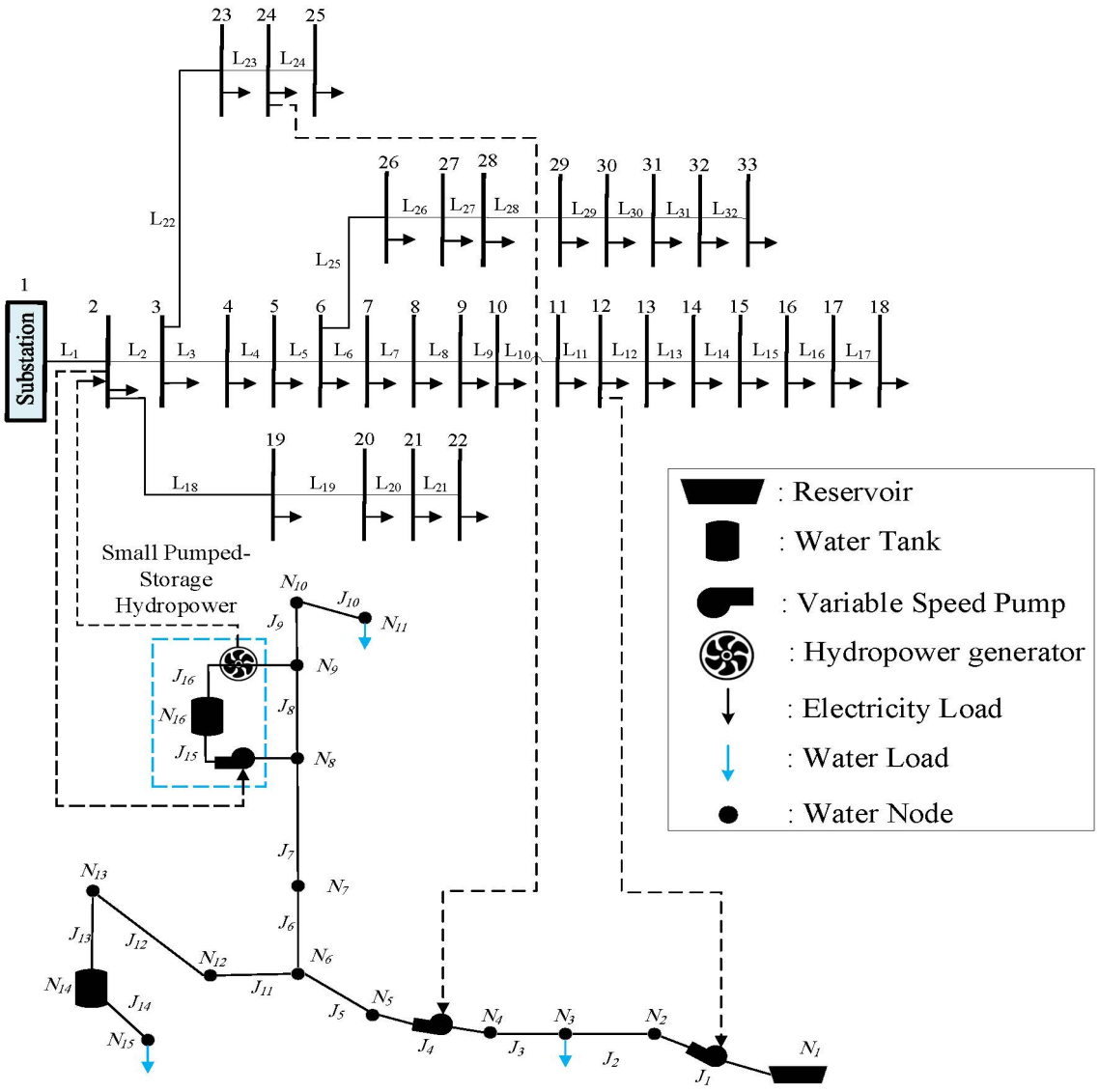
33-Bus Power Distribution with 16-Node Water Distribution Test Systems Integrated with Small Pumped-Storage Hydropower



- **16-Node Water Distribution System (WDS)**

Pump Performance Characteristic Function Data (WDS)

Pumps	a	b	c
Pump 1 (Pipe 1)	150	15	2
Pump 2 (Pipe 4)	150	15	2

Water Storage Tank Characteristic Data (WDS)

