Comparison of power system simulation software PSS NETOMAC with open source calculation tool Matpower

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***Abstract*—Load flow states the sinusoidal steady state of a system. In a Network, power flow is studied using load flow analysis. It calculates the voltage, voltage angle, active power reactive power and losses in the system. In this research paper, the static load analysis of eleven bus network is analyzed in Power System Simulator and Network Torsion Machine Control(PSS NETOMAC) and Matpower. Modeling and simulation of network is carried out and the results are being compared based on nodal voltage, nodal Voltage angle, generator power, losses occurred during load flow and iteration time. This paper also explains how the Matpower which is an open source software, can be used for load flow simulation.**

***Index Terms*—Load flow, Matpower, PSS NETOMAC.**

I. Introduction

The load flow is the most important network computation in a power system. In load flow studies, magnitude and angle of voltage, current flow, real and reactive power produced or absorbed and power losses can be calculated at each node [1]. The main task of this paper is to run static load flow analysis on a given medium voltage network, to determine the nodal voltage, nodal angle, generator power and the line losses in the network and to compare the results in both PSS NETOMAC and Matpower [2].

II. MEDIUM VOLTAGE NETWORK.

Figure 1 shows 20 kV network with 11 Bus and 12 branches. The node K1 is connected to the Slack generator G5 which is connected to node K3 via 12.5 MVA ($20/110$ kV) star-delta transformer T2 to node K2. The node K0 is connected to the generator G1 which is connected to node K3 via 2 MVA transformer star-delta T1 ($0.4/20$ kV). A phase angle shift of $30°$ degrees between star and delta connected transformer is assumed. This network has 5 generators with 2 transformers and 8 loads, connected to the house nodes and photovoltaic power plants, which are connected to the respective nodes as per the network. The maximum load for house connection is 1 kW. More detailed network parameters are described : table I shows the types of nodes and values, table II shows parameters of transformers in electrical network and table III shows parameters of the elements connected to grid.

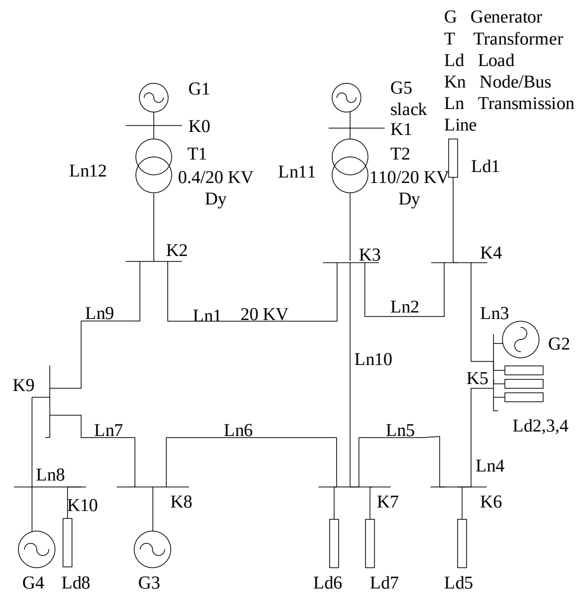


Fig. 1. Single line diagram of 11 bus medium voltage network system [3].

Loads are being modeled as negative generators. The generators have reactive power limits within -3 MVAr to 3 MVAr. Buses are divided into load bus (PQ), generator bus (PV) and slack bus. At slack node, a reference voltage of magnitude of 1.0 per unit (p.u) and angle $0°$ degree is considered.

III. Comparison of Results between PSS NETOMAC and MATPOWER.

Here the simulation is compared based on static load flow analysis with generator reactive power limits. In Matpower, 11 buses are represented from bus from 0 to 10 and Newton-raphson algorithm is used [4]–[8]. In PSS NETOMAC, nodes

TABLE I
PARAMETERS OF BUSES IN ELECTRICAL NETWORK.

Bus /Node	Type	V(p.u)	Phase(deg.)	P (MW)	Q (MVAr)
K1	Slack	1	0	x	x
K2	PV	1	x	0	x
K3	PV	1	x	0	x
K4	PQ	x	x	-0.63	-0.2
K5	PQ	x	x	-0.8	-0.6
K6	PQ	x	x	-1	-0.2
K7	PQ	x	x	-1.03	-0.2
K8	PV	1	x	1	x
K9	PQ	x	x	0	0
K10	PV	1	x	1.9	x
K0	PV	1	x	2	x

TABLE II
PARAMETERS OF TRANSFORMERS.

