**Protection System Planning for Distribution Networks: a Probabilistic Approach – Data**

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**Distribution Network Data**

**Table 1 – Bus Data**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Node | P\_a (W) | Q\_a (VAr) | P\_b | Q\_b | P\_c | Q\_c | Node | P\_a (W) | Q\_a (VAr) | P\_b | Q\_b | P\_c | Q\_c |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 69 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 2147 | 914 | 2147 | 914 | 2147 | 914 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 71 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 4 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 | 72 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 73 | 2607 | 1110 | 2607 | 1110 | 2607 | 1110 |
| 6 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 74 | 583 | 248 | 583 | 248 | 583 | 248 |
| 7 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 75 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 8 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 76 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 9 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 77 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 10 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 78 | 1809 | 771 | 1809 | 771 | 1809 | 771 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 79 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 80 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 13 | 2637 | 1123 | 2637 | 1123 | 2637 | 1123 | 81 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 14 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 82 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 15 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 83 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 84 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 17 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 | 85 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 18 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 86 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 87 | 4753 | 2025 | 4753 | 2025 | 4753 | 2025 |
| 20 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 88 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 21 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 89 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 22 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 90 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 23 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 91 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 92 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 |
| 25 | 920 | 392 | 920 | 392 | 920 | 392 | 93 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 | 94 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 95 | 7207 | 3070 | 7207 | 3070 | 7207 | 3070 |
| 28 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 96 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 97 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 30 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 98 | 1840 | 784 | 1840 | 784 | 1840 | 784 |
| 31 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 99 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 100 | 7207 | 3070 | 7207 | 3070 | 7207 | 3070 |
| 33 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 101 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 34 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 102 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 35 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 103 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 104 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 3803 | 1620 | 3803 | 1620 | 3803 | 1620 | 105 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 38 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 106 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 107 | 33273 | 14174 | 33273 | 14174 | 33273 | 14174 |
| 40 | 920 | 392 | 920 | 392 | 920 | 392 | 108 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 109 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 110 | 33273 | 14174 | 33273 | 14174 | 33273 | 14174 |
| 43 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 111 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 44 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 112 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 45 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 113 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 |
| 46 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 | 114 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 307 | 131 | 307 | 131 | 307 | 131 | 115 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 116 | 9200 | 3919 | 9200 | 3919 | 9200 | 3919 |
| 49 | 0 | 0 | 0 | 0 | 0 | 0 | 117 | 9200 | 3919 | 9200 | 3919 | 9200 | 3919 |
| 50 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 118 | 9200 | 3919 | 9200 | 3919 | 9200 | 3919 |
| 51 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 119 | 9200 | 3919 | 9200 | 3919 | 9200 | 3919 |
| 52 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 120 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | 0 | 0 | 0 | 0 | 0 | 0 | 121 | 9200 | 3919 | 9200 | 3919 | 9200 | 3919 |
| 54 | 368 | 157 | 368 | 157 | 368 | 157 | 122 | 16867 | 7185 | 16867 | 7185 | 16867 | 7185 |
| 55 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 123 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 124 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 125 | 4753 | 2025 | 4753 | 2025 | 4753 | 2025 |
| 58 | 0 | 0 | 0 | 0 | 0 | 0 | 126 | 4753 | 2025 | 4753 | 2025 | 4753 | 2025 |
| 59 | 3067 | 1306 | 3067 | 1306 | 3067 | 1306 | 127 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 |
| 60 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 | 128 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 61 | 1165 | 496 | 1165 | 496 | 1165 | 496 | 129 | 0 | 0 | 0 | 0 | 0 | 0 |
| 62 | 920 | 392 | 920 | 392 | 920 | 392 | 130 | 13800 | 5879 | 13800 | 5879 | 13800 | 5879 |
| 63 | 1687 | 719 | 1687 | 719 | 1687 | 719 | 131 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | 0 | 0 | 0 | 0 | 0 | 0 | 132 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 65 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 133 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 23000 | 9798 | 23000 | 9798 | 23000 | 9798 | 134 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 67 | 1073 | 457 | 1073 | 457 | 1073 | 457 | 135 | 34500 | 14697 | 34500 | 14697 | 34500 | 14697 |
| 68 | 0 | 0 | 0 | 0 | 0 | 0 | 136 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 2 – Line Data**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| From node | To node | Branch length (km) | Cable Type | Rate of Permanent Faults (faults/km/year) | Rate of Temporary Faults | Percentage of Residential Consumers **\*** | Percentage of Commercial Consumers **\*** | Percentage of Industrial Consumers **\*** | Number of Consumers Per Phase **\*** |
| 136 | 1 | - | Transf | - | - | 50 | 30 | 20 | 0 |
| 1 | 2 | 0.9 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 2 | 3 | 0.05 | 3 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 3 | 4 | 0.1 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 3 | 5 | 0.04 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 5 | 6 | 0.2 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 6 | 7 | 0.2 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 7 | 8 | 0.2 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 8 | 9 | 0.01 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 9 | 10 | 0.05 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 10 | 11 | 0.1 | 2 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 11 | 12 | 0.06 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 0 |
| 12 | 13 | 0.03 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 13 | 14 | 0.16 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 14 | 15 | 0.03 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 12 | 16 | 0.01 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 16 | 17 | 0.02 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 17 | 18 | 0.04 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 18 | 19 | 0.04 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 0 |
