International Journal of Smart Electrical Engineering, Vol.8, No.2, Spring 2019
ISSN: 2251-9246
EISSN: 2345-6221
pp. 51:58

A New Method for Simplification and Reduction of State Estimation's Computational Complexity in Stability Analysis of Power Systems

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Abstract

The dynamic stability problem is one of the challenges that is constantly being discussed in power systems. Meanwhile, one of the most important factors, which will have a direct impact on its determination, is the system state estimation. To monitor the stability of the power system, one of the determinative factors is the accuracy and speed of the state estimation equations' input data. Therefore, in this paper, the Factorized Load Flow Method was used as a method for estimating input data of the system stability analysis. In this study, factorized load flow method was presented in full details in terms of theoretical relations and simulation results, and in order to prove its performance efficiency a comparison was made between its results with the results of the Newton-Raphson method. The conducted comparisons and investigations showed that the proposed method can determine the needed inputs for state estimation with high speed and precision. The proposed method was simulated using coding environment of MATLAB software and it was shown that this idea enjoyed an appropriate quality for reducing the computational complexity and increasing the accuracy and speed of state estimation.

Keywords: Dynamic stability of power system, Factorized Load flow, state estimation, Newton-Raphson Method
Article history: Received 11-Jan-2020; Revised 24-Jan-2020; Accepted 02-Jun-2020.

1. Introduction

Although early researches and methods regarding load flow were proposed in the 1950s, efficient techniques, such as Newton-Raphson, were introduced in the 1970s, which was highly comparative with other methods [1] [2]. Until then, a number of papers and methods were used to improve previous ones, including component modeling, computational complexity reduction using parallel computation, static Jacobin, second order methods, and etc., that these early ideas were widely used in the industry [3]. All the mentioned methods had the problem of increasing the complexity of the number of the equations in solving the nonlinear equations. In addition, the low accuracy of the final obtained results was another shortcoming of these methods. After that, a method was proposed based on Newton-Raphson in the polar form that its successful implemented version is known as the fast-decoupled load-flow method [4]. These methods were presented to solve various problems of load-flow in power systems [5]. In the recent years, power system state estimation has been the researchers' great interest which has been done by SCADA systems. In this method, SCADA systems were applied for measuring the active and reactive powers. This method had a lower accuracy level of answers due to the application of rough approximations [6]. Among all the methods which have been discussed by different articles so far, the use of the load-flow problem for nonlinear and combined loads have been considered as a challenge and these methods always provide the required analyses in terms of load linearity. The method that is represented in this study can more accurately engage nonlinear loads in load-flow computation.

This study aimed at providing a new method for conducting the load-flow computations with changing the traditional load-flow methods in order to be used in system state estimation with higher efficiency. Simplification of the state estimation in power systems for analyzing network stability, converting nonlinear constraints to linear ones in analyzing network parameters, the more robust response for power system state estimation by the proposed method, and computational complexity and less iteration compared to Newton-Raphson method are among the purposes of this study.

2. Factorized Load Flow Method

In fact, this method of load-flow is a technique for simplifying state estimation equations which by partitioning Jacobian matrix into sub-factors makes the state estimation algorithm able to perform network stability computation more accurately and quickly. In general, load-flow problems can be described as follows [7] -[8]:

1) Calculation of Slack bus power in a given voltage

2) Calculation of the angles of the voltage phasors and reactive power of the PV-buses in a given voltage and active power

3) Calculation of the size of voltage angle and its angle for PQ-buses in a given active and reactive power.

$$P_i = \sum_{j=1}^{n} e_i (G_{ij} e_j - B_{ij} f_j) + f_i (G_{ij} f_j + B_{ij} e_j) \tag{1}$$

$$Q_i = \sum_{j=1}^{n} f_i (G_{ij} e_j - B_{ij} f_j) + e_i (G_{ij} f_j + B_{ij} e_j) \tag{2}$$

$$|V_i|^2 = e_i^2 + f_i^2 \tag{3}$$

Given the above relations, we know that the first and second relations were used to calculate the active and reactive powers of the slack bus and PQ bus, and the third relation was used to calculate the voltage size of the PV buses. The load-flow was explained as the factorized equations as follows:

$$P = \vec{e}\, Ge - \vec{e}\, Bf + \vec{f}\, Be + \vec{f}\, Gf \tag{4}$$

To incorporate the PV buses, using the following relation B and G were transformed into B_1 and G_1 and were placed in above ones:

$$B_1(i,j) = B(i,j)\ ,\ G_1(i,j) = G(i,j) \quad if\ "i"\ is\ a\ PQ\ bus \tag{5}$$

$$B_1(i,j) = 1\ ,\ G_1(i,j) = 0 \quad if\ i \neq j \quad if\ "i"\ is\ a\ PV\ bus \tag{6}$$

$$G_1(i,j) = 1\ ,\ B_1(i,j) = 0 \quad if\ i \neq j \quad if\ "i"\ is\ a\ PV\ bus \tag{7}$$

