**Modified 4 Bus Test System:**

The following systems are modifications to the IEEE 4 Node Test Feeder with a delta-grounded wye step down transformer. The top system is the base system which is purely intended for static power flow, the middle system incorporates a pv system and a padmount transformer, the bottom system incorporates an induction motor

A diagram of a diagram of a machine

Description automatically generated

Nodes 1-4 have not been modified.

Both the primary line (Node 1-Node 2) and the secondary lines (Node 3-Node 4), (Node 4-Node 5), and (Node 5-Node 6) will be constructed using the pole configuration shown in below.

A picture containing diagram, line, drawing

Description automatically generated

Phase Conductor: 336,400 26/7

GMR = 0.0244 ft., Resistance = 0.306 Ω/mile, Diameter = 0.721 inch

Neutral Conductor: 4/0 6/1 ACSR

GMR = 0.00814 ft., Resistance = 0.592 Ω/mile, Diameter = 0.563 inch

The source is a 12.47 kV line-to-line infinite bus.

The transformer has the following:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Connection | kVA | kVLL-high | kVLL-low | R-% | X-% |
| Step-Down | 6000 | 12.47 | 4.16 | 1.0 | 6.0 |

Load 1 Data:

|  |  |  |
| --- | --- | --- |
|  | Balanced | Unbalanced |
| **Phase-1** |  |  |
| kW | 1800 | 1275 |
| Power Factor | 0.9 lag | 0.9 lag |
| **Phase-2** |  |  |
| kW | 1800 | 1800 |
| Power Factor | 0.9 lag | 0.95 lag |
| **Phase-3** |  |  |
| kW | 1800 | 2375 |
| Power Factor | 0.9 lag | 0.85 lag |

Load 2 Data:

|  |  |  |
| --- | --- | --- |
|  | Balanced | Unbalanced |
| **Phase-1** |  |  |
| kW | 200 | 175 |
| Power Factor | 0.9 lag | 0.9 lag |
| **Phase-2** |  |  |
| kW | 200 | 225 |
| Power Factor | 0.9 lag | 0.95 lag |
| **Phase-3** |  |  |
| kW | 200 | 200 |
| Power Factor | 0.9 lag | 0.85 lag |

Motor Data:

*Ratings:*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Conn | Conn | kV | kW | kVA | Pole | rpm |
| IM | D | 0.48 | 372 | 478 | 4 | 1791 |

*Dynamic Parameters:*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| H | D | Rs | Rr | Xs | Xr | Xm | m |
| 1.6 | 1 | 0.007 | 0.0062 | 0.0409 | 0.0267 | 3.62 | 2.0 |

PV Data:

*Ratings:*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Conn | Ph-1 | Ph-1 | Ph-2 | Ph-2 | Ph-3 | Ph-3 |
|  | kVA | pf | kVA | pf | kVA | pf |
| D | 120 | 0.95 | 120 | 0.95 | 120 | 0.95 |

*Dynamic Parameters:*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| R | X | Kp | kVDC | KP Tol | Safe Voltage |
| 0.5 | 0.5 | 0.01 | 0.03 | 0.1 | 0 |

Padmount transformer:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| kVA | kV-high | kV-low | R - % | X - % |
| 500 | 4.16 – Gr.W | 0.48 – Gr.W | 1.1 | 2 |

**Powerflow Results**

This section details the steady state powerflow results for all three systems and compares them across simulation platforms

**Base Case**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **OpenDSS** | **GridLab-D** | **Simscape** |
| **Node-2** |  |  |  |
| V1 | 7098.3 / -0.3 | 7097.355 / -0.30785 |  |
| V2 | 7120.2 / -120.4 | 7122.654 / 239.6148 |  |
| V3 | 7108.9 / 119.5 | 7106.796 / 119.5318303 |  |
| **Node-3** |  |  |  |
| V1 | 2258.5 / -36.8 | 2219.573 / -34.2637 |  |
| V2 | 2313. / -152.1 | 2240.842 / 206.1693 |  |
| V3 | 2128.6 / 86.7 | 2234.01 / 85.85916 |  |
| **Node-4** |  |  |  |
| V1 | 1905.2 / -42.7 | 1828.944 / -40.7268 |  |
| V2 | 2032.8 / -157.5 | 2008.542 / 200.5284 |  |
| V3 | 1819.4 / 79.5 | 1914.66 / 79.54826 |  |
| **Node-5** |  |  |  |
| V1 | 1891.3 / -43.0 | 1813.553 / -41.0446 |  |
| V2 | 2032.8 / -157.5 | 1999.647 / 200.2757 |  |
| V3 | 1819.4 / 79.5 | 1902.185 / 79.2541 |  |
| **Node-6** |  |  |  |
| V1 | 1877.4 / -43.3 | 1798.218 / -41.3679 |  |
| V2 | 2010.8 / -158.0 | 1990.79 / 200.0208 |  |
| V3 | 1795.6 / 78.8 | 1889.761 / 78.95599 |  |
| **Current 1-2** |  |  |  |
| Ia | 385.75 / -35.8 |  |  |
| Ib | 386.46 / -156.3 |  |  |
| Ic | 388.81 / 84.0 |  |  |
| **Current 3-4** |  |  |  |
| Ia | 1159.8 / -66.1 |  |  |
| Ib | 1159.9 / 174.0 |  |  |
| Ic | 1160.7 / 53.9 |  |  |
| **Current 4-5** |  |  |  |
| Ia | 117.32 / -66.6 |  |  |
| Ib | 117.33 / 173.5 |  |  |
| Ic | 117.43 / 53.4 |  |  |
| **Current 5-6** |  |  |  |
| Ia | 117.32 / -66.6 |  |  |
| Ib | 117.33 / 173.5 |  |  |
| Ic | 117.43 / 53.4 |  |  |

