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.


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 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](image)

From Fig. 1, it can be written as

\[ I_l = \frac{V(i) \angle \delta(i) - V(j) \angle \delta(j)}{R + jX} \]

\[ I_l = \sum_{n=1}^{n} |V_i| |V_j| \angle \theta_l + \delta \]

The real and reactive power at bus i is

\[ P_i + jQ_i = V_i I_i^* \]

The complex power \( S_{ij} \) from bus i to j and \( S_{ji} \) from bus j to i are

\[ S_{ij} = V_i I_j^* \]

\[ S_{ji} = V_j I_i^* \]

And the power loss in line i to j is

\[ S_{lij} = S_{ij} + S_{ji} \]

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

\[ P_l = \sum_{n=1}^{n} V_i V_j \cos(\theta_{ij} - \delta_l + \delta_j) \]

\[ Q_l = \sum_{n=1}^{n} V_i V_j \sin(\theta_{ij} - \delta_l + \delta_j) \]

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

\[ \frac{\Delta P}{\Delta Q} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \]

where: \( J_1 = \frac{\partial P_l}{\partial \delta}, J_2 = \frac{\partial P_l}{\partial \theta_{ij}}, J_3 = \frac{\partial Q_l}{\partial \delta}, J_4 = \frac{\partial Q_l}{\partial \theta_{ij}} \)

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 \( \Delta P_l \) and \( \Delta Q_l \) 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.

### 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 pytbon programming is run the Newton Raphson iterative solved for 1440 times. Therefore, the profile for load flow was created using this pytton 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

\[ X(t_i) = AY(t_i) + n(t_i) \]  

where:
- \( X(t_i) = [X_1(t_i) \ldots X_M(t_i)]^T \): M is dimensional vector of observed signals.
- \( Y(t_i) = [Y_1(t_i) \ldots Y_N(t_i)]^T \): 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 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 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,

\[ Z(t_i) = A^{-1}X(t_i) \]  

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

\[ Z(t_i) = WX(t_i) \]  

where:
- \( X(t) = [X_1(t_i) \ldots X_M(t_i)]^T \) : M is dimensional vector of observed signals.
- \( Z(t) = [Z_1(t_i) \ldots Z_N(t_i)]^T \) : N is dimensional vector of unknown source signals.
- \( W \): M×N unknown matrix called separating matrix.
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 Python 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 1 p.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.

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<th>Load pf (per-unit)</th>
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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

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<th>Set V (pu)</th>
<th>Source, kW</th>
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TABLE III
ERRORS BETWEEN ESTIMATION AND ACTUAL LOAD PROFILES IN DC POWER FLOW DISTRIBUTION SYSTEM

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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.

REFERENCES