| 19 | 20 | 0.05 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 20 | 21 | 0.15 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 19 | 22 | 0.03 | 1 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 11 | 23 | 0.07 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 23 | 24 | 0.05 | 2 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 24 | 25 | 0.02 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 25 | 26 | 0.03 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 26 | 27 | 0.06 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 0 |
| 27 | 28 | 0.04 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 28 | 29 | 0.02 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 0 |
| 29 | 30 | 0.12 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 30 | 31 | 0.02 | 3 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 29 | 32 | 0.02 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 27 | 33 | 0.005 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 33 | 34 | 0.025 | 2 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 34 | 35 | 0.01 | 1 | 0.072 | 0.98 | 70 | 25 | 5 | 30 |
| 24 | 36 | 0.07 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 36 | 37 | 0.01 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 37 | 38 | 0.01 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 38 | 39 | 0.07 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 39 | 40 | 0.1 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 39 | 41 | 0.06 | 2 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 41 | 42 | 0.05 | 2 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 41 | 43 | 0.01 | 2 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 43 | 44 | 0.03 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 41 | 45 | 0.04 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 45 | 46 | 0.06 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 39 | 47 | 0.02 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 47 | 48 | 0.12 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 48 | 49 | 0.05 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 49 | 50 | 0.02 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 50 | 51 | 0.17 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 51 | 52 | 0.1 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 49 | 53 | 0.06 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 0 |
| 53 | 54 | 0.03 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 54 | 55 | 0.13 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 55 | 56 | 0.02 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 53 | 57 | 0.08 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 57 | 58 | 0.05 | 3 | 0.072 | 0.98 | 15 | 5 | 80 | 0 |
| 58 | 59 | 0.06 | 3 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 58 | 60 | 0.02 | 3 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 60 | 61 | 0.04 | 1 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 49 | 62 | 0.01 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 62 | 63 | 0.05 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 63 | 64 | 0.03 | 4 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 64 | 65 | 0.02 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 65 | 66 | 0.03 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 66 | 67 | 0.02 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 67 | 68 | 0.03 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 0 |
| 68 | 69 | 0.02 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 68 | 70 | 0.02 | 2 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 70 | 71 | 0.05 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 68 | 72 | 0.04 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 72 | 73 | 0.04 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 73 | 74 | 0.02 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 74 | 75 | 0.11 | 4 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 75 | 76 | 0.02 | 1 | 0.072 | 0.98 | 15 | 5 | 80 | 20 |
| 64 | 77 | 0.03 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 77 | 78 | 0.05 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 78 | 79 | 0.07 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 79 | 80 | 0.07 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 80 | 81 | 0.03 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 81 | 82 | 0.03 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 82 | 83 | 0.05 | 2 | 0.072 | 0.98 | 50 | 30 | 20 | 0 |
| 83 | 84 | 0.05 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 83 | 85 | 0.03 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 85 | 86 | 0.03 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 86 | 129 | 0.02 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 129 | 87 | 0.13 | 3 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 87 | 88 | 0.005 | 1 | 0.072 | 0.98 | 50 | 30 | 20 | 10 |
| 79 | 89 | 0.05 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 79 | 90 | 0.18 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 90 | 91 | 0.02 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 91 | 92 | 0.03 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 92 | 93 | 0.07 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 93 | 94 | 0.1 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 93 | 95 | 0.04 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 93 | 96 | 0.05 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 96 | 97 | 0.06 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 96 | 98 | 0.11 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 98 | 99 | 0.04 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 99 | 100 | 0.11 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 99 | 101 | 0.06 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 101 | 102 | 0.04 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 96 | 103 | 0.03 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 103 | 104 | 0.15 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 104 | 105 | 0.21 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 104 | 106 | 0.03 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 106 | 107 | 0.1 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 107 | 108 | 0.1 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 108 | 109 | 0.03 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 109 | 110 | 0.02 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 110 | 111 | 0.17 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 111 | 112 | 0.11 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 108 | 113 | 0.11 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 113 | 114 | 0.2 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 114 | 115 | 0.2 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 114 | 116 | 0.2 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 116 | 117 | 0.2 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 117 | 118 | 0.11 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 118 | 119 | 0.07 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 91 | 120 | 0.07 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 120 | 121 | 0.07 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 121 | 122 | 0.13 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 120 | 123 | 0.02 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 123 | 124 | 0.02 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 124 | 125 | 0.04 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 124 | 126 | 0.04 | 2 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 126 | 127 | 0.02 | 1 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 127 | 128 | 0.06 | 3 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 129 | 130 | 0.07 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 105 | 131 | 0.02 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 131 | 132 | 0.1 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 131 | 133 | 0.04 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 0 |
| 133 | 134 | 0.04 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |
| 134 | 135 | 0.04 | 4 | 0.072 | 0.98 | 5 | 10 | 85 | 5 |

