Example

Code written by Knapoj Chaimanekorn,

Sat. 20 August 2022

1. Balanced Fault Analysis of a 11-Bus Power System

In [1]:
```
import numpy as np
from pyeps import *
```
executed in 357ms, finished 19:52:55 2022-08-20

In [2]:
```
# Build bus impedance matrix from zdata...
# From bus (No.), To bus (No.), R (pu.), X(pu.)

zdata = np.array([
    [0,1,0,0.2],
    [0,10,0,0.15],
    [0,11,0,0.25],
    [1,2,0,0.06],
    [2,3,0.08,0.3],
    [2,5,0.04,0.15],
    [2,6,0.12,0.45],
    [3,4,0.10,0.40],
    [3,6,0.04,0.4],
    [4,6,0.15,0.6],
    [4,9,0.18,0.70],
    [4,10,0,0.08],
    [5,7,0.05,0.43],
    [6,8,0.06,0.48],
    [7,8,0.06,0.35],
    [7,11,0,0.1],
    [8,9,0.052,0.48]
])

zbus = zbuild(zdata)
```
executed in 32ms, finished 19:52:55 2022-08-20

In [3]:
```
from sympy import *
from IPython.display import display, Latex
init_printing(use_latex='mathjax')

# Display 11x11 Bus impedance matrix
display(Latex("$\mathbf{Z}_{bus} = $"), Matrix(np.round(zbus,4)))
```
executed in 2.18s, finished 19:52:57 2022-08-20

$\mathbf{Z}_{bus} =$

$$\begin{bmatrix}
0.005+0.1365i & 0.0065+0.1175i & 0.0009+0.0823i & -0.0044+0.0405i & 0.0023+0.0998i & 0.0003+0.0773i & -0.0019+0.0495i & -0.0011+0.0582i & -0.0018+0.051i & -0.0029+0.0264i & -0.0014+0.0353i \\
0.0065+0.1175i & 0.0084+0.1527i & 0.0011+0.107i & -0.0058+0.0527i & 0.003+0.1298i & 0.0003+0.1005i & -0.0025+0.0643i & -0.0015+0.0757i & -0.0024+0.0663i & -0.0038+0.0343i & -0.0018+0.0459i \\
0.0009+0.0823i & 0.0011+0.107i & 0.0311+0.2334i & 0.0001+0.0954i & -0.0009+0.0949i & 0.0137+0.1385i & -0.0017+0.0607i & 0.0049+0.0937i & 0.0029+0.0942i & 0.0001+0.0622i & -0.0012+0.0434i \\
-0.0044+0.0405i & -0.0058+0.0527i & 0.0001+0.0954i & 0.008+0.1564i & -0.0057+0.0496i & -0.0003+0.0914i & -0.0045+0.0412i & -0.0012+0.0761i & -0.0003+0.1085i & 0.0052+0.102i & -0.0032+0.0294i \\
0.0023+0.0998i & 0.003+0.1298i & -0.0009+0.0949i & -0.0057+0.0496i & 0.0279+0.2335i & -0.0004+0.094i & 0.0047+0.0998i & 0.0015+0.0904i & 0.0738i & -0.0037+0.0323i & 0.0033+0.0713i \\
0.0003+0.0773i & 0.0003+0.1005i & 0.0137+0.1385i & -0.0003+0.0914i & -0.0004+0.094i & 0.0297+0.2371i & 0.0755i & 0.0125+0.1359i & 0.0089+0.1177i & -0.0002+0.0596i & 0.0539i \\
-0.0019+0.0495i & -0.0025+0.0643i & -0.0017+0.0607i & -0.0045+0.0412i & 0.0047+0.0998i & 0.0755i & 0.0102+0.2008i & 0.0038+0.1323i & 0.0036+0.0956i & -0.0029+0.0268i & 0.0073+0.1434i \\
-0.0011+0.0582i & -0.0015+0.0757i & 0.0049+0.0937i & -0.0012+0.0761i & 0.0015+0.0904i & 0.0125+0.1359i & 0.0038+0.1323i & 0.0339+0.2982i & 0.0276+0.2082i & -0.0008+0.0496i & 0.0027+0.0945i \\
-0.0018+0.051i & -0.0024+0.0663i & 0.0029+0.0942i & -0.0003+0.1085i & 0.0738i & 0.0089+0.1177i & 0.0036+0.0956i & 0.0276+0.2082i & 0.0677+0.4536i & -0.0002+0.0708i & 0.0026+0.0683i \\
-0.0029+0.0264i & -0.0038+0.0343i & 0.0001+0.0622i & 0.0052+0.102i & -0.0037+0.0323i & -0.0002+0.0596i & -0.0029+0.0268i & -0.0008+0.0496i & -0.0002+0.0708i & 0.0034+0.1187i & -0.0021+0.0192i \\
-0.0014+0.0353i & -0.0018+0.0459i & -0.0012+0.0434i & -0.0032+0.0294i & 0.0033+0.0713i & 0.0539i & 0.0073+0.1434i & 0.0027+0.0945i & 0.0026+0.0683i & -0.0021+0.0192i & 0.0052+0.1739i
\end{bmatrix}$$

