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IMPLEMENTATION OF POWER FLOW ANALYSIS WITH COMPLEX VARIABLE TO IMPROVE THE COMPUTATIONAL EFFICIENCY

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ABSTRACT :-*Important implication of the Complex - Variable Newton - Raphson load flow analysis is that Jacobian size reduces to approximately half in comparison with the traditional Real-Variable Newton-Raphson method. This significant reduction in memory access achieved will lead to the advantage of substantial reduction in computing time which will increase the efficiency. In this paper we have use MATLAB to compare computational time require for load flow analysis with complex variables and with real variables. Numerical results on 3 – bus system, IEEE 13 and 300– bus system are presented to show the effectiveness of the proposed method.*

Keywords *-Complex – Variable Newton Raphson method, Computational time, Jacobian size, Load flow analysis, Newton – Raphson method.*

I. INTRODUCTION

Load flow analysis is important aspect of power system analysis. The Newton – Raphson method using Taylor series expansion is assess as best solution for good reliability and fast convergence property. [1] The Newton – Raphson Solution is a preferred algorithm for nonlinear equations solved on workstation or personal computer systems. [2] However the Newton – Raphson method use real variable jacobian matrix, which requires about twice as memory to do the same computation as with complex variable. [3] For large system where computational memory is much more, an algorithm using complex arithmetic could be more efficient.

This paper presents an extensive calculation of jacobian matrix with complex variables in section II.Algorithm of Complex – Variable Newton Raphson is presented in section III. Comparison of computational time in both Real – Variable Newton – Raphson method and Complex – variable Newton – Raphson method with numerical results on 3 – bus system [1] and IEEE 13 and 300– bus system[4] are presented in section IV.

II. NEWTON – RAPHSON METHOD WITH JACOBIAN IN COMPLEX FORM

This technique is based on the extension of the Newton – Raphson method with its jacobian in complex form. A general three – phase network can be represent by an apparent power equation system in matrix form,

$$S_{bus}^{*} = \mathrm{V}_{\mathrm{bus}}^{*}\,\mathrm{I}_{\mathrm{bus}} \qquad (1)$$

$$\mathrm{I}_{\mathrm{bus}} = (\mathrm{Y}_{\mathrm{bus}}\,\mathrm{V}_{\mathrm{bus}}) \qquad (2)$$

Where$\mathrm{V}_{\mathrm{bus}}$,$\mathrm{I}_{\mathrm{bus}}$ - bus voltage and current matrix and $\mathrm{Y}_{\mathrm{bus}}$ - bus admittance matrix. Formation of complex form jacobian matrix is done by partial derivation of equation (1).

Jacobian Matrix in complex form,

$$\Delta V_{bus} = \mathrm{J}^{-1} \cdot \Delta \mathrm{S}_{\mathrm{bus}}^{*} \ (3)$$

$$[\Delta \mathrm{V}_{\mathrm{bus}}] = \left[\frac{\partial S_{bus}^{*}}{\partial \mathrm{V}_{\mathrm{bus}}}\right]^{-1} [\Delta \mathrm{S}_{bus}^{*}] (4)$$

Here ΔV_{bus} is change in bus voltage, J is the jacobian matrix and $\Delta \mathrm{S}_{\mathrm{bus}}^{*}$ is change in apparent power of the power system. In power system there are mainly three types of buses PQ buses (/Load buses), PV buses (/Generator buses), Slack bus. For i^{th} bus in n – bus system change in apparent power is,

$$\Delta S_i^{*} = S_{scheduled\ ,i}^{*} - S_{calculated\ ,i}^{*} \ (5)$$

Here$S^*_{scheduled\ ,i}$,$S^*_{calculated\ \ ,i}$ are the scheduled value of apparent power and calculated value of apparent power.

$\Delta S_i^* = \left(P_{sch,i} - jQ_{sch,i}\right) - (V_i^* \sum_{k=1}^{n} Y_{ik} V_k)$ (6)

Here $P_{sch,i}$,$Q_{sch,i}$are real and reactive scheduled powers,V_i, V_k are bus voltage at bus 'i' and bus 'k',Y_{ik} is admittance between bus 'i' and bus 'k'.

