132 kV Power Factory study case

Workshop 1 – Part 2
Monday 14.09.2020 – Friday 18.09.2020

- Session 4
  - 11 kV Power Factory study case – dynamic iterative loss calculation method
- Session 5
  - 132 kV Power Factory study case – how the loss pattern is affected by changes in power flow direction as the traditional top-down system is challenged
- Session 6
  - Review on loss calculation procedures and tools
    - Review note D1.1 with gap analysis

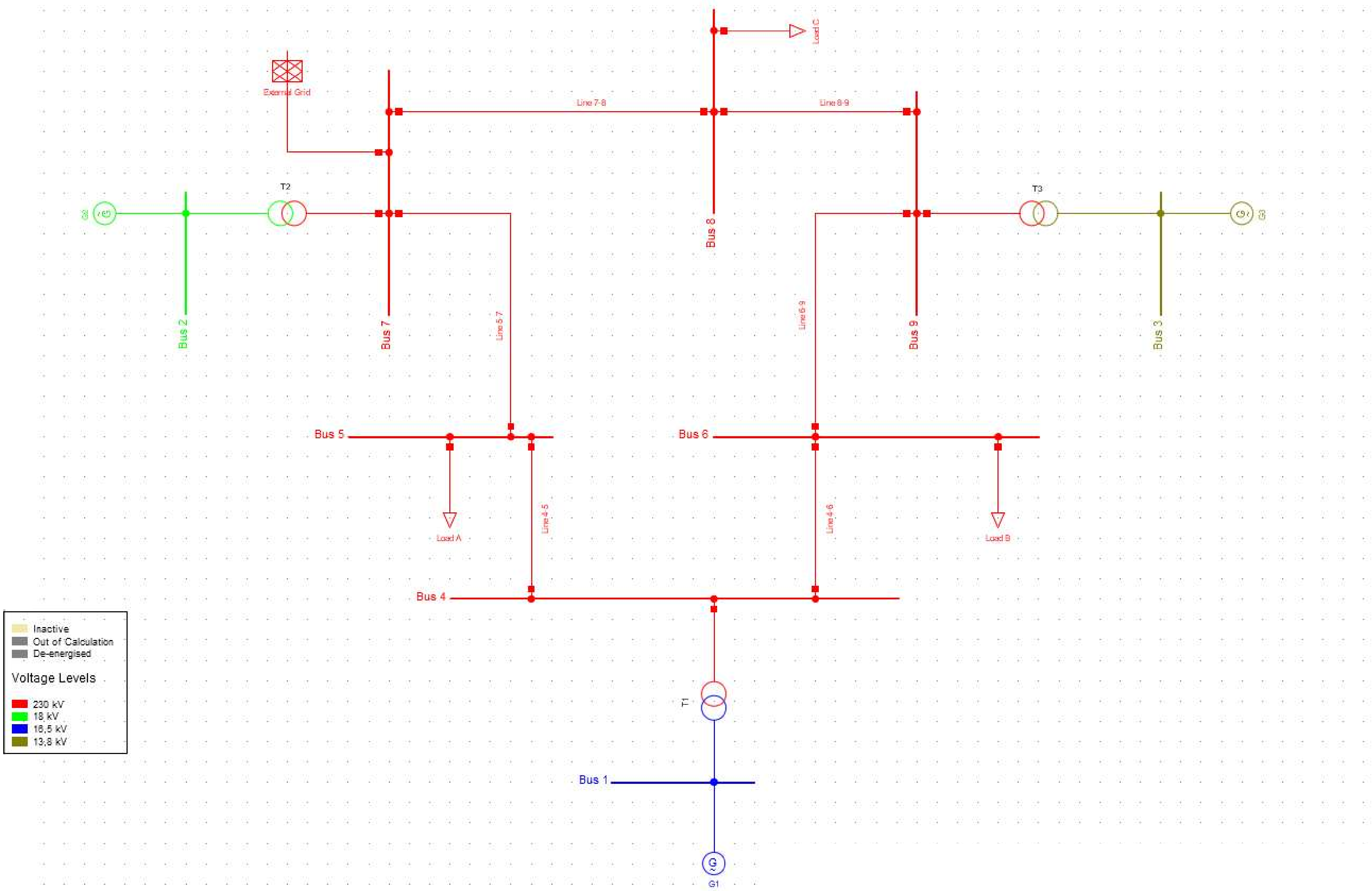
Pre-recorded sessions released on Monday 14.09.2020

QA session: Monday 21.09.2020

Case study – PF Nine bus System

- Three generators (DVG) distributed in a sub-transmission network
  - G1 keeps active power balance (“slack” or “reference machine”)
  - G2 and G3 at fixed active power outputs (163 MW resp. 85 MW)
- “External grid” represents an overlaying transmission level that previously provided all power to this system alone (top-down)

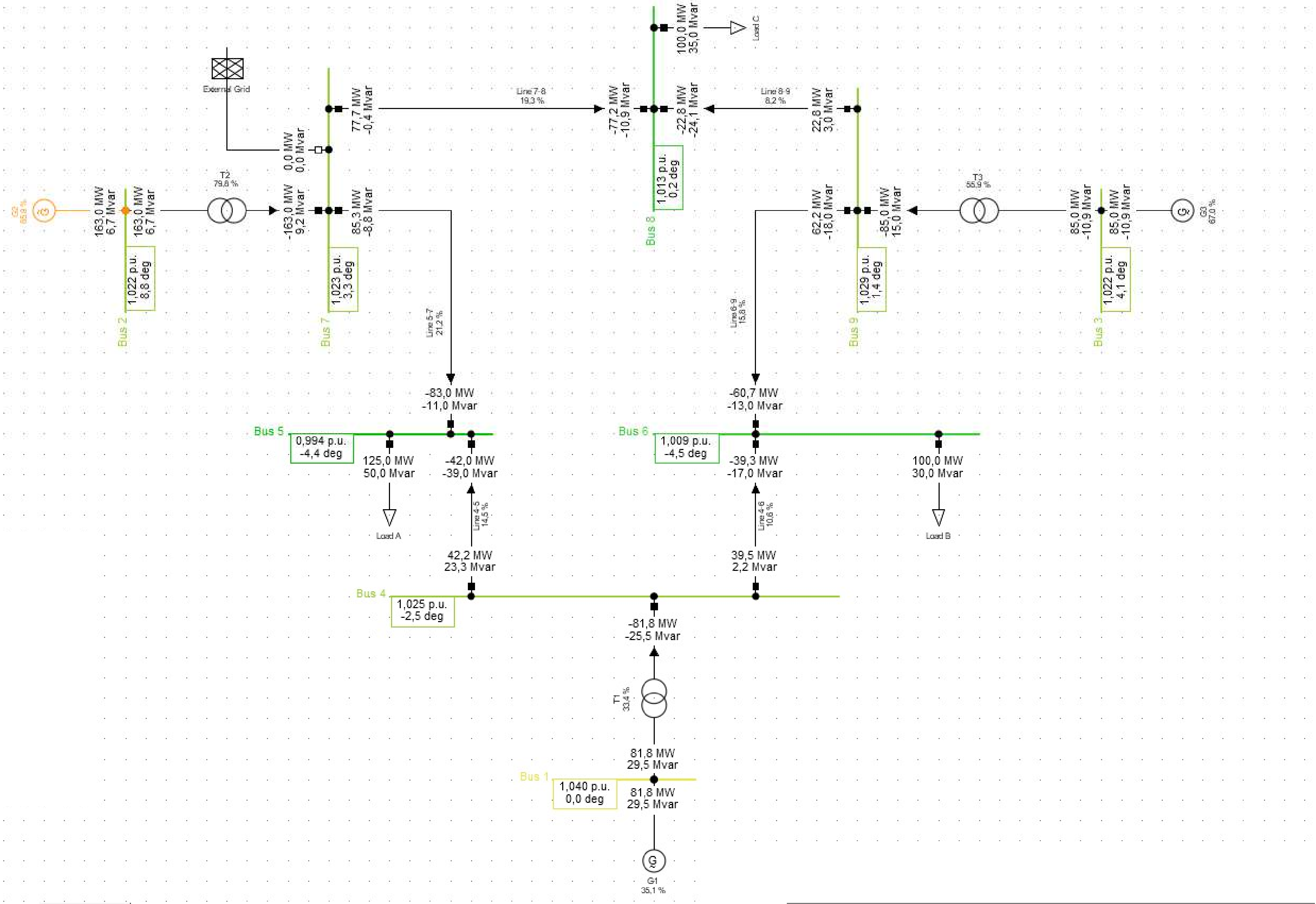
- Let’s study some cases and see how the loss pattern changes with DVG