**\* Loads are connected to the end node.**

**Table 3 – Distributed Generators Data**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Generator | Capacity (kVA) | Cut in Wind (m/s) | Cut off Wind (m/s) | Nominal Wind (m/s) | Transient Impedance (Ω) |
| DG 1 | 1000 | - | - | - | 0.0692 + j19.8322 |
| DG 2 | 1000 | - | - | - | 0.0692 + j19.8322 |
| DG 3 | 1000 | - | - | - | 0.0692 + j19.8322 |
| Wind Farm | 1000 | 4 | 25 | 13 | 0.0692 + j19.8322 |
| Solar Farm | 50 | - | - | - | - |

Each generator is connected to the distribution system through a 13.8/6.6 kV transformer with X = 0.06 pu and R = 0.007 pu and corresponding apparent power.

**Table 4 – Stochastic Variables Parameters**

|  |  |  |
| --- | --- | --- |
| Variable | Probability Density Function | PDF Parameters |
| Load | Normal | µ = node nominal power, σ = 0.4\*µ/3 |
| Wind Speed | Weibull | α = 2.22, β = 9.70 |
| Solar Irradiation | Uniform (Real) | Min = 0.0, Max = 1.0 |
| Fault Location | Uniform (Integer) | Min = 1, Max = 136 |
| Fault Impedance | Lognormal | µ = 1.60944 [ln(5)], σ = 1 |

The fault type is modelled as follows: 60% single phase, 20% phase-phase, 15% three-phase, 5% two-phase-ground. Faults are applied in all phases for every fault type, *e.g.*, a single phase fault may be applied to phase A, B or C, according to a uniform distribution.

The wind farm power ( in each iteration is calculated as follows:

Where is the generator’s nominal power, is the turbine’s cut in speed, is the turbine’s nominal speed, and is the wind’s velocity (determined randomly according to the Weibull distribution).

The solar farm injection is given by the product of a random number (generated according to a uniform distribution) and the plant’s capacity.

