Nodal Load Profiles Estimation for Time Series Load Flow Using Independent Component Analysis

Mashitah Mohd Hussain, Salleh Serwan, and Zuhaina Hj Zakaria

Abstract—This paper presents a method to estimate load profile in a multiple power flow solutions for every minutes in 24 hours per day. A method to calculate multiple solutions of non linear profile is introduced. The Power System Simulation/Engineering (PSS®E) and python has been used to solve the load power flow. The result of this power flow solutions has been used to estimate the load profiles for each load at buses using Independent Component Analysis (ICA) without any knowledge of parameter and network topology of the systems. The proposed algorithm is tested with IEEE 69 test bus system represents for distribution part and the method of ICA has been programmed in MATLAB R2012b version. Simulation results and errors of estimations are discussed in this paper.

Keywords—Electrical Distribution System, Power Flow Solution, Distribution Network, Independent Component Analysis, Newton Raphson, Power System Simulation for Engineering.

I. INTRODUCTION

THE definition of energy load profile is an estimation of the total energy demand from a power system or sub-system over a period of time. The load profile is used to ensure customers are billed accurately as well as to identify the type of customer class in power system. The benefit of profiling is it can allow electricity services provider to determine the tariff more precisely. Each customer daily load profiles may have a different profile's shape depends on type of customer users. It is essential to estimate load profiles behavior while the data profile as referral for system operation and planning. Independent component analysis is one of the state estimation technique used to scan the system data using only the profiles shape in distribution network.

Power flow analysis provide the specific information for load pattern for instance bus voltage, real and reactive line flows, line losses and load bus. However, it is requires the information of parameter and topology. This research is to assist the analysis to estimate the load bus using only profiles at line flows to the system. In fact, these data are essential to operation and planning for power systems to serve future

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loads. Load modeling techniques have been described in [1] and the power flow solution has been elaborated in [2]. To accomplish the load flow calculation the efficient procedure is presented in an electrical distribution system. The methods used to calculate load flow solution are Gauss-Seidel, Newton-Raphson and fast decoupled as shown in [3]. The concept of Newton Raphson for network simulation is employ to describe a technique for solving the power flow equations. This paper aims to estimate the load profile using only information profiles at load flow solution. The result of IEEE 69 test bus system is presented circumstantially by means of error comparison. For one instant power flow solutions, the system is assumed to be statistical voltage stability and in steady state condition.

Raymond and Thomas [4] have proposed a methodology of solving low voltage power flow simulations to compute active and reactive power magnitude devises a fixed- point iteration rule. In this paper, the efficient method has been presented to perform the load flows using PSS®E software and Matlab for load at buses.

ICA is noted as statistical technique that is able to separate the mixed signals into their source signals, with condition the source signals are non-Gaussian and statistically independent. There are many ICA applications that have been applied successfully in many areas such as combined text and image features, airport radio sources separation, estimate harmonic sources identification and all about separation of speech signals discussed in [5]. Fixed-point algorithm can optimize the contrast functions quickly and reliably [6].

Section II of this paper is specified load flow solution using PSS®E software. Section III demonstrates the formulation method for independent component analysis which applied to distribution network. Section IV presents the result for original and estimated load profiles for 69 bus system.

II. DC POWER FLOW SOLUTION

A. Analysis of Power Flow Calculation

Power System Simulation for Engineering is composed a set of program for power system generation, transmission and distribution network performance either for steady state and also dynamic condition.

In order to estimate the load profiles, the load flow solution first need to be solved which assume constant for active and reactive power injection. The load model consists of a voltage which depends to load admittance. The model is assumed to

be original system due to admittance matrix is effecting to the load buses.