Load C
External Grid
Line 7-8
Line 8-9
T2
T3
Bus 8
Bus 2
Bus 7
Bus 9
Bus 3
Line 5-7
Line 6-9
Bus 5
Bus 6
Load A
Line 4-5
Line 4-6
Load B
Bus 4
Inactive
Out of Calculation
De-energised
Voltage Levels
230 kV
18 kV
16,5 kV
13,8 kV
T1
Bus 1
G1

Case 1 – G1 keeps active power balance

- G1 keeps active power balance (slack)
- G2 and G3 at fixed active power outputs
- External grid disconnected



Load C
100,0 MW
35,0 Mvar
External Grid
Line 7-8
19,3 %
Line 8-9
8,2 %
77,7 MW
-0,4 Mvar
-77,2 MW
-10,9 Mvar
-22,8 MW
-24,1 Mvar
22,8 MW
3,0 Mvar
0,0 MW
0,0 Mvar
1,013 p.u.
0,2 deg
Bus 8
T2
79,8 %
T3
55,9 %
G2
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
-163,0 MW
9,2 Mvar
85,3 MW
-8,8 Mvar
62,2 MW
-18,0 Mvar
-85,0 MW
15,0 Mvar
85,0 MW
-10,9 Mvar
85,0 MW
-10,9 Mvar
G3
67,0 %
1,022 p.u.
8,8 deg
Bus 2
1,023 p.u.
3,3 deg
Bus 7
1,029 p.u.
1,4 deg
Bus 9
1,022 p.u.
4,1 deg
Bus 3
Line 5-7
21,2 %
Line 6-9
15,8 %
-83,0 MW
-11,0 Mvar
-60,7 MW
-13,0 Mvar
Bus 5
0,994 p.u.
-4,4 deg
125,0 MW
50,0 Mvar
-42,0 MW
-39,0 Mvar
Bus 6
1,009 p.u.
-4,5 deg
-39,3 MW
-17,0 Mvar
100,0 MW
30,0 Mvar
Load A
Load B
Line 4-5
14,5 %
Line 4-6
10,6 %
42,2 MW
23,3 Mvar
39,5 MW
2,2 Mvar
Bus 4
1,025 p.u.
-2,5 deg
-81,8 MW
-25,5 Mvar
T1
33,4 %
81,8 MW
29,5 Mvar
Bus 1
1,040 p.u.
0,0 deg
81,8 MW
29,5 Mvar
G1
35,1 %

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|                  |                                                                 |   DIgSILENT   | Project:                   |
|                  |                                                                 | PowerFactory  |----------------------------
|                  |                                                                 |    2019 SP4   | Date:  2020-02-14          |
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| Load Flow Calculation                                                                                              Grid Summary |
-----------------------------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence               |   Automatic Model Adaptation for Convergence          No          |
|    Automatic tap adjustment of transformers        No      |   Max. Acceptable Load Flow Error for                             |
|    Consider reactive power limits                  No      |      Nodes                                           1,00 kVA    |
|                                                            |      Model Equations                                 0,10 %      |
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| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow          | Annex:                      / 1  |
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| Grid: Nine-bus System      Summary                                                                                              |
|                                                                                                                                 |
| No. of Substations     0         No. of Busbars        9         No. of Terminals      0         No. of Lines          6        |
| No. of 2-w Trfs.       3         No. of 3-w Trfs.      0         No. of syn. Machines  3         No. of asyn.Machines  0        |
| No. of Loads           3         No. of Shunts/Filters 0         No. of SVS            0                                        |
|                                                                                                                                 |
| Generation            =     329,78  MW          25,34   Mvar      330,75  MVA                                                  |
| External Infeed       =       0,00  MW           0,00   Mvar        0,00  MVA                                                  |
| Inter Grid Flow       =       0,00  MW           0,00   Mvar                                                                   |
| Load P(U)             =     325,00  MW         115,00   Mvar      344,75  MVA                                                  |
| Load P(Un)            =     325,00  MW         115,00   Mvar      344,75  MVA                                                  |
| Load P(Un-U)          =      -0,00  MW           0,00   Mvar                                                                   |
| Motor Load            =       0,00  MW           0,00   Mvar        0,00  MVA                                                  |
| Grid Losses           =       4,78  MW         -89,66   Mvar                                                                   |
| Line Charging         =                       -139,84   Mvar                                                                   |
| Compensation ind.     =                          0,00   Mvar                                                                   |
| Compensation cap.     =                          0,00   Mvar                                                                   |
|                                                                                                                                 |
| Installed Capacity    =     519,50  MW                                                                                          |
| Spinning Reserve      =     189,72  MW                                                                                          |
|                                                                                                                                 |
| Total Power Factor:                                                                                                             |
|   Generation          =         1,00  [-]                                                                                       |
|   Load/Motor          =  0,94 / 0,00  [-]                                                                                       |
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|                 |                                                                 |   DIgSILENT   | Project:                          |
|                 |                                                                 | PowerFactory  |-----------------------------------
|                 |                                                                 |    2019 SP4   | Date:  2020-02-14                 |
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| Load Flow Calculation                                                                                              Grid Summary |
------------------------------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence             |   Automatic Model Adaptation for Convergence          No              |
|    Automatic tap adjustment of transformers         No   |   Max. Acceptable Load Flow Error for                                 |
|    Consider reactive power limits                   No   |      Nodes                                           1,00 kVA         |
|                                                          |      Model Equations                                 0,10 %           |
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------------------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow            | Annex:                    / 1  |
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| Grid: Nine-bus System      Summary                                                                                              |
|                                                                                                                                  |
| No. of Substations     0          No. of Busbars        9          No. of Terminals      0          No. of Lines           6     |
| No. of 2-w Trfs.       3          No. of 3-w Trfs.      0          No. of syn. Machines  3          No. of asyn.Machines   0     |
| No. of Loads           3          No. of Shunts/Filters 0          No. of SVS            0                                        |
|                                                                                                                                  |
| Generation           =     329,78  MW          25,34   Mvar      330,75  MVA                                                     |
| External Infeed      =       0,00  MW           0,00   Mvar        0,00  MVA                                                     |
| Inter Grid Flow      =       0,00  MW           0,00   Mvar                                                                      |
| Load P(U)            =     325,00  MW         115,00   Mvar      344,75  MVA                                                     |
| Load P(Un)           =     325,00  MW         115,00   Mvar      344,75  MVA                                                     |
| Load P(Un-U)         =      -0,00  MW           0,00   Mvar                                                                      |
| Motor Load           =       0,00  MW           0,00   Mvar        0,00  MVA                                                     |
| Grid Losses          =       4,78  MW         -89,66   Mvar                                                                      |
| Line Charging        =                       -139,84   Mvar                                                                      |
| Compensation ind.    =                          0,00   Mvar                                                                      |
| Compensation cap.    =                          0,00   Mvar                                                                      |
|                                                                                                                                  |
| Installed Capacity   =     519,50  MW                                                                                            |
| Spinning Reserve     =     189,72  MW                                                                                            |
|                                                                                                                                  |
| Total Power Factor:                                                                                                              |
|   Generation         =         1,00  [-]                                                                                         |
|   Load/Motor         =  0,94 / 0,00  [-]                                                                                         |
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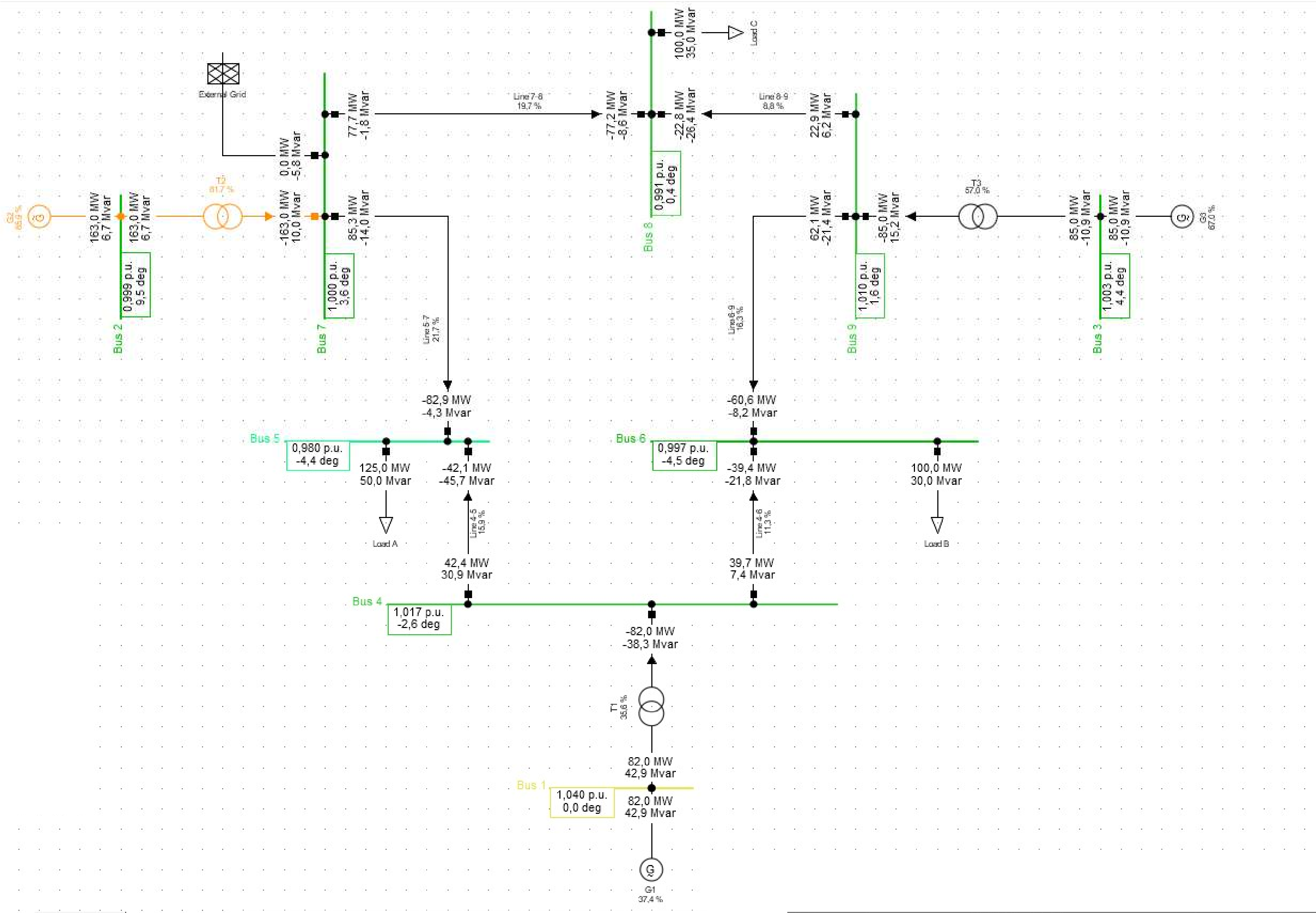
Grid Losses 4,78 MW