**Table 5 – Interruption Cost Depending on the Consumer Type**

|  |  |
| --- | --- |
| Consumer Type | Interruption Cost ($/kWh) |
| Residential | 1.50 |
| Commercial | 3.00 |
| Industrial | 4.64 |

**Table 6 – Protective/Maneuvering Devices’ Cost**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Device | Operational Current Range (A) | Acquisition Cost ($) | Installation/Uninstallation Cost ($) | Annual Maintenance Cost ($) |
| Fuse | 0-6 | 300 | 100 | 50 |
| 6-10 | 400 |
| 10-15 | 500 |
| 15-25 | 600 |
| 25-40 | 700 |
| 40-65 | 800 |
| 65-100 | 900 |
| 100-140 | 1000 |
| 140-200 | 1100 |
| Automatic Recloser | 0-1000 | 15000 | 2000 | 1000 |
| Automatic Sectionalizing Switch | 0-1000 | 3500 | 800 | 350 |
| Island Interconnection Device | 0-1000 | 20000 | 2500 | 1500 |

**NSGA-II Parameters**

The algorithm developed for this paper adopts the following parameters: population with 500 individuals and 2000 generations. The recombination and mutation indexes are refreshed every generation according to (1) and (2), respectively.

(1)

(2)

Where and are, respectively, the recombination and mutation indexes at generation and is the limit of generations. , , , and.

In addition to the Crowding Distance routine we also employ a Euclidian distance calculation as a dissimilarity measure. The potential of each individual within its frontier is given by (3).

(3)

Where is the potential of an individual at generation , is the individual’s crowding distance value calculated for generation , and is the Euclidian distance calculated for generation . Whenever two individuals have similar codification, a negative Euclidian distance is attributed to one of them, according to the following parameters:

1. The solution that belongs to the worse frontier receives the negative value;
2. The solution with most constraint violations receives the negative value;
3. The solution with the higher value for the sum of the normalized objective functions receives the negative value.

Individuals with negative potential are replaced with new solutions every generation.

**Protection System Design**

**Table 7 – Phase Currents for Short-Circuit and Nominal Operation**

|  |  |  |  |
| --- | --- | --- | --- |
| Protective Device | Maximum Short-Circuit Current | Minimum Short-Circuit Current | Operating Current |
| Substation Relay | 1900 A | 550 A | 314.50 A |
| Fuse 50 | 2100 A | 650 A | 16.28 A |
| IID 80 | 100 A | 50 A | 35.30 A |
| IID 107 | 200 A | 100 A | 62.12 A |
| IID 120 | 150 A | 50 A | 41.47 A |

**Table 8 – Neutral Currents for Short-Circuit and Nominal Operation**

|  |  |  |  |
| --- | --- | --- | --- |
| Protective Device | Maximum Short-Circuit Current | Minimum Short-Circuit Current | Operating Current |
| Substation Relay | 1290 A | 195 A | 24.01 A |
| Fuse 50 | 1740 A | 345 A | 5.73 A |
| IID 80 | 120 A | 30 A | 8.05 A |
| IID 107 | 210 A | 45 A | 7.98 A |
| IID 120 | 105 A | 30 A | 0.98 A |

**Table 9 – Protective Devices Sizing and Parameters**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Protective Device | Unit | Curve | Time Dial | Maximum Acting Time (sec) | Minimum Acting Time (sec) | Pickup Current (A) |
| Substation Relay | Phase | Very Inverse | 3 | - | 6.610 | 524 |
| Neutral | Very Inverse | 9 | - | 6.312 | 143 |
| IID 80 | Phase | Very Inverse | 1.5 | - | 7.037 | 42 |
| Neutral | Extremely Inverse | 10 | - | 6.891 | 12 |
| IID 107 | Phase | Very Inverse | 3 | - | 8.421 | 65 |
| Neutral | Very Inverse | 10 | - | 5.916 | 15 |
| IID 120 | Phase | Very Inverse | 2 | - | 8.452 | 60 |
| Neutral | Very Inverse | 10 | - | 6.705 | 10 |
| Fuse (80T) | - | - | - | 5.826 | 0.08 | - |