The load flow of radial distribution system can be analyzed from point of view of a single line diagram which can be represented as shown in Fig. 1 below,
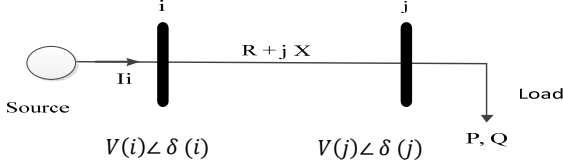

Fig. 1 Electrical equivalent of a branch

From Fig. 1, it can be written as

$$I_i = \frac{V(i)\angle\delta(i) - V(j)\angle\delta(j)}{R + jX}$$
$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j|\angle\theta_{ij} + \delta_j \qquad (1)$$

The real and reactive power at bus i is

$$P_i + jQ_i = V_i I_i^* \qquad (2)$$

The complex power S_{ij} from bus i to j and S_{ji} from bus j to I are

$$S_{ij} = V_i I_{ij}^* \qquad (3)$$
$$S_{ji} = V_j I_{ji}^* \qquad (4)$$

And the power loss in line i to j is

$$S_{Lij} = S_{ij} + S_{ji} \qquad (5)$$

Consider the line connecting the two buses i and j in Fig. 1 the real and imaginary parts are,

$$P_i = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (6)$$
$$Q_i = \sum_{j=1}^{n} V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) \qquad (7)$$

The Newton method is assuming initial guesses of all unknown variables. Equations above are in term of the independent variables with voltage magnitude in per unit and phase angle in radians. In short form, the Jacobian matrix is the partial derivatives of equation (6) and (7) can be written as

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \qquad (8)$$

where: $J_1 = \frac{\partial P_i}{\partial\delta}$, $J_2 = \frac{\partial P_i}{\partial|V_i|}$, $J_3 = \frac{\partial Q_i}{\partial\delta_i}$, $J_4 = \frac{\partial Q_i}{\partial|V_i|}$

Fig. 2 shows the procedure to calculate line flow and line losses from bus i to bus j using Newton-Raphson method. The calculation for procedure above is repeated until value ΔP_i and ΔQ_i is very small. Fig. 3 shows a 69 node power system

which consists of six laterals including main feeder [7]. The load flow of distribution system below consists of 69 buses and 48 load bus. Bus 1 is assumed to be source which voltage magnitude is set to 1p.u.
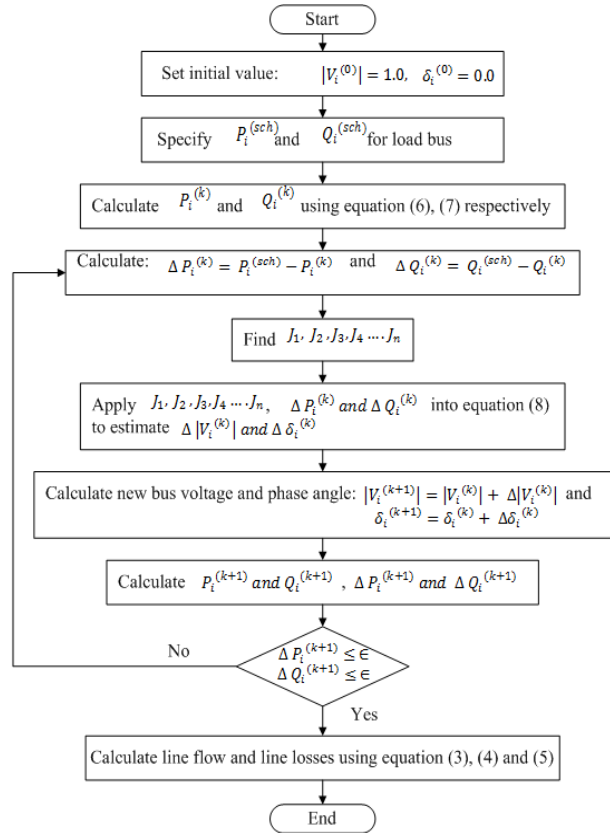

Fig. 2 Basic procedure for power flow solution

Fig. 3 IEEE 69-bus power system with 69 nodes
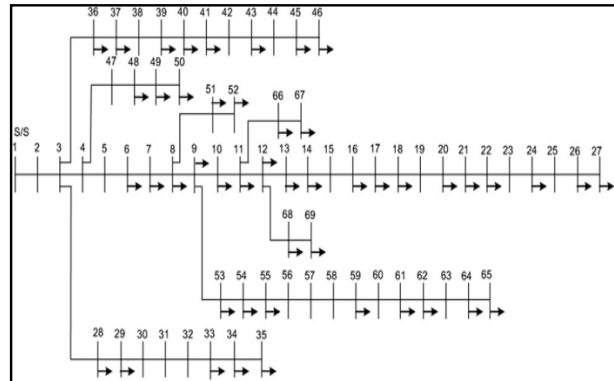
B. Time Series Load Flow Solution

