(3)
      FCA=PAR(4)
      VDA=PAR(5)
      VCA=PAR(6)
      IBMAX=PAR(7)
      IBMIN=PAR(8)
          VDIODE=PAR(9)

          DUMMY=0.
C------------------------------------------------------
C**** first and following calls in time step
    ELSE
          DUMMY=S(ISTORE)
C****   Set inputs
      VB=XIN(1)
      IB=XIN(2)
      F=XIN(3)
      VC=XIN(4)
      VD=XIN(5)

C****   check on discharge rate
      IF(IB.LT.0.)THEN
           IF(IB.LT.IBMIN)THEN
             FAIL=1
       ENDIF
      ELSE
           IF(IB.GT.IBMAX)THEN
        FAIL=2
           ENDIF
      ENDIF

C****   initially no restrictions are made, battery can either
C****   be charged or discharged
          IF(DUMMY.EQ.0.)THEN

C****    check on low limit of F and V
          IF((F.LT.FD).OR.(VB.LT.VD))THEN
C****      load will be disconnected from battery and from cell,
C****      but cell can still charge battery
```

```
          VLOAD=0.
          VCELL=VDIODE+VB
          DUMMY=1.
C****     check on high limit of voltage
         ELSEIF((F.GT.FC).OR.(VB.GT.VC))THEN
C****       cell will be disconnected from battery and load,
C****       battery will be discharged
          VCELL=-333.
C****       this is just a characteristic value that the cell
C****       recognizes that it is being disconnected
          VLOAD=VB
          DUMMY=2.
         ELSE
C****       no restrictions
          VCELL=VDIODE+VB
          VLOAD=VB
         ENDIF

        ELSEIF(DUMMY.EQ.1.)THEN
C****     battery can only begin to discharge again, when VB is
C****     greater than VDA and F is greater then FDA
         IF((F.LT.FDA).OR.(VB.LT.VDA))THEN
          VLOAD=0.
          VCELL=VDIODE+VB
         ELSE
C****       no restrictions
          VCELL=VDIODE+VB
          VLOAD=VB
          DUMMY=0.
         ENDIF

        ELSEIF(DUMMY.EQ.2.)THEN
C****     battery can only begin to charge again, when VB is
C****     less than VCA and F is less than FCA
         IF((F.GT.FCA).OR.(VB.GT.VCA))THEN
          VCELL=-333.
          VLOAD=VB
          DUMMY=2.
         ELSE
C****       no restrictions
          VCELL=VDIODE+VB
          VLOAD=VB
          DUMMY=0.
         ENDIF
     ENDIF
    ENDIF

    S(ISTORE)=DUMMY

C**** SET OUTPUTS
```

```
OUT(1)=VCELL
OUT(2)=VLOAD
OUT(3)=FAIL

END
```

Shunt Type Charge Controller: Part A

```
C*********************************************************************
   SUBROUTINE TYPE74(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C    version from: 12/22/89
C****************************************************************C**** Subroutine
represents a charge controller for a system including
C**** PV-array, load and battery storage.
C**** The controler represents a shunt type controler.  A multi step
C**** control scheme is implemented. That means if the battery voltage
C**** exceeds the gassing voltage specified by the user, the current
C**** into the battery will be limitted to the current corresponding
C**** to the gassing voltage. Excess energy is shunted through a
C**** dissipater.
C**** A blocking diode is included in the model to prevent that the
C**** battery is being discharged through the cell. It is assumed that
C**** voltage drop at the diode is constant throughout the simulation
C**** and just depends on the diode material used in the system.
C**** The user has to provide this information as a parameter.
C**** Another diode is included in the undervoltage protection
C**** device. This way the battery can be disconnected from the load,
C**** i.e. the battery won't be discharged, while the array can still
C**** charge the battery.
C*****************************************************************
C**** variables:
C    F -- fractional State of Charge
C    FD -- discharge limit on F
C    FC -- charge limit on F
C    FDA -- F after which battery can be discharged again,
C          after being charged
C    FCA -- F after which battery can be charged again,
C          after being discharged
C    GUARD -- signal from undervoltage regulator
C    IB -- battery current [amps]
C    SIGNAL -- signals that undervoltage limit is exceeded
C    SUV -- signal to undervoltage regulator
C    VB -- battery voltage [volts]
C    VCA -- limit on voltage, above battery can again begin to charge
C          after being discharged
C    VCELL -- voltage send to cell
C    VC -- high limit on voltage, when battery charging-cutoff voltage
C    VDA -- limit on voltage, above battery can again begin to discharge
```

```
C          after being charged
C    VDIODE -- voltage of diode
C    VD -- low limit on voltage, when battery discharging
C    VLOAD -- voltage send to load

      IMPLICIT NONE
      INTEGER INFO
      INTEGER ISTORE,NSTORE,IAV
      REAL TIME,XIN,OUT,T,DTDT,PAR,S
      REAL VB,VD,VC,VDA,VCA,VDIODE
      REAL VCELL,VLOAD,DUMMY
      REAL SIGNAL,SUV,GUARD
      REAL IB,F,FD,FC,FDA,FCA
      DIMENSION XIN(7), OUT(5), PAR(6), INFO(10)

      COMMON /STORE/ NSTORE,IAV,S(5000)
C**** store is used to store values from previous timestep

      INFO(6)=5
      INFO(9)=1

      DUMMY=S(ISTORE)
C-----------------------------------------------------------------
C**** Initial call of component
      IF(INFO(7).LT.0)THEN
C****     storage allocation
        INFO(10)=1
        CALL TYPECK(1,INFO,7,6,0)
        ISTORE=INFO(10)
C****     Initialization of auxiliary variables used in secant
C****     method
        S(ISTORE)=0.