Tanks	Initial Volume (m^3)	Target Volume (m^3)	Maximum Volume (m^3)	Maximum Charge/Discharge Flow Rate (m^3//hour)
T1 (N14)	1200	1200	9000	1080

Water Demand Data

Hour	Node N3 (m^3/sec)	Node N11 (m^3/sec)	Node N15 (m^3/sec)
8	0.078	0.078	0.078
9	0.0676	0.0676	0.0676
10	0.052	0.052	0.052
11	0.078	0.078	0.078
12	0.104	0.104	0.104
13	0.104	0.104	0.104
14	0.156	0.156	0.156
15	0.182	0.182	0.182
16	0.208	0.208	0.208
17	0.208	0.208	0.208
18	0.208	0.208	0.208
19	0.208	0.208	0.208
20	0.208	0.208	0.208
21	0.208	0.208	0.208
22	0.208	0.208	0.208
23	0.156	0.156	0.156
24	0.104	0.104	0.104
1	0.104	0.104	0.104
2	0.052	0.052	0.052
3	0.052	0.052	0.052
4	0.052	0.052	0.052
5	0.052	0.052	0.052
6	0.078	0.078	0.078
7	0.078	0.078	0.078

Water Node Data

Nodes	Elevation (m)	Minimum Pressure (m)	Maximum Pressure (m)
I1	10.6	0	500
I2	9.7	20	500
I3	0	20	500
I4	5	20	500
I5	55	20	500
I6	126	20	500
I7	121	20	500
I8	126	20	500
I9	157	20	500
I10	156	20	500
I11	156.65	20	500
I12	128	20	500
I13	124.13	20	500
I14	123	20	500
I15	106.42	20	500
I16	150	20	500

Water Pipes Data

Pipes	Minimum Flow Rate (m^3/sec)	Maximum Flow Rate (m^3/sec)
P1	0	0.9
P2	0	0.9
P3	0	0.9
P4	0	0.9
P5	0	0.9
P6	0	0.9
P7	0	0.9
P8	0	0.9
P9	0	0.9
P10	0	0.9
P11	0	0.9
P12	0	0.9
P13	0	0.9
P14	0	0.9
P15	0	0.9
P16	0	0.9

Water Reservoir Data

Reservoir	Maximum Inflow Rate (m^3/sec)
R1 (N1)	0.9

Energy Tariffs Applied to WDS

Hour	Time-of-Use ($/kWh)	Dynamic ($/kWh)
8	0.09	0.1836
9	0.075	0.0756
10	0.075	0.0648
11	0.075	0.0432
12	0.075	0.0432
13	0.075	0.0432
14	0.11	0.0432
15	0.11	0.0432
16	0.11	0.0864
17	0.11	0.1296
18	0.11	0.1836
19	0.11	0.2376
20	0.11	0.162
21	0.11	0.1296
22	0.11	0.108
23	0.11	0.0972
24	0.09	0.0756
1	0.09	0.0756
2	0.09	0.0648
3	0.09	0.0648
4	0.09	0.0648
5	0.09	0.0756
6	0.09	0.1188
7	0.09	0.1944

Pumped-Storage Hydropower (PSH) Unit Data

Pump Location	Pipe 15
Hydropower Generator Location	Pipe 16
Pumping efficiency (%)	85
Generating efficiency (%)	90
Tank Location	Node 16
Tank Initial Volume (m^3)	1200
Tank Target Volume (m^3)	1200
Tank Maximum Volume (m^3)	9000
Tank Maximum Charge/Discharge Flow Rate (m^3//hour)	1080

- **33-Bus Power Distribution System**

Substation Bus Data

Bus	Apparent Power Base (MVA)	Nominal Voltage Base (kV)
b1	100	13.3

Bus Data

Buses	Minimum Voltage Limit (p.u)	Maximum Voltage Limit (p.u)
b2-b33	0.9	1.05

Power and water distribution system coupling points

Pumps	Buses
Pump 1 (Pipe 1)	b12
Pump 2 (Pipe 4)	b24
PSH	b2

Active power Demand (kW)