There are many software to simulate the power system network such as Matlab, PSAT, PowerWorld, PSpice, PSS/E, MATPOWER and etc. The Power System Simulation for Engineering (PSS®E) was selected to run power flow solution from Fig. 3 above. PSS®E is widely used in this country to analyse power system network. But then this method can only

be obtained for one instant. Therefore, Phyton programming is used to generate load profile for time series in 24-hours for every minute (1440 times).

The design of PSS®E provides determining the mathematical technique and data base structure flow. It is also called modern simulation on computer hardware which is more constraint. Record the simulation and the solutions for each load flow of 69 bus system are saved. Then open file that was saved into pyhton programming. The pyhton programming is run the Newton Raphson iterative solved for 1440 times. Therefore, the profile for load flow was created using this phyton programming.

III. Load Profiles Estimation using Independent Component Analysis

In blind source separation, there is only the observations or measurements are known, source signal and the way sources are mixed or the mixing environment are unknown [8]. The source is to be ensuring a non-gaussian distribution. The method to measure non-gaussianity is known as kurtosis and negentropy which is to maximize the separating linear mixtures of statistical independent source signals [9].

Independent component analysis (ICA) aims to extract the sources that are combined linearly [10]. The model is unable to be observed directly (latent variables) and it is definitely known as generative model which is observed the generated data by the process of mixing components [11]. In this paper, the Independent Component Analysis (ICA) algorithm was applied to estimate load profiles at each buses in distribution network with only information profiles at power flow system.

The basic linear combination of statistically independent component variables is

$$X(t_i) = AY(t_i) + n(t_i) \qquad (9)$$

where:
$X(t) = [X_1(t_i) \dots X_M(t_i)]^T$: M is dimensional vector of observed signals.
$Y(t) = [Y_1(t_i) \dots Y(t_i)]^T$: N is dimensional vector of unknown source signals.
A : M× N is unknown matrix called mixing matrix.
$n(t_i)$: N is dimensional noise vector.

Independent component analysis is notation to extract the signals from a set of signal mixtures which have a term of set of mixing coefficients. Load flow profile is represents as signal mixtures for this study. The mixing coefficient matrix, A is used to implement a geometric transformation of each point. The result of mixture point is transformed back to the source signal using a set of unmixing coefficients, W which inverse the mixing geometric transformation. Each mixing signal is obtained by combining source signals. Details explanation is elaborated in Fig. 4 and 5 where the source signals can be estimated if coefficient of matrix W is known.

Fig. 6 represents the general process of ICA. The data are whitened to removed the mean and adjust the variance to unity. When the signal passing through to the ICA, it is

requires process to reconstruct the signal. The mixing matrix, A is assumed to be unknown. The only known information is observed signals, X (t) and need to estimate the value of A and then Z (t) using the information. When the mixing matrix A is estimated, the constant (weight, W) matrix can be determined where mixing matrix of A is its inverse of matrix W and Z (t) is inverse matrix of Y(t) which is also represent for new form of Y(t). The equation is shown as below,

$$Z(t_i) = A^{-1}X(t_i) \qquad (10)$$

Thus, the linear transformation of the observed variables is given as,

$$Z(t_i) = WX(t_i) \qquad (11)$$

where:
$X(t) = [X_1(t_i) \dots X_M(t_i)]^T$: M is dimensional vector of observed signals.
$Z(t) = [Z_1(t_i) \dots Z_M(t_i)]^T$: N is dimensional vector of unknown source signals.
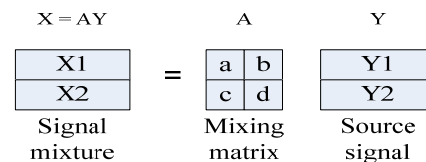W : M× N unknown matrix called separating matrix.