C****   SET PARAMETERS
        VDA=PAR(1)
           FD=PAR(2)
           FC=PAR(3)
           FDA=PAR(4)
           FCA=PAR(5)
           VDIODE=PAR(6)

           DUMMY=0.
C-----------------------------------------------------------------
C**** first and following calls in time step
      ELSE
C****     Following calls in time step
C****     Set inputs
        VB=XIN(1)
        VLOAD=XIN(2)
           GUARD=XIN(3)
```

```
      IB=XIN(4)
      F=XIN(5)
      VC=XIN(6)
      VD=XIN(7)

    IF(INFO(7).EQ.0)THEN
     IF(DUMMY.EQ.1.)THEN
        DUMMY=11.
       ELSEIF(DUMMY.EQ.22)THEN
        DUMMY=0.
       ENDIF
    ENDIF

C****   initially no restrictions are made, battery can either
C****   be charged or discharged
      IF(DUMMY.EQ.0.)THEN

C****    F-checks
       IF((F.GT.FC).AND.(IB.GT.0.))THEN
C****      very little current into battery
C****      current is shunted through a dissipative device
        VCELL=VDIODE+VB
        VLOAD=VB
        SIGNAL=0.
        SUV=2.
        DUMMY=2.

       ELSEIF((F.LT.FD).AND.(IB.LT.0.))THEN
C****      no current out of battery
C****      direct coupled mode: array direct connected to load
        VCELL=VDIODE+VLOAD
     SIGNAL=1.
     SUV=0.
        DUMMY=1.

       ELSE

C****      check voltage
        IF(VB.LT.VD)THEN
C****        satisfying the load is prior to charging the battery

         VCELL=VDIODE+VLOAD
      SIGNAL=1.
         SUV=0.
         DUMMY=1.

        ELSEIF(VB.GT.VC)THEN
C****       current is shunted through a dissipative device
C****       to reduce the battery voltage: trickle charge
```

```
         VCELL=VDIODE+VB
         VLOAD=VB
         SIGNAL=0.
         SUV=3.
         DUMMY=22.

        ELSE
C****      no restrictions
         VCELL=VDIODE+VB
         VLOAD=VB
         SIGNAL=0.
         SUV=0.
        ENDIF
    ENDIF

      ELSEIF(DUMMY.EQ.1.)THEN
C****   direct coupled mode: array direct connected to load
       VCELL=VDIODE+VLOAD
    SIGNAL=1.
    SUV=0.

      ELSEIF(DUMMY.EQ.11.)THEN
C****    try to run the system with battery
C****    battery is disconnected from load
       VCELL=VDIODE+VDIODE+VB
       VLOAD=VDIODE+VB
    SIGNAL=0.
    SUV=1.
       DUMMY=12.

      ELSEIF(DUMMY.EQ.12.)THEN
C****    try to run the system with battery
       IF((E.LT.EDA).OR.(VB.LT.VDA))THEN
C****      battery is still disconnected from load

        IF(GUARD.EQ.1.)THEN
C****       battery would be discharged; switch to
C****       direct coupled mode
         VCELL=VDIODE+VLOAD
         SIGNAL=1.
         SUV=0.
         DUMMY=1.
        ELSE
C****       dummy=11 mode is continued
         VCELL=VDIODE+VDIODE+VB
         VLOAD=VDIODE+VB
      SIGNAL=0.
      SUV=1.
        ENDIF
       ELSE
```

```
C****      no restrictions
          VCELL=VDIODE +VB
          VLOAD=VB
          SIGNAL=0.
          SUV=0.
          DUMMY=0.
         ENDIF

        ELSEIF(DUMMY.EQ.2.)THEN
C****     battery can only begin to charge again, when F is
C****     less than FCA
         IF(IB.GT.0)THEN
C****     battery is still on charge

          IF(F.GT.FCA)THEN
C****        very little current into battery
C****        current is shunted through a dissipative device
           VCELL=VDIODE+VB
           VLOAD=VB
           SIGNAL=0.
           SUV=2.
           DUMMY=2.

          ELSE
           IF(VB.GT.VC)THEN
C****          current is shunted through a dissipative device
C****          to reduce the battery voltage: trickle charge
  VCELL=VDIODE+VB
            VLOAD=VB
            SIGNAL=0.
            SUV=3.
            DUMMY=22.