Bus\Hour	8	9	10	11	12	13	14	15	16	17	18	19
b2	92.4	90.2	87.4	85.5	82.9	81.5	81.3	80.8	80.8	84.2	94.5	100.0
b3	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b4	110.9	108.3	104.8	102.6	99.5	97.9	97.6	96.9	96.9	101.1	113.4	120.0
b5	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b6	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b7	184.9	180.5	174.7	171.1	165.9	163.1	162.7	161.5	161.6	168.4	189.0	200.0
b8	184.9	180.5	174.7	171.1	165.9	163.1	162.7	161.5	161.6	168.4	189.0	200.0
b9	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b10	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b11	41.6	40.6	39.3	38.5	37.3	36.7	36.6	36.3	36.4	37.9	42.5	45.0
b12	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b13	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b14	110.9	108.3	104.8	102.6	99.5	97.9	97.6	96.9	96.9	101.1	113.4	120.0
b15	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b16	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b17	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b18	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b19	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b20	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b21	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b22	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b23	83.2	81.2	78.6	77.0	74.7	73.4	73.2	72.7	72.7	75.8	85.0	90.0
b24	388.2	379.0	366.9	359.2	348.4	342.5	341.6	339.2	339.3	353.7	396.9	420.0
b25	388.2	379.0	366.9	359.2	348.4	342.5	341.6	339.2	339.3	353.7	396.9	420.0
b26	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0

b27	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b28	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b29	110.9	108.3	104.8	102.6	99.5	97.9	97.6	96.9	96.9	101.1	113.4	120.0
b30	184.9	180.5	174.7	171.1	165.9	163.1	162.7	161.5	161.6	168.4	189.0	200.0
b31	138.6	135.4	131.0	128.3	124.4	122.3	122.0	121.1	121.2	126.3	141.7	150.0
b32	194.1	189.5	183.4	179.6	174.2	171.2	170.8	169.6	169.6	176.9	198.4	210.0
b33	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
Bus\Hour	**20**	**21**	**22**	**23**	**24**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
b2	97.3	94.8	89.7	82.1	75.1	71.3	68.9	68.3	69.3	71.4	77.6	87.1
b3	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b4	116.8	113.8	107.6	98.5	90.1	85.6	82.6	81.9	83.2	85.7	93.2	104.6
b5	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b6	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b7	194.7	189.6	179.3	164.2	150.1	142.6	137.7	136.5	138.6	142.9	155.3	174.3
b8	194.7	189.6	179.3	164.2	150.1	142.6	137.7	136.5	138.6	142.9	155.3	174.3
b9	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b10	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b11	43.8	42.7	40.4	36.9	33.8	32.1	31.0	30.7	31.2	32.1	34.9	39.2
b12	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b13	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b14	116.8	113.8	107.6	98.5	90.1	85.6	82.6	81.9	83.2	85.7	93.2	104.6
b15	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b16	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b17	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b18	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b19	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b20	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b21	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b22	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b23	87.6	85.3	80.7	73.9	67.6	64.2	62.0	61.4	62.4	64.3	69.9	78.4
b24	408.8	398.1	376.6	344.8	315.2	299.4	289.2	286.7	291.1	300.0	326.0	366.0
b25	408.8	398.1	376.6	344.8	315.2	299.4	289.2	286.7	291.1	300.0	326.0	366.0
b26	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b27	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b28	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3
b29	116.8	113.8	107.6	98.5	90.1	85.6	82.6	81.9	83.2	85.7	93.2	104.6
b30	194.7	189.6	179.3	164.2	150.1	142.6	137.7	136.5	138.6	142.9	155.3	174.3
b31	146.0	142.2	134.5	123.1	112.6	106.9	103.3	102.4	104.0	107.2	116.4	130.7
b32	204.4	199.1	188.3	172.4	157.6	149.7	144.6	143.4	145.6	150.0	163.0	183.0
b33	58.4	56.9	53.8	49.3	45.0	42.8	41.3	41.0	41.6	42.9	46.6	52.3

Reactive power Demand (kVAr)

