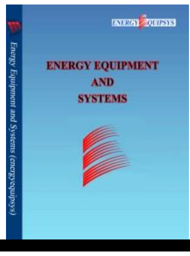
Energy Equipment and Systems

http://energyequipsys.ut.ac.ir
www.energyequipsys.com



Measurements and parameters estimation in power systems containing UPFC

Authors

Mehdi Ahmadi Jirdehi [a*]
Reza Hemmati [a]
Sadjad Galvani [b]

[a] Department of Electrical Engineering, Kermanshah University of Technology, Kermanshah, Iran

[b] Department of Electrical and Computer Engineering, Urmia University, Urmia, Iran

Article history:

Received : 3 May 2017
Accepted : 10 October 2018

ABSTRACT

This paper presents a new algorithm for validation (identification and correction) of measurement and parameter errors (branch parameters as well as unified power flow controller (UPFC) parameters), simultaneously. The algorithm is composed of three steps. First, in the step 1, state estimation (SE) is solved by the modified weighted least square (MWLS) and then, the normalized measurement residual and Lagrange multiplier vectors are computed. The errors in measurement and parameter are identified in the step 2. Finally, in the step 3, erroneous measurement and parameter values are corrected. The correction algorithm is based on a proposed approach without the using of augmented state vector (ASV). The IEEE-14 bus system and 230 kV East Azerbaijan network of Iran modified by incorporating UPFC are used as test systems. Simulation results demonstrate the effectiveness of the proposed method. Also, results indicate that the proposed method can validate the erroneous values with lower error percentage.

Keywords: State Estimation; MWLS; UPFC; Measurement Errors; Parameter Errors; East Azerbaijan Network of Iran.

1. Introduction

In energy control centers (ECC), SE was carried out based on measurements and a mathematical model [1, 2]. In this model is considered several assumptions. For example, power system configuration and its parameters are considered without any errors. In practical, these assumptions are not true and the stored parameter values in the database may be incorrect. Thus, it is very important that these errors be validate [3]. The influence of parameter errors on SE problem is studied in detail in another study [4]. The parameter errors validation using supervisory control and data acquisition (SCADA) measurements and phasor measurement units (PMU) are discussed in several published papers [5, 6]. Also, in [7] the SE solution sensitivities to series and shunt parameters of branch are analyzed.

Identification of errors in measurement set is done by the most state estimators and all other types of errors are ignored. The identification of these errors can be effectively done using the largest normalized residual approach [8]. To detect measurement errors, a new method based on innovation index definition has been proposed in [9]. Also, a bad data identification approach using a robust method is presented in [10] for the power system SE with equality constraints.

On the other hand, operating power systems containing UPFCs require parameters monitoring associated with device control. Despite the best efforts of operators and planning engineers, maintaining an error free on-line data for UPFC parameters may not

* Corresponding author: Mehdi Ahmadi Jirdehi
Department of Electrical Engineering, Kermanshah University of Technology, Kermanshah, Iran
Email: m.ahmadi@kut.ac.ir

always be possible because of the uncertainties involved in system operation [11]. Consequently, correct monitoring of UPFC parameters also becomes crucial for power system control [12]. Some techniques for power system SE with UPFC have been proposed. In [13], a method based on Hopfield neural network has been applied to the SE embedded with UPFC. A WLS algorithm for power systems SE containing FACTS devices has been described in [14]. UPFC power injection model is employed in [15] and UPFC affect on power flow is transferred to the two nodes of the corresponding branch. In [16], the SE of systems with UPFC is solved using interior point (IP) method. Also, the predictor-corrector IP method is proposed in [17].

As a result, in all methods of error estimation the following limitations are common:

1. Before parameter error estimation, a primary set of suspicious parameters are required.
2. The ASV method for parameter estimation requires high computational capacity in estimation process.
3. With ASV method
4. It may obtain some unreasonable results when ASV method is applied, such as negative resistances and unacceptable large parameter values.
5. Before parameter error identification, measurement errors have to be eliminated.
6. Most of branch parameter estimation approaches address only the branch series admittances and assume that the influence of branch shunt admittances is insignificant on SE solution [18].

In this paper, a new method is proposed for simultaneous error identifying and correcting in measurement and branch and UPFC parameter in three stages. The proposed method is based on the normalized Lagrange multipliers and normalized residuals by calculation of SE. Also, a new linear approximation approach is proposed to estimate and correct the erroneous values of measurements and parameters. The main advantage of the proposed method is that the measurement errors as well as the branch and UPFC parameter errors can be identified and then corrected, even when they appear simultaneously. There is not any need to specify a suspect set of parameters that are necessary in other recently published methods and this is important advantage of proposed method. Finally, simulation results on the IEEE-14 bus test system and 230 kV East Azerbaijan network of Iran with UPFC show the validity of proposed method.