In [4]:

```
# Balanced fault analysis at bus 8
symfault(zdata,zbus)
```

executed in 4.93s, finished 19:53:02 2022-08-20

```
Enter Faulted Bus No. -> 8
Enter Fault Impedance Zf = R + Xj in complex form (for bolted fault enter 0). Zf = 0

Balanced three-phase fault at bus No. 8
Total fault current = 3.3319 Per unit

Bus Voltages during the fault in per unit
  Bus No.    Magnitude (pu.)    Angle (deg.)
---------  -----------------  --------------
        1             0.8082         -1.818
        2             0.7508        -2.5443
        3             0.6882        -1.5987
        4             0.7491        -2.4902
        5             0.7007        -2.3762
        6             0.5454        -1.0194
        7             0.5618        -3.8128
        8             0              0
        9             0.3008         2.4499
       10             0.8362        -1.4547
       11             0.6866        -2.2272

Line currents for fault at bus No. 8
  From    To    Magnitude (pu.)    Angle (deg.)
------  ----  -----------------  --------------
     1     2             0.9697        -82.4034
     2     3             0.2053        -87.8751
     2     5              0.323        -79.9626
     2     6             0.4427        -81.6497
     3     6             0.3556        -88.0987
     4     3             0.1503        -88.4042
     4     6             0.3305        -82.3804
     4     9             0.6229        -81.3672
     5     7              0.323        -79.9626
     6     8             1.1274        -83.8944
     7     8              1.582        -84.0852
     8     F             3.3319        -83.5126
     9     8             0.6229        -81.3672
    10     4             1.1029        -82.6275
    11     7             1.2601         -85.141
```

2. Unbalanced Fault Analysis Using Symmetrical Components

In [5]:

```
# Build bus impedance matrix from zdata...
# From bus (No.), To bus (No.), R (pu.), X(pu.)
zdata1 = np.array([
    [0,1,0,0.25],
    [0,2,0,0.25],
    [1,2,0,0.125],
    [1,3,0,0.15],
    [2,3,0,0.25]
])
zdata2 = zdata1
zdata0 = np.array([
    [0,1,0,0.4],
    [0,2,0,0.1],
    [1,3,0,0.35],
    [1,2,0,0.3],
    [2,3,0,0.7125]
])

# Sequence bus impedance matrix.
zbus1 = zbuild(zdata1)
zbus2 = zbus1
zbus0 = zbuild(zdata0)
```

executed in 32ms, finished 19:53:02 2022-08-20

In [6]:

```
display(Latex("$\mathbf{Z}_{bus}^0 = $"), Matrix(np.round(zbus0,4)))
display(Latex("$\mathbf{Z}_{bus}^1 = \mathbf{Z}_{bus}^2 = $"), Matrix(np.round(zbus0,4)))
```

executed in 62ms, finished 19:53:02 2022-08-20

$$\mathbf{Z}_{bus}^0 = \begin{bmatrix} 0.182i & 0.0545i & 0.14i \\ 0.0545i & 0.0864i & 0.065i \\ 0.14i & 0.065i & 0.35i \end{bmatrix}$$

$$\mathbf{Z}_{bus}^1 = \mathbf{Z}_{bus}^2 = \begin{bmatrix} 0.182i & 0.0545i & 0.14i \\ 0.0545i & 0.0864i & 0.065i \\ 0.14i & 0.065i & 0.35i \end{bmatrix}$$