           ELSE
C****         no restrictions
            VCELL=VDIODE+VB
            VLOAD=VB
            SIGNAL=0.
            SUV=0.
            DUMMY=0.
           ENDIF
          ENDIF

         ELSE
C****      no restrictions
          VCELL=VDIODE+VB
          VLOAD=VB
          SIGNAL=0.
          SUV=0.
```

```
        DUMMY=0.
       ENDIF

    ELSEIF(DUMMY.EQ.22.)THEN
C****     current is shunted through a dissipative device
C****     to reduce the battery voltage: trickle charge
       VCELL=VDIODE+VB
       VLOAD=VB
       SIGNAL=0.
       SUV=3.
       DUMMY=22.
      ENDIF
   ENDIF
C-------------------------------------------------------
   S(ISTORE)=DUMMY
C**** set outputs
   OUT(1)=VCELL
   OUT(2)=VLOAD
   OUT(3)=SIGNAL
   OUT(4)=SUV
   OUT(5)=DUMMY
   END
```

Shunt Type Controller: Part B

```
C*******************************************************************
   SUBROUTINE TYPE75(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C    version from: 12/22/89
C*******************************************************************
C**** Subroutine represents a charge controller for a system including
C**** PV-array, load and battery storage.
C**** The controler represents a part of a shunt type controler:
C**** the undervoltage and overvoltage protection
C*******************************************************************
C**** Variables:
C    IB -- battery current [amps]
C    SUV -- control signal: incoming
C    GUARD -- control signal: outgoing
C    IBMAX -- maximum battery current permitted
C    IBMIN -- minimum battery current permitted
C    FAIL -- message: =1 IBMIN is exceed
C                     =2 IBMAX is exceed
C    IC -- current corresponding to VC [amps]
C    VC -- gassing voltage of the battery [volts]
C    VB -- battery voltage [volts]
C    IDISS -- dissipated current [amps]
C    VDISS -- voltage drop at dissipater [volts]
C    PDISS -- dissipated power [watts]
C*******************************************************************
```

```
      IMPLICIT NONE

      INTEGER INFO
      REAL TIME,XIN,OUT,T,DTDT,PAR
      REAL IB,SUV,GUARD,IBMAX,IBMIN,FAIL
      REAL IC,VC,VB,IDISS,VDISS,PDISS

      DIMENSION XIN(5),PAR(2),OUT(4),INFO(10)

C*****************************************************************

      INFO(6)=4
      INFO(9)=0

C**** PARAMETERS
      IBMAX=PAR(1)
      IBMIN=PAR(2)

      FAIL=0.
C**** Set inputs
      IB=XIN(1)
      VB=XIN(2)
      IC=XIN(3)
      VC=XIN(4)
      SUV=XIN(5)

      IF(SUV.EQ.1.)THEN
C****    undervoltage protection
C****    check on IB
          IF(IB.LT.0.)THEN
           GUARD=1.
           IB=0.
          ELSE
           GUARD=0.
          ENDIF
      ELSEIF(SUV.EQ.2.)THEN
C****    that is when battery SOC (upper limit) is exceeded
C****    current gets shunted through dissipater
        IDISS=IB-0.1
        VDISS=VB
        IF(IDISS.LT.0.)THEN
         IDISS=0.
         VDISS=0.
        ELSE
         IB=0.1
        ENDIF
      ELSEIF(SUV.EQ.3.)THEN
C****    trickle charge at constant charge rate IC
        IDISS=IB-IC
        VDISS=VC
```

```
     IF(IDISS.LT.0.)THEN
       IDISS=0.
       VDISS=0.
     ELSE
       IB=IC
     ENDIF

    ELSEIF(SUV.EQ.0.)THEN
         GUARD=0.
    ENDIF
C**** check on discharge rate
    IF(IB.LT.IBMIN)THEN
      FAIL=1.
    ELSEIF(IB.GT.IBMAX)THEN
      FAIL=2.
    ENDIF

    PDISS=IDISS*VDISS
C**** set outputs
    OUT(1)=IB
    OUT(2)=GUARD
    OUT(3)=PDISS
    OUT(4)=FAIL

    END
```

Appendix B

TRNSYS DECKS

Direct-Coupled Systems

```
****************************************************************
*    PV-cell connected to a separately excited DC motor and a
*    centrifugal pump
****************************************************************
* Simulation starts at TIME 1 and will run 24 hours with a
* time step of 1
SIMULATION 1 24 1
*
WIDTH 80
* use relative tolerances
TOLERANCES .001 .001
*
LIMITS 60 10
*
EQUATIONS 3
SUN=[2,6]/3.6
SUNA=[2.6]/3.6*83.692
QHOUR=[6,3]*3600
****************************************************************
UNIT 1 TYPE 9 DATA READER (FORMATED)
PARAMETERS 13
*N DELTATd HOURS  IH     TA     LUNIT FORMATED
3   1   -1 1 0 -2 1 0 3 .1 273 1    1
(4X,F3.0,7X,F4.0,2X,F3.0)
****************************************************************
UNIT 2 TYPE 16 SOLAR RADIATION PROCESSOR
PARAMETERS 7
*RADMODE TRACKMOD N    LAT  SC   SHFT IE
1     1      152    43.1 4871 0    -1
INPUTS 6
*I  td1  td2   rhog beta gamma
1,2  1,19  1,20  0,0  0,0  0,0
0  0    0    0.2 40  0
****************************************************************
```