Transformer	High voltage	Low voltage	type	reactance	suseptance
T1	110 kV	20 kV	Dy	12.5%	8%
T2	20 kV	0.4 kV	Yd	12.5%	8%

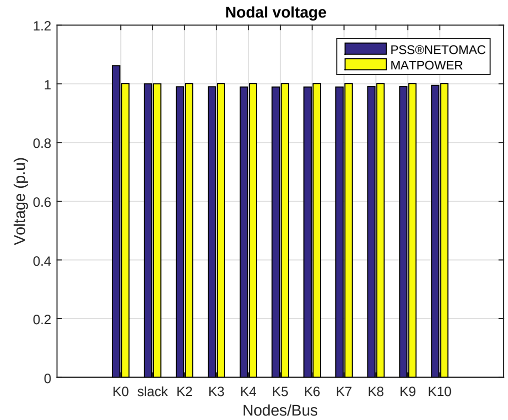
are represented by K0 to K10. At the Slack bus, voltage is 1 p.u and angle $0°$ degree [9]–[12].

A. Nodal voltages

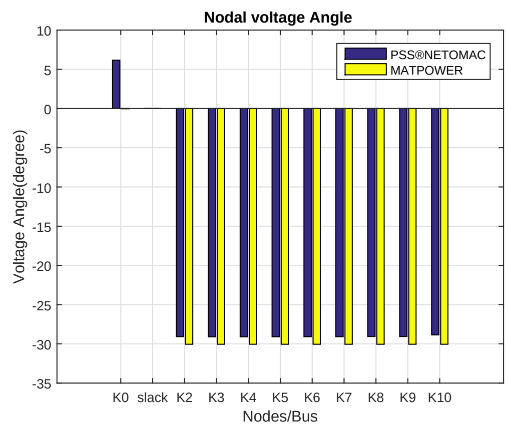
Figure 2a shows the maximum voltage magnitude occurs at K0 : 1.062 p.u in PSS NETOMAC as compared to 1.001 p.u in Matpower. The minimum voltage, in PSS NETOMAC is 0.989 p.u at bus K6 as compared to 1.0 p.u in Matpower at bus K11. This difference occurs because in Matpower, at PV bus, voltage is fixed whereas in PSS NETOMAC, there is brute force approach that allows the generator reactive power limits to be respected at the expense of the voltage set-point.

TABLE III
PARAMETERS IN ELECTRICAL NETWORK.

Element	Dimension	Specification
Ld1	630 kW	H0
Ld2	400 kW	L0
Ld3	250 kW	G0
Ld4	400 kW	H0
Ld5	1000 kW	G0
Ld6	630 kW	H0
Ld7	400 kW	G0
Ld8	100 kW	H0
G1	2000 kW	PV
G2	250 kW	BHKW
G3	1500 kW	PV
G4	2000 kW	Wind
T1	2000 kVA	0.4/20 kV
T2	12.5 MVA	110/20 kV
Ln1	500 m	Cable: NA2XS2Y $3 \times 1 \times 150\ mm^2$
Ln2	1200 m	Cable: NA2XS2Y $3 \times 1 \times 120\ mm^2$
Ln3	400 m	Cable: NA2XS2Y $3 \times 1 \times 95\ mm^2$
Ln4	1000 m	Cable: NA2XS2Y $3 \times 1 \times 95\ mm^2$
Ln5	200 m	Cable: NA2XS2Y $3 \times 1 \times 70\ mm^2$
Ln6	600 m	Cable: NA2XS2Y $3 \times 1 \times 70\ mm^2$
Ln7	100 m	Cable: NA2XS2Y $3 \times 1 \times 95\ mm^2$
Ln8	2000 m	Overhead Line: $3 \times 1 \times 70\ mm^2$
Ln9	900 m	Cable: NA2XS2Y $3 \times 1 \times 120\ mm^2$
Ln10	700 m	Overhead Line: $3 \times 1 \times 95\ mm^2$



