International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2018 | Issue 37 | Volume 10 | Number 4 | Pages 36-42

REACTIVE POWER LINEARIZATION FOR LOAD FLOW ASSESSMENT

A.M. Hashimov N.R. Rahmanov H.B. Guliyev A.A. Mustafayev

Azerbaijan Research Institute of Energetics and Energy Design, Azerenerji JSC, Baku, Azerbaijan
ahashimov@azerenerji.gov.az, ard.nariman@gmail.com, huseyngulu@mail.ru

Abstract- The reactive power linearized model is proposed for the purpose of estimating bus voltage magnitudes and transmission line power flows. The proposed method is driven by a realistic non-conforming stochastic load model that is based on the quadrative power flow calculation formulation. The load flows are computed from linearized models of these qualities with respect to the independent stochastic load variables. The method is validated via continuation load flow simulations in which problem is fully solved for incorporated compensator and without compensator power flow nonlinearities equations and operating constraints. The proposed method is demonstrated with the IEEE Reliability Test System.

Keywords: Power Grid, Voltage, Reactive Power, Load Flow Design Method, Linearization Methods.

I. INTRODUCTION

The analysis of steady-state regimes is the basis for planning, operation and management of power grids (PG), the importance of which increases during the functioning of the system under the power energy market conditions.

The load flow calculation is based on the solution of a system of nonlinear algebraic equations, describing the steady state. To solve these equations, various computational algorithms are proposed and developed, by means of which the methods for solving nonlinear algebraic equations, known in the references, are realized [1-5]. These methods are iterative and the effectiveness of their application depends on the complexity of the system under study. In this regard, all subsequent developments for the improvement of algorithms based on the use of the above methods are reduced to an acceptable simplification of models describing the steady-state regimes [6, 7].

In this paper, we propose a method obtained by means of linearization of reactive power equations. The proposed method has the ability to quickly calculate the voltages on the load bus and the reactive power injections on the generator bus. Initially, the idea of linearization of reactive power equations was proposed in [8-10]. In this paper we propose a mathematical formulation of the method.

II. SIMPLIFIED FORMULATION OF MODEL FOR CALCULATING REACTIVE POWER FLOWS

The n nodal typical PG scheme is considered, in which the balance of reactive power in the i node, polar form and relative units is important:

$$q_i = v_i \sum_{k=1}^{n} v_k \; Y_{i,k} \sin\left(\theta_i - \theta_k - \varphi_{i,k}\right) \tag{1}$$

In this equation, the number of unknowns depends on the node type: if node i is of type PQ, then the unknown are voltages, or if node i is of type PV, then unknown is q_i. The phase angles of the voltages are the main parameters that can be pre-calculated by means of power flow of direct current. It should be noted that the DC load flow conductivity matrix differs from the full conductivity matrix in the Equation (1); in this latter case, in fact, the elements must take into account not only the longitudinal but also the transverse conductivity of each network element.

Returning to the Equation (1), neglecting the longitudinal and transverse active conductivity and assuming B_i, k as reactive conductivity module of a typical element of the conductivity matrix, we obtain as:

$$\begin{aligned} q_i &= v_i \sum_{k=1}^{n} v_k \; Y_{i,k} \sin\left(\theta_i - \theta_k - \varphi_{i,k}\right) = \\ &= -v_i^2 B_{i,i} - v_i \sum_{\substack{k=1 \\ k \neq i}} v_k B_{i,k} \cos\left(\theta_i - \theta_k\right) \end{aligned} \tag{2}$$

If the base voltage is used as a relative value, the modulus of voltage can be expressed as a small variation with respect to 1:

$$v_j = 1 + \Delta v_j , \quad \forall j \in \left[1, \ldots, n\right] \tag{3}$$

Replacing and neglecting the value of the second order in Equation (3), we obtain the Equation (4). For each g of the generator node the Δv is known, here for $i \in \left[1, g\right]$ we obtain Equation (5).

