Department of Electrical and Electronic Engineering
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EEE 306: Project

Investigating the effect of HVDC connection and large industrial loads in IEEE 39-bus network

System description

Consider the IEEE 39 bus (New England) test system shown below. Nominal frequency is 50 Hz. IEEE 39 bus system is well known as 10-machine New-England Power System. This system's parameters are specified in a paper by T. Athay et al [1] and are published in a book titled 'Energy Function Analysis for Power System Stability' [2]. This case is used to study simultaneous damping of local and inter-are modes in a system with a highly symmetrical structure.

Single line diagram

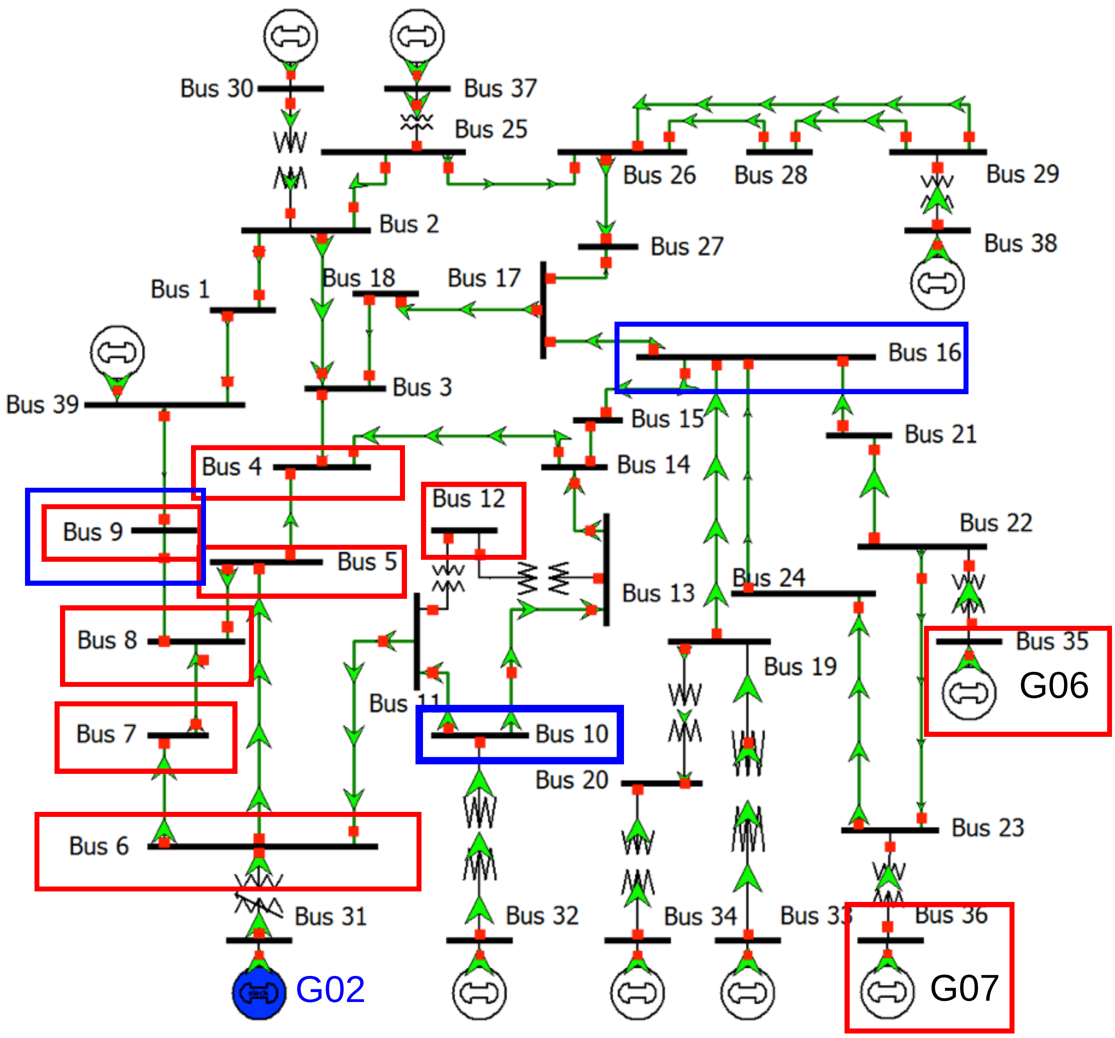

Figure 1: IEEE 39-Bus System

Network data

Table 1: Bus data

Bus ID	**Voltage (kV)**
B1	345
B2	345
B3	345
B4	345
B5	345
B6	345
B7	345
B8	345
B9	345
B10	345
B11	345
B12	138
B13	345
B14	345
B15	345
B16	345
B17	345
B18	345
B19	345
B20	230
B21	345
B22	345
B23	345
B24	345
B25	345
B26	345
B27	345
B28	345
B29	345
B30	16.5
B31	16.5
B32	16.5
B33	16.5
B34	16.5
B35	16.5
B36	16.5
B37	16.5
B38	16.5
B39	345