(a) Voltage

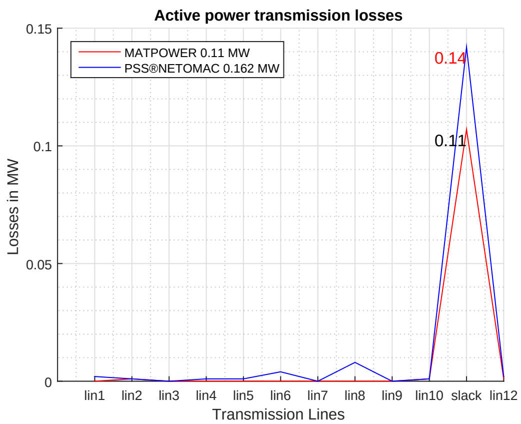


(b) Voltage angle

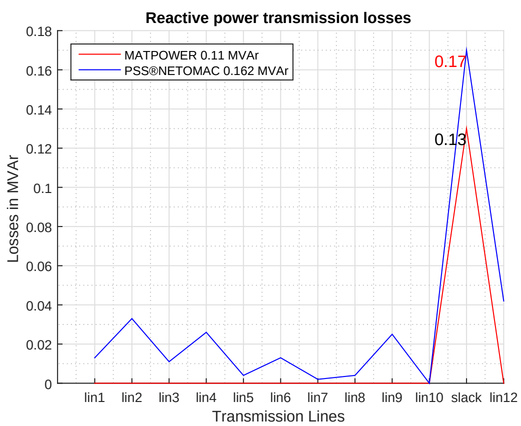
Fig. 2. Voltage at the nodes from K0 to K10 between PSS NETOMAC and Matpower.

In brute force algorithm of PSS NETOMAC, an outer loop around the AC power flow solution is done. If any generator has a violated reactive power limit, its reactive injection is fixed at the limit, the corresponding bus is converted into a PQ bus and the power flow is solved again.This procedure is repeated until there is/are no more violation(s) in reactive power of generator [11]–[14].

In fixed PV bus voltage algorithm of Matpower, real power and voltage magnitude is fixed whereas voltage angle or reactive power is compensated.At K1 Slack bus, voltage is 1 p.u and angle $0°$ degree in both softwares. Figure 2b shows that the maximum voltage angle occurs at K0, $6.1162°$ degrees in PSS NETOMAC as compared to $0.034°$ degree in Matpower. The minimum voltage angle, $-29.105°$ degrees in PSS NETOMAC at bus K3 as compared to $-30.05°$ degrees in Matpower at bus K5. This difference occurs due to brute force and fixed PV bus voltage algorithm.

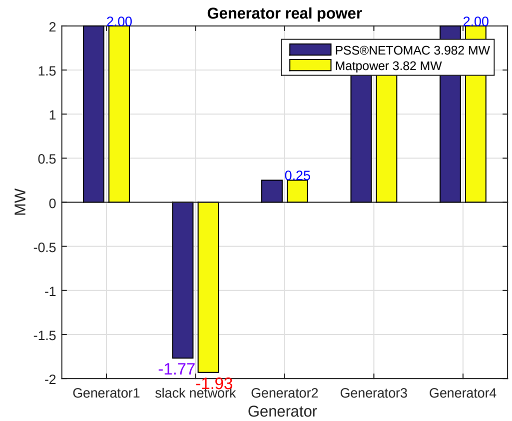


(a) Active power loss

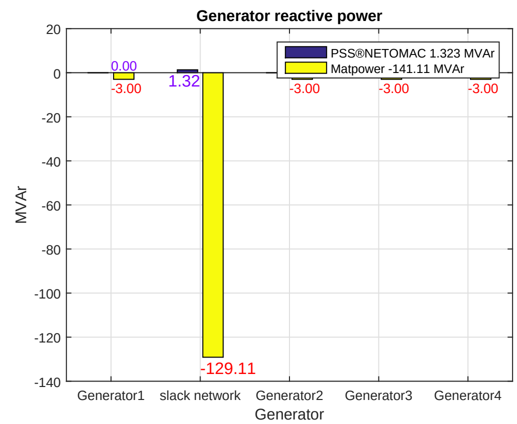


(b) Reactive power loss

Fig. 3. Transmission losses (active and reactive) which occur at various transmission lines in the network.



(a) Active power



(b) Reactive power

Fig. 4. Generators results

B. Transmission line losses.

Figure 3 compares transmission line losses which occur at various transmission lines, the maximum power loss occurs at line 11 (the line connecting node 1 and node 3) for both PSS NETOMAC and Matpower. Total active power loss in Matpower is 0.11 MW as compared to 0.162 MW in PSS NETOMAC. Total reactive power loss in Matpower is 0.13 MVAr whereas in PSS NETOMAC, it is 0.088 MVAr.

The difference in power loss is due to calculation approach in medium voltage Π (pi) equivalent circuit of frequency 50 Hz for the transmission line. In Matpower, lumped element Π equivalent circuit is considered, series impedance losses using equation 1 and shunt impedance losses using equations 2 and 3 are calculated separately. In PSS NETOMAC, admittance matrix (Y_{bus}) method approach uses equations 4, 5, 6, 7 and 8 [12]–[14].