```
UNIT 3 TYPE 62 PV-CELL
PARAMETERS 9
*ISCR VOCR TCR  SUNREF  VMR    IMR     MISC      MVOC      NCS
2.9   20.  301. 1000.   16.5   2.67    1.325E-3  -77.5E-3  36
PARAMETERS 9
*NS NP  TCNOCT TANOCT SUNNOCT AREA  TAUAL EG   RS
14  10  319    293    800     0.427 .9    1.12 -1
INPUTS 4
*SUN TA   V   MODE
2,6  1,3  4,2  0,0
0    0    0    1
***************************************************************
LOOP 2 REPEAT 30
4  6
***************************************************************
UNIT 4 TYPE 66 DC-MOTOR
PARAMETERS 8
*TYPE NMAX  IRAT IMAX  KF   CSTAT CVISC  RA
1     70    20   25    .59  0.5   0.02   1.44 0.7
INPUTS 5
*I   V   N   TM  MODE
3,2  3,1  6,1 6,2 0,0
0    0    0   0   1
***************************************************************
UNIT 6 TYPE 68 PUMP
PARAMETERS 6
*K1    K2        NREF  NMAX  POFF QNOM
30.48  4.2104E5  50.   58.3  -1   15
INPUTS 1
*TL
4,4
0
***************************************************************
UNIT 7 TYPE 25 PRINTER 1
PARAMETERS 4
*PRINT EVERY HOUR
1 1 24 7
INPUTS 6
3,1  3,2  3,3  3,4  3,5  SUN
V    I    P    PMAX UTIL SUN
***************************************************************
UNIT 8 TYPE 25 PRINTER 2
PARAMETERS 4
1 1 24 9
INPUTS 5
6,2  6,1  QHOUR  6,4  6,5
TM   N    Q      H    ETA
***************************************************************
UNIT 9 TYPE 25 PRINTER 3
PARAMETERS 4
```

```
1 1 24 10
INPUTS 2
6,8   4,8
FAILP FAILM
***********************************************************
UNIT 10 TYPE 25 PRINTER 4
PARAMETERS 4
1 1 24 11
INPUTS 6
3,3  4,5 4,6   6,6 6,7   SUNA
PCELL PEL PMECHM PHYD PMECHM SUNA
***********************************************************
END


*****************************************************************
*   PV-array connected to a series DC motor and a
*     centrifugal pump
*****************************************************************
* Simulation starts at TIME 1 and will run 24 hours with a
* time step of 1
SIMULATION 1 24 1
*
WIDTH 80
* use relative tolerances
TOLERANCES .001 .001
*
LIMITS 60 10
*
EQUATIONS 3
SUN=[2,6]/3.6
SUNA=[2,6]/3.6*83.692
QHOUR=[6,3]*3600
***************************************************************
UNIT 1 TYPE 9 DATA READER (FORMATED)
PARAMETERS 13
*N DELTATd HOURS  IH    TA    LUNIT FORMATED
3   1  -1 1 0 -2 1 0 3 .1 273 1   1
(4X,F3.0,7X,F4.0,2X,F3.0)
***************************************************************
UNIT 2 TYPE 16 SOLAR RADIATION PROCESSOR
PARAMETERS 7
*RADMODE TRACKMOD N   LAT SC  SHFT IE
1     1     152    43.1 4871 0   -1
INPUTS 6
*I  td1  td2  rhog beta gamma
1,2  1,19  1,20  0,0  0,0  0,0
0  0   0   0.2  40  0
***************************************************************
```

```
UNIT 3 TYPE 62 PV-CELL
PARAMETERS 9
*ISCR VOCR TCR SUNREF VMR   IMR    MISC     MVOC     NCS
2.9   20.  301. 1000.   16.5   2.67    1.325E-3  -77.5E-3  36
PARAMETERS 9
*NS NP  TCNOCT TANOCT SUNNOCT AREA  TAUAL EG   RS
14  10  319    293    800    0.427  .9   1.12  -1
INPUTS 4
*SUN TA  V   MODE
2,6  1,3  4,2  0,0
0  0  0  1
***************************************************************
LOOP 2 REPEAT 30
4  6
***************************************************************
UNIT 4 TYPE 66 DC-MOTOR
PARAMETERS 9
*TYPE NMAX  IRAT IMAX  KF    CSTAT CVISC  RA   RF
2    70    20   25    .0275  0.5   0.02   1.44 0.7
INPUTS 5
*I   V   N  TM  MODE
3,2   3,1   6,1 6,2 0,0
0    0   0  0  1
***************************************************************
UNIT 6 TYPE 68 PUMP
PARAMETERS 6
*K1   K2       NREF  NMAX  POFF QNOM
30.48  4.2104E5  50.    58.3  -1   15
INPUTS 1
*TL
4,4
0
***************************************************************
UNIT 7 TYPE 25 PRINTER 1
PARAMETERS 4
*PRINT EVERY HOUR
1  1 24  7
INPUTS 6
3,1  3,2  3,3  3,4  3,5  SUN
V   I   P   PMAX UTIL SUN
***************************************************************
UNIT 8 TYPE 25 PRINTER 2
PARAMETERS 4
1  1 24  9
INPUTS 5
6,2  6,1  QHOUR  6,4  6,5
TM  N   Q    H   ETA
***************************************************************
UNIT 9 TYPE 25 PRINTER 3
PARAMETERS 4
```

```
1  1 24  10
INPUTS 2
6,8    4,8
FAILP  FAILM
**********************************************************
UNIT 10 TYPE 25 PRINTER 4
PARAMETERS 4
1  1 24  11
INPUTS 6
3,3   4,5  4,6     6,6  6,7     SUNA
PCELL PEL  PMECHM  PHYD PMECHM SUNA
**********************************************************
END
```

Systems with Battery Storage