Bus\Hour	8	9	10	11	12	13	14	15	16	17	18	19
b2	55.5	54.1	52.4	51.3	49.8	48.9	48.8	48.5	48.5	50.5	56.7	60.0
b3	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
b4	73.9	72.2	69.9	68.4	66.4	65.2	65.1	64.6	64.6	67.4	75.6	80.0
b5	27.7	27.1	26.2	25.7	24.9	24.5	24.4	24.2	24.2	25.3	28.3	30.0
b6	18.5	18.0	17.5	17.1	16.6	16.3	16.3	16.2	16.2	16.8	18.9	20.0
b7	92.4	90.2	87.4	85.5	82.9	81.5	81.3	80.8	80.8	84.2	94.5	100.0
b8	92.4	90.2	87.4	85.5	82.9	81.5	81.3	80.8	80.8	84.2	94.5	100.0
b9	18.5	18.0	17.5	17.1	16.6	16.3	16.3	16.2	16.2	16.8	18.9	20.0
b10	18.5	18.0	17.5	17.1	16.6	16.3	16.3	16.2	16.2	16.8	18.9	20.0
b11	27.7	27.1	26.2	25.7	24.9	24.5	24.4	24.2	24.2	25.3	28.3	30.0
b12	32.3	31.6	30.6	29.9	29.0	28.5	28.5	28.3	28.3	29.5	33.1	35.0
b13	32.3	31.6	30.6	29.9	29.0	28.5	28.5	28.3	28.3	29.5	33.1	35.0
b14	73.9	72.2	69.9	68.4	66.4	65.2	65.1	64.6	64.6	67.4	75.6	80.0
b15	9.2	9.0	8.7	8.6	8.3	8.2	8.1	8.1	8.1	8.4	9.5	10.0
b16	18.5	18.0	17.5	17.1	16.6	16.3	16.3	16.2	16.2	16.8	18.9	20.0
b17	18.5	18.0	17.5	17.1	16.6	16.3	16.3	16.2	16.2	16.8	18.9	20.0
b18	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
b19	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
b20	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
b21	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
b22	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
b23	46.2	45.1	43.7	42.8	41.5	40.8	40.7	40.4	40.4	42.1	47.2	50.0
b24	184.9	180.5	174.7	171.1	165.9	163.1	162.7	161.5	161.6	168.4	189.0	200.0
b25	184.9	180.5	174.7	171.1	165.9	163.1	162.7	161.5	161.6	168.4	189.0	200.0
b26	23.1	22.6	21.8	21.4	20.7	20.4	20.3	20.2	20.2	21.1	23.6	25.0
b27	23.1	22.6	21.8	21.4	20.7	20.4	20.3	20.2	20.2	21.1	23.6	25.0
b28	18.5	18.0	17.5	17.1	16.6	16.3	16.3	16.2	16.2	16.8	18.9	20.0
b29	64.7	63.2	61.1	59.9	58.1	57.1	56.9	56.5	56.5	59.0	66.1	70.0
b30	554.6	541.5	524.1	513.2	497.7	489.3	488.0	484.6	484.7	505.3	567.0	600.0
b31	64.7	63.2	61.1	59.9	58.1	57.1	56.9	56.5	56.5	59.0	66.1	70.0
b32	92.4	90.2	87.4	85.5	82.9	81.5	81.3	80.8	80.8	84.2	94.5	100.0
b33	37.0	36.1	34.9	34.2	33.2	32.6	32.5	32.3	32.3	33.7	37.8	40.0
Bus\Hour	**20**	**21**	**22**	**23**	**24**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
b2	58.4	56.9	53.8	49.3	45	42.8	41.3	41	41.6	42.9	46.6	52.3
b3	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9
b4	77.9	75.8	71.7	65.7	60	57	55.1	54.6	55.5	57.2	62.1	69.7
b5	29.2	28.4	26.9	24.6	22.5	21.4	20.7	20.5	20.8	21.4	23.3	26.1
b6	19.5	19	17.9	16.4	15	14.3	13.8	13.7	13.9	14.3	15.5	17.4
b7	97.3	94.8	89.7	82.1	75.1	71.3	68.9	68.3	69.3	71.4	77.6	87.1
b8	97.3	94.8	89.7	82.1	75.1	71.3	68.9	68.3	69.3	71.4	77.6	87.1
b9	19.5	19	17.9	16.4	15	14.3	13.8	13.7	13.9	14.3	15.5	17.4
b10	19.5	19	17.9	16.4	15	14.3	13.8	13.7	13.9	14.3	15.5	17.4