Case 2 – G1 keeps active power balance – with external grid connected

- G1 keeps active power balance (slack)
- G2 and G3 at fixed active power outputs
- External grid connected
  - external grid contributes with some Mvar only



External Grid
0,0 MW
-5,8 Mvar
77,7 MW
-1,8 Mvar
Line 7-8
19,7 %
-77,2 MW
-8,6 Mvar
-22,8 MW
-26,4 Mvar
Line 8-9
8,8 %
22,9 MW
6,2 Mvar
100,0 MW
35,0 Mvar
Load C
0,991 p.u.
0,4 deg
Bus 8
G2
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
T2
0,999 p.u.
9,5 deg
Bus 2
-163,0 MW
10,0 Mvar
85,3 MW
-14,0 Mvar
1,000 p.u.
3,6 deg
Bus 7
Line 5-7
21,7 %
62,1 MW
-21,4 Mvar
-85,0 MW
15,2 Mvar
T3
57,0 %
85,0 MW
-10,9 Mvar
85,0 MW
-10,9 Mvar
G3
67,0 %
1,010 p.u.
1,6 deg
Bus 9
1,003 p.u.
4,4 deg
Bus 3
Line 6-9
16,3 %
-82,9 MW
-4,3 Mvar
-60,6 MW
-8,2 Mvar
Bus 5
0,980 p.u.
-4,4 deg
125,0 MW
50,0 Mvar
Load A
-42,1 MW
-45,7 Mvar
Line 4-5
15,9 %
42,4 MW
30,9 Mvar
Bus 6
0,997 p.u.
-4,5 deg
-39,4 MW
-21,8 Mvar
Line 4-6
11,3 %
39,7 MW
7,4 Mvar
100,0 MW
30,0 Mvar
Load B
Bus 4
1,017 p.u.
-2,6 deg
-82,0 MW
-38,3 Mvar
T1
35,6 %
82,0 MW
42,9 Mvar
Bus 1
1,040 p.u.
0,0 deg
82,0 MW
42,9 Mvar
G1
37,4 %

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|                 |                                                                     |   DIgSILENT   | Project:                   |
|                 |                                                                     | PowerFactory  |----------------------------
|                 |                                                                     |    2019 SP4   | Date:  2020-02-14          |
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| Load Flow Calculation                                                                                             Grid Summary |
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|     AC Load Flow, balanced, positive sequence              |   Automatic Model Adaptation for Convergence           No         |
|     Automatic tap adjustment of transformers        No     |   Max. Acceptable Load Flow Error for                             |
|     Consider reactive power limits                  No     |      Nodes                                            1,00 kVA   |
|                                                            |      Model Equations                                  0,10 %     |
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| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow            | Annex:                  / 1  |
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| Grid: Nine-bus System      Summary                                                                                          |
|                                                                                                                              |
| No. of Substations     0          No. of Busbars        9         No. of Terminals      0         No. of Lines          6     |
| No. of 2-w Trfs.       3          No. of 3-w Trfs.      0         No. of syn. Machines  3         No. of asyn.Machines  0     |
| No. of Loads           3          No. of Shunts/Filters 0         No. of SVS            0                                     |
|                                                                                                                              |
| Generation            =     330,04  MW           38,65  Mvar      332,30  MVA                                               |
| External Infeed       =       0,00  MW           -5,76  Mvar        5,76  MVA                                               |
| Inter Grid Flow       =       0,00  MW            0,00  Mvar                                                                 |
| Load P(U)             =     325,00  MW          115,00  Mvar      344,75  MVA                                               |
| Load P(Un)            =     325,00  MW          115,00  Mvar      344,75  MVA                                               |
| Load P(Un-U)          =       0,00  MW            0,00  Mvar                                                                 |
| Motor Load            =       0,00  MW            0,00  Mvar        0,00  MVA                                               |
| Grid Losses           =       5,04  MW          -82,11  Mvar                                                                 |
| Line Charging         =                        -135,35  Mvar                                                                 |
| Compensation ind.     =                           0,00  Mvar                                                                 |
| Compensation cap.     =                           0,00  Mvar                                                                 |
|                                                                                                                              |
| Installed Capacity    =     519,50  MW                                                                                       |
| Spinning Reserve      =     189,46  MW                                                                                       |
|                                                                                                                              |
| Total Power Factor:                                                                                                          |
|   Generation          =         0,99  [-]                                                                                    |
|   Load/Motor          =  0,94 / 0,00  [-]                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------|
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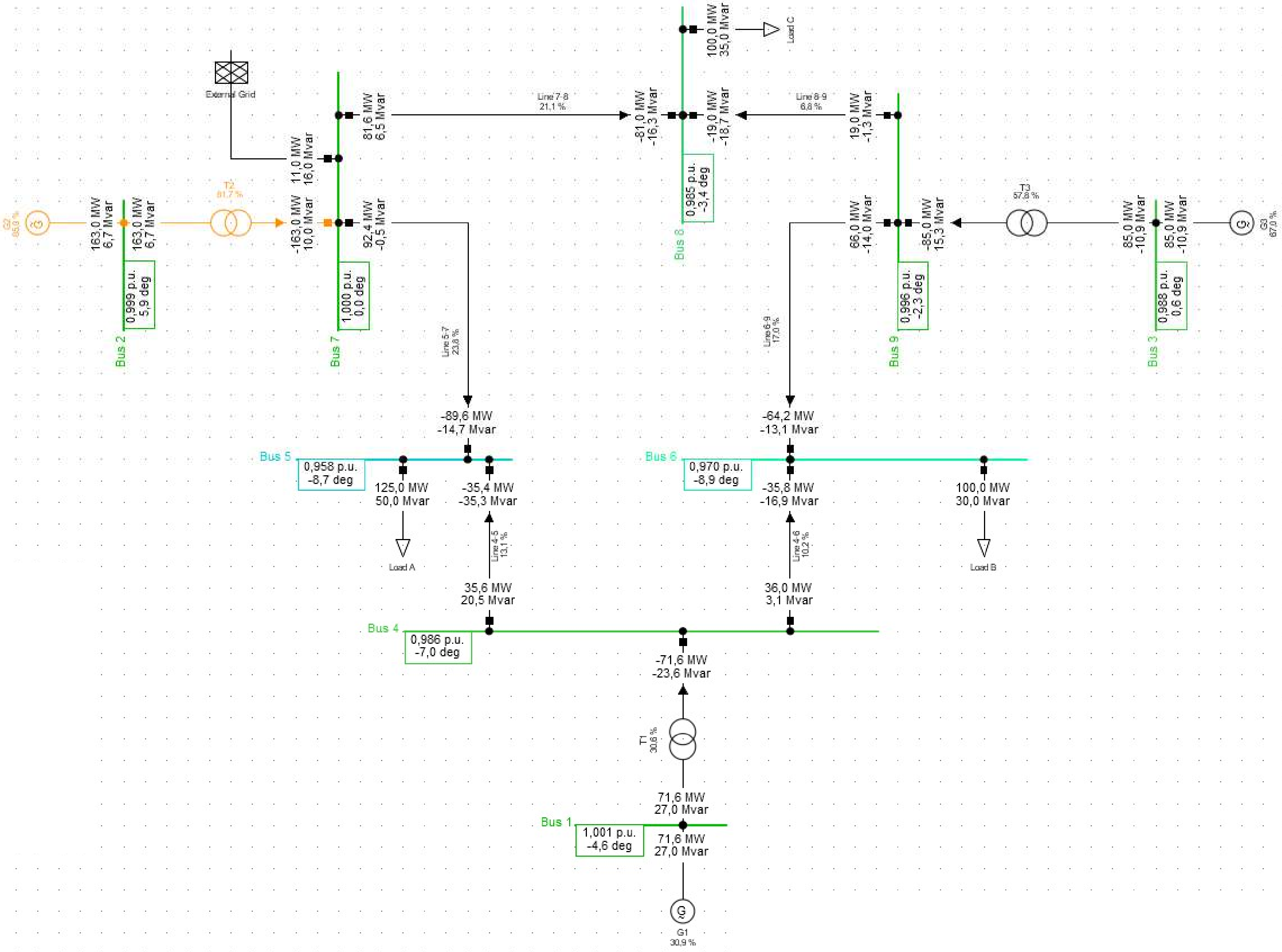
Grid Losses 5,04 MW