```
*****************************************************************
*        PV-cell connected with a DC motor, a centrifugal pump,
*        a battery and a series type charge controller
*****************************************************************
* Simulation starts at 1st of June and will run 48 hours with a
* time step of one
SIMULATION 1 48 1
*
WIDTH 80
* use absolute tolerances
TOLERANCES  .001  .001
*
LIMITS  100  10
*
EQUATIONS 7
NS=14
NP=20
AREA=0.427
IBAT=[3,2]-[4,1]
SUN=[2,6]/3.6
QHOUR=[6,3]*3600
SUNA=[2,6]/3.6*NS*NP*AREA
*****************************************************************
UNIT 1 TYPE 9 DATA READER (FORMATED)
PARAMETERS 13
*N DELTATd HOURS   IH      TA      LUNIT FORMATED
3    1    -1 1 0   2 1 0  3 .1 273 1     1
(4X,F3.0,7X,F4.0,2X,F3.0)
*****************************************************************
UNIT 2 TYPE 16 SOLAR RADIATION PROCESSOR
PARAMETERS 7
*RADMODE TRACKMOD N     LAT  SC   SHFT  IE
1       1        152    43.1 4871 0    -1
```

```
INPUTS 6
*1  td1  td2  rhog beta gamma
1,2  1,19  1,20  0,0  0,0  0,0
0  0   0   0.2 40  0
*****************************************************************
UNIT 5 TYPE 70 BATTERY (250 AH lead acid)
PARAMETERS 7
*QM  CP CS  EFF   VC  VD ICTOL
250  2  102 0.95  2.3 -1  0.01
PARAMETERS 7
*ESC  ESD  GC  GD  MC   MD ED
2.25   2.10  0.08  0.08  0.864  1.  1.8
PARAMETERS 7
*RD   IDI KDI  QC   QD   RSC  RSD
2.4E-3   2.5  29.3  -8.75  294.12  0.012  0.002
INPUTS 1
*IBAT
IBAT
15.0
DERIVATIVES 1
250.
*****************************************************************
UNIT 14 TYPE 73 SERIES CHARGE CONTROLER
PARAMETERS 9
*FD FC FDA FCA  VDA VCA  IBMAX IBMIN VDIODE
0.7 1  0.72 0.98  223  215  40   -40  0.7
INPUTS 5
*VB IB  F  VC  VD
5,6 5,5 5,2 5,8 5,7
0  0  0  0  0
*****************************************************************
UNIT 3 TYPE 62 PV-CELL
PARAMETERS 9
*ISCR VOCR TCR SUNREF VMR  IMR  MISC   MVOC   NCS
2.9  20.  301. 1000.  16.5  2.67   1.325E-3  -77.5E-3  36
PARAMETERS 9
*NS NP  TCNOCT TANOCT SUNNOCT AREA  TAUAL EG  RS
NS  NP  319   293   800   0.427  .9   1.12  -1
INPUTS 4
*SUN TA  V   MODE
2,6  1,3  14,1  0,0
0  0  0   0
*****************************************************************
LOOP 2 REPEAT 50
4  6
*****************************************************************
UNIT 4 TYPE 66 DC-MOTOR
PARAMETERS 8
*TYPE NMAX  IRAT IMAX  KF  CSTAT CVISC  RA
```

```
1   70  20  30   .59 0.5  0.02  1.44
INPUTS 5
*I  V   N  TM  MODE
0,0   14,2  6,1 6,2 0,0
0   0   0  0  0
*************************************************************
UNIT 6 TYPE 68 PUMP
PARAMETERS 6
*K1   K2      NREF  NMAX  POFF QNOM
30.48  4.2104E5  50.   65   -1   15
INPUTS 1
*TL
4,4
0
*************************************************************
UNIT 8 TYPE 25 PRINTER 1
PARAMETERS 4
*PRINT EVERY HOUR
1  1 48  7
INPUTS 6
3,1  3,2  3,3  3,4  3,5  SUN
V   I   P   PMAX UTIL SUN
*************************************************************
UNIT 9 TYPE 25 PRINTER 2
PARAMETERS 4
*PRINT EVERY HOUR
1  1 48  8
INPUTS 5
3,1   4,2   5,6  5,1 5,2
VCELL VLOAD VBAT SOC F
*************************************************************
UNIT 11 TYPE 25 PRINTER 3
PARAMETERS 4
1  1 48  11
INPUTS 5
6,2  6,1  QHOUR  6,4  6,5
TM  N   Q    H   ETA
*************************************************************
*UNIT 13 TYPE 25 PRINTER 4
*PARAMETERS 4
*1  1 48  13
*INPUTS 6
*3,3  4,5  4,6    6,6  6,7    SUNA
*PCELL PEL  PMECHM  PHYD PMECHM SUNA
*************************************************************
UNIT 13 TYPE 25 PRINTER 4
PARAMETERS 4
1  1 48  13
INPUTS 4
3,5  SUN QHOUR 5,2
```