2.UPFC modeling for state estimation problem

The UPFC steady-state model is suitable for implementation in the conventional WLS state estimation algorithm [14]. A UPFC consists of the series and shunt voltage converters connected to a branch which is capable of simultaneously controlling voltage magnitude as well as active and reactive power flows [19-20]. In this model, the UPFC converters are assumed lossless. This implies that there is no absorption or generation of active power by the two converters and at its output the active power demanded by the series converter is supplied from AC power system by the shunt converter via the common DC link. The voltage of DC link capacitors (V_{dc}) remains constant. Hence, the active power supplied to the shunt converter (P_{sh}) must be equal to the active power demanded by the series converter (P_{se}) at DC link. Then the following equality constraint has to be guaranteed.

$$P_{se} + P_{sh} = 0 \qquad (1)$$

It is a UPFC constraint which should be added to the estimation equations.

UPFC steady-state model including the branch is shown in Fig. 1. This model consists of one series voltage source ($\hat{V}_{se} = V_{se}\angle\theta_{se}$) in addition to one shunt voltage source ($\hat{V}_{sh} = V_{sh}\angle\theta_{sh}$) and their source impedances $\hat{Z}_{se}$ and $\hat{Z}_{sh}$, respectively.

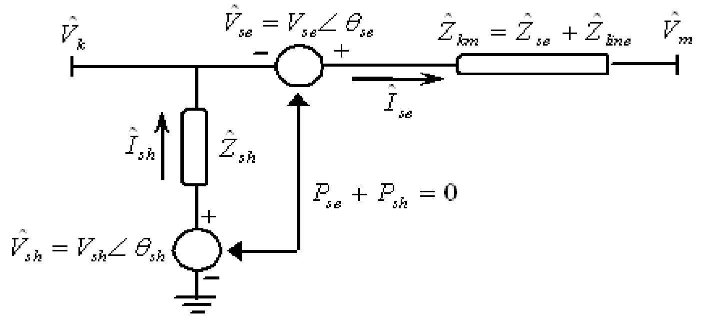


Fig.1: UPFC steady-state model

3. Problem formulation

The SE can be formulated by mathematical model that is relationship between the measurements, the state variables and the branch and UPFC parameters as follows:

$$\mathbf{z} = h(\mathbf{x},\mathbf{p}) + \mathbf{e} \quad (2)$$

where **z** is the measurement vector (m×1) and **x** is the system state vector (n×1). The nonlinear function h(**x,p**) relates the measurements and parameter errors to the state variables. m and n are the number of measurements and state variables to be estimated, respectively. **P** is the vector of power system branch and UPFC parameter errors, and **e** denotes measurement error vector with zero mean value and covariance matrix **R**, which is a diagonal matrix with diagonal elements σ_{ii}^2, where σ_{ii}^2 is the variance of the i^{th} measurement. If there are no errors in branch and UPFC parameters, the power system parameter error vector **P** will be zero. Therefore, the conventional WLS state estimation approach in the presence of parameter errors can be written as the following optimization problem:

$$\begin{aligned}&\text{Minimize} \quad J(\mathbf{x}) = \left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right]^T \cdot \mathbf{R}^{-1} \cdot \left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right] \quad (3)\\&\text{Subject to} \quad \mathbf{p} = 0\end{aligned}$$

The super index T indicates transposition. If the Lagrange multipliers analysis is applied to solve this problem, the objective function J(**x**) can be written as follows:

$$L(\mathbf{x},\mathbf{p},\boldsymbol{\lambda}) = \left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right]^T \cdot \mathbf{R}^{-1} \cdot \left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right] - \boldsymbol{\lambda}^T \mathbf{p} \quad (4)$$

Krush Kuhn-Tucker (KKT) conditions can be used for the solving of this function:

$$\frac{\partial L(\mathbf{x},\mathbf{p},\boldsymbol{\lambda})}{\partial \mathbf{x}} = \mathbf{H}_X^T \cdot \mathbf{R}^{-1}\left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right] = 0 \quad (5)$$

$$\frac{\partial L(\mathbf{x},\mathbf{p},\boldsymbol{\lambda})}{\partial \mathbf{p}} = \mathbf{H}_P^T \cdot \mathbf{R}^{-1} \cdot \left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right] + \boldsymbol{\lambda} = 0 \quad (6)$$

$$\frac{\partial L(\mathbf{x},\mathbf{p},\boldsymbol{\lambda})}{\partial \boldsymbol{\lambda}} = \mathbf{p} = 0 \quad (7)$$

where, $\boldsymbol{H}_x = \partial h(\boldsymbol{x},\boldsymbol{p})/\partial \boldsymbol{x}$, $\boldsymbol{H}_p = \partial h(\boldsymbol{x},\boldsymbol{p})/\partial \boldsymbol{p}$ and $\boldsymbol{\lambda}$ are Jacobian matrix of the measurement function, Jacobian matrix of parameters and Lagrange multiplier vector, respectively. The modified state Jacobian matrix for SE with UPFC must be adjusted which indicated in [21]. Note that, $\boldsymbol{\lambda}$ can be now expressed in terms of $\mathbf{r}$ using Eq. (6) as follows:

$$\boldsymbol{\lambda} = \mathbf{S_P} \cdot \mathbf{r} = -\left[\mathbf{H}_P^T \cdot \mathbf{R}^{-1}\right] \cdot \left[\mathbf{z} - h(\mathbf{x},\mathbf{p})\right] \quad (8)$$

where $\boldsymbol{S}_p = -[\boldsymbol{H}_P^T . \boldsymbol{R}^{-1}]$ is the parameter sensitivity matrix and $\boldsymbol{r} = \boldsymbol{z} - h(\hat{\boldsymbol{x}}, \boldsymbol{p})$ represents the measurement residual vector. An iterative solution of the conventional WLS state estimation used for estimation of state vector **x** by solving the following normal equations:

$$\begin{aligned}&\Delta\mathbf{x}^k = \mathbf{G}(\mathbf{x}^k)^{-1} \cdot \mathbf{H}_X^T(\mathbf{x}^k) \cdot \mathbf{R}^{-1} \cdot \left(\mathbf{z} - h(\mathbf{x}^k, 0)\right) \quad (9)\\&\mathbf{x}^{k+1} = \mathbf{x}^k + \Delta\mathbf{x}^k\end{aligned}$$

where, k is the iteration index, and gain matrix $\boldsymbol{G}(\boldsymbol{x}^{\boldsymbol{k}})$ is given by $\mathbf{G}(\mathbf{x}^k) = \mathbf{H}_X^T(\mathbf{x}^k) \cdot \mathbf{R}^{-1} \cdot \mathbf{H}_X(\mathbf{x}^k)$.

4.Proposed method

The proposed method is composed of three stages: Stage 1- SE solution and computation of the normalized measurement residual vector (r^N) and the normalized Lagrange multiplier vector (λ^N); Stage 2- Identification of erroneous measurement and parameter; Stage 3- Correction of identified measurement and parameter. All of them will be presented in the following. Note that the proposed approach deals with series and shunt admittances in the classical steady-state π-equivalent model of branches. If the physical parameters of the lines resistances (r_{i-j}) and reactances (x_{i-j}) are required, the chain rule must be used as indicated in [22]. The flowchart of the proposed algorithm is shown in Fig. 2.

Stage 1. SE solution and computation of the r^N and λ^N vectors

In this paper, the normalized measurement residual test (r^N) is selected for detection and identification of measurement errors [1]. The residual vector ($\mathbf{r}$) which is defined in Eq. (8), is normalized as follows:

$$r_i^N = \frac{r_i}{\sqrt{\Omega(i,i)}} \qquad i=1,\ldots,m \tag{10}$$

$$\mathbf{\Omega} = cov(\mathbf{r}) = \left\{\mathbf{I} - \mathbf{H}_X\left(\mathbf{H}_X^T \cdot \mathbf{R}^{-1} \cdot \mathbf{H}_X\right)^{-1} \mathbf{H}_X^T \cdot \mathbf{R}^{-1}\right\}$$

where r_i^N is the i^{th} element of $\mathbf{r}^N$ vector and $\sqrt{\Omega(i,i)}$ is the standard deviation of the i^{th} component of the residual vector. Also, $\mathbf{I}$ is the identity matrix.