Case 3 – External grid keeps active power balance

- G1 dispatched to fixed active power output 71,6 MW (previous slack)
- G2 and G3 at fixed active power outputs
- External grid keeps active power balance (new slack)
  - external grid contributes with MW and Mvar



External Grid
Line 7-8
21,1 %
Line 8-9
6,8 %
Load C
100,0 MW
35,0 Mvar
81,6 MW
6,5 Mvar
-81,0 MW
-16,3 Mvar
-19,0 MW
-18,7 Mvar
19,0 MW
-1,3 Mvar
11,0 MW
16,0 Mvar
T2
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
-163,0 MW
10,0 Mvar
92,4 MW
-0,5 Mvar
0,999 p.u.
5,9 deg
1,000 p.u.
0,0 deg
0,985 p.u.
-3,4 deg
Bus 2
Bus 7
Bus 8
T3
57,8 %
66,0 MW
-14,0 Mvar
-85,0 MW
15,3 Mvar
85,0 MW
-10,9 Mvar
85,0 MW
-10,9 Mvar
0,996 p.u.
-2,3 deg
0,988 p.u.
0,6 deg
Bus 9
Bus 3
Line 5-7
23,8 %
Line 6-9
17,0 %
-89,6 MW
-14,7 Mvar
-64,2 MW
-13,1 Mvar
Bus 5
0,958 p.u.
-8,7 deg
125,0 MW
50,0 Mvar
-35,4 MW
-35,3 Mvar
Bus 6
0,970 p.u.
-8,9 deg
-35,8 MW
-16,9 Mvar
100,0 MW
30,0 Mvar
Load A
Line 4-5
13,1 %
Line 4-6
10,2 %
Load B
35,6 MW
20,5 Mvar
36,0 MW
3,1 Mvar
Bus 4
0,986 p.u.
-7,0 deg
-71,6 MW
-23,6 Mvar
T1
30,6 %
71,6 MW
27,0 Mvar
Bus 1
1,001 p.u.
-4,6 deg
71,6 MW
27,0 Mvar
G1
30,9 %

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|                 |                                                                 |   DIgSILENT   | Project:                  |
|                 |                                                                 | PowerFactory  |---------------------------
|                 |                                                                 |    2019 SP4   | Date:  2020-02-14         |
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| Load Flow Calculation                                                                                           Grid Summary |
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|     AC Load Flow, balanced, positive sequence                  |   Automatic Model Adaptation for Convergence          No         |
|     Automatic tap adjustment of transformers        No         |   Max. Acceptable Load Flow Error for                            |
|     Consider reactive power limits                  No         |      Nodes                                            1,00 kVA   |
|                                                                |      Model Equations                                  0,10 %     |
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| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow            | Annex:                 / 1   |
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| Grid: Nine-bus System      Summary                                                                                           |
|                                                                                                                              |
| No. of Substations     0          No. of Busbars        9          No. of Terminals      0          No. of Lines          6     |
| No. of 2-w Trfs.       3          No. of 3-w Trfs.      0          No. of syn. Machines  3          No. of asyn.Machines  0     |
| No. of Loads           3          No. of Shunts/Filters 0          No. of SVS            0                                      |
|                                                                                                                              |
| Generation            =     319,60  MW           22,80   Mvar       320,41  MVA                                               |
| External Infeed       =      11,02  MW           15,95   Mvar        19,39  MVA                                               |
| Inter Grid Flow       =       0,00  MW            0,00   Mvar                                                                |
| Load P(U)             =     325,00  MW          115,00   Mvar       344,75  MVA                                               |
| Load P(Un)            =     325,00  MW          115,00   Mvar       344,75  MVA                                               |
| Load P(Un-U)          =      -0,00  MW           -0,00   Mvar                                                                |
| Motor Load            =       0,00  MW            0,00   Mvar         0,00  MVA                                               |
| Grid Losses           =       5,62  MW          -76,25   Mvar                                                                |
| Line Charging         =                        -130,84   Mvar                                                                |
| Compensation ind.     =                           0,00   Mvar                                                                |
| Compensation cap.     =                           0,00   Mvar                                                                |
|                                                                                                                              |
| Installed Capacity    =     519,50  MW                                                                                       |
| Spinning Reserve      =     199,90  MW                                                                                       |
|                                                                                                                              |
| Total Power Factor:                                                                                                          |
|   Generation          =         1,00  [-]                                                                                    |
|   Load/Motor          =  0,94 / 0,00  [-]                                                                                    |
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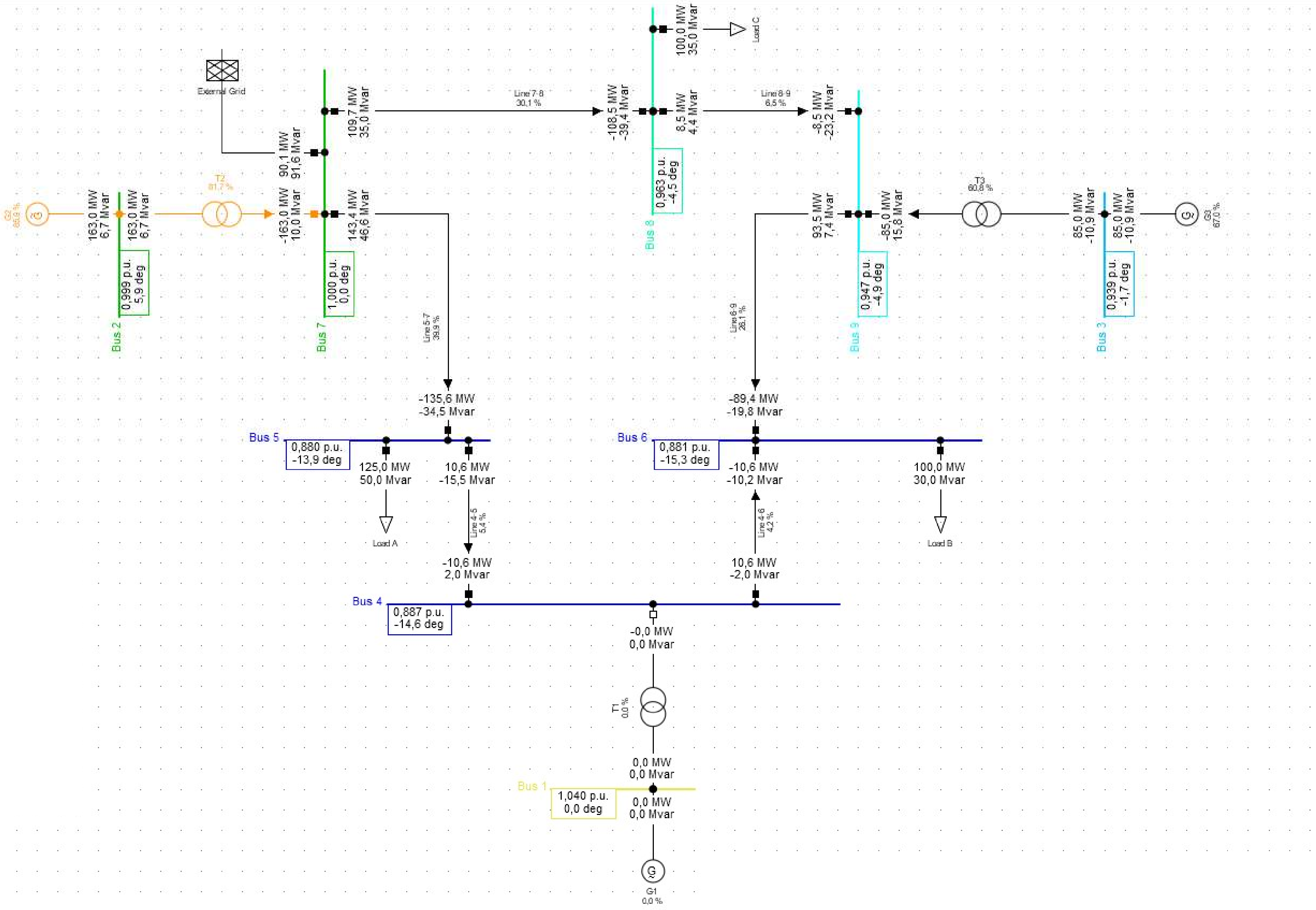
Grid Losses 5,62 MW