If bus 'i' is slack bus then iterative calculation is not done.

For PQ buses, Real load and Reactive load are known whereas voltage magnitude and voltage phase angle is unknown. If bus 'i' is a PQ bus then ΔS_i^* is calculated as shown in equation (6).

For PV buses, Real power generated and voltage magnitude are known whereas voltage phase angle and reactive power generation is unknown. If bus 'i' is a PV bus then ΔS_i^* is calculated as shown below,

$\Delta S_i^* = \Delta P_i$

Since Q_i is not defined in PV bus, in each iteration.

$$\Delta Q_i = 0$$

$\Delta S_i^* = \left(P_{sch,i}\right) - real(V_i^* \sum_{k=1}^{n} Y_{ik} V_k)$ (7)

2.1 Calculation of Jacobian element with complex variables:

For PQ and PV buses change in apparent power is known from equation (6) and (7). Calculation of jacobian matrix $\partial S^*_{bus} / \partial \mathrm{V}_{\mathrm{bus}}$ is given here. One thing should be noted that ΔV_{bus} is calculated for PQ and PV buses, similar way ΔS_{bus} is given for PQ and PV buses. Hence jacobian matrix $\partial S^*_{bus} / \partial \mathrm{V}_{\mathrm{bus}}$ has dimension of {(number of PQ buses + number of PV buses) x (number of PQ buses + number of PV buses)} = (n-1) x (n-1).Here n is the total number of the buses.

2.1.1 Diagonal Elements in $\frac{\partial S^*_{bus}}{\partial \mathrm{V}_{\mathrm{bus}}}$matrix:

In n – bus system, diagonal element of jacobian matrix for bus 'i',

$$\frac{\partial S_i^*}{\partial V_i} = \frac{\partial}{\partial V_i}\left\{V_i^* \sum_{k=1}^{n} Y_{ik} V_k\right\}$$

$$= \frac{\partial}{\partial V_i}\{V_i^*\}\left(\sum_{k=1}^{n} Y_{ik} V_k\right) + V_i^* \frac{\partial}{\partial V_i}\{\sum_{k=1}^{n} Y_{ik} V_k\}$$

$$= \frac{\partial}{\partial V_i}\left\{V_i\, e^{-j2\delta_i}\right\}\left(\sum_{k=1}^{n} Y_{ik} V_k\right) + V_i^* \frac{\partial}{\partial V_i}\{Y_{ii} V_i\}$$

$$= \left\{e^{-j2\delta_i}\right\}\left(\sum_{k=1}^{n} Y_{ik} V_k\right) + V_i^* Y_{ii}$$

$= \left\{e^{-j2\delta_i}\right\}\left(\frac{S^*_{calculated\ \ ,i}}{V_i^*}\right) + V_i^* Y_{ii}$ (8)

Generally phase angle of all bus voltages are nearer to zero radian hence we can take the approximation that δ_i is approximately constant and there for we get result shown in (8).

2.1.2 Off - Diagonal Elements in $\frac{\partial S_{bus}^*}{\partial \mathrm{V}_{\mathrm{bus}}}$ matrix:

In n – bus system, bus 'i' and bus 'j' are two different buses then off – diagonal element of jacobian matrix,

$$\frac{\partial S_i^*}{\partial \mathrm{V}_j} = \frac{\partial}{\partial \mathrm{V}_j}\left\{V_i^* \sum_{k=1}^{n} Y_{ik} V_k\right\}$$

$$= V_i^* \frac{\partial}{\partial \mathrm{V}_j}\left\{\sum_{k=1}^{n} Y_{ik} V_k\right\}$$

$$= V_i^* \frac{\partial}{\partial \mathrm{V}_j}\{Y_{ij} V_j\}$$

$$= V_i^* Y_{ij} \quad (9)$$

III. COMPLEX – VARIABLE NEWTON – RAPHSON ALGORITHM

The iterative algorithm for the solution of the load flow problem by the Complex – Variable Newton – Raphson method is as follows:

1. With $\mathrm{V}_{\mathrm{bus}}$ at the slack bus fixed at $1+j0$, we assume $\mathrm{V}_{\mathrm{bus}}$ at all PQ buses and δ at all PV buses. If information is absent then flat voltage start is used.
2. Calculation of apparent power at i bus,

$$S_{calculated\ ,i}^* = V_i^* \sum_{k=1}^{n} Y_{ik} V_k \quad (10)$$

   Now, we calculate ΔS_i^* for PQ buses from equation (6) and for PV buses, calculate ΔS_i^* from equation (7) respectively. If ΔS_i^* are less than the prescribed tolerance then we stop the iteration and print the entire solution including line flows.
3. If convergence criteria is not satisfied, we calculate the complex jacobian element using equation (8) and (9).
4. We solve the equation (4) for correction of complex bus voltage $\Delta \mathrm{V}_{\mathrm{bus}}$.
5. Now we update the complex bus voltage for PQ buses and PV buses,

$$\mathrm{V}_{bus}^{(r+1)} = \mathrm{V}_{bus}^{(r)} + \Delta\mathrm{V}_{bus}^{(r)} \quad (11)$$

   Then return to step 2.

IV. NUMERICAL RESULTS

Dimension of jacobian in traditional Newton – Raphson method is (2n-m-2) x (2n-m-2) whereas dimension of jacobian in Complex – Variable Newton – Raphson method is (n-1) x (n-1). Here n is total number of buses and m is total number of PV buses. It is clear that dimension of jacobian in Complex – Variable Newton – Raphson method is almost half compare to previous one. In NR algorithm jacobian should be calculated and inverted in each iteration, which is the major time consuming part in computer programming. Hence implementing complex algorithm time consumption should be much lower.
Both methods are compared using MATLAB software for 3 – bus system, [1] IEEE 13 and 300– bussystem. [4]Computer Hardware used is Intel(R) Core(TM) i5-2450M CPU processor used with 2.50GHz base frequency and 4GB RAM. Results obtained from the MATLAB software are verified with MATPOWER results.

Schematic diagram of 3 – bus system is presented in fig.1. In this example 1st bus is slack bus, 2nd bus is PQ bus and 3rd bus is PV bus. Each line resistance is 0.02pu, each line reactance is j0.08pu and a total shunt admittance is j0.02pu. Controllable reactive power source is available at bus 3 with constraint, $0 < Q_{G3} < 1.5$pu. Apparent power at each bus are shown in figure 1.

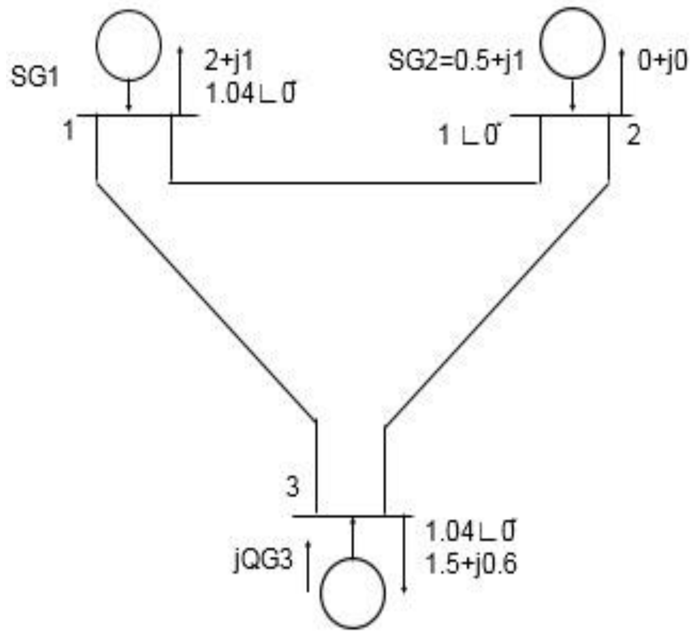

Fig.1: 3 – bus system

An example of IEEE – 13 bus system is presented here. In this bus system 1st bus is slack bus, 4th and 10th bus are PV buses and remaining buses are PQ buses. Data of IEEE – 13 bus system are given in the Appendix.