In [7]:

```
# Line to Ground fault at bus 3 with fault impedance Zf = j0.1 pu...
lgfault(zdata0,zbus0,zdata1,zbus1,zdata2,zbus2)
```

executed in 9.53s, finished 19:53:12 2022-08-20

```
Enter Faulted Bus No. -> 3
Enter Fault Impedance Zf = R + Xj in complex form (for bolted fault enter 0). Zf = 0.1j

Single line to-ground fault at bus No. 3
Total fault current = 2.7523 Per unit

Bus Voltages during the fault in per unit
  Bus No.       Phase A        Phase A       Phase B        Phase B       Phase C        Phase C
              Mag. (pu.)    Ang. (deg.)    Mag. (pu.)    Ang. (deg.)    Mag. (pu.)    Ang. (deg.)
---------  ------------  -------------  ------------  -------------  ------------  -------------
        1         0.633              0        1.0046       -120.453        1.0046        120.453
        2        0.7202              0        0.9757       -117.433        0.9757        117.433
        3        0.2752              0        1.0647       -125.567        1.0647        125.567

Line currents for fault at bus No. 3
  From    To       Phase A        Phase A       Phase B        Phase B       Phase C        Phase C
                Mag. (pu.)    Ang. (deg.)    Mag. (pu.)    Ang. (deg.)    Mag. (pu.)    Ang. (deg.)
------  ----  ------------  -------------  ------------  -------------  ------------  -------------
     1     3        1.6514            -90             0        78.6901             0        63.4349
     2     1        0.3761            -90         0.156            -90         0.156            -90
     2     3        1.1009            -90             0        114.775             0        42.8789
     3     F        2.7523            -90             0        18.4349             0        18.4349
```

In [8]:
```
# Line to Line fault at bus 3 with fault impedance Zf = j0.1 pu...
llfault(zdata0,zbus0,zdata1,zbus1,zdata2,zbus2)
```

executed in 3.63s, finished 19:53:15 2022-08-20

```
Enter Faulted Bus No. -> 3
Enter Fault Impedance Zf = R + Xj in complex form (for bolted fault enter 0). Zf = 0.1j

Line to-line fault at bus No. 3
Total fault current = 3.2075 Per unit

Bus Voltages during the fault in per unit
```

Bus No.	Phase A Mag. (pu.)	Phase A Ang. (deg.)	Phase B Mag. (pu.)	Phase B Ang. (deg.)	Phase C Mag. (pu.)	Phase C Ang. (deg.)
1	1	0	0.672	-138.073	0.672	138.073
2	1	0	0.6939	-136.102	0.6939	136.102
3	1	0	0.5251	-162.216	0.5251	162.216

```
Line currents for fault at bus No. 3
```

From	To	Phase A Mag. (pu.)	Phase A Ang. (deg.)	Phase B Mag. (pu.)	Phase B Ang. (deg.)	Phase C Mag. (pu.)	Phase C Ang. (deg.)
1	2	0	-90	0.2566	0	0.2566	180
1	3	0	-90	1.9245	180	1.9245	-0
2	3	0	0	1.283	180	1.283	-0
3	F	0	0	3.2075	180	3.2075	-0

In [9]:
```
# Double Line to Ground fault at bus 3 with fault impedance Zf = j0.1 pu...
dlgfault(zdata0,zbus0,zdata1,zbus1,zdata2,zbus2)
```

executed in 4.09s, finished 19:53:19 2022-08-20

```
Enter Faulted Bus No. -> 3
Enter Fault Impedance Zf = R + Xj in complex form (for bolted fault enter 0). Zf = 0.1j

Double line to-ground fault at bus No. 3
Total fault current = 1.9737 Per unit

Bus Voltages during the fault in per unit
```

Bus No.	Phase A Mag. (pu.)	Phase A Ang. (deg.)	Phase B Mag. (pu.)	Phase B Ang. (deg.)	Phase C Mag. (pu.)	Phase C Ang. (deg.)
1	1.0066	0	0.5088	-135.864	0.5088	135.864
2	0.9638	0	0.574	-136.702	0.574	136.702
3	1.0855	0	0.1974	180	0.1974	180

```
Line currents for fault at bus No. 3
```

From	To	Phase A Mag. (pu.)	Phase A Ang. (deg.)	Phase B Mag. (pu.)	Phase B Ang. (deg.)	Phase C Mag. (pu.)	Phase C Ang. (deg.)
1	2	0.1118	-90	0.3682	-31.2091	0.3682	-148.791
3	F	0	-90	4.0583	165.927	4.0583	14.0735
3	1	0	90	2.435	-14.0735	2.435	-165.927
3	2	0	90	1.6233	-14.0735	1.6233	-165.927

In [ ]:
```
```