slightly more impedance between generation source and loads as G1 is limited in its generation

Case 4 – External grid keeps active power balance – disconnected distributed generation

- G1 disconnected (previous slack)
- G2 and G3 at fixed active power outputs
- External grid keeps active power balance (new slack)


External Grid
Line 7-8
30,1 %
Line 8-9
6,5 %
Load C
100,0 MW
35,0 Mvar
109,7 MW
35,0 Mvar
-108,5 MW
-39,4 Mvar
8,5 MW
4,4 Mvar
-8,5 MW
-23,2 Mvar
90,1 MW
91,6 Mvar
0,963 p.u.
-4,5 deg
Bus 8
T2
81,7 %
T3
60,8 %
G2
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
-163,0 MW
10,0 Mvar
143,4 MW
46,6 Mvar
93,5 MW
7,4 Mvar
-85,0 MW
15,8 Mvar
85,0 MW
-10,9 Mvar
85,0 MW
-10,9 Mvar
G3
67,0 %
0,999 p.u.
5,9 deg
Bus 2
1,000 p.u.
0,0 deg
Bus 7
0,947 p.u.
-4,9 deg
Bus 9
0,939 p.u.
-1,7 deg
Bus 3
Line 5-7
39,9 %
Line 6-9
28,1 %
-135,6 MW
-34,5 Mvar
-89,4 MW
-19,8 Mvar
Bus 5
0,880 p.u.
-13,9 deg
125,0 MW
50,0 Mvar
10,6 MW
-15,5 Mvar
Bus 6
0,881 p.u.
-15,3 deg
-10,6 MW
-10,2 Mvar
100,0 MW
30,0 Mvar
Load A
Line 4-5
5,4 %
Line 4-6
4,2 %
Load B
-10,6 MW
2,0 Mvar
10,6 MW
-2,0 Mvar
Bus 4
0,887 p.u.
-14,6 deg
-0,0 MW
0,0 Mvar
T1
0,0 %
0,0 MW
0,0 Mvar
Bus 1
1,040 p.u.
0,0 deg
0,0 MW
0,0 Mvar
G1
0,0 %

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|                 |                                                                  |    DIgSILENT    | Project:                       |
|                 |                                                                  | PowerFactory    |--------------------------------
|                 |                                                                  |    2019 SP4     | Date:  2020-02-14              |
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| Load Flow Calculation                                                                                            Grid Summary |
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|     AC Load Flow, balanced, positive sequence              |    Automatic Model Adaptation for Convergence           No        |
|     Automatic tap adjustment of transformers        No     |    Max. Acceptable Load Flow Error for                            |
|     Consider reactive power limits                  No     |       Nodes                                              1,00 kVA  |
|                                                            |       Model Equations                                    0,10 %    |
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| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow            | Annex:                 / 1  |
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| Grid: Nine-bus System      Summary                                                                                            |
|                                                                                                                               |
| No. of Substations     0         No. of Busbars       9         No. of Terminals      0         No. of Lines          6       |
| No. of 2-w Trfs.       3         No. of 3-w Trfs.     0         No. of syn. Machines  3         No. of asyn.Machines  0       |
| No. of Loads           3         No. of Shunts/Filters 0        No. of SVS            0                                       |
|                                                                                                                               |
| Generation             =    248,00  MW           -4,20   Mvar       248,04  MVA                                              |
| External Infeed        =     90,11  MW           91,60   Mvar       128,49  MVA                                              |
| Inter Grid Flow        =      0,00  MW            0,00   Mvar                                                                |
| Load P(U)              =    325,00  MW          115,00   Mvar       344,75  MVA                                              |
| Load P(Un)             =    325,00  MW          115,00   Mvar       344,75  MVA                                              |
| Load P(Un-U)           =     -0,00  MW           -0,00   Mvar                                                                |
| Motor Load             =      0,00  MW            0,00   Mvar         0,00  MVA                                              |
| Grid Losses            =     13,11  MW          -27,60   Mvar                                                                |
| Line Charging          =                       -116,63   Mvar                                                                |
| Compensation ind.      =                         0,00   Mvar                                                                |
| Compensation cap.      =                         0,00   Mvar                                                                |
|                                                                                                                               |
| Installed Capacity     =    519,50  MW                                                                                        |
| Spinning Reserve       =    271,50  MW                                                                                        |
|                                                                                                                               |
| Total Power Factor:                                                                                                           |
|   Generation           =        1,00  [-]                                                                                     |
|   Load/Motor           =  0,94 / 0,00  [-]                                                                                    |
|-------------------------------------------------------------------------------------------------------------------------------|
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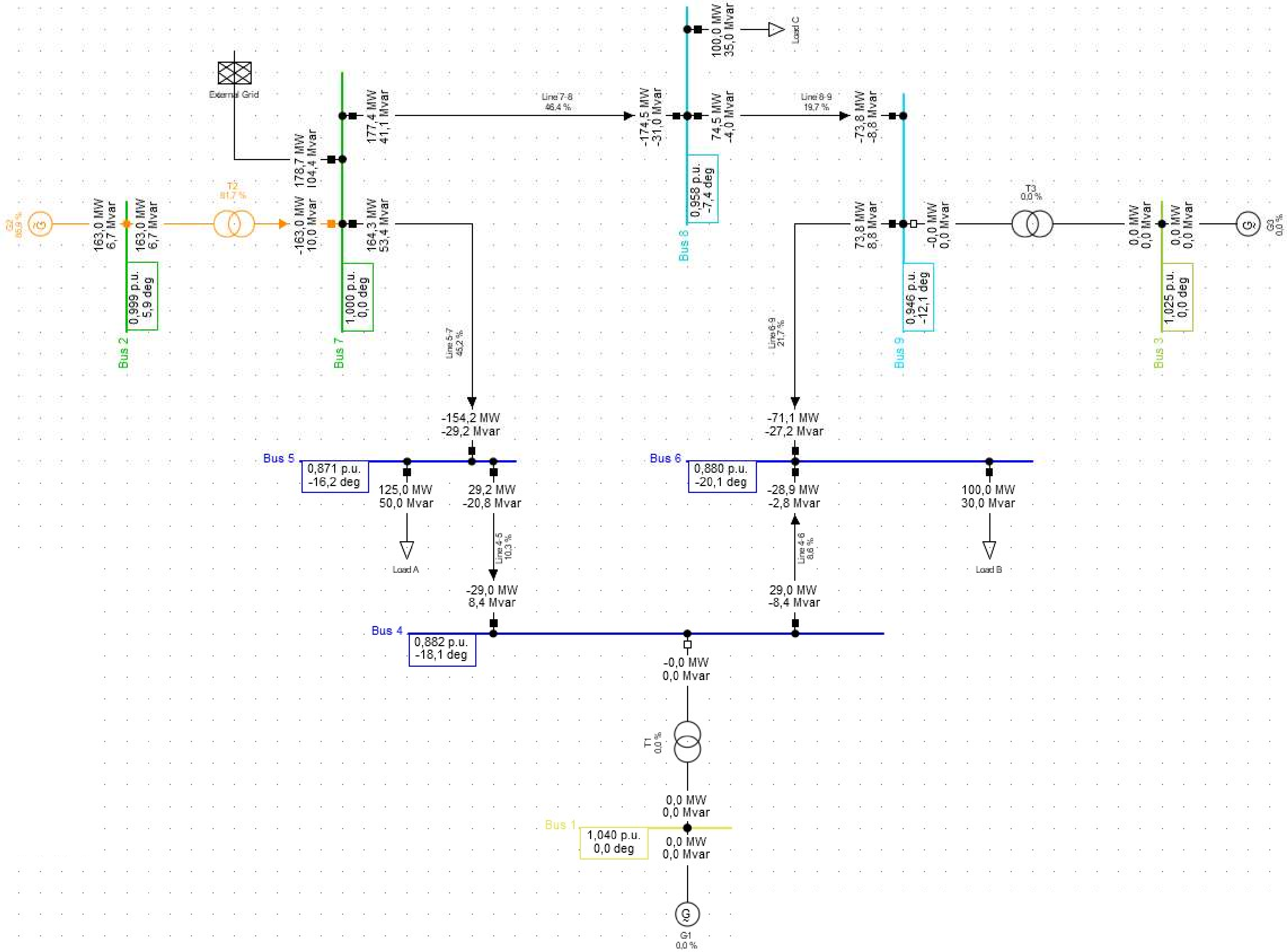
Grid Losses 13,11 MW