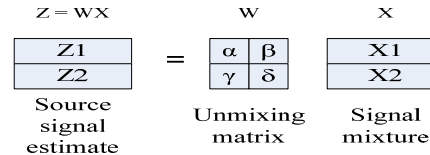Fig. 4 Schematic diagram of vector matrix before applying FastICA

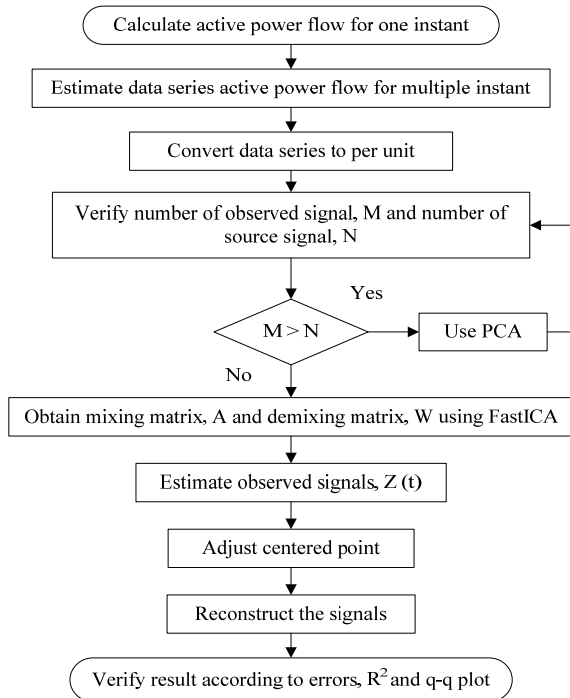Fig. 5 Schematic diagram of vector matrix when apply FastICA

Calculate active power flow for one instant

↓

Estimate data series active power flow for multiple instant

↓

Convert data series to per unit

↓

Verify number of observed signal, M and number of source signal, N

↓

M > N —Yes→ Use PCA

↓ No

Obtain mixing matrix, A and demixing matrix, W using FastICA

↓

Estimate observed signals, Z (t)

↓

Adjust centered point

↓

Reconstruct the signals

↓

Verify result according to errors, R^2 and q-q plot

Fig. 6 Procedure to estimate load bus

IV. RESULT AND DISCUSSION

The standard 69 test bus system shown in Fig. 3 was computed with PSS®E software. From the simulation the value of voltage, active and reactive power at each bus and their losses can be obtained. The phyton programming was build to run the simulation time series for every minute in 24 hours. The bus system consists of 69 buses, 48 loads and assumes bus 1 as a source to the system. The load flow solution is shown in Table I. Voltage magnitude was set to 1p.u and the active and reactive power losses are 195.7055 kW and 90.49132 kVar as shown in Table III. The errors between estimated and original load profiles are calculated as shown in Table II. The quantile- quantile plot is also been used to observe the performance of the analysis which compared both actual and estimated profiles shown in Fig. 7. X- quantile and Y- quantile represents for actual and measured profiles respectively. From the graph, the horizontal and vertical point are considered to be normal distributed where the plotting are against each other and the q-q plot shown that the results are also close to straight line. Therefore, the ICA algorithm can be proposed as a tool to interpolate a load shape for every bus.

In conclusion, ICA technique has shown its ability to estimate the load profiles at distribution using only information at certain substation.