b11	29.2	28.4	26.9	24.6	22.5	21.4	20.7	20.5	20.8	21.4	23.3	26.1
b12	34.1	33.2	31.4	28.7	26.3	25	24.1	23.9	24.3	25	27.2	30.5
b13	34.1	33.2	31.4	28.7	26.3	25	24.1	23.9	24.3	25	27.2	30.5
b14	77.9	75.8	71.7	65.7	60	57	55.1	54.6	55.5	57.2	62.1	69.7
b15	9.7	9.5	9	8.2	7.5	7.1	6.9	6.8	6.9	7.1	7.8	8.7
b16	19.5	19	17.9	16.4	15	14.3	13.8	13.7	13.9	14.3	15.5	17.4
b17	19.5	19	17.9	16.4	15	14.3	13.8	13.7	13.9	14.3	15.5	17.4
b18	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9
b19	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9
b20	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9
b21	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9
b22	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9
b23	48.7	47.4	44.8	41	37.5	35.6	34.4	34.1	34.7	35.7	38.8	43.6
b24	194.7	189.6	179.3	164.2	150.1	142.6	137.7	136.5	138.6	142.9	155.3	174.3
b25	194.7	189.6	179.3	164.2	150.1	142.6	137.7	136.5	138.6	142.9	155.3	174.3
b26	24.3	23.7	22.4	20.5	18.8	17.8	17.2	17.1	17.3	17.9	19.4	21.8
b27	24.3	23.7	22.4	20.5	18.8	17.8	17.2	17.1	17.3	17.9	19.4	21.8
b28	19.5	19	17.9	16.4	15	14.3	13.8	13.7	13.9	14.3	15.5	17.4
b29	68.1	66.4	62.8	57.5	52.5	49.9	48.2	47.8	48.5	50	54.3	61
b30	584.1	568.8	538	492.5	450.3	427.8	413.1	409.6	415.9	428.6	465.8	522.9
b31	68.1	66.4	62.8	57.5	52.5	49.9	48.2	47.8	48.5	50	54.3	61
b32	97.3	94.8	89.7	82.1	75.1	71.3	68.9	68.3	69.3	71.4	77.6	87.1
b33	38.9	37.9	35.9	32.8	30	28.5	27.5	27.3	27.7	28.6	31.1	34.9

Feed-in Tariff

Feed-in Tariff	0.03 ($/kWh)

Upstream Grid Price

Hour	**Price ($/kWh)**	**Hour**	**Price ($/kWh)**
8	0.0749	**20**	0.0709
9	0.0339	**21**	0.0530
10	0.0308	**22**	0.0467
11	0.0137	**23**	0.0403
12	0.0136	**24**	0.0316
13	0.0139	**1**	0.0306
14	0.0144	**2**	0.0263
15	0.0146	**3**	0.0263
16	0.0302	**4**	0.0263
17	0.0578	**5**	0.0302
18	0.0800	**6**	0.0528
19	0.1050	**7**	0.0872

33-Bus Power Distribution Lines Data

Line		Resistance (Ohm)	Reactance (Ohm)
From Bus	To Bus		
b1	b2	0.0922	0.047
b2	b3	0.493	0.2511
b3	b4	0.366	0.1864
b4	b5	0.3811	0.1941
b5	b6	0.819	0.707
b6	b7	0.1872	0.6188
b7	b8	1.7114	1.2351
b8	b9	1.03	0.74
b9	b10	1.044	0.74
b10	b11	0.1966	0.065
b11	b12	0.3744	0.1238
b12	b13	1.468	1.155
b13	b14	0.5416	0.7129
b14	b15	0.591	0.526
b15	b16	0.7463	0.545
b16	b17	1.289	1.721
b17	b18	0.732	0.574
b2	b19	0.164	0.1565
b19	b20	1.5042	1.3554
b20	b21	0.4095	0.4784
b21	b22	0.7089	0.9373
b3	b23	0.4512	0.3083
b23	b24	0.898	0.7091
b24	b25	0.896	0.7011
b6	b26	0.203	0.1034
b26	b27	0.2842	0.1447
b27	b28	1.059	0.9337
b28	b29	0.8042	0.7006
b29	b30	0.5075	0.2585
b30	b31	0.9744	0.963
b31	b32	0.3105	0.3619
b32	b33	0.341	0.5302