$$
\begin{aligned}
&q_i = -\left(1+\Delta v_i\right)^2 B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{n}\left(1+\Delta v_i\right)\left(1+\Delta v_k\right)B_{i,k}\cos\left(\theta_i-\theta_k\right) \approx \\
&\approx -B_{i,i} - 2\Delta v_i B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{n}(1+\Delta v_i+\Delta v_k)B_{i,k}\cos\left(\theta_i-\theta_k\right) = \\
&= -B_{i,i} - 2\Delta v_i B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \\
&-\Delta v_i \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \sum_{\substack{k=1\\ k\neq i}}^{n}\Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right)
\end{aligned}
\tag{4}
$$

$$
\begin{aligned}
&q_i + \sum_{\substack{k=g+1\\ i}}^{n} \Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right) = \\
&= -B_{i,i} - 2\Delta v_i B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \\
&-\Delta v_i \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \sum_{\substack{k=1\\ k\neq i}}^{g}\Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right)
\end{aligned}
\tag{5}
$$

For each (n–g) load node, suppose for $i\in\left[g+1,n\right]$, we obtain as follows:

$$
\begin{aligned}
&2\Delta v_i B_{i,i} + \Delta v_i \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) + \sum_{\substack{k=g+1\\ k\neq i}}^{g}\Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right) = \\
&= -q_i^0 - B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \sum_{k=1}^{g}\Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right)
\end{aligned}
\tag{6}
$$

where, q_i^0 is a known reactive power, damped by the load in the i node.

Converting the n equation such that the first "g" are important for generator nodes and the remaining (n-g) important for load nodes, the system can be described as follows:

$$
\begin{vmatrix} I & R^{gc} \\ O & R^{cc} \end{vmatrix}
\begin{vmatrix} q^{g} \\ \Delta v^{c} \end{vmatrix}
=
\begin{vmatrix} q^{\Sigma g} \\ q^{\Delta c} \end{vmatrix}
\tag{7}
$$

where,

$$R_{h,j}^{gc} = B_{i,k}\cos\left(\theta_i-\theta_k\right) \tag{8}$$

with $i=h,\;\; k=j+g,\;\; h\in\left[1,g\right],\;\;\; j\in\left[1,n-g\right]$.

$$R_{h,h}^{c,c} = 2B_{i,i} + \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) \tag{9}$$

with $i=h+g$ and $h\in\left[1,n-g\right]$

$$R_{h,j}^{c,c} = B_{i,k}\cos\left(\theta_i-\theta_j\right) \tag{10}$$

where, $h\neq j,\; i=h+g,\;\; k=j+g,\; h,\; j\in\left[1,n-g\right]$

$$
\begin{aligned}
&q_i^{\Sigma g} = -B_{i,i} - 2\Delta v_i B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{g} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \\
&-\Delta v_i \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \sum_{\substack{k=1\\ k\neq i}}^{g}\Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right)
\end{aligned}
\tag{11}
$$

with $i\in\left[1,g\right]$

$$
\begin{aligned}
&g_i^{\Delta c} = -q_i^0 - B_{i,i} - \sum_{\substack{k=1\\ k\neq i}}^{n} B_{i,k}\cos\left(\theta_i-\theta_k\right) - \\
&-\sum_{k=1}^{g}\Delta v_k B_{i,k}\cos\left(\theta_i-\theta_k\right)
\end{aligned}
\tag{12}
$$

with $i\in\left[g+1,n\right]$

Considering the Equation (7) as a product of second order, we obtain an unknown vector

$$R^{cc}\Delta v^{c} = q \tag{13}$$

which is a linear system (n-g) of equations with unknown variables ΔU^{c}

$$\Delta v^{c} = R^{cc-1} q^{\Delta c} \tag{14}$$

The previous equation allows to calculate the voltages in the load nodes. It is important to note that the matrix transport order R^{cc} is equal to $l\times l$, where l is the number of load nodes.

Considering once again the Equation (7) as a product of the first load and unknown vector, we finally get the expression of the reactive power produced by generators:

$$q^{g} = q^{\Sigma g} - R^{gc}\Delta v^{c} \tag{15}$$

where, Δv^{c} is known from the Equation (14).

III. SIMULATION RESULTS

On the basis of the proposed method, computational experiments are performed for the IEEE RTS-30 standard scheme, the data and mode of the scheme are given in detail in [11-13]. This scheme has 13 generating units, 82 branches and 30 nodes. The peak load is 442 MW. The topology of scheme with 30 nodes is shown in Figure 1.