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} \vec{e} & \vec{f} \\ \vec{f} & -\vec{e} \end{bmatrix} \begin{bmatrix} G & -B \\ B & G \end{bmatrix} \begin{bmatrix} e \\ f \end{bmatrix} \tag{8}$$

by differentiating both sides of the above relation, we have:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \Delta\vec{e} & \Delta\vec{f} \\ \Delta\vec{f} & -\Delta\vec{e} \end{bmatrix} \begin{bmatrix} G & -B \\ B & G \end{bmatrix} \begin{bmatrix} e \\ f \end{bmatrix} + \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \vec{e} & \vec{f} \\ \vec{f} & -\vec{e} \end{bmatrix} \begin{bmatrix} G & -B \\ B & G \end{bmatrix} \begin{bmatrix} \Delta e \\ \Delta f \end{bmatrix} \tag{9}$$

The right side of the above equation is consisted of two parts, the first part of which is due to flow changes and the second part is because of voltage variations. It should be mentioned that power changes rather than flow changes can be discarded, and the above matrix can be rewritten as follows:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \neq \begin{bmatrix} \vec{e} & \vec{f} \\ \vec{f} & -\vec{e} \end{bmatrix} \begin{bmatrix} G & -B \\ B & G \end{bmatrix} \begin{bmatrix} \Delta e \\ \Delta f \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} \Delta e \\ \Delta f \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{11}$$

$$J = \begin{bmatrix} \vec{e} & \vec{f} \\ \vec{f} & -\vec{e} \end{bmatrix} \begin{bmatrix} G & -B \\ B & G \end{bmatrix} \tag{12}$$

$$J^{-1} = \begin{bmatrix} G & -B \\ B & G \end{bmatrix}^{-1} \begin{bmatrix} \vec{e} & \vec{f} \\ \vec{f} & -\vec{e} \end{bmatrix}^{-1} = J_1 . J_2 \tag{13}$$

In the above relation, the J1 expression is constant and only the J2 part is variable. Since J1 matrix is a diagonal one, it can easily be reversed as follows:

$$J_1 = \begin{bmatrix} G & -B \\ B & G \end{bmatrix}^{-1} = \begin{bmatrix} R & X \\ -X & R \end{bmatrix} \tag{14}$$

where Z=R+Jx is the impedance matrix of the network.

$$J_2 = \frac{1}{k} \begin{bmatrix} -\vec{e}^{\,-1} & -\vec{f}^{\,-1} \\ -\vec{f}^{\,-1} & \vec{e}^{\,-1} \end{bmatrix} \tag{15}$$

K is the determinant of the J_2 matrix and is calculated as follows:

$$K = -\prod_{i=1}^{n} e_i - \prod_{i=1}^{n} f_i \tag{16}$$

The above process continues as long as the following condition is satisfied:

$$\max(\Delta e, \Delta f) \leq \varepsilon \quad (17)$$

In above relations, we introduced the factorized load flow method. In order to study the effect of factorized load flow method on the network, we applied the state estimation equations using the weighted least squares method. The obtained data from the solution of the factorized load flow are the state estimation equations' inputs. The relations for state estimation by the weighted least squares are summarized in the following ones [9-12]:

$$z = h(x) + e \quad (18)$$

$$J = \sum_{i=1}^{m} W_i r_1^2 \quad (19)$$

$$G_k \, \Delta x_k = H_K^T W \left[z - h(x_k) \right] \quad (20)$$

where

$H_k = \partial h / \partial x$: evaluated Jacobian in $x = x_k$,

$G_k = H_k^T W H_k$: gain matrix

$W = R^{-1} = diag(w_i)$: weighted matrix

and $\Delta x_k = x_{k+1} - x_k$ is the number of the iterations. When the proper tolerance is achieved from Δx_k, the iterations will be terminated. Finally, the estimation covariance is:

$$\mathrm{cov}(\hat{x}) = G_k^{-1} \quad (21)$$

In the following analyses, the flowchart of the used algorithm for calculating state estimation to analyze the stability of the power system is provided.