Table 2: Line data

Line ID	**From Bus**	**To Bus**	**Line voltage (kV)**	**R (p.u.)**	**X (p.u.)**	**B (p.u.)**	**Distance (km)**
L1	1	2	345	0.0035	0.0411	0.6987	275.5
L2	1	39	345	0.0010	0.0250	0.7500	167.6
L3	2	3	345	0.0013	0.0151	0.2572	101.2
L4	2	25	345	0.0070	0.0086	0.1460	57.6
L5	3	4	345	0.0013	0.0213	0.2214	142.8
L6	3	18	345	0.0011	0.0133	0.2138	89.1
L7	4	5	345	0.0008	0.0128	0.1342	85.8
L8	4	14	345	0.0008	0.0129	0.1382	86.5
L9	5	6	345	0.0002	0.0026	0.0434	17.4
L10	5	8	345	0.0008	0.0112	0.1476	75.1
L11	6	7	345	0.0006	0.0092	0.1130	61.7
L12	6	11	345	0.0007	0.0082	0.1389	55
L13	7	8	345	0.0004	0.0046	0.0780	30.8
L14	8	9	345	0.0023	0.0363	0.3804	243.3
L15	9	39	345	0.0010	0.0250	1.2000	167.6
L16	10	11	345	0.0004	0.0043	0.0729	28.8
L17	10	13	345	0.0004	0.0043	0.0729	28.8
L18	13	14	345	0.0009	0.0101	0.1723	67.7
L19	14	15	345	0.0018	0.0217	0.3660	145.4
L20	15	16	345	0.0009	0.0094	0.1710	63.0
L21	16	17	345	0.0007	0.0089	0.1342	59.7
L22	16	19	345	0.0016	0.0195	0.3040	130.7
L23	16	21	345	0.0008	0.0135	0.2548	90.5
L24	16	24	345	0.0003	0.0059	0.0680	39.5
L25	17	18	345	0.0007	0.0082	0.1319	55.0
L26	17	27	345	0.0013	0.0173	0.3216	116.0
L27	21	22	345	0.0008	0.0140	0.2565	93.8
L28	22	23	345	0.0006	0.0096	0.1846	64.3
L29	23	24	345	0.0022	0.0350	0.3610	234.6
L30	25	26	345	0.0032	0.0323	0.5130	216.5
L31	26	27	345	0.0014	0.0147	0.2396	98.5
L32	26	28	345	0.0043	0.0474	0.7802	317.7
L33	26	29	345	0.0057	0.0625	1.0290	418.9
L34	28	29	345	0.0014	0.0151	0.2490	101.2

Table 3: Transformer data

Name	S (MVA)	Duplic	From Bus	To Bus	Primary	Secondary	R (p.u.)	X (p.u.)
T01	300	1	12	11	138	345	0.0048	0.1305
T02	300	1	12	13	138	345	0.0048	0.1305
T03	700	1	6	31	345	16.5	0.0045	0.175
T04	800	1	10	32	345	16.5	0.004	0.16
T05	800	1	19	33	345	16.5	0.0056	0.1136
T06	300	2	20	34	230	16.5	0.0054	0.108
T07	800	1	22	35	345	16.5	0.0035	0.1144
T08	700	1	23	36	345	16.5	0.0035	0.1904
T09	700	1	25	37	345	16.5	0.0042	0.1624
T10	1000	1	2	30	345	16.5	0.006	0.181
T11	1000	1	29	38	345	16.5	0.008	0.156
T12	1000	1	19	20	345	230	0.007	0.138

Table 4: Generator data

Generator	Bus no.	MVA rating	Dispatched P (MW)	Specified generation voltage V (p.u.)
G 01	39	10000	1000.0	1.0300
G 02	31	700	slack	0.9820
G 03	32	800	650.0	0.9831
G 04	33	800	632.0	0.9972
G 05	34	2x300	508.0	1.0123
G 06	35	800	650.0	1.0493
G 07	36	700	560.0	1.0635
G 08	37	700	540.0	1.0278
G 09	38	1000	830.0	1.0265
G 10	30	1000	250.0	1.0475

Table 5: Load data

Load	Bus no.	P (MW)	Q (MVAR)
L01	03	322.0	2.4
L02	04	500.0	184.0
L03	07	233.8	84.0
L04	08	522.0	176.0
L05	12	7.5	88.0
L06	15	320.0	153.0
L07	16	329.0	32.3
L08	18	158.0	30.0
L09	20	628.0	103.0
L10	21	274.0	115.0
L11	23	247.5	84.6
L12	24	308.6	-92.2
L13	25	224.0	47.2
L14	26	139.0	17.0
L15	27	281.0	75.5
L16	28	206.0	27.6
L17	29	283.5	26.9
L18	31	9.2	4.6
L19	39	1104.0	250.0
Total		6097.1	1408.9

Tasks

1. Perform the load flow analysis with the data given above. If the load flow converges, the data has been entered correctly. Export/save the results of the load flow in your PC, it will be needed later.
2. Modify the network as mentioned in the following steps.