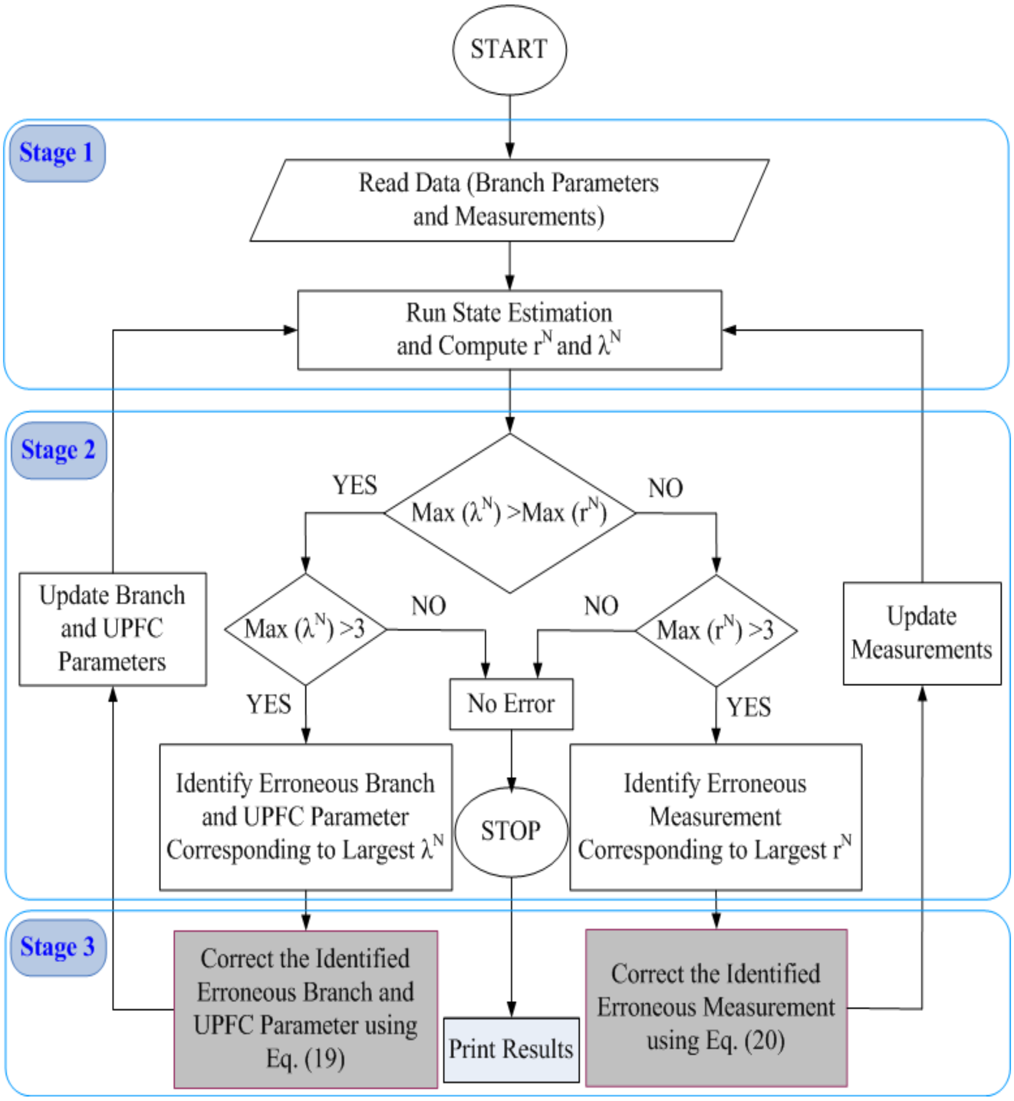


Fig.2. The flowchart of the proposed algorithm

On the other hand, the normalized Lagrange multiplier vector ($\boldsymbol{\lambda}^N$) is proposed for identification of branch and UPFC parameter errors. It is assumed that all Lagrange multipliers are distributed according to a normal distribution with zero mean value and a non-zero covariance. The covariance matrix ($\boldsymbol{\Lambda}$) can be derived from the relation between Lagrange multipliers and measurement residuals as follows:

$$\Lambda = cov(\boldsymbol{\lambda}) = [\mathbf{S_P}] \cdot cov(\mathbf{r}) \cdot [\mathbf{S_P}]^T = [\mathbf{S_P}] \cdot [\boldsymbol{\Omega}] \cdot [\mathbf{S_P}]^T \quad (11)$$

$$\boldsymbol{\Omega} = \left\{ \mathbf{I} - \mathbf{H}_X \left(\mathbf{H}_X^T \cdot \mathbf{R}^{-1} \cdot \mathbf{H}_X \right)^{-1} \mathbf{H}_X^T \cdot \mathbf{R}^{-1} \right\}$$

The Lagrange multipliers can be normalized using the diagonal elements of the covariance matrix according to the following equation:

$$\lambda_i^N = \frac{\lambda_i}{\sqrt{\Lambda(i,i)}}, \quad i=1,\ldots,n_p \quad (12)$$

where n_p is the total number of power system branch and UPFC parameters. Also, the vector $\boldsymbol{\lambda}^N$ is a Gaussian random variable with zero mean and unit variance.

In summary, in the stage 1, the following steps should be taken:

Step 1: Read power system data (branch parameters and available measurements).

Step 2: Start iteration, set the iteration index, k=1 and initialize bus voltages at flat start.

Step 3: Run the conventional WLS state estimator and compute $\Delta\mathbf{x}^k$ using Eq.(9).

Step 4: Check for convergence. If $\Delta\mathbf{x}^k$ is lower than the convergence tolerance, go to Step 5; otherwise, update $\mathbf{x}^{k+1} = \mathbf{x}^k + \Delta\mathbf{x}^k$ and go to Step 3. (In this paper, the selected convergence tolerance is 10^{-6})

Step 5: Compute the $\mathbf{r}^N$ using Eq. (10) and the $\boldsymbol{\lambda}^N$ using Eq. (12).

Stage 2. Identification of erroneous measurement and parameter

In this stage, the measurement and branch and UPFC parameter error are identified based on the results of stage 1. The measurement which has the largest normalized residual (larger than threshold) is identified as erroneous measurement. Also, the parameter which has the largest normalized Lagrange multiplier (larger than threshold) is identified as erroneous parameter. Note that in this paper, a typical threshold of 3 is selected for error identification [1].