more impedance between generation source and loads

low voltage levels at the furthest bus

Case 5 – External grid keeps active power balance – more disconnected distributed generation

- G1 disconnected (previous slack)
- G3 disconnected
- G2 at fixed active power output
- External grid keeps active power balance (new slack)


External Grid
Line 7-8
46,4 %
Line 8-9
19,7 %
100,0 MW
35,0 Mvar
Load C
177,4 MW
41,1 Mvar
-174,5 MW
-31,0 Mvar
74,5 MW
-4,0 Mvar
-73,8 MW
-8,8 Mvar
178,7 MW
104,4 Mvar
0,958 p.u.
-7,4 deg
Bus 8
T2
81,7 %
T3
0,0 %
G2
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
-163,0 MW
10,0 Mvar
164,3 MW
53,4 Mvar
73,8 MW
8,8 Mvar
-0,0 MW
0,0 Mvar
0,0 MW
0,0 Mvar
0,0 MW
0,0 Mvar
G3
0,0 %
0,999 p.u.
5,9 deg
1,000 p.u.
0,0 deg
0,946 p.u.
-12,1 deg
1,025 p.u.
0,0 deg
Bus 2
Bus 7
Bus 9
Bus 3
Line 5-7
45,2 %
Line 6-9
21,7 %
-154,2 MW
-29,2 Mvar
-71,1 MW
-27,2 Mvar
Bus 5
0,871 p.u.
-16,2 deg
125,0 MW
50,0 Mvar
29,2 MW
-20,8 Mvar
Bus 6
0,880 p.u.
-20,1 deg
-28,9 MW
-2,8 Mvar
100,0 MW
30,0 Mvar
Load A
Line 4-5
10,3 %
Line 4-6
8,8 %
Load B
-29,0 MW
8,4 Mvar
29,0 MW
-8,4 Mvar
Bus 4
0,882 p.u.
-18,1 deg
-0,0 MW
0,0 Mvar
T1
0,0 %
0,0 MW
0,0 Mvar
Bus 1
1,040 p.u.
0,0 deg
0,0 MW
0,0 Mvar
G1
0,0 %

9

```
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|                  |                                                                  |   DIgSILENT   | Project:                |
|                  |                                                                  | PowerFactory  |-------------------------
|                  |                                                                  |   2019 SP4    | Date:  2020-02-14       |
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----------------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                            Grid Summary |
----------------------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, balanced, positive sequence              |   Automatic Model Adaptation for Convergence          No         |
|     Automatic tap adjustment of transformers       No      |   Max. Acceptable Load Flow Error for                            |
|     Consider reactive power limits                 No      |      Nodes                                          1,00 kVA   |
|                                                             |      Model Equations                                0,10 %     |
----------------------------------------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow          | Annex:                   / 1  |
----------------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      Summary                                                                                            |
|                                                                                                                                |
| No. of Substations     0         No. of Busbars        9         No. of Terminals      0         No. of Lines          6      |
| No. of 2-w Trfs.       3         No. of 3-w Trfs.      0         No. of syn. Machines  3         No. of asyn.Machines  0      |
| No. of Loads           3         No. of Shunts/Filters 0         No. of SVS            0                                        |
|                                                                                                                                |
| Generation            =     163,00  MW            6,70   Mvar      163,14  MVA                                              |
| External Infeed       =     178,71  MW          104,37   Mvar      206,95  MVA                                              |
| Inter Grid Flow       =       0,00  MW            0,00   Mvar                                                               |
| Load P(U)             =     325,00  MW          115,00   Mvar      344,75  MVA                                              |
| Load P(Un)            =     325,00  MW          115,00   Mvar      344,75  MVA                                              |
| Load P(Un-U)          =       0,00  MW            0,00   Mvar                                                               |
| Motor Load            =       0,00  MW            0,00   Mvar        0,00  MVA                                              |
| Grid Losses           =      16,71  MW           -3,93   Mvar                                                               |
| Line Charging         =                        -115,81   Mvar                                                               |
| Compensation ind.     =                           0,00   Mvar                                                               |
| Compensation cap.     =                           0,00   Mvar                                                               |
|                                                                                                                                |
| Installed Capacity    =     519,50  MW                                                                                     |
| Spinning Reserve      =     356,50  MW                                                                                     |
|                                                                                                                                |
| Total Power Factor:                                                                                                            |
|   Generation          =          1,00  [-]                                                                                    |
|   Load/Motor          =   0,94 / 0,00  [-]                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------|
```