```
UTIL SUN QHOUR F
*************************************************************
END


*******************************************************************
*       PV-cell connected with a DC motor, a centrifugal pump,
*       a battery and a shunt type charge controller
*******************************************************************
* Simulation starts at 1st of June and will run 48 hours with a
* time step of one
SIMULATION 1 48 1
*
WIDTH 80
* use absolute tolerances
TOLERANCES .001 .001
*
LIMITS 100 10
*
EQUATIONS 7
NS=14
NP=20
AREA=0.427
IBAT=[3,2]-[4,1]
SUN=[2,6]/3.6
QHOUR=[6,3]*3600
SUNA=[2,6]/3.6*NS*NP*AREA
*******************************************************************
UNIT 1 TYPE 9 DATA READER (FORMATED)
PARAMETERS 13
*N DELTATd HOURS  IH     TA     LUNIT FORMATED
3   1   -1 1 0  -2 1 0  3 .1 273  1    1
(4X,F3.0,7X,F4.0,2X,F3.0)
*******************************************************************
UNIT 2 TYPE 16 SOLAR RADIATION PROCESSOR
PARAMETERS 7
*RADMODE TRACKMOD N     LAT  SC  SHFT IE
1      1       152    43.1 4871 0    -1
INPUTS 6
*I   td1   td2   rhog beta gamma
1,2  1,19  1,20  0,0  0,0  0,0
0   0    0    0.2  40   0
*****************************************************************
UNIT 5 TYPE 70 BATTERY (250 AH lead acid)
PARAMETERS 7
*QM  CP CS  EFF   VC  VD ICTOL
250  2   102  0.95   2.3  -1   0.01
PARAMETERS 7
*ESC  ESD  GC   GD   MC    MD ED
```

```
2.25  2.10  0.08  0.08  0.864  1.  1.8
PARAMETERS 7
*RD    IDI KDI  QC    QD     RSC   RSD
2.4E-3   2.5  29.3   -8.75  294.12  0.012  0.002
INPUTS 1
*IBAT
18,1
15.0
DERIVATIVES 1
250.
*****************************************************************
UNIT 16 TYPE 74 SHUNT CHARGE CONTROLER PART A
PARAMETERS 6
*VDA  FD FC   FDA  FCA   VDIODE
223   0.7 0.99  0.72 0.98  0.7
INPUTS 7
*VB  VLOAD GUARD IB  F   VC  VD
5,6  4,2    18,2  5,5 5,2 5,8 5,7
0  0   0   0  0  0  0
*****************************************************************
UNIT 3 TYPE 62 PV-CELL
PARAMETERS 9
*ISCR VOCR TCR  SUNREF  VMR    IMR    MISC     MVOC      NCS
2.9   20.  301. 1000.   16.5   2.67    1.325E-3  -77.5E-3  36
PARAMETERS 9
*NS NP  TCNOCT TANOCT SUNNOCT AREA   TAUAL EG    RS
NS  NP   319    293    800     0.427  .9    1.12  -1
INPUTS 4
*SUN TA   V    MODE
2,6  1,3  16,1   16,3
0   0   0    0
*****************************************************************
LOOP 2 REPEAT 50
4  6
*****************************************************************
UNIT 4 TYPE 66 DC-MOTOR
PARAMETERS 8
*TYPE NMAX  IRAT IMAX  KF   CSTAT CVISC  RA
1    70   20   30    .59  0.5   0.02   1.44
INPUTS 5
*I   V    N  TM  MODE
3,2   16,2  6,1 6,2 16,3
0   0    0  0  0
*****************************************************************
UNIT 6 TYPE 68 PUMP
PARAMETERS 6
*K1   K2      NREF  NMAX  POFF QNOM
30.48  4.2104E5  50.   65   -1   15
INPUTS 1
*TL
```

```
4,4
0
*****************************************************************
UNIT 18 TYPE 75 SHUNT CHARGE CONTROLLER PART B
PARAMETERS 2
*IBMAX IBMIN
40  -40
INPUTS 5
*IB  VB  IC  VC  SUV
IBAT 5,6 5,9 5,8 16,4
0  0 0 0 0
*****************************************************************
UNIT 8 TYPE 25 PRINTER 1
PARAMETERS 4
*PRINT EVERY HOUR
1  1 48  7
INPUTS 6
3,1  3,2  3,3  3,4  3,5  SUN
V   I   P   PMAX UTIL SUN
*****************************************************************
UNIT 9 TYPE 25 PRINTER 2
PARAMETERS 4
*PRINT EVERY HOUR
1  1 48  8
INPUTS 5
3,1   4,2   5,6  5,1 5,2
VCELL VLOAD VBAT SOC F
*****************************************************************
UNIT 11 TYPE 25 PRINTER 3
PARAMETERS 4
1  1 48  11
INPUTS 5
6,2  6,1  QHOUR  6,4  6,5
TM  N   Q    H   ETA
*************************************************************
*UNIT 13 TYPE 25 PRINTER 4
*PARAMETERS 4
*1  1 48  13
*INPUTS 6
*3,3  4,5  4,6    6,6  6,7    SUNA
*PCELL PEL PMECHM  PHYD PMECHM SUNA
*************************************************************
UNIT 13 TYPE 25 PRINTER 4
PARAMETERS 4
1  1 48  13
INPUTS 4
3,5  SUN QHOUR 5,2
UTIL SUN QHOUR F
*************************************************************
END
```

System with Battery Storage and Maximum Power Tracking