Consequently, the identification stage can be summarized by below steps as follows:

Step 1: If $max|\lambda^N, r^N| < 3$, no error in measurement and branch and UPFC parameter is identified. Then print the SE results. Otherwise:

A: If $max|\lambda^N| > max|r^N|$ the branch or UPFC parameter corresponding to $max|\lambda^N|$ should be considered as erroneous parameter, correct the corresponding parameter using the proposed method is described in the stage 3.

B: If $max|r^N| > max|\lambda^N|$ the measurement corresponding to $max|r^N|$ should be considered as erroneous measurement and should be corrected using the proposed method is described in the stage 3.

Stage 3. Correction of identified erroneous measurement and parameter

After the identification of erroneous measurements and parameters (branch and UPFC parameters) in the stage 2, Should be addressed to correct identified errors using a new proposed linear approximation approach that is explained in this stage in details.

In the all related literature, if a parameter is identified as erroneous, it is corrected by estimating its value using the method described in [23] using ASV (In this method, SE solution execution provides the optimal estimation of state variables as well as erroneous parameters). The estimated parameter value is substituted in database and then WLS algorithm is repeated. This parameter error correction method needs to solve WLS algorithm for estimating the correct parameter value with high computational capacity and extra iteration in estimation process. The proposed method in this paper overcame this problem by eliminating necessary ASV and the erroneous parameter values can be corrected using a linear approximation with high accuracy.

As noted above, after identification of branch and UPFC parameter errors, the algorithm is repeated once to perform the augmented SE approach for each erroneous parameter estimation. This means that in the presence of multiple parameter errors in power system, they should be estimated one by one using the augmented SE approach. Hence, this process needs to be run multiple times to correct whole of parameter errors. Such a performance of this method results in increase of computational volume and iteration numbers in estimation process. The proposed linear approximation approach is described below. Let Eq. (2) be rewritten as:

$$\mathbf{z} = h(\mathbf{x},\mathbf{p}_0) + \left[h(\mathbf{x},\mathbf{p}) - h(\mathbf{x},\mathbf{p}_0)\right] + \mathbf{e} \qquad (13)$$

where $\mathbf{P}$ and $\boldsymbol{P}_0$ are actual and erroneous values of the branch and UPFC parameters, respectively. The term in square brackets in Eq.(13) is equivalent to an additional measurement error and can be linearized as:

$$[h(x,p) - h(x,p_0)] = \left[\frac{\partial h(x,p)}{\partial p}\right].e_p = H_p.e_p \qquad (14)$$

where $\boldsymbol{e}_p$ is vector of branch and UPFC parameter errors, considering a random Gaussian variable with zero mean value and covariance matrix of $\boldsymbol{R}_p$.

By combining Eqs. (13) and (14), a linear relationship can be established between residual measurement vector $\mathbf{r}$ and parameter errors vector $\boldsymbol{e}_p$:

$$r = z - h(\hat{x}, p_0) = H_p.e_p \qquad (15)$$

By using Eqs. (15) and (8), parameter errors vector $\boldsymbol{e}_p$ can be written as follows:

$$\mathbf{e_p} = \frac{\boldsymbol{\lambda}}{\mathbf{S_p} \cdot \mathbf{H_p}} = \frac{\boldsymbol{\lambda}}{\mathbf{G_p}} \qquad (16)$$

where $\boldsymbol{G}_p$ is parameter gain matrix ($n_p \times n_p$). Suppose that the i^{th} branch parameter is identified as erroneous. Thus $\lambda_i^{bad} = G_p(i,i) \cdot e_p(i)$.

Besides, the covariance matrix of λ can be obtained as follows:

$$\Lambda = cov(\lambda) = cov\left[(\mathrm{G_p} \cdot \mathrm{e_p})(\mathrm{G_p} \cdot \mathrm{e_p})^T\right] = \left[\mathrm{G_p}\right] \cdot cov\left[\mathrm{e_p} \cdot \mathrm{e_p}^T\right] \cdot \left[\mathrm{G_p}\right]^T = \left[\mathrm{G_p}\right] \cdot [\mathrm{R_p}] \cdot \left[\mathrm{G_p}\right]^T = \left[\mathrm{G_p}\right] \cdot [\mathrm{R_p}] \qquad (17)$$

Consequently, parameter error vector $\boldsymbol{e}_p$ for the ith branch and UPFC parameter in Eq. (16) can be written as follows:

$$e_p(i) = \frac{\lambda_i^{bad}}{G_p(i,i)} = \frac{R_P(i,i)}{\Lambda(i,i)} \cdot \lambda_i^{bad} \qquad (18)$$

So, actual branch and UPFC parameter value can be estimated as:

$$p_i^{correct} = p_i^{bad} - \frac{R_P(i,i)}{\Lambda(i,i)} \cdot \lambda_i^{bad} \qquad (19)$$

where, p_i^{bad} and $p_i^{correct}$ are erroneous values of identified branch and UPFC parameter and estimated (corrected) value of erroneous parameter, respectively. Also, $\boldsymbol{R}_p(\boldsymbol{i},\boldsymbol{i})$ is the i^{th} diagonal element of $\boldsymbol{R}_p$.