TABLE I
VOLTAGE LOAD FLOW AND POWER FACTOR FOR 69- BUS SYSTEM FOR ONE INSTANT CYCLE

| Node Bus	Voltage magnitude (per-unit)	Load pf (per-unit)	Node Bus	Voltage magnitude (per-unit)	Load pf(per-unit)
1	1.00000	-	36	0.99993	0.90178
2	0.99997	-	37	0.99979	0.87215
3	0.99994	-	38	0.99964	-
4	0.99986	-	39	0.99960	0.85823
5	0.99912	-	40	0.99960	0.92016
6	0.99070	0.82639	41	0.99897	-
7	0.98195	0.83727	42	0.99870	-
8	0.97987	0.92183	43	0.99867	0.92650
9	0.97880	0.90837	44	0.99866	-
10	0.97406	0.85902	45	0.99857	0.86254
11	0.97302	0.89206	46	0.99857	0.89293
12	0.97003	0.89172	47	0.99982	-
13	0.96725	0.90399	48	0.99867	0.91203
14	0.96449	0.92845	49	0.99506	0.87312
15	0.96176	-	50	0.99451	0.80747
16	0.96125	0.90681	51	0.97984	0.85473
17	0.96041	0.94700	52	0.97983	0.83484
18	0.96040	0.89205	53	0.97615	0.84071
19	0.95996	-	54	0.97308	0.89986
20	0.95967	0.89447	55	0.96883	0.88669
21	0.95922	0.85990	56	0.96467	-
22	0.95921	0.94734	57	0.94442	-
23	0.95914	-	58	0.93382	-
24	0.95900	0.92632	59	0.92971	0.72533
25	0.95884	-	60	0.92491	-
26	0.95877	0.87917	61	0.91793	0.87259
27	0.95875	0.90042	62	0.91763	0.91050
28	0.99994	0.88254	63	0.91722	
29	0.99987	0.83326	64	0.91524	0.72299
30	0.99975	-	65	0.91472	0.91349
31	0.99973	-	66	0.97297	0.86809
32	0.99963	-	67	0.97296	0.86244
33	0.99938	0.83011	68	0.96972	0.88850
34	0.99905	0.86813	69	0.96972	0.90483
35	0.99898	0.83782	-	-	-

Bus 13

X-axis – Time (hour)
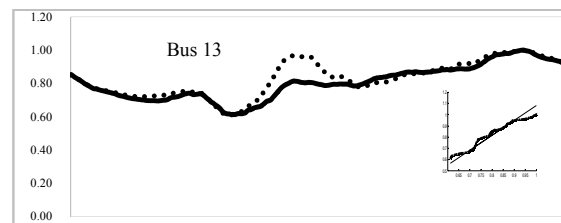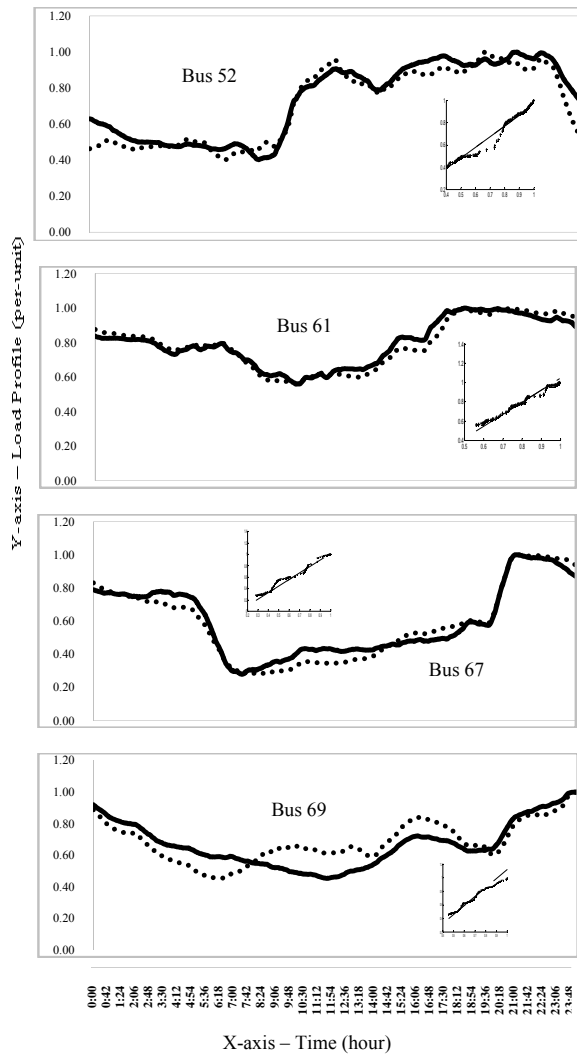
Fig. 7 Comparison result between actual and estimated load profiles and their q-q plot. Solid line represents actual profile and round dot represents estimated profile

TABLE II
ACTIVE AND REACTIVE POWER FOR IEEE 69-TEST BUS SYSTEM AT 12:00PM ONLY

Set V (pu)	1	Source, kW	3977.805
kW	3977.805	Source, kVar	2328.202
kVar	2328.202	Loss, kW	195.7055
Load, kW	3782.1	Loss, kVar	90.49132
Load, kVar	2237.71	-	-