Tables 1 and 2 show the results of calculations of load flow in the considered network before and after reactive power compensation. Nodal data assumed as inputs is known: the bus type, injection of P and V for nodes (PV), injections of active and reactive powers (for PQ nodes). The allowable reactive power generation for each generator and the possible min and max voltage values are also specified.

The voltage profiles in the nodes of the considered network before and after reactive power compensation are shown on the Figure 2. As is evident, after the compensation the voltage in the nodes is within the established limits.

Voltage and reactive power errors are always not more than 1.5% and 10%, respectively. The standard (mean-square) error for the voltage is 0.5% and 4.6% for reactive power. Including the time required for the calculation of load flow, the algorithm execution over speeding was 6-7 times higher than the known methods.

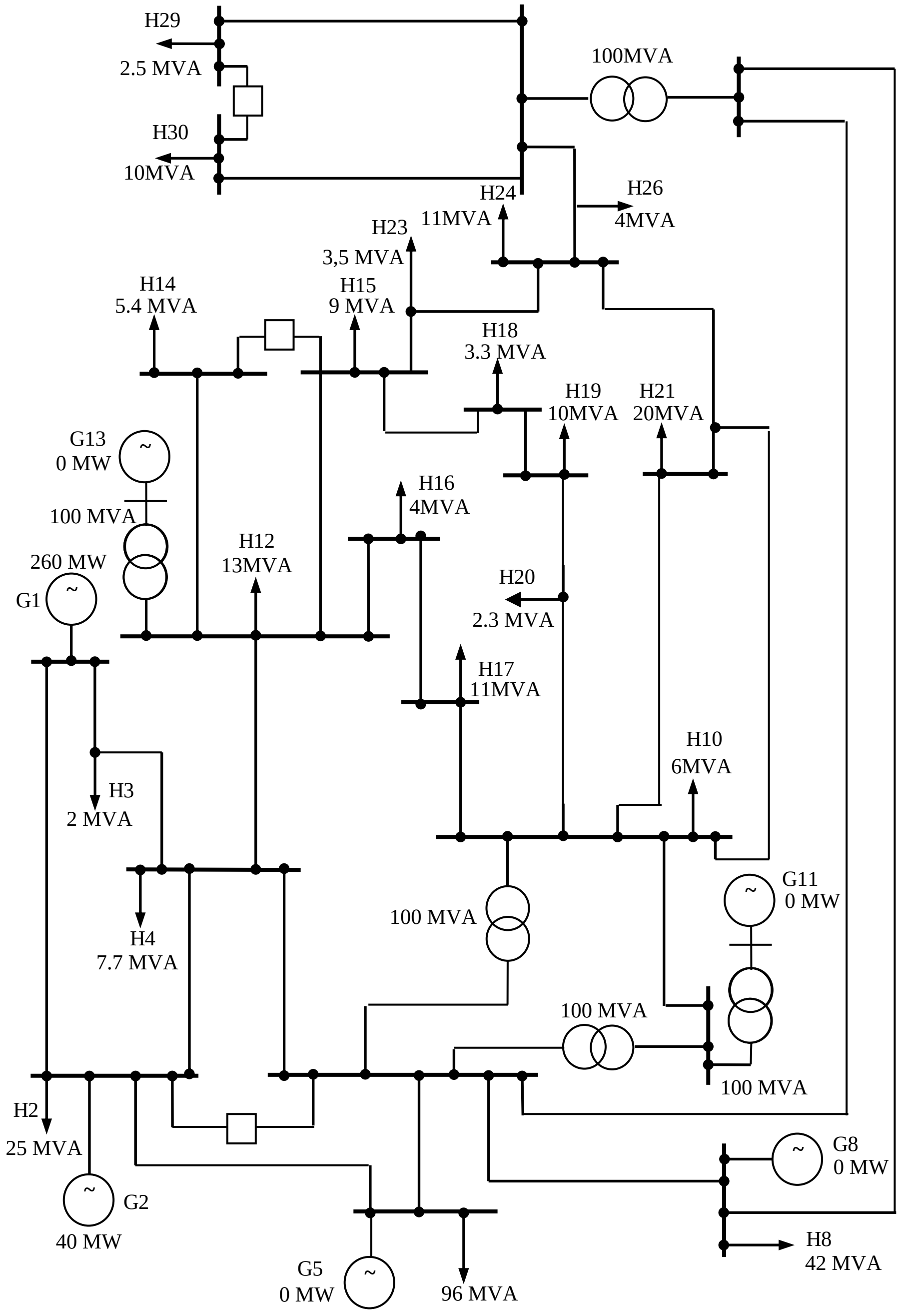

Figure 1. Standard diagram of the IEEE RTS-30 electrical network

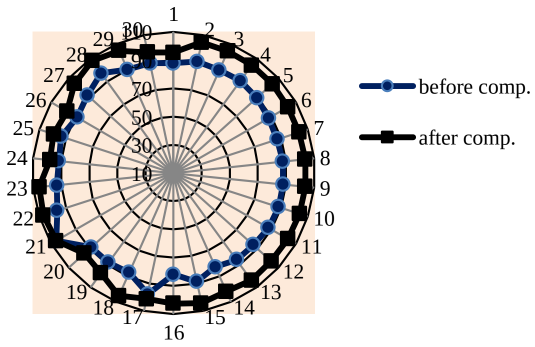

Figure 2. Voltage profiles in the network nodes before compensation and after compensation

Table 1. Results of load flow calculation in IEEE RTS-30 standard network without reactive power before compensation

Bus	Voltage	Generation		Load		PTL	Load flow			cosφ
No	V, %	MW	MVAr	MW	MVAr	No	MW	MVAr	I, A	%
13-7	87.786	0	0	31.92	15.26	13-5	21.422	-15.798	132.6	-80.5