The proposed methodology is faster than all other methodologies in error estimation and also gives more accurate answers in identification and estimation process of branch and UPFC parameter errors. So, the mentioned limitations in identification and estimation of parameter can be efficiently developed by the proposed method.

On the other hand, one of the important indexes in accuracy of SE results in power systems is redundancy index. All detection and identification approaches of parameter errors require high redundancy. If a system has more measurement errors, removing bad data will reduce redundancy and observability. In this paper, the measurement errors were not deleted and their true value is estimated by a corrective method. A similar corrective equation for parameter errors can be used for measurement errors as follows:

$$Z_i^{correct} = Z_i^{bad} - \frac{R(i,i)}{\Omega(i,i)} \cdot r_i^{bad} \qquad (20)$$

$$r_i^{bad} = Z_i^{bad} - h\left(\hat{x}_i^{bad}\right)$$

Therefore, the steps of the final stage can be mentioned as follows:

Step 1: If a branch or UPFC parameter is identified as erroneous parameter, correct the erroneous parameter by estimating its value using Eq. (19). Substitute the estimated parameter value in database, go to stage 1.

Step 2: If a measurement is identified as erroneous measurement, correct the erroneous measurement using Eq. (20). Update database and go to stage 1.

This process containing three stages continues until the whole measurement and parameter errors are identified and corrected.

5.Simulation results

The performance of proposed methodology is evaluated in this section. In this regards, a WLS SE algorithm, based on the proposed method for validation of errors has been developed to include UPFC device. Simulations were carried out on the IEEE-14 bus test system and 230 KV East Azerbaijan network of Iran as a real system. By adding a Gaussian noise into the calculated values of load flow solution, the true measurement values are obtained. On the other hand, to obtain the initial parameters (bad parameters), errors are added to the true values of parameters. These errors are considered as 50% of the true values. Also, the bad measurements are selected as 50% of the measurement values. Also, the proposed method has been implemented in MATLAB environment on a laptop computer with a 2 GHz Pentium 2 CPU and 1 GB of RAM. In the following sections, $\boldsymbol{g}_{i-j}$, $\boldsymbol{b}_{i-j}$ and $\boldsymbol{bc}_{i-j}^{shunt}$ are series conductance, series susceptances and shunt susceptances of the π-equivalent model of the branch connecting buses i and j, respectively.

5.1.Simulation results on the IEEE-14 bus test system

In this section, multiple errors are considered in measurements, UPFC parameters ($\boldsymbol{V}_{sh}$,$\boldsymbol{V}_{se}$, $\boldsymbol{\theta}_{sh}$, $\boldsymbol{\theta}_{se}$) as well as branch parameters occurring for the IEEE-14 test system whose data can be found in [24]. One UPFC was installed on line 6-12 at bus number 6 whose parameters are given in [12]. Also, measurements which are assumed to be available for this system are presented in [21]. The simulated multiple errors are listed in Table 1, which includes two measurement errors and two branch parameter errors as well as two UPFC parameter errors, simultaneously. Also, the true and erroneous values of these variables are given in Table 1. The convergence criteria is $\left|r_{i\,max}^{N}\right| < 3$ and $\left|\lambda_{i\,max}^{N}\right| < 3$ and after reach this criteria, the erroneous branch and UPFC parameters and measurements were identified and estimated. After successful identification and correction of bad data and parameter, all normalized residuals and Lagrange multipliers were lower than threshold. The validation results are shown in Table 2. These results show identified erroneous parameter or measurement and estimated values of these measurements or parameters in each error identification cycle. Also, this table shows the two largest normalized residuals (r^N) for measurements and Lagrange multipliers (λ^N) for parameters as well as correction percentage. The correction percentage is defined as follows:

$$Percentage\ of\ correction=\left|\frac{true\ value\text{-}estimated\ value}{true\ value}\right|\times 100 \qquad (21)$$

Table 1. Simulated simultaneous errors on the IEEE-14 bus test system.

Erroneous Measurements or Parameters	True Value	Initial Value
g_{3-4}	1.986 (p.u.)	2.979 (p.u.)
b_{5-6}	-3.968 (p.u.)	-5.952 (p.u.)
P_{4-5}^{flow}	-0.618 (p.u.)	-0.927 (p.u.)
Q_{12-13}^{flow}	0.0115 (p.u.)	0.0172 (p.u.)
$V_{se(6-12)}$	0.0771 (p.u.)	0.1156 (p.u.)
$\theta_{sh(6-12)}$	-15.213 (Deg)	-22.819 (Deg)

Table 2. Total validation results for multiple errors on the IEEE-14 bus test system.