As illustrated in the flowchart, in this method of load-flow, like the other ones, the Y_{bus} network matrix is formed when the network data is initially entered into the computational algorithm. After the formation of the Y_{bus} matrix, Jacobian matrix is formed by the factorized method and the conditions for the calculation of the factorized load flow are prepared. Having accomplished the first load flow stage, the initial data enters into the state estimation matrix in order to estimate the state of the system. Here, using the least squares method with the maximum similarity, the state estimation was achieved. The output data of the state estimation is provided and then the condition for the analysis of the dynamic stability of the power system is presented.

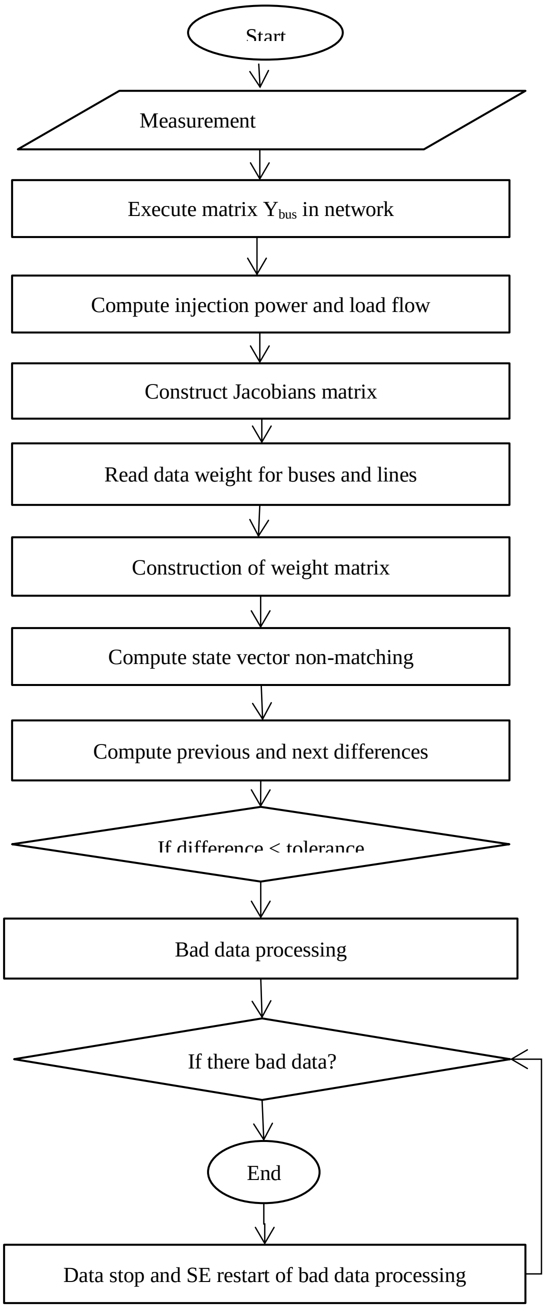

Fig.1. *The flowchart of the used algorithm in the factorized load flow*

3. The Required Systems for Simulation

In this paper, the idea of the factorized load flow can be implemented for distribution and transmission networks. Hence, it was tested for the standard IEEE 6, 14, 30, 57-bus systems. The obtained results of this idea had a more optimal effect on distribution networks than transmission networks. The underlying reason for choosing these systems in order to perform the load-flow computation and efficiency assessment of the proposed method was that, firstly, these networks often model distribution and transmission with a better approximation for the above mentioned systems, and secondly, these networks are more conventional for testing and evaluating such examinations.

In order to simulate, at first the standard data of the intended systems were elicited and matrix Y_{bus} was formed by applying the impedance data of the lines into the program. After the admittance matrix formation, generated and consumed powers were applied to the simulation program in the form of the P and Q matrices.

Depending on the network specifications, the program detected the slack, PV, and PQ buses. After performing the necessary calculations on the input data, the values of P, Q, the size of voltages and their phasor and the flow of the branches were determined by several iterations [13-16].

A) Simulation Analysis of IEEE-6 Bus System

IEEE 6-bus system was located in the presence of three generating units in 1, 2, 3 buses and a certain number of conventional loads according to the intended IEEE standard. Additional information for this system is provided below. Figure 2 and Table 1 show the 6-bus system diagram and the data load flow of the system, respectively.