In Matpower,series losses is

$$series_{losses} = \left| \frac{(\frac{V_f}{N} - V_t)^2}{R + \mathrm{j}X_s} \right| \tag{1}$$

shunt losses are

$$F_{chrg} = \left| \frac{\frac{V_f}{N}^2}{\mathrm{j}\frac{B}{2}} \right| \tag{2}$$

$$T_{chrg} = \left| \frac{V_t^2}{\mathrm{j}\frac{B}{2}} \right| \tag{3}$$

where

$series_{losses}$ is series transmission losses.
$R + \mathrm{j}X_s$ is series impedance.
$\mathrm{j}\frac{B}{2}$ is shunt impedance.
N is transformer ratio.
V_f is voltage from branch.
V_t is voltage to branch.
F_{chrg} is power losses from branch charging losses.
T_{chrg} is power losses to branch charging losses.

In PSS NETOMAC,

$$I_{ik} = -Y_{bus} \times (V_i - V_k) \tag{4}$$

$$P_i + \mathrm{j}Q_i = V_i \times (I_i)^* \tag{5}$$

$$P_k + \mathrm{j}Q_k = V_k \times (I_k)^* \tag{6}$$

transmission losses are

$$P_{ik} = P_i - P_k \tag{7}$$

$$Q_{ik} = Q_i - Q_k \tag{8}$$

where
Y_{bus} is admittance matrix.
I_{ik} is current flow between node i and node k.
P_i and P_k:are real power at node i and k respectively.
Q_i and Q_k:are reactive power at node i and k respectively.
V_i is voltage at from branch.
V_k is voltage to branch.
$R + \mathrm{j}X_s$ is series impedance.
$\mathrm{j}C/2$ is shunt impedance.
$(I_i)^*$ is complex conjugate of current I_i.

The maximum active power loss is 0.107 MW in Matpower as compared to 0.142 MW in PSS NETOMAC at Line11 (Node 1 to Node 3). The maximum reactive power loss is 0.13 MVAr in Matpower and 0.17 MVAr in PSS NETOMAC at Line11. The maximum power loss occurs at same Line11 for both softwares which indicates the fact of similar power flow method see figure 1.

C. Generator power

In Matpower, figure 4a shows the slack generator has -1.93 MW and -129.11 MVAr. Total generation (actual) reactive power is -138 MVAr and branch charging (injection) is 139.4 MVAr. Other generators respect lower limit of the reactive power of -3 MVAr. In PSS NETOMAC, figure 4b slack generator has -1.768 MW and 1.323 MVAr. Other generators take the reactive power of 0 MVAr. This difference is due to approach,in Matpower, losses are calculated using series and shunt losses of transmission lines as given in subsection III-B. These losses are compensated by slack generator. This is given by branch charging (injection) see equations 2 and 3. In PSS NETOMAC, the reactive power required for transmission[branch charging (injection)] is not taken into account. Instead, an optimum way of reactive power losses compensation method is implemented using Y_{bus} method and brute force algorithm as given in subsection III-B [11], [12].

D. Iterations and convergence time

Table IV shows the results of Newton Raphson's method power flow converged in 6 iterations in Matpower. It converges in 0.34 second. PSS NETOMAC converges in 5 seconds. Load flow converged after 14 iteration(s).

E. Graphical user interface (GUI) and script language

PSS NETOMAC has more user friendly GUI when compared to Matpower. Many softwares such as NETDRAW can be integrated with PSS NETOMAC whereas Matpower is based on MATLAB, which is more of a rigid script format [13], [15].

TABLE IV
MAXIMUM P AND Q MISMATCH WITH RESPECT TO NUMBER OF ITERATIONS IN MATPOWER.

Number of iterations	max Pand Q mismatch (p.u.)
0	$2.35e+04$
1	$2.00e+04$
2	$2.95e+03$
3	$5.02e+02$
4	$3.39e+01$
5	$1.75e-01$
6	$4.61e-06$

IV. CONCLUSION

Static load flow simulation shows a comparison between two softwares based on nodal voltage, voltage angle, transmission power loss, generator results and GUI. The differences and similarities in the results are due to different algorithms : losses calculation algorithm of Π model, line charging injections of both of the shunt elements of Π model, Newton Raphson algorithm, iteration limits, fixed PV bus, Y_{bus} and brute force method. PSS NETOMAC has more advantages when compared to Matpower such as optimum distribution in generator reactive power. However Matpower is an open source software which can be modified for optimum results.

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