<u>Adding a HVDC line</u>

- Add two buses with the following parameters:

Bus ID	Voltage (kV)
B39_REC	100
B39_INV	100

- We will add two tap-changing-under-load transformers (TCUL XMER) into the network. Click on the three dots (…) on the Dbase ID column and a pop-up window named *Voltage*

Regulating Transformer appears. Enter the following parameters inside the pop-up window:

Name	**S (MVA)**	**From bus**	**To bus**	**HV (kV)**	**LV (kV)**	**Z1, Z0 (p.u.)**	**X1/R1, X0/R0 (p.u.)**
T_INV	800	B9	B9_INV	345	100	0.0566	37.453
T_REC	800	B39	B39_REC	345	100	0.0566	37.453

Inside *Tap controls* section inside the pop-up window, enter discrete taps to be 21, min. voltage 90% and max. voltage 110% for both of the TCUL transformers.

- We will convert on HVAC line of the network to a HVDC line. For this, select DC LINE equipment from the drop-down menu. Give it an ID (say, DC1).

From bus	**To bus**
B39_REC	B9_INV

Right click on the ID (DC1) and click on *Open Equipment Dialog.* A pop-up window named *DC line* appears. Enter the following data:

Database ID	DC1
Control mode	Constant power mode
Desired power	500 MW
Desired voltage	500 kV
Compounding resistance	2 ohms
Current margin	10%
Min. Extinction angle	10 degrees
Max. Extinction angle	26 degrees
Min. Ignition angle	18 degrees
Max. Ignition angle	24 degrees
Desired Ignition angle	18 degrees

Now, click on the three dots (…) on the Dbase ID column. A pop-up window named *DC Line Database Dialogue* appears. Create a new database ID for the DC line (say, DC1).

DC line resistance	1 ohm
Number of rectifier bridges	4
Number of inverter bridges	4

- Finally, go to the *Line* data and uncheck the tick sign of L15, which connects B9 and B39. This HVAC line has been replaced with an HVDC line.

<u>Adding an industrial plant (induction motors)</u>

- select *Induction Motor* equipment from the drop-down menu, give it an ID (say, IM1).
- Add the induction motor at Bus 23.
- Set,

  Duplicity: 10

  Motor type: Load factor 1

  Load factor 1, 2, 3: 100%
- Click on the three dots (…) on the Dbase ID column. A pop-up window named *Induction Machine Database Dialogue* appears. Create a new database ID for the induction motor (say, IM1).

Voltage	345 kV	**Efficiency**	90%
MVA rating	100 MVA	**Speed**	750 RPM
HP rating	96527.69 HP	**Rated frequency**	50 Hz
KW rating	72000 kW	**Sub-transient R**	0.00556
Power factor	0.8	**Sub-transient X**	0.3

3. Perform the load flow analysis of the modified. If the load flow converges, the data has been entered correctly. Compare the new results with that of the old one. Spot the differences. Are there abnormalities in the modified network? If so, how and why did they originate? Explain.
4. There are many correcting measures/devices which can be connected in a power system in order to fix overvoltage/undervoltage problems, such as – static capacitors,

synchronous condensers, FACTS devices etc. Your goal is to eradicate the abnormalities in the load flow of the modified network using corrective devices.

However, please note that you are not allowed to bring fundamental change to the network, which includes:

- Adding/deleting an existing line
- Adding/deleting an existing load (i.e. static load)
- Adding/deleting an existing generator
- Adding/deleting an existing transformer

N.B.: For any missing data, assume standard values. Also, for design problem part, it may not have a unique answer. The solution will depend on your design approach.

Submission guidelines

1. Project will be done in groups of four (4).
2. Each group has to submit a comprehensive report showing detail analysis (calculations, reasoning behind placement of additional equipment, results before and after correcting abnormalities etc.).
3. Each group has to provide a 10-minute presentation on the project. Every member of the team has to participate in the presentation.
4. **Project progress review 1 (load flow demonstration):** Sunday, 6 June, 2021.
5. **Project progress review 2:** Sunday, 20 June, 2021
6. **Project final presentation:** Sunday, 11 July, 2021.
7. **Project final report submission:** Sunday, 25 July, 2021

References

[1] T. Athay, R. Podmore, and S. Virmani, “A Practical Method for the Direct Analysis of Transient Stability,” *IEEE Trans. Power Appar. Syst.*, vol. PAS-98, no. 2, pp. 573–584, 1979, doi: 10.1109/TPAS.1979.319407.

[2] K. R. Padiyar, “Energy Function Analysis for Power System Stability,” *Electr. Mach. Power Syst.*, vol. 18, no. 2, pp. 209–210, Mar. 1990, doi: 10.1080/07313569008909464.