Step	$J(x)$ in last Iteration	Identified bad Measurement or Parameter	Estimated Measurement or Parameter	Percentage of Correction	$r^N or \lambda^N$	Measurement or Parameter
1	2.849 × 10^{+3}	b_{5-6}	-3.953 (p.u.)	0.378	**72.652**	b_{5-6}
					53.145	b_{4-7}
2	1.805 × 10^{+3}	P_{4-5}^{flow}	-0.617 (p.u.)	0.1618	**46.226**	P_{4-5}^{flow}
					34.251	b_{5-6}
3	910.553	$\theta_{sh(6-12)}$	-15.296 (p.u.)	0.545	**29.412**	$\theta_{sh(6-12)}$
					26.523	P_6^{inj}
4	463.290	$V_{se(6-12)}$	0.0769 (p.u.)	0.259	**22.185**	$V_{se(6-12)}$
					18.725	Q_{6-12}^{flow}
5	60.798	Q_{12-13}^{flow}	0.0115 (p.u.)	0	**9.743**	Q_{12-13}^{flow}
					7.782	bc_{12-13}^{shunt}
6	34.2598	g_{3-4}	1.990 (p.u.)	0.201	**5.743**	g_{3-4}

As seen in Table 2, the proposed method has estimated and corrected erroneous branch and UPFC parameters and measurements with high precision. It Just be compared with the true values listed in Table 1. The estimated state and UPFC control variables, after identification and estimation of erroneous parameters and measurements using the proposed method are shown in Table 3. The overall computation time of the proposed method by considering of all identification cycle is 0.3 seconds.

5.2. Simulation results on 230 kV East Azerbaijan network of Iran

230 kV branch involves the highest amount of power exchange in power network of Iran. Azerbaijan Regional Electric Company (AREC) grid includes North-west area of Iran power system [25]. Schematic interconnection of substations in AREC responsibility scope is presented in [25]. Its coverage includes three provinces of Iran (West Azerbaijan as zone 1, East Azerbaijan as zone 2 and Ardabil as zone 3). Also, it exchanges electric energy with foreign countries such as Nakhchivan, Azerbaijan, Armenia and Turkey. In near future, cooperation with Iraq's power system will be developed [25]. Azerbaijan power system specification in 2016 and UPFC location with the network extension are given in [25]. Therefore, in this paper branch and UPFC parameters and measurements are identified and corrected based on scheduled planning for 2016 as horizon year as indicated in [25]. Based on scheduled planning for 2016, developing installed units and constructing new power plants will increase generation capacity to 4150 MW and the forecasted demand will be 4372 MW (55.3 and 103 percent of growth in comparison with 2009).

In this paper, the proposed method is applied for 230 kV East Azerbaijan network of Iran as zone 2. Therefore, based on [25], the optimal location of UPFC in 2016 in zone 2 is branch BD835 (Sardrood to Vali) at the Sardrood bus. One-line diagram of this network is depicted in Fig. 3. East Azerbaijan includes 11 buses whose dispatching code and branches are shown in Fig. 3. In this zone, Tabriz 2 bus is selected as slack bus with zero phase angle value.

By applying the proposed method, the branch and UPFC parameters and measurements listed in Table 4, are identified as erroneous and estimated by the proposed method for one snapshot measurements.

Table 3. Estimated states and UPFC variables of the IEEE-14 bus test system.

Estimated State Variables					
Bus No.	**Voltage V (p.u.)**	**Voltage θ (Deg)**	**Bus No.**	**Voltage V (p.u.)**	**Voltage θ (Deg)**
1	1.062	0	**2**	1.0432	-4.957
3	1.011	-12.750	**4**	1.021	-10.523
5	1.0298	-9.096	**6**	1.067	-15.211
7	1.0512	-13.577	**8**	1.0831	-13.590
9	1.0364	-15.179	**10**	1.0332	-15.467
11	1.0433	-15.460	**12**	1.0723	-14.467
13	1.050	-15.448	**14**	1.0214	-16.354

UPFC Control Variables				
Type	**V (p.u.)**	**θ (Deg)**	**P (p.u.)**	**Q (p.u.)**
Series Source	0.0769	44.021	0.0054	0.0129
Shunt Source	1.0902	-15.296	-0.0054	0.4381

Finally, after the estimation and correction of erroneous measurements and branch and UPFC parameters, the SE results for this network (voltage magnitudes and phase angles) can be obtained that are given in Table 5.

As can be seen in simulation results, by using the proposed method, it is possible to validate the stored data in the database. It is important to highlight that the simulation results are used to update and estimate the erroneous measurements and branch and UPFC values available in the database of the North-west dispatching center of Iran.