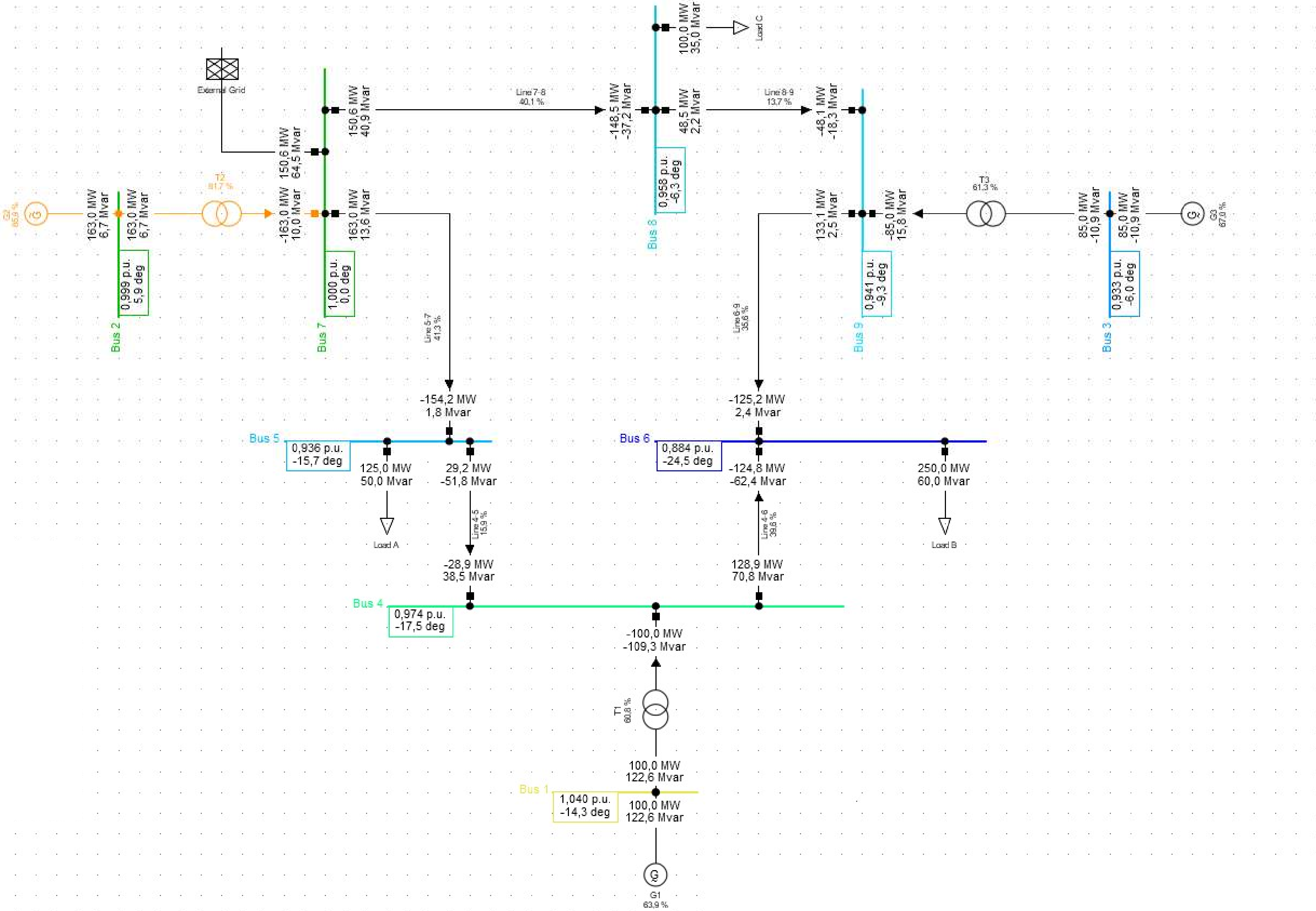
Grid Losses 16,71 MW

even more impedance between generation source and loads

low voltage levels at the furthest bus

Case 2x – G1 keeps active power balance – reaches ceiling – with external grid connected

- G1 keeps active power balance (slack) – with increasing system load (+150 MW) and reaches its ceiling (100 MW)
- G2 and G3 at fixed active power outputs
- External grid connected
  - external grid takes over as slack



External Grid
Line 7-8
40,1 %
Line 8-9
13,7 %
Load C
100,0 MW
35,0 Mvar
150,6 MW
64,5 Mvar
150,6 MW
40,9 Mvar
-148,5 MW
-37,2 Mvar
48,5 MW
2,2 Mvar
-48,1 MW
-18,3 Mvar
G2
T2
81,7 %
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
-163,0 MW
10,0 Mvar
163,0 MW
13,6 Mvar
0,999 p.u.
5,9 deg
1,000 p.u.
0,0 deg
0,958 p.u.
-6,3 deg
Bus 2
Bus 7
Bus 8
T3
61,3 %
133,1 MW
2,5 Mvar
-85,0 MW
15,8 Mvar
85,0 MW
-10,9 Mvar
85,0 MW
-10,9 Mvar
G3
67,0 %
0,941 p.u.
-9,3 deg
0,933 p.u.
-6,0 deg
Bus 9
Bus 3
Line 5-7
41,3 %
Line 6-9
35,6 %
-154,2 MW
1,8 Mvar
-125,2 MW
2,4 Mvar
Bus 5
0,936 p.u.
-15,7 deg
125,0 MW
50,0 Mvar
29,2 MW
-51,8 Mvar
Load A
Line 4-5
15,9 %
Bus 6
0,884 p.u.
-24,5 deg
-124,8 MW
-62,4 Mvar
250,0 MW
60,0 Mvar
Load B
Line 4-6
39,6 %
-28,9 MW
38,5 Mvar
128,9 MW
70,8 Mvar
Bus 4
0,974 p.u.
-17,5 deg
-100,0 MW
-109,3 Mvar
T1
60,8 %
100,0 MW
122,6 Mvar
Bus 1
1,040 p.u.
-14,3 deg
100,0 MW
122,6 Mvar
G1
63,9 %

```
-----------------------------------------------------------------------------------------------------------------------------------
|                  |                                                                 |   DIgSILENT   | Project:                         |
|                  |                                                                 | PowerFactory  |----------------------------------
|                  |                                                                 |    2019 SP4   | Date:  2020-02-14                |
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-----------------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                              Grid Summary |
-----------------------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, balanced, positive sequence              |    Automatic Model Adaptation for Convergence          No          |
|     Automatic tap adjustment of transformers        No     |    Max. Acceptable Load Flow Error for                              |
|     Consider reactive power limits                  No     |       Nodes                                            1,00 kVA    |
|                                                            |       Model Equations                                  0,10 %      |
-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow              | Annex:                  / 1   |
-----------------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      Summary                                                                                              |
|                                                                                                                                 |
| No. of Substations     0          No. of Busbars       9         No. of Terminals      0          No. of Lines          6        |
| No. of 2-w Trfs.       3          No. of 3-w Trfs.     0         No. of syn. Machines  3          No. of asyn.Machines  0        |
| No. of Loads           3          No. of Shunts/Filters 0        No. of SVS            0                                          |
|                                                                                                                                 |
| Generation            =     348,00  MW          118,38   Mvar      367,58  MVA                                                  |
| External Infeed       =     150,57  MW           64,47   Mvar      163,79  MVA                                                  |
| Inter Grid Flow       =       0,00  MW            0,00   Mvar                                                                   |
| Load P(U)             =     475,00  MW          145,00   Mvar      496,64  MVA                                                  |
| Load P(Un)            =     475,00  MW          145,00   Mvar      496,64  MVA                                                  |
| Load P(Un-U)          =       0,00  MW           -0,00   Mvar                                                                   |
| Motor Load            =       0,00  MW            0,00   Mvar        0,00  MVA                                                  |
| Grid Losses           =      23,57  MW           37,85   Mvar                                                                   |
| Line Charging         =                        -121,39   Mvar                                                                   |
| Compensation ind.     =                           0,00   Mvar                                                                   |
| Compensation cap.     =                           0,00   Mvar                                                                   |
|                                                                                                                                 |
| Installed Capacity    =     519,50  MW                                                                                          |
| Spinning Reserve      =     171,50  MW                                                                                          |
|                                                                                                                                 |
| Total Power Factor:                                                                                                             |
|   Generation          =          0,95  [-]                                                                                      |
|   Load/Motor          =   0,96 / 0,00  [-]                                                                                      |
|---------------------------------------------------------------------------------------------------------------------------------|
```