TABLE III
ERRORS BETWEEN ESTIMATION AND ACTUAL LOAD PROFILES IN DC POWER FLOW DISTRIBUTION SYSTEM

Load Bus	Average Abs Error	Minimum Abs Error	Maximum Abs Error	Error, R^2	Correlation Coefficient
6	0.08417	0.00023	0.32436	0.66494	0.86020
7	0.05731	0.00002	0.29405	0.80593	0.91457
8	0.06054	0.00001	0.26527	0.56748	0.93250

9	0.05056	0.00004	0.21787	0.90513	0.92595
10	0.03479	0.00003	0.15420	0.90621	0.94823
11	0.11860	0.00020	0.34749	0.62099	0.73137
12	0.02957	0.00000	0.16183	0.89003	0.94354
13	0.03904	0.00000	0.09550	0.82157	0.92478
14	0.04704	0.00008	0.11550	0.79271	0.89034
16	0.03892	0.00003	0.16661	0.57520	0.95043
17	0.06653	0.00013	0.21256	0.86261	0.94766
18	0.08414	0.00007	0.19162	0.86038	0.92757
20	0.11703	0.00020	0.28934	0.76409	0.75707
21	0.09558	0.00001	0.36781	0.65534	0.76387
22	0.06272	0.00012	0.20095	0.89932	0.94833
24	0.07075	0.00000	0.18860	0.92367	0.96108
26	0.05816	0.00014	0.17562	0.75682	0.86996
27	0.05970	0.00004	0.17367	0.84953	0.95684
28	0.02636	0.00005	0.07619	0.73839	0.97806
29	0.03584	0.00004	0.08159	0.54923	0.74110
33	0.09315	0.00002	0.20139	0.79510	0.93609
34	0.05513	0.00000	0.15707	0.52106	0.94515
35	0.03891	0.00008	0.11913	0.79655	0.89249
36	0.03545	0.00004	0.16978	0.47211	0.88955
37	0.06159	0.00004	0.24115	0.67861	0.83350
39	0.09508	0.00008	0.21861	0.74572	0.86355
40	0.01331	0.00002	0.05315	0.87053	0.95084
41	0.02427	0.00000	0.10218	0.99270	0.96283
43	0.04274	0.00008	0.14914	0.67849	0.96697
45	0.05259	0.00011	0.16212	0.94362	0.93329
46	0.04885	0.00002	0.12937	0.62846	0.90705
48	0.05798	0.00001	0.17060	0.69869	0.89645
49	0.05978	0.00003	0.16833	0.72845	0.89883
50	0.05139	0.00010	0.20748	0.71784	0.89935
51	0.03038	0.00000	0.19023	0.90428	0.95094
52	0.04521	0.00000	0.19745	0.93995	0.96951
53	0.06919	0.00001	0.29885	0.87930	0.92350
54	0.04500	0.00013	0.16607	0.81008	0.90005
55	0.05011	0.00000	0.13862	0.89292	0.94495
59	0.03109	0.00013	0.10387	0.19733	0.93744
61	0.02635	0.00006	0.08079	0.95197	0.97569
62	0.04325	0.00001	0.16048	0.86404	0.93448
64	0.07987	0.00002	0.21996	0.82142	0.87502
65	0.05418	0.00001	0.19704	0.81340	0.89234
66	0.05507	0.00006	0.23939	0.59542	0.87482
67	0.03854	0.00001	0.08722	0.96331	0.98148
68	0.04533	0.00002	0.16283	0.86185	0.92836
69	0.04472	0.00012	0.09849	0.58041	0.94396

V. CONCLUSION

In this paper, a Power System Simulation for Engineering and phyton has been proposed which its computes a voltage magnitude and angles at buses of the system. Then ICA is done by MATLAB 2012b which used to estimate load profiles at each load bus. Both simulation methods have been tested on

69 bus standard test systems. The calculated load profiles and the estimated load profiles were seen to be very close to actual results. In conclusion, the load bus still can be estimated even though the parameters values and topology are unknown. The method might be used in system planning and operation, although this paper shows the potential as a tool to give an expected reading load data on the power system. Further improvements are expected.

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