						13-6	-53.342	0.538	265.8	100.0
3-14	90.567	0	0	8.680	2.240	3-12	-11.128	-3.707	226.6	94.9
						3-15	2.448	1.467	55.1	85.8
3-15	89.647	0	0	11.48	3.500	3-12	-25.107	-11.143	536.1	91.4
						3-14	-2.426	-1.447	55.1	85.9
						3-18	8.704	3.376	182.2	93.2
						3-23	7.349	5.713	181.7	78.9
3-16	90.631	0	0	4.900	2.520	3-12	-10.215	-6.638	235.2	83.9
						3-17	5.315	4.118	129.8	79.1
3-17	89.445	0	0	12.60	8.120	3-10	-7.313	-4.108	164.1	87.2
						3-16	-5.287	-4.012	129.8	79.7
3-18	87.799	0	0	4.480	1.260	3-15	-8.587	-3.139	182.2	93.9
						3-19	4.107	1.879	90.0	90.9
3-19	87.225	0	0	13.30	4.760	3-18	-4.090	-1.845	90.0	91.2
						3-20	-9.210	-2.915	193.8	95.3
3-20	87.813	0	0	3.080	0.980	3-10	-12.331	-3.978	258.2	95.2
						3-19	9.251	2.998	193.8	95.1
3-21	88.046	0	0	24.50	15.68	3-10	-21.909	-13.958	516.2	84.3
						3-22	-2.591	-1.722	61.8	83.3
3-22	88.127	0	0	0	0	3-10	-10.573	-6.476	246.1	85.3
						3-21	2.592	1.725	61.8	83.3
						3-24	7.981	4.751	184.4	85.9
3-23	87.546	0	0	4.480	2.240	3-15	-7.241	-5.496	181.7	79.7
						3-24	2.761	3.256	85.3	64.7
3-24	86.126	0	0	12.18	6.190	3-22	-7.853	-4.552	184.4	86.5
						3-23	-2.730	-3.191	85.3	65.0
						3-25	-1.597	1.553	45.3	-71.7
3-25	85.887	0	0	0	0	3-24	1.610	-1.531	45.3	-72.5
						3-26	5.027	3.410	123.7	82.8
						3-27	-6.637	-1.879	140.5	96.2
3-26	82.898	0	0	4.900	3.220	3-25	-4.900	-3.220	123.7	83.6
3-29	88.763	0	0	3.360	1.260	3-27	-8.602	-2.222	185.6	96.8
						3-30	5.242	0.962	111.3	98.4