```
***********************************************************************************
*       PV-cell connected with a max. power point tracker, a DC motor, a centrifugal
*       pump, a battery and a series type charge controller
***********************************************************************************
* Simulation starts at 1st of June and will run 24 hours with a
* time step of one
SIMULATION 1 24 1
*
WIDTH 80
* use absolute tolerances
TOLERANCES .001 .001
*
LIMITS 100 10
*
EQUATIONS 7
NS=14
NP=20
AREA=0,427
IBAT=[3,2]-[4,1]
SUN=[2,6]/3.6
QHOUR=[6,3]*3600
SUNA=[2,6]/3.6*NS*NP*AREA
******************************************************************
UNIT 1 TYPE 9 DATA READER (FORMATED)
PARAMETERS 13
*N DELTATd HOURS  IH     TA      LUNIT FORMATED
3   1   -1 1 0  -2 1 0 3 .1 273 1    1
(4X,F3.0,7X,F4.0,2X,F3.0)
******************************************************************
UNIT 2 TYPE 16 SOLAR RADIATION PROCESSOR
PARAMETERS 7
*RADMODE TRACKMOD N     LAT SC  SHFT IE
1     1      152    43.1 4871 0    -1
INPUTS 6
*I  td1  td2  rhog beta gamma
1,2  1,19  1,20  0,0  0,0  0,0
0  0    0    0.2 40  0
****************************************************************
UNIT 3 TYPE 70 BATTERY (250 AH lead acid)
PARAMETERS 7
*QM  CP CS  EFF   VC  VD ICTOL
250  3   102  0.95  2.3  -1  0.01
PARAMETERS 7
*ESC  ESD  GC   GD   MC   MD ED
2.25  2.10  0.08  0.08  0.864  1.  1.8
```

```
PARAMETERS 7
*RD   IDI KDI  QC   QD    RSC   RSD
2.4E-3   2.5  29.3  -8.75  294.12  0.012  0.002
INPUTS 1
*IBAT
IBAT
15.0
DERIVATIVES 1
200.
*****************************************************************
UNIT 14 TYPE 73 SERIES CHARGE CONTROLER
PARAMETERS 9
*FD FC FDA FCA  VDA  VCA  IBMAX IBMIN VDIODE
0.6  1   0.63 0.98  223  215   40    -40   0.7
INPUTS 5
*VB IB  F  VC  VD
5,6 5,5 5,2 5,8 5,7
0  0  0  0  0
*****************************************************************
UNIT 3 TYPE 62 PV-CELL
PARAMETERS 9
*ISCR VOCR TCR  SUNREF  VMR   IMR    MISC    MVOC     NCS
2.9   20.  301. 1000.   16.5   2.67    1.325E-3  -77.5E-3  36
PARAMETERS 9
*NS NP  TCNOCT TANOCT SUNNOCT AREA   TAUAL EG   RS
NS  NP  319    293    800     0.427  .9    1.12  -1
INPUTS 4
*SUN TA   V    MODE
2,6  1,3  0,0   0,0
0   0   0   0
*****************************************************************
UNIT 15 TYPE 65 MAXIMUM POWER TRACKER
PARAMETERS 1
*EFF
0.98
INPUTS 4
*IMAX VMAX  VB   MODE
3,7   3,6   14,1 0,0
0    0    0    0
*****************************************************************
LOOP 2 REPEAT 50
4  6
*****************************************************************
UNIT 4 TYPE 66 DC-MOTOR
PARAMETERS 8
*TYPE NMAX  IRAT IMAX  KF   CSTAT CVISC  RA
1    70    20   30    .59  0.5   0.02   1.44
INPUTS 5
*I   V    N  TM  MODE
0,0   14,2  6,1 6,2 0,0
```