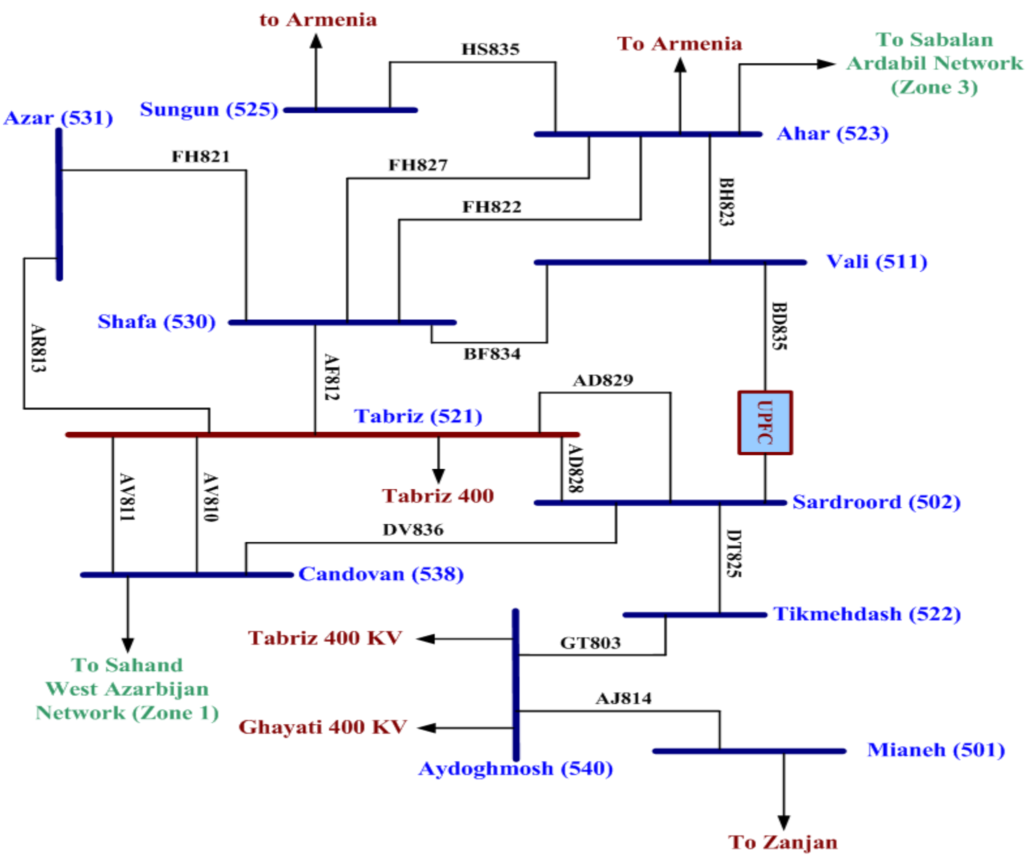


Fig. 3. One-line diagram of 230 kV East Azerbaijan network of Iran.

Table 4. Simulation results on 230 KV East Azerbaijan network of Iran.

Step	Identified Erroneous Measurement or Parameter	Max $r^N or \lambda^N$	Initial Value	Estimated Value
1	$P_{502-522}^{flow}$	78.34	127.23 (MW)	128.94 (MW)
2	$g_{523-511}$	52.31	2.0415 (p.u.)	2.0528 (p.u.)
3	P_{521}^{inj}	32.87	566.24 (MW)	569.75 (MW)
4	$\theta_{sh(502-511)}$	14.56	-10.54 (Deg)	-10.89 (Deg)
5	$b_{531-530}$	5.78	-48.962 (p.u.)	-49.183 (p.u.)

Table 5. The SE results after correction of erroneous measurement and parameter.

Dispatching Code	Voltage Magnitude (KV)	Phase Angle (Degree)
521	229.688	0
530	228.830	-0.054
531	228.043	-0.479
523	229.512	-2.890
525	230.124	-4.423
511	228.115	-0.202
501	231.305	-5.432
502	228.307	-0.052
522	224.872	-3.981
540	231.564	-5.051
538	229.079	-0.036

6. Conclusion

This paper proposed a new three stages method to simultaneously identify and correct the measurements and branch and UPFC parameter errors. In the stage 1, by solution of modified SE, the normalized vectors computed. Identification of errors in measurement and branch and UPFC parameters presented in the stage 2. Finally, identified erroneous measurement and parameter values (branch and UPFC parameters), corrected using a proposed approach with linear approximation without the need of ASV method, in the stage 3. The proposed method implemented and tested on the IEEE-14 bus system and 230 kV East Azerbaijan network of Iran as a real network. These examples illustrated the performance of the proposed method and it is shown that it can identify and correct the erroneous measurements and branch parameters with higher accuracy.

References

[1] Abur A, Exposito AG. Power system state estimation: Theory and implementation. New