3-30	81.781	0	0	14.84	2.660	3-27	-9.695	-1.881	211.3	98.2
						3-29	-5.145	-0.779	111.3	98.9
13-2	97.849	40.00	50.00	30.38	17.80	13-1	-257.26	-38.577	1162	98.9
						13-4	62.021	19.032	290.0	95.6
						13-5	118.23	29.158	544.4	97.1
						13-6	86.631	22.607	400.2	96.8
3-27	87.199	0	0	0	0	3-25	6.707	2.014	140.5	95.8
						3-29	8.849	2.689	185.6	95.7
						3-30	10.162	2.760	211.3	96.5
						13-28	-25.719	-7.463	537.3	96.0
3-28	88.426	0	0	0	0	13-6	-26.400	-7.764	136.1	95.9
						13-8	0.678	-3.434	17.3	-19.4
						3-27	25.723	11.198	138.8	91.7
13-5	88.721	0.000	40.00	131.8	26.60	13-2	-110.86	-1.839	546.6	100.0
						13-7	-21.014	15.239	128.0	-81.0
13-1	106.000	402.1	125.8	0	0	13-2	270.80	73.613	1158	96.5
						13-3	131.24	52.243	583.1	92.9
1-13	96.642	0.000	24.00	0	0	3-12	0.000	24.000	1303.4	0.0
3-12	93.166	0	0	15.68	10.56	3-14	11.334	4.136	226.6	93.9
						3-15	25.728	12.367	536.1	90.1
						3-16	10.386	6.997	235.2	82.9
						13-4	-63.130	-10.863	1202	98.6
						1-13	0.001	-23.137	434.5	0.0
13-4	91.74	0	0	10.64	2.240	13-2	-59.473	-14.557	294.1	97.1
						13-3	-117.54	-19.170	572.0	98.7
						13-6	103.23	8.521	497.5	99.7
						3-12	63.142	22.966	322.7	94.0
13-3	93.675	0	0	3.360	1.680	13-1	-123.16	-26.608	588.3	97.7
						13-4	119.80	24.928	571.4	97.9
13-8	88.776	0.000	40.00	42.00	42.00	13-6	-41.325	-2.084	203.9	99.9
						13-28	-0.675	0.084	3.4	-99.2
1-9	92.121	0	0	0	0	3-10	38.900	17.849	812.8	90.9
						13-6	-38.902	4.885	744.6	-99.2
						1-11	0.001	-22.733	431.7	0.0