```
0   0   0 0 0
**************************************************************
UNIT 6 TYPE 68 PUMP
PARAMETERS 6
*K1   K2       NREF   NMAX  POFF QNOM
30.48  4.2104E5  50.    65    -1   15
INPUTS 1
*TL
4,4
0
**************************************************************
UNIT 8 TYPE 25 PRINTER 1
PARAMETERS 4
*PRINT EVERY HOUR
1  1 96  7
INPUTS 6
3,1  3,2  3,3  3,4  3,5  SUN
V   I   P   PMAX UTIL SUN
**************************************************************
UNIT 9 TYPE 25 PRINTER 2
PARAMETERS 4
*PRINT EVERY HOUR
1  1 96  8
INPUTS 5
3,1   4,2   5,6  5,1 5,2
VCELL VLOAD VBAT SOC F
**************************************************************
UNIT 11 TYPE 25 PRINTER 3
PARAMETERS 4
1  1 96  11
INPUTS 5
6,2  6,1  QHOUR  6,4  6,5
TM   N   Q    H   ETA
**************************************************************
*UNIT 13 TYPE 25 PRINTER 4
*PARAMETERS 4
*1  1 96  13
*INPUTS 6
*3,3   4,5  4,6     6,6  6,7    SUNA
*PCELL PEL  PMECHM  PHYD PMECHM SUNA
**************************************************************
UNIT 13 TYPE 25 PRINTER 4
PARAMETERS 4
1  1 96  13
INPUTS 4
3,5  SUN QHOUR 5,2
UTIL SUN QHOUR F
**************************************************************
END
```

Appendix C

SIMULATION DATA

This Appendix contains the data used for the simulations performed in Chapters 2, 3, 4, and 5.

Motor - Centrifugal Fan Data

	Series	Sep. excited
RA [ohms]	1.5	1.5
RF [ohms]	0.7	n/a
$k\phi$ [Vs]	n/a	0.621
MAF [henry]	0.0675	n/a
n-rated [1/s]	25	25

The coefficients for the fan torque-speed relation according to equation (3.3.15) are:

$a = 0.3$ $b = 0.00039$ $c = 1.8$

The static and viscous friction components of the motor are:

$c_{stat} = 0.2$ Nm $c_{visc} = 0.015$ Nm*s

Motor - Centrifugal Pump Data

	Series	Sep. excited
RA [ohms]	1.44	1.44
RF [ohms]	0.7	n/a
kϕ [Vs]	n/a	0.59
MAF [henry]	0.0275	n/a
n-rated [1/s]	38.4	38.4

The static and viscous friction components of the motor are:

$c_{stat} = 0.5$ Nm $\qquad c_{visc} = 0.02$ Nm*s

The Pump data are read from Figure 3.14. The two following tables contain the head-flowrate and the efficiency-flowrate profiles at a reference speed of 3000 Rpm.

Q [m^3/s]	Head [m]
0	37.795
0.00063	37.49
0.00126	36.881
0.00189	36.271
0.00252	35.357
0.00315	34.138
0.00378	32.309
0.00441	29.566
0.00504	26.822
0.00567	22.86

Q [m^3/s]	efficiency
0.002019	0.45
0.002587	0.5
0.003218	0.55
0.004354	0.58
0.005363	0.55
0.005742	0.5

PV Array Data for a Single Module

	Solarex MSX-30	Kyocera
I_{SCREF}	1.82	2.9
V_{OCREF}	21.3	20
T_{CREF}	298	301
Φ_{REF}	1000	1000
V_{MPREF}	17.8	16.5
I_{MPREF}	1.68	2.67
μ_{ISC}	0.0015	0.001325
μ_{VOC}	-0.073	-0.0775
T_{CNOCT}	318	319
Φ_{NOCT}	1000	800
T_{ANOCT}	293	293
ε_G	1.12	1.12
Area-module	0.259	0.427

The parameters for a **lead-acid battery** are taken from *TRNSYS* [2].

$E_{SC} = 2.25$ V

$E_{SD} = 2.10$ V

$G_C = 0.08$

$G_D = 0.08$

$M_C = 0.864$

$M_D = 1.0$

$E_D = 1.8$ V

$R_D = 2.4\text{E-}3$ ohms

$I_{DI} = 2.5$ amps

$K_{DI} = 29.3$

The following parameters depend on the size of the battery and can be obtained using the proposed relations [2]:

$$Q_C = -0.035\, Q_M \qquad Q_D = \frac{Q_M}{0.85}$$

$$R_{SC} = \frac{3.0}{Q_M} \qquad R_{SD} = \frac{0.5}{Q_M}$$

For all simulations, the rated capacity, Q_M, was taken to be 250 ampere-hours and the charging efficiency was assumed to be 0.95.

Appendix D

COMPARISON DATA

This Appendix contains the data for the comparison between the simulations and the experiments conducted at the Florida Solar Energy Center.

Pump-Motor Data

The motor parameters were obtained from measured I-V motor-pump curves and the rated motor data. Simulations were run for two different sets of motor parameters (indicated as estimated - 1 and estimated - 2; see also Chapter 6). The pump performance data were given in a combined form together with the motor data. The head-flowrate profiles were given as a function of voltage and electric power. To run simulations, the pump data are required in an explicit form (as head-flowrate and efficiency-flowrate profiles for a reference speed). The motor-pump relations derived in Chapter 3 were used to make the data compatible to the requirements of the simulations. Therefore, two different sets of pump performance data are given corresponding to the two different sets of motor parameters.

rated permanent magnet motor data: 36 V-DC, 1500 Rpm, 1/2 Hp

motor parameters

estimated - 1: $RA = 0.43$ $k\phi = 0.188$

estimated - 2: $RA = 0.59$ $k\phi = 0.173$

The motor loss coefficients were assumed to be: $c_{stat} = 0.25$ Nm $c_{visc} = 0.011$ Nms

Pump performance data for estimated - 1:

Q [m^3/s]	Head [m]	efficiency
0.000208	18.5	0.24
0.00049	17.5	0.37
0.000764	15	0.43
0.000903	14	0.42
0.00118	10	0.32
0.0014	7	0.22

Pump performance data for estimated - 2:

Q [m^3/s]	Head [m]	efficiency
0.00025	17.5	0.33
0.00044	17	0.41
0.000628	16	0.44
0.000903	14	0.34
0.001183	8.5	0.27
0.001389	4	0.15

The pump performance data are provided at the reference speed of 1500 Rpm.

PV Array

Single module ratings:

T_{CREF} = 50°C

Φ_{REF} = 1000 W/m^2

V_{OCREF} = 18.0 V

V_{MPREF} = 13.56 V

I_{SCREF} = 4.87 amps

I_{MPREF} = 4.32 amps

the following parameters were assumed

T_{CNOCT} = 319 °K

T_{ANOCT} = 293 °K

Φ_{NOCT} = 800 W/m^2

AREA = 0.720 m^2

μ_{ISC} = 3.e-3 A/K

μ_{VOC} = -75.5e-3 V/K

NCS = 36

$\tau\alpha_{AVE}$ = 0.9

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