Another example of IEEE – 300 bus system is presented here. In this bus system total number of buses are 300, total number of transmission lines are 304, total number of transformers are 107, total number of shunt branches are 29, slack bus number is 278, and slack bus voltage magnitude is 1.0507pu. [4]

Comparison of computational time in both method for the 3 – bus system, IEEE 13 and 300 – bus system is shown in the chart.

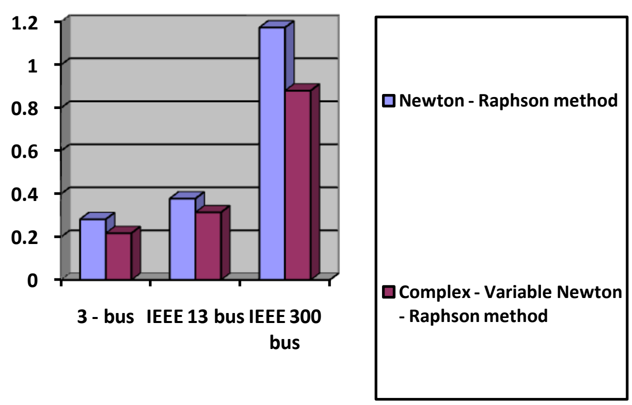

Fig.2: Comparison of computational time in both methods (Time in Seconds).

Table.1: Result analysis of proposed method

Test System	Execution time for proposed method (Seconds)	Execution time for traditional method (Seconds)	Convergence criteria (pu)
3 bus system	0.217381	0.282192	0.001
IEEE 13 bus system	0.314162	0.378046	0.001
IEEE 300 bus system	0.879869	1.173159	0.001

From the results, it can be seen that proposed method has same precision level with less computational time.Hence it can be verified that Complex – Variable Newton – Raphson method is computationally more efficient than the traditional Newton – Raphson method for given test cases.

V. CONCLUSION

Newton – Raphson method with complex variables is proposed in this paper and it is verified with the help of standard 3 bus system, IEEE 13 and 300 bus system. By comparing the computational time requirement in both methods, the complex variable Newton- Raphson method is found to be computationally more efficient.

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APPENDIX

IEEE 13 bus system data:
Busdata:

$$P_i = P_{G,i} - P_{L,i}$$
$$Q_i = Q_{G,i} - Q_{L,i}$$

V_{sp} = Voltage magnitude (pu)
δ_i = Voltage phase angle (radian)

Bus No:	Type	P_i	Q_i	V_{sp}	δ_i
1	3	0	0	0.95	0
2	1	0	0.24	0.9	0
3	1	-0.12	-0.04	1.0	0
4	2	-0.16	0	1.0	0
5	1	0	0.36	0.95	0
6	1	-0.08	-0.04	1.0	0
7	1	-0.12	-0.04	1.0	0
8	1	-0.6	-0.2	0.9	0
9	1	-0.12	-0.04	1.0	0
10	2	-0.08	0	1.0	0
11	1	-0.4	-0.04	0.95	0
12	1	-0.04	0.2	1.0	0
13	1	-0.08	0.16	0.95	0

Line data:

From bus	To bus	G (pu)	B (pu)	R (pu)	X (pu)
1	2	0	0	0.099	0.1
1	3	0	0	0.05	0.1
3	5	0	0	0.05	0.1
3	4	0	0	0.05	0.1
6	3	0	0	0.05	0.1
6	4	0	0	0.05	0.1
2	5	0	0	0.05	0.1
11	5	0	0	0.099	0.1
3	11	0	0	0.05	0.1
9	11	0	0	0.05	0.1
9	10	0	0	0.05	0.1
7	9	0	0	0.05	0.1
7	10	0	0	0.05	0.1
8	10	0	0	0.05	0.1
3	12	0	0	0.05	0.1
13	11	0	0	0.05	0.1
12	13	0	0	0.05	0.1