1-11	97.254	0.000	24.00	0	0	1-9	0.000	24.000	1295	0.0
3-10	90.109	0	0	8.122	12.67	1-9	-38.900	-15.474	812.8	92.9
						3-17	7.342	4.182	164.1	86.9
						3-20	12.535	4.433	258.2	94.3
						3-21	22.212	14.610	516.2	83.5
						3-22	10.717	6.772	246.1	84.5
						13-6	-22.028	-1.896	429.3	99.6
13-6	89.428	0	0	0	0	13-2	-81.715	-10.978	403.2	99.1
						13-4	-101.69	-3.895	499.7	99.9
						3-7	54.329	1.156	266.7	100.0
						3-8	41.586	2.281	203.7	99.8
						3-28	26.562	7.310	134.7	96.4
						1-9	38.905	-1.117	190.3	100.0
						3-10	22.031	5.243	110.7	97.3

Table 2. Results of load flow calculation in IEEE RTS-30 standard network without reactive power after compensation

Bus	Voltage	Generation		Load		PTL	Load flow			$\cos\varphi$
No	*V*, %	MW	MVAr	MW	MVAr	No	MW	MVAr	*I*, A	%
3-14	95.241	0	0	31.920	15.262	13-5	22.716	7.605	110.0	-98.8
						13-6	-54.636	-7655	253.4	99.0
		0	0	8.680	-1.044	3-12	-10.596	1.534	179.0	-99.0
						3-15	1.916	-0.49	33.1	-96.9
3-15	104.625	0	0	11.480	-4.117	3-12	-24.420	3.053	412.8	-99.2
						3-14	-1.908	0.497	33.1	-96.8
						3-18	8.258	-0.49	138.7	-99.8
						3-23	6.589	1.057	111.9	98.7
3-16	104.257	0	0	4.900	2.520	3-12	-10.009	-1.86	170.8	98.3
						3-17	5.109	-0.66	86.4	-99.2
13-17	104.127	0	0	12.600	3.783	3-10	-7.504	-4490	146.9	85.8
						3-16	-5.096	0.707	86.4	-99.1
3-18	103.584	0	0	4.480	0.187	3-15	-8.191	0.627	138.7	-99.7
						3-19	3.711	-0.81	64.2	-97.7
3-19	103.458	0	0	13.300	-1.662	3-18	-3.702	0.832	64.2	-99.6
						3-20	-9.598	0.830	162.9	-99.6
3-20	103.720	0	0	3.080	-0.096	3-10	-12.707	0.867	214.8	-99.8
						3-19	9.627	-0.77	162.9	-99.7
3-21	103.813	0	0	24.500	5.981	3-10	-21.419	-2.55	363.5	99.3
						3-22	-3.081	-3.42	77.6	66.9
3-22	103.925	0	0	0.000	-2.160	3-10	-10.165	-0.55	171.4	99.9
						3-21	3.083	3.430	77.6	66.8
						3-24	7.083	-0.72	119.8	-99.5
3-23	103.485	0	0	4.480	1.160	3-15	-6548	-0.97	111.9	98.9
						3-24	2.068	-0.19	35.1	-99.6
3-24	103.274	0	0	12.180	-0.539	3-22	-7.029	0.803	119.8	-99.4
						3-23	-2.063	0.205	35.1	-99.5
						3-25	-3.089	-0.46	52.9	98.9
3-25	103.991	0	0	0.000	-1.081	3-24	3.106	0.500	52.9	98.7
						3-26	4.970	2.286	92.0	90.9
						3-27	-8.076	-1.70	138.9	97.8
3-26	101.948	0	0	4.900	2.181	3-25	-4.900	-2.18	92.0	91.4
3-29	104.359			3.360	-4.185	3-27	-8.599	2.649	150.8	-95.6
						3-30	5.239	1.537	91.5	96.0
3-30	102.506	0	0	14.840	0.559	3-27	-9.667	0.854	165.6	-99.6
						3-29	-5173	-1.41	91.5	96.5
13-2	101.318	0	0	30.380	17.780	13-1	-252.72	17.27	1093	-99.8
						13.4	61.044	0.868	263.6	100.0
						13-5	115.75	15.53	504.2	99.1
						13-6	85.546	-1.45	369.4	-100
3-27	105.192	0	0	0.000	-12.172	3-25	8.145	1.836	138.9	97.6
						3-29	8.762	-2.34	150.8	-96.6
						3-30	9.954	-0.31	165.6	-100
						13-28	-26.861	12.90	496.3	-90.0
13-28	97.594	0	0	0	0	13-6	-27.465	9.443	130.2	-94.6
						13-8	0.601	0.361	3.1	85.7
						3-27	26.864	-9.80	128.2	-93.9
13-5	95.008	0.000	40.00	131.88	26.600	13-2	-109.44	6.924	564.9	-99.8
						13-7	-22.432	6.476	107.5	-96.1
13-1	06.000	395.075	30.73	0	0	13-2	264.74	13.05	1093	99.9
						13-3	130.33	17.68	542.7	99.1
1-13	07.100	0.000	11.98	0	0	3-12	0.000	11.98	587.4	0.0
3-12	05.533	0	0	15.680	7.159	3-14	10.724	-1.26	179.0	-99.3