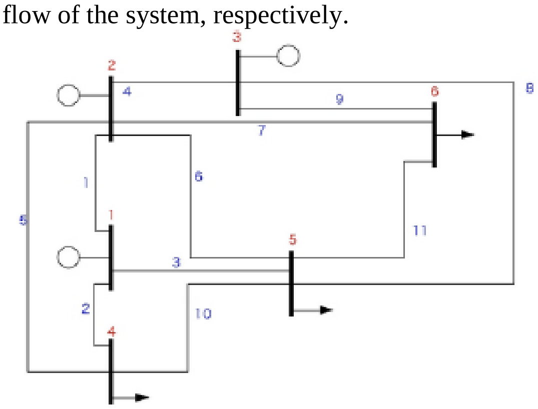

Fig.2. *IEEE 6-bus system diagram*

Table.1.
Load Flow Data of the IEEE 6-Bus System

Bus no.	***/V/***	***<V***	***P***	***Q***
1	1.06000000000000	0	107.576241579603	27.2624565963614
2	1.05000000000000	-3.38616047921834	49.9999999994100	64.0155758809108
3	1.07000000000000	-3.99036380315793	59.9999999970142	87.8377417994122
4	0.992866070265404	-4.01566432080840	-69.9999999903924	-69.9999999719218
5	0.988379184083505	-5.06295319432958	-69.9999999845157	-69.9999999493518
6	1.00498959231120	-5.67264864166001	-69.9999999889640	-69.9999999520750

The duration of the calculation is 0.010586 seconds. A comparison of the duration of the load flow calculations for this system with the Newton-Raphson method is provided in the following table (Table 2).

Table.2.
Time Performance Comparison

Load Flow Method	***Calculation duration***	***Iteration Numbers to Get the Answer***
Newton-Raphson	0.28169	**6**
Factorized Load Flow	0.01058	**4**

B) Simulation Analysis of the IEEE 14-Bus System

IEEE 14-bus system was placed, in the presence of 3 generating units, in 1, 2, 3 buses and a given number of conventional loads according to IEEE standard. Additional information for this system is provided below. After simulating of the model for this system, the outputs of the network were obtained which is presented in Table 3.The duration of the calculation is 0.471473 seconds. A comparison of the duration of the load flow calculations for the system with the Newton-Raphson method is provided in the following table (Table 4).

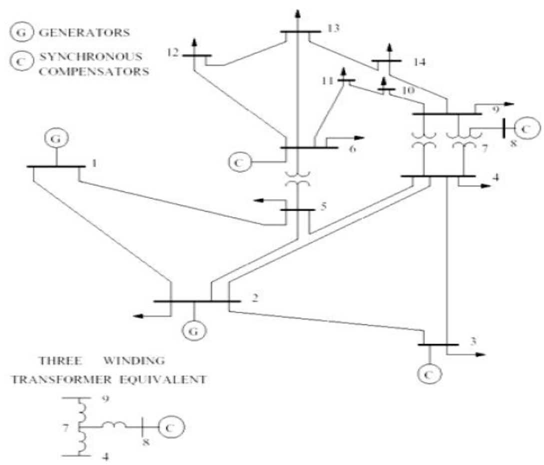

Fig.3. *IEEE 14-bus system diagram*

Table.3.
The Load Flow Outputs of IEEE 14-Bus System

Bus no.	|V|	<V	P	Q
1	1.06000000000000	0	232.434714543037	-16.9918666716144
2	1.04500000000316	-5.0674422372474	18.2999912492863	31.6450291993941
3	1.01000000000690	-13.035227261783	-94.2000898939021	5.9643376411377
4	1.01769442769245	-10.836223365979	-47.8007988940222	3.89896556802563
5	1.01965554526853	-8.4662241602005	-7.59971975613709	-1.60003600791095
6	1.07000000033304	-13.973964147603	-11.2002674687400	5.06066194917141
7	1.06137613934468	-14.089220444996	-0.00071990331734707	-0.000681557675527
8	1.09000000011439	-13.089220045539	4.57888689742170e-06	17.7121818008863
9	1.05577581366219	-14.775175771530	-29.4993080588181	-16.5990850713062
10	1.05083833969881	-14.919286387688	-8.99977279791580	-5.79942371176804
11	1.05681290317699	-14.578656473762	-3.49992510729293	-1.79985916002878
12	1.05519059532275	-14.834504179616	-6.09991719118726	-1.59977596007130
13	1.05034314303308	-14.921105443648	-13.4996849285976	-5.79944721622973
14	1.03542063390020	-15.839320185547	-14.8994770229416	-4.99890442467049

Table.4.
Time Performance Comparison

Load Flow Method	***Calculation duration***	***Iteration Numbers to Get the Answer***
Newton-Raphson	0.91037	**5**
Factorized Load Flow	0.47147	**3**

C) Simulation Analysis of the IEEE-6 Bus System

IEEE 30-bus system was developed, with the presence of 6 generating units and a given number of conventional loads according to IEEE standard. Additional information for this system is provided below. After simulating this model system, the output data of the network were achieved that is presented in Table 5.