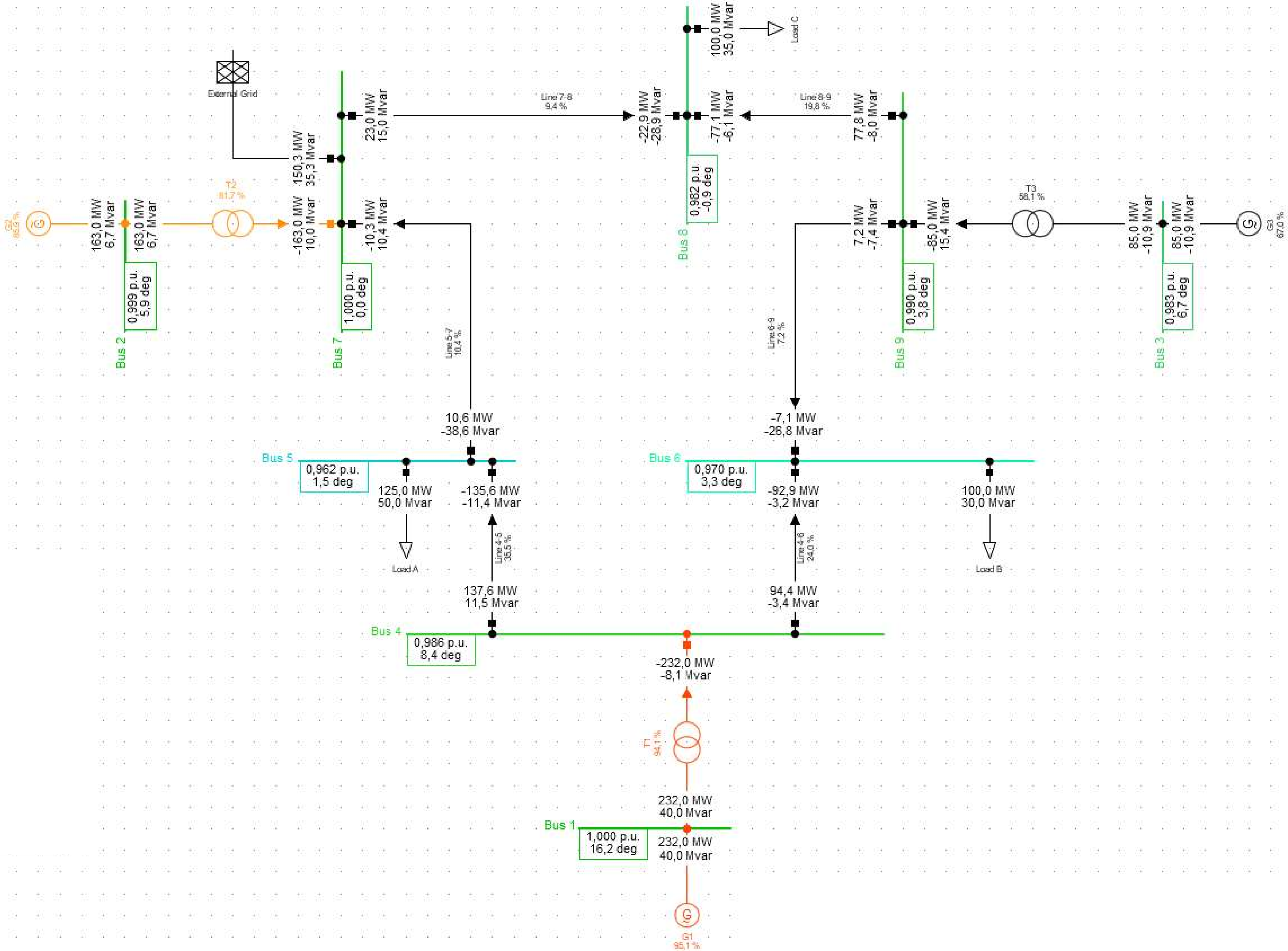
Grid Losses 23,57 MW

Losses not directly comparable as the load is higher than other presented cases

Case 2xx – aggregated production > max load in sub-transmission system

- Traditional top-down system changed – change in net active power flow direction – aggregated production > max load

- G1 with increasing generation (+150 MW compared Case 2) – without any ceiling in this case
- G2 and G3 at fixed active power outputs
- External grid connected
  - external grid is fed with 150 MW



External Grid
Load C
100,0 MW
35,0 Mvar
Line 7-8
9,4 %
Line 8-9
19,8 %
23,0 MW
15,0 Mvar
150,3 MW
35,3 Mvar
-22,9 MW
-28,9 Mvar
-77,1 MW
-6,1 Mvar
77,8 MW
-8,0 Mvar
0,982 p.u.
-0,9 deg
Bus 8
G2
163,0 MW
6,7 Mvar
163,0 MW
6,7 Mvar
T2
81,7 %
-163,0 MW
10,0 Mvar
-10,3 MW
10,4 Mvar
0,999 p.u.
5,9 deg
Bus 2
1,000 p.u.
0,0 deg
Bus 7
7,2 MW
-7,4 Mvar
-85,0 MW
15,4 Mvar
T3
58,1 %
85,0 MW
-10,9 Mvar
85,0 MW
-10,9 Mvar
G3
67,0 %
0,990 p.u.
3,8 deg
Bus 9
0,983 p.u.
6,7 deg
Bus 3
Line 5-7
10,4 %
Line 6-9
7,2 %
10,6 MW
-38,6 Mvar
-7,1 MW
-26,8 Mvar
Bus 5
0,962 p.u.
1,5 deg
125,0 MW
50,0 Mvar
-135,6 MW
-11,4 Mvar
Bus 6
0,970 p.u.
3,3 deg
-92,9 MW
-3,2 Mvar
100,0 MW
30,0 Mvar
Load A
Line 4-5
35,5 %
Line 4-6
24,0 %
Load B
137,6 MW
11,5 Mvar
94,4 MW
-3,4 Mvar
Bus 4
0,986 p.u.
8,4 deg
-232,0 MW
-8,1 Mvar
T1
94,1 %
232,0 MW
40,0 Mvar
Bus 1
1,000 p.u.
16,2 deg
232,0 MW
40,0 Mvar
G1
95,1 %

```
---------------------------------------------------------------------------------------------------------------------------
|                |                                                           |   DIgSILENT   | Project:                        |
|                |                                                           | PowerFactory  |---------------------------------
|                |                                                           |    2019 SP4   | Date:  2020-02-21               |
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---------------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                        Grid Summary |
---------------------------------------------------------------------------------------------------------------------------
|    AC Load Flow, balanced, positive sequence            |    Automatic Model Adaptation for Convergence          No        |
|    Automatic tap adjustment of transformers       No    |    Max. Acceptable Load Flow Error for                           |
|    Consider reactive power limits                 No    |       Nodes                                            1,00 kVA  |
|                                                         |       Model Equations                                  0,10 %    |
---------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      System Stage: Nine-bus System | Study Case: 01- Load Flow            | Annex:                / 1  |
---------------------------------------------------------------------------------------------------------------------------
| Grid: Nine-bus System      Summary                                                                                       |
|                                                                                                                          |
| No. of Substations     0         No. of Busbars       9         No. of Terminals      0         No. of Lines          6   |
| No. of 2-w Trfs.       3         No. of 3-w Trfs.     0         No. of syn. Machines  3         No. of asyn.Machines  0   |
| No. of Loads           3         No. of Shunts/Filters 0        No. of SVS            0                                   |
|                                                                                                                          |
| Generation           =     480,00  MW          35,80   Mvar     481,33  MVA                                             |
| External Infeed      =    -150,32  MW          35,35   Mvar     154,42  MVA                                             |
| Inter Grid Flow      =       0,00  MW           0,00   Mvar                                                             |
| Load P(U)            =     325,00  MW         115,00   Mvar     344,75  MVA                                             |
| Load P(Un)           =     325,00  MW         115,00   Mvar     344,75  MVA                                             |
| Load P(Un-U)         =       0,00  MW          -0,00   Mvar                                                             |
| Motor Load           =       0,00  MW           0,00   Mvar       0,00  MVA                                             |
| Grid Losses          =       4,68  MW         -43,85   Mvar                                                             |
| Line Charging        =                       -130,68   Mvar                                                             |
| Compensation ind.    =                          0,00   Mvar                                                             |
| Compensation cap.    =                          0,00   Mvar                                                             |
|                                                                                                                          |
| Installed Capacity   =     519,50  MW                                                                                    |
| Spinning Reserve     =      39,50  MW                                                                                    |
|                                                                                                                          |
| Total Power Factor:                                                                                                      |
|   Generation         =          1,00  [-]                                                                                |
|   Load/Motor         =   0,94 / 0,00  [-]                                                                                |
|--------------------------------------------------------------------------------------------------------------------------|
```

Grid Losses 4,68 MW

Lower loading on the longer (high impedance) lines

G2's generation goes straight out into the external grid from its busbar

Case study – PF Nine bus System

- Conclusions
  - DVG generally decreases the losses locally in a sub-transmission system as there is production closer to the loads
    - Less impedance between generation source and loads
  - DVG with aggregated production > max load might result in even lower losses in the sub-transmission network
    - But the impact at transmission level depends on the resulting generation situation there

Workshop 1 – Part 2
Monday 14.09.2020 – Friday 18.09.2020

- Session 4
  - 11 kV Power Factory study case – dynamic iterative loss calculation method
- Session 5
  - 132 kV Power Factory study case – how the loss pattern is affected by changes in power flow direction as the traditional top-down system is challenged
- Session 6
  - Review on loss calculation procedures and tools
    - Review note D1.1 with gap analysis

Pre-recorded sessions released on Monday 14.09.2020

QA session: Monday 21.09.2020