						3-15	24.788	-2.32	412.8	-996
						3-16	10.099	2.049	170.8	98.0
						13-4	-61.292	6.197	1021	-99.5
						1-13	0.000	-11.8	195.8	0.0
13-4	97.955	0	0	10.640	2.240	13-2	-58.991	1.797	263.4	-100
						13-3	-118.04	9.984	529.0	-99.6
						13-6	105.76	-16.5	475.0	-98.3
						3-12	61.301	2.527	274.0	99.9
13-3	99.256	0	0	3.360	1.680	13-1	-123.33	3.575	543.7	-100
						13-4	119.97	-5.25	529.2	-99.9
13-8	97.063	0.000	40.00	42.000	42.000	13-6	-41.404	2.403	186.9	-99.8
						13-28	-0.596	-4.40	20.0	13.4
1-9	104.313	0	0	0.000	-2.176	3-10	38.433	-3.17	646.8	-99.7
						13-6	-38.434	24.84	767.5	-84.0
						1-11	0.001	-19.4	327.0	0.0
1.11	108.200	0.000	20.22	0	0	1-9	0.000	20.22	980.9	0.0
3.10	104.726	0	0	8.122	-21.328	1-9	-38.433	4.675	646.8	-99.3
						3-17	7.527	4.550	146.9	85.6
						3-20	12.849	-0.55	214.8	-99.9
						3-21	21.570	2.879	363.5	99.1
						3-22	10.235	0.694	171.4	99.8
						13-6	-21.869	9.082	395.6	-92.4
13-6	97.474	0	0	0	0	13-2	-81.404	10.32	368.2	-99.2
						13-4	-103.67	20.56	474.3	-98.1
						13-7	55.528	8.817	252.3	9.8
						13-8	41.623	-2.48	181.1	-99.8
						13-28	27.617	-10.1	132.0	-93.9
						1-9	34.438	-20.8	196.2	-87.9
						3-10	21.872	-6.24	102.1	-96.2

IV. CONCLUSION

It is proposed a method of the reactive power model linearization, which allows for calculating quickly the voltage in the nodes, as well as the active and reactive power in the branches. The effectiveness of the method in assessment of the reliability of operation and optimization of load flow in the electrical network is shown.

REFERENCES

[1] N.R. Rahmanov, V.G. Kurbatskiy, H.B. Guliyev, N.B. Tomin, Z.A. Mammadov, "Probabilistic Assessment of Power System Mode with a Varying Degree of Wind Sources Integration", E3S Web of Conferences, Methodological Problems in Reliability Study of Large Energy Systems (RSES'2017), Vol. 25, pp. 1-5, Bishkek, Kyrgyzstan, September 11-15, 2017,

[2] H.B. Guliyev, N.R. Rakhmanov, "Probabilistic Modeling of Load Flow in Power Grid with Distributed Generation and Renewable Sources", Electronic Modeling, Vol. 38, No. 5, Kiev, Ukraine, pp. 101-112, 2016.

[3] J. McCauley, S. Asganpoor, L. Bertling, H. Billinion, H. Chao, J. Chen, J. Endrenyi, R. Fletcher, A. Ford, C. Ginning, G. Hamoud, D. Logan, A.P. Meliopoulos, M. Ni, N. Rau, L. Salvaderi, M. Schilling, Y. Schlumberger, A. Schneider, C. Singh, "Probabilistic Security Assessment for Power System Operations", Power Engineering Society General Meeting, Vol. 1, pp. 212-220, 2005.

[4] J. Arillaga, C.P. Amold, B.J. Harker, "Computer Modelling of Electrical Power Systems", Wiley & Sons, New York, 1983.

[5] R. Marconato, "Electric Power Systems", Vol. 2, CEI, Milano, Italy, 2004.

[6] S.C. Savulescu, "Equivalents for Security Analysis of Power Systems", IEEE Transactions on PAS, Vol. PAS-100, Issue 5, 1981.

[7] P. Pelacci, D. Poli, "The Influence of Wind Generation on Power System Reliability and the Possible Use of Hydrogen Storages", Electric Power Systems, Research (Elsevier), Vol. 80, Issue 3, pp. 249-255, 2010.

[8] R. Kaye, F. Wu, "Analysis of Linearized Decoupled Power Flow Approximations for Steady-State Security Assessment", IEEE Transactions on Circuits and Systems, Vol. 31, No. 7, 1984.

[9] A.P. Meliopoulos, A.G. Bakirtis, R. Kovacs, "Power System Reliability Evolution Using Stochastic Load Flows", IEEE Transactions on Power Apparatus and System, Vol. PAS-103, No. 5, pp. 1084-1091, May 1984.