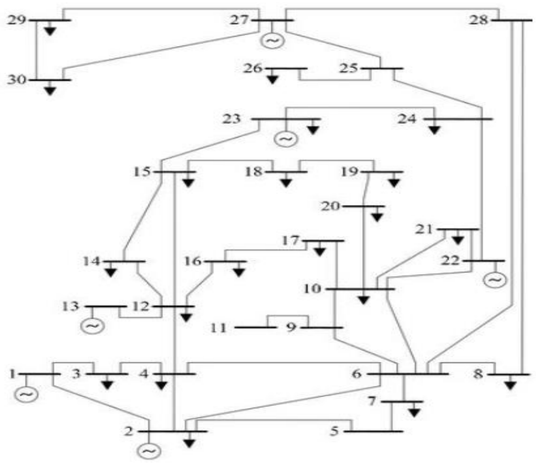

Fig.4. *IEEE 30-bus system diagram*

The duration of the calculation is 0.724422 seconds. A comparison of the duration of the load flow calculations for the system with the Newton-Raphson method is provided in the following table (Table 6).

A) Simulation Analysis of the IEEE 57-Bus System

IEEE 57-bus system with the presence of 6 generating units and a certain numbers of conventional load flows according to IEEE standard was developed. After simulating of this system model, output data of the network were achieved as showed in Table 7.

The duration of the calculation is 0.9012145 seconds. A comparison of the duration of the load flow calculations for the system with the Newton-Raphson method is provided in the following table (Table 8).

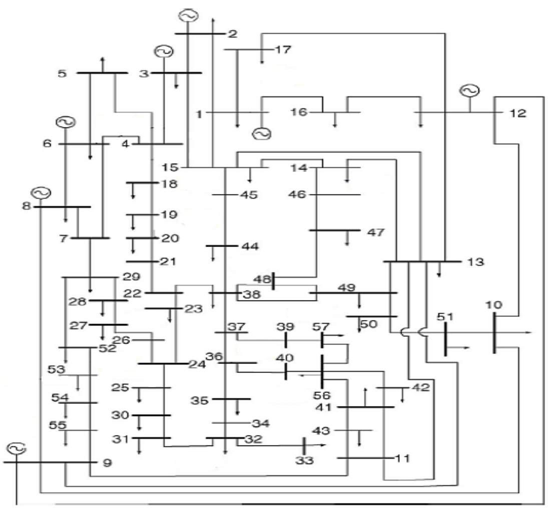

Fig.5. *IEEE 57-bus system diagram*

Table.5.
Load Flow Data of IEEE-30 Bus System

Bus no.	|V|	<V	P	Q
1	1.06000000000000	0	260.956947838691	-20.4178833939322
2	1.04500000000000	-5.37824301407092	18.3000000015581	43.3694619315988
3	1.02117768415769	-7.52865958252892	-2.40000000187920	-1.19999999891275
4	1.01230043019664	-9.27943239717890	-7.59999999035537	-1.59999999635492
5	1.01000000000000	-14.1487671061164	-94.1999999857723	16.6587907462008
6	1.01062574925043	-11.0550233151031	6.35900336103372e-09	2.7404077426275e-09
7	1.00259708390453	-12.8523187674071	-22.7999999967072	-10.8999999878703
8	1.01000000000000	-11.7973853774390	-29.9999999951877	6.11126660752134
9	1.05113171196665	-14.0979690178913	-2.2740505217113e-14	-9.0547333645275e-14
10	1.04537895354553	-15.6881731633695	5.80000002329159	-1.99999999534129
11	1.08200000000000	-14.0979690178913	4.30211422042248e-14	16.0574459865785
12	1.05733892987716	-14.9329077097551	-11.2000000148827	-7.49999998639229
13	1.07100000000000	-14.9329077097551	8.67361737988404e-15	10.4507186439717
14	1.04250780611547	-15.8245220021615	-6.19999999728866	-1.59999999261195
15	1.03791588112959	-15.9163633312539	-8.19999999423021	-2.49999999077270
16	1.04462584373018	-15.5154241163102	-3.49999999720017	-1.79999999593270
17	1.04015025347279	-15.8499478579068	-8.99999999544853	-5.79999998678230
18	1.02839628927814	-16.5301888457814	-3.19999999787163	-0.899999995640003
19	1.02589993308941	-16.7037223023899	-9.49999999295447	3.39999998586748
20	1.02998672981766	-16.5071925000123	-2.19999999910146	-0.699999996833170
21	1.03298219404379	-16.1306668384592	-17.4999999866278	-11.1999999714027
22	1.03351363173282	-16.1164373864620	-1.1042556972917e-09	4.7589013970262e-10
23	1.02742898429876	-16.3066259405065	-3.19999999748165	-1.59999999495222
24	1.02184577173146	-16.4827871447226	8.69999999216499	-6.69999997929389
25	1.01761861390450	-16.0545591249370	-8.5386672244965e-10	2.5539800020301e-10
26	0.999946402954339	-16.4739809831140	-3.49999999430328	-2.29999999149072
27	1.02353851072247	-15.5300800386894	-1.3924966481498e-08	-6.4319661001532e-09
28	1.00710104609662	-11.6772967361456	2.81200005786649e-09	6.2774174101381e-10
29	1.00370578504731	-16.7593130256149	-2.39999999717700	-0.899999994666484
30	0.992234798981229	-17.6416130945472	-10.5999999871696	-1.89999997581857