**Induction Motor Case**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **OpenDSS** | **GridLab-D** | **Simscape** |
| **Node-2** |  |  |  |
| V1 | 7089.4 / -0.4 |  |  |
| V2 | 7112.5/ -120.4 |  |  |
| V3 | 7102.0/ 119.5 |  |  |
| **Node-3** |  |  |  |
| V1 | 2245.5/ -37.2 |  |  |
| V2 | 2295.4 / -152.4 |  |  |
| V3 | 2114.1/ 86.4 |  |  |
| **Node-4** |  |  |  |
| V1 | 1867.0/ -43.7 |  |  |
| V2 | 1988.3 / -158.4 |  |  |
| V3 | 1780.4/ 78.7 |  |  |
| **Node-5** |  |  |  |
| V1 | 1846.7/ -44.2 |  |  |
| V2 | 1969.6/ -158.8 |  |  |
| V3 | 1762.3/ 78.1 |  |  |
| **Node-6** |  |  |  |
| V1 | 1832.5/ -44.5 |  |  |
| V2 | 1958.4/ -159.1 |  |  |
| V3 | 1750.1/ 78.8 |  |  |
| **Current 1-2** |  |  |  |
| Ia | 420.68 / -36.0 |  |  |
| Ib | 419.44 / -157.3 |  |  |
| Ic | 416.95 / -83.6 |  |  |
| **Current 3-4** |  |  |  |
| Ia | 1252.8 / -66.0 |  |  |
| Ib | 1267.7 / 173.3 |  |  |
| Ic | 1247.7 / 53.0 |  |  |
| **Current 4-5** |  |  |  |
| Ia | 188.63 / -60.8 |  |  |
| Ib | 202.61 / 174.4 |  |  |
| Ic | 181.88 / 52.9 |  |  |
| **Current 5-6** |  |  |  |
| Ia | 120.36 / -67.7 |  |  |
| Ib | 120.38 / 172.3 |  |  |
| Ic | 120.46 / 52.3 |  |  |

**PV Case**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **OpenDSS** | **GridLab-D** | **Simscape** |
| **Node-2** |  |  |  |
| V1 |  |  |  |
| V2 |  |  |  |
| V3 |  |  |  |
| **Node-3** |  |  |  |
| V1 |  |  |  |
| V2 |  |  |  |
| V3 |  |  |  |
| **Node-4** |  |  |  |
| V1 |  |  |  |
| V2 |  |  |  |
| V3 |  |  |  |
| **Node-5** |  |  |  |
| V1 |  |  |  |
| V2 |  |  |  |
| V3 |  |  |  |
| **Node-6** |  |  |  |
| V1 |  |  |  |
| V2 |  |  |  |
| V3 |  |  |  |
| **Current 1-2** |  |  |  |
| Ia |  |  |  |
| Ib |  |  |  |
| Ic |  |  |  |
| **Current 3-4** |  |  |  |
| Ia |  |  |  |
| Ib |  |  |  |
| Ic |  |  |  |
| **Current 4-5** |  |  |  |
| Ia |  |  |  |
| Ib |  |  |  |
| Ic |  |  |  |
| **Current 5-6** |  |  |  |
| Ia |  |  |  |
| Ib |  |  |  |
| Ic |  |  |  |

**Dynamics Results**

This section details the results of dynamic simulations. There are two dynamic cases presented. The first is a due to a three-phase fault and the second is due to a single phase fault.

**Induction Motor Case**

The modified 4 node circuit with the IM placed at bus 4 is shown below. The red x indicates the fault which occurs at bus 4.

A diagram of a diagram

Description automatically generated

Fault occurs at t = 0.0833 s and lasts for 0.3333 s until t = 0.4167 where it clears. The following results show the motor current during the initial fault, fault current subsiding, and the inrush current as the fault clears and the system is restored.

A graph of a graph

Description automatically generated