[10] S. Aboreshaid, R. Billinton, "Probabilistic Evaluation of Voltage Stability", IEEE Transactions on Power System, Vol. 14, No. 1, pp. 342-348, February 1999.

[11] J.M.S. Pinheiro, C.R.R. Dornellas, M.Th. Schilling, AG.G. Melo, J.C.O. Mello, "Probing the New IEEE Reliability Test System (RTS-96): Hl-II Assessment", IEEE Transactions on Power Systems, Vol. 13. No. 1, pp. 171-176, 1998.

[12] C. Grigg, P. Albrecht, R. Allan, M. Havaraju, R. Billinton, Q. Chen, C. Fong, S. Haddad, S. Kuruganty, W. Li, R. Mukerji, D. Patton, N. Rau, D. Reppen, A. Schneider, M. Shahidehpour, C. Singh, "The IEEE Reliability Test System - 1996. A Report Prepared by the Reliability Methods Subcommittee", IEEE Transactions on Power Systems, Vol. 14, No. 13, pp. 1010-1020, 1999.

[13] "The IEEE Reliability Test System - 1996. IEEE TASC Force Report", IEEE Transactions on Power Systems, Vol. 14, No. 3, pp. 1010-1018, 1999.

BIOGRAPHIES

Arif Mamed Hashimov was born in Shahbuz, Nakhchivan, Azerbaijan on September 28, 1949. He is a Professor of Power Engineering (1993); Chief Editor of Scientific Journal of "Power Engineering Problems" from 2000; Director of Institute of Physics of Azerbaijan National Academy of Sciences (Baku, Azerbaijan) from 2002 up to 2009; Academician from 2007; the First Vice-President of Azerbaijan National Academy of Sciences from 2007 up to 2013; and Director of Azerbaijan Research Institute of Energetics and Energy Design from 2014 till now. He is laureate of Azerbaijan State Prize (1978); Honored Scientist of Azerbaijan (2005); Cochairman of International Conferences on "Technical and Physical Problems of Power Engineering" (ICTPE) and Editor in Chief of International Journal on "Technical and Physical Problems of Engineering" (IJTPE). Now he is a High Consultant in "Azerenerji" JSC, Baku, Azerbaijan. His research areas are theory of non-linear electrical Networks with distributed parameters, neutral earthing and ferroresonant processes, alternative energy sources, high voltage physics and techniques, electrical physics. His publications are 310 articles and patents and 5 monographs.

Nariman R. Rahmanov received the M.Sc. and Ph.D. degrees from Azerbaijan State Oil and Chemistry Institute (Baku, Azerbaijan) in 1960 and 1968, respectively. He received the Doctor of Technical Sciences in Power Engineering from Novosibirsk Electrotechnical Institute, Russia in 1990. He is a Professor since 1990 and Director of Azerbaijan Scientific Research Institute of Energetic and Energy Design (Baku, Azerbaijan) from 2007 up to 2009, and Deputy Director of the same institute and SPII from 2009 up to present. He is Director of Azerbaijan-Norway Center of Cleaner Production and Energy Efficiency (CPEE Center). He is the member of IEEE, Academician of International Eco-Energy Academy (Baku, Azerbaijan), Co-Chairman of International Conference on "Technical and Physical Problems of Electrical Engineering" (ICTPE), member of Editorial Boards of International Journal on "Technical and Physical Problems of Engineering" (IJTPE) and Journal of Power Engineering Problems. His research areas are power systems operation and control, distributed systems, alternative energy sources. His publications are more than 220 articles and patents, and also 3 monographs.

Huseyngulu Bayram Guliyev received his M.Sc. and Ph.D. degrees and is a Lead Scientific Researcher, Manager of the Scientific Branch "Monitoring and Control of the Reactive Power" in Azerbaijan Research Institute of Energetics and Energy Design (Baku, Azerbaijan). Currently, he is an Associate Professor of Automation and Control Department in Azerbaijan Technical University (Baku, Azerbaijan). He has more than 140 published articles and 2 patents. His research interests are power systems operation and control, distributed generation systems, application of artificial intelligence to power systems control design and power quality.

Arif A. Mustafayev is a graduate student at Azerbaijan Research Institute of Energetics and Energy Design, Azerenerji JSC, Baku, Azerbaijan.