Table.6.
Time Performance Comparison

Load Flow Method	***Calculation duration***	***Iteration Numbers to Get the Answer***
Newton-Raphson	2.01212	**7**
Factorized Load Flow	0.72442	**5**

4. Comparing the Extracted Metrics by MATLAB Software

As seen, the proposed factorized load flow method on 6, 14, 30, and 57-bus systems was investigated. In addition, the simulation results were also presented using Newton-Raphson method. In Figures 6 and 7, a graph for comparing the speed of processing both of the investigated methods and the number of iterations for calculations are presented. As seen in Fig.8, Newton-Raphson load flow method resulted in a more significant computational speed in comparison with factorized load flow method. It proves the effectiveness of the proposed method with a higher accuracy in calculating the state estimation for the stability analysis of the power system.

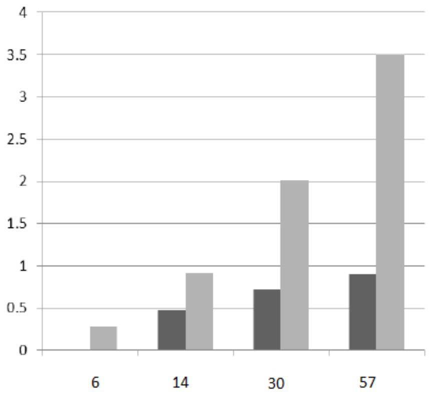

Fig.6. *Time duration graph of the load flow calculation for different IEEE systems using Newton-Raphson and factorized load flow methods*

Table.7.
Time Performance Comparison

Load Flow Method	***Calculation duration***	***Iteration Numbers to Get the Answer***
Newton-Raphson	3.00313	**8**
Factorized Load Flow	0.9012145	**4**

Table.8.
Load Flow Data of the IEEE 57-Bus System

Bus no.	|V|	<V	P	Q
1	1.06000000000000	0	424.832119270101	220.287030435919
2	1.01000000000000	-0.83087217989871	-3.00000001560116	-161.330975526302
3	0.985000000000000	-5.58952494264851	-0.999999993087284	-31.7438618244322
4	0.980819063644121	-6.93068173116495	3.97086096055820e-08	-1.45294461845884e-09
5	0.976513461567152	-8.12672167199077	12.9999999682727	-3.99999993215019
6	0.980000000000000	-8.24815001250701	-74.9999998827332	1.36698364775886
7	0.984352774382569	-7.16586444921843	9.35586955679456e-08	1.18287265712430e-08
8	1.00500000000000	-4.03745759520502	299.999999609652	39.8830307894119
9	0.980000000000000	-9.13737357669929	-120.999999813380	-26.9021556622615
10	0.986677508799226	-10.9949362503961	-4.99999993414201	-1.99999995629977
11	0.975247211786222	-9.76700278828758	5.73323190825706e-08	5.55089048311726e-09
12	1.01500000000000	-10.0113531413612	-66.9999998636666	85.2749076270187
13	0.981140632726746	-9.39574550635465	-17.9999998689608	-2.29999989612913
14	0.973685623424922	-8.97140267725160	-10.4999998270435	-5.29999987827167
15	0.993237001583135	-6.86445949123373	-22.0000000113396	-4.99999984287012
16	1.01934502179895	-8.47588945988106	-42.9999999565634	-2.99999979845159
17	1.03043626615206	-5.14502896922367	-41.9999999776618	-7.99999989508795
18	1.00102291804660	-11.3154099729310	-27.2000000261480	-9.79999974736822
19	0.971564245291351	-12.8257737056217	-3.29999996922889	-0.599999954866816
20	0.965839795656704	-13.0527912050696	-2.29999998553816	-0.999999960927338
21	1.01160202580491	-12.5222359930690	1.57478877516665e-08	4.86698177095910e-09
22	1.01300686190625	-12.4702371161195	3.84421494097981e-10	-1.11322676013699e-10
23	1.01154835324602	-12.5343165568359	-6.29999991669087	-2.09999986147285
24	1.00164855555428	-12.8719640361262	6.81868998881937e-08	3.36940849030838e-08
25	0.985355144817703	-17.7240485957470	-6.30000038720952	-3.19999973296571
26	0.960965866864592	-12.5652958207035	1.40140163934869e-07	1.43825579380446e-07
27	0.982588419111110	-11.0829902765714	-9.29999991514540	-0.499999868559312
28	0.997309881548902	-10.0457070595823	-4.59999994072192	-2.29999993878761
29	1.01059171640256	-9.33162390518992	-17.0000003172789	-2.59999984415093
30	0.965613928321279	-18.2680629856090	-3.59999979154904	-1.79999969494468
31	0.939107367616025	-18.9300170600689	-5.79999960017686	-2.89999939441619
32	0.953202223699454	-18.0678580486855	-1.60000039219753	-0.799999967203884
33	0.950916203109391	-18.1072513898130	-3.79999969716535	-1.89999972188656
34	0.962514720306468	-13.7307559199338	2.07361517512086e-07	9.00189685323625e-08
35	0.969519969216902	-13.4898622784552	-5.99999979786072	-2.99999978527549
36	0.979114717541031	-13.2205013781008	1.11452678336787e-08	-1.11559225140486e-08
37	0.988185797657876	-13.0345603693557	-6.10070438196275e-08	3.01869423014932e-08
38	1.01620171995663	-12.3335480103287	-13.9999998659986	-6.99999971713973
39	0.986103449773034	-13.0786198481275	9.00458203675199e-08	1.22811385933873e-08
40	0.976061631145611	-13.2421205717542	1.12922609015859e-07	-8.85689475052068e-09
41	0.998095009531332	-13.6361683463033	-6.30000020055362	-2.99999992889623
42	0.968716488054561	-15.0961160866867	-7.09999985071899	-4.39999974604130
43	1.01105464368817	-10.9244004171109	-2.00000000000002	-0.999999975054707
44	1.02063238965748	-11.4715620546358	-11.9999999078622	-1.79999981499189
45	1.04070692016318	-8.92757155315570	-1.63262075762736e-07	-1.10332402915234e-07
46	1.06347305282922	-10.7286525025445	-2.32986103208746e-07	-6.28008672064913e-08
47	1.03672638228079	-12.1134996992705	-29.6999999532635	-11.5999994245746
48	1.03073440254591	-12.2092111280718	2.98454720558109e-08	-2.16520261426291e-08
49	1.03911484826561	-12.5183714081578	-18.0000002345324	-8.49999961244601
50	1.02549983302983	-12.9769352903802	-20.9999997790958	-10.4999996482725
51	1.05310746072136	-12.0732137660966	-18.0000000707215	-5.29999978170973
52	0.980673114696541	-11.0547225328292	-4.89999994860340	-2.19999993272945
53	0.971211943243968	-11.8084776266687	-19.9999997873906	-9.99999964127858
54	0.996473266433639	-11.2633242099812	-4.09999996849199	-1.39999995399638
55	1.03083183608242	-10.3529279496453	-6.80000005400027	-3.39999987119868
56	0.970805709992318	-15.6362444314471	-7.59999991789463	-2.19999975890818
57	0.967443736801877	-16.1575390183029	-6.69999996213422	-1.99999979679256

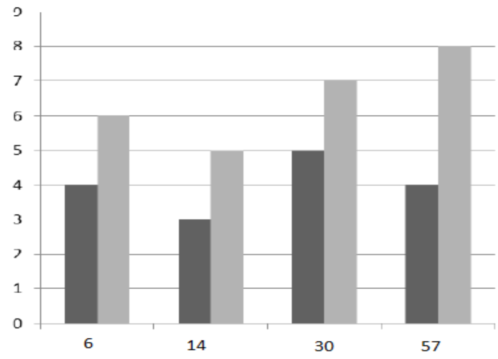

Fig.7. *The comparison graph of the iteration numbers of the factorized load flow and Newton-Raphson methods for different IEEE systems*

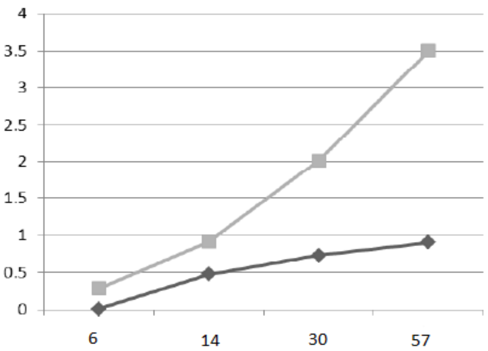

Fig.8. *The comparison graph of the state estimation calculation time duration for both Newton-Raphson and factorized load flow methods*

5. Results

One of the challenges that is always being discussed in the power system is the dynamic stability issue. Of these, one of the most important factors that has a direct impact on its determination is the state estimation theory. To monitor the stability of the power system, the main determinant is the accuracy and speed of the state estimation has input data. Therefore, in the present study, the factorized load flow method was used as a method for estimating the input data of the system stability analysis. In this paper, one of the most effective factors, which is called factorized load flow method, was studied. The proposed method was simulated using the MATLAB coding environment, the simulation results of both Newton-Raphson load flow method and the proposed method were analysed, and it was shown that the proposed idea had an adequate quality for reducing the computational complexity and increasing the accuracy and speed of the state estimation equations. The analysis of the obtained simulation results showed that the proposed method could be very useful in dynamic analysis of the power system due to the direct impact on the speed and accuracy enhancement of the state estimation computation. The strengths of the suggested idea were presented in different sections of the paper, but one of the weaknesses of this method is its inefficacy in systems with the presence of the dispersed generation resources that have a random nature.

References

[1] W. F. Tinney and C. E. Hart, ―Power flow solution by Newton's method,‖ IEEE Trans. Power App. Syst., vol. PAS-86, no. 11, pp.1449–1460, Nov. 1967.

[2] W. F. Tinney and J. W. Walker, ―Direct solutions of sparse network equations by optimally ordered triangular factorization,‖ Proc. IEEE, vol. 55, no. 11, pp. 1801–1809, Nov. 1967.

[3] B. Sttot, ―Review of load f low calculation methods,‖ Proc. IEEE, vol. 62, no. 7, pp. 916 929, Jul. 1974.

[4] B. Stott and O. Alsac, ―Fast decoupled load flow,‖ IEEE Trans. Power App. Syst., vol. PAS-93, no. 3, pp. 859–869, May 1974.

[5] Electric Energy Systems: Analysis and Operation, A. Gómez-Expósito, A. Conejo, and C. Cañizares, Eds. Boca Raton, FL,USA: CRC, 2008.

[6] F. C. Schweppe, J. Wildes, and D. B. Rom, ―Power system static state estimation, part I, II, III,‖ IEEE Trans. Power App. Syst., vol. PAS-89, no. 1, pp. 120–135, Jan. 1970.

[7] Load Flow," Power Systems, IEEE Transactions on , vol.28, no.4, pp.4607,4614, Nov. 2013.

[8] Hongga Zhao, "A New State Estimation Model of Utilizing PMU Measurements," Power System Technology, 2006. PowerCon 2006. International Conference on, vol., no., pp.1, 5, 22-26 Oct. 2006

[9] A. Abur and A. Gómez-Expósito, Power System State Estimation: Theory and Implementation. New York, NY, USA: Marcel Dekker, 2004.

[10] F. Aschmoneit, N. Peterson, and E. Adrian, ―State estimation with equality constraints,‖ in Proc. 10th PICA Conf., Toronto, ON, Canada, May 1977, pp. 427–430.

[11] A. Gómez-Expósito, A. Abur, A. de la Villa Jaén, and C. Gómez- Quiles, ―A multilevel state estimation paradigm for smart grids,‖ Proc. IEEE, vol. 99, no. 6, pp. 952–976, Jun. 2011.

[12] C. Gómez-Quiles, A. de la Villa Jaén, and A. Gómez-Expósito, ―A factorized approach to WLS state estimation,‖ IEEE Trans. Power Syst., vol. 26, no. 3, pp. 1724–1732, Aug. 2011.

[13] Benigni, A.; Junqi Liu; Ponci, F.; Monti, A.; Pisano, G.; Sulis, S., "Decoupling Power System State Estimation by Means of Stochastic Collocation," Instrumentation and Measurement, IEEE Transactions on , vol.60, no.5, pp.1623,1632, May 2011

[14] A. Simoes-Costa and V. H. Quintana "A robust numerical technique for power system state estimation", IEEE Trans.Power App. Syst., vol. PAS-100, no. 2, pp.691 -698 1981

[15] R. G. Cespedes "New method for the analysisof distribution networks", IEEE Trans. PowerDel., vol. 5, no. 1, pp.391 -396 1990.

[16] D. Das, D. P. Kothari and A. Kalam "Simple and efficient method for load flowsolution of radial distribution networks", Int.J. Elect. Power Energy Syst., vol. 17, no. 5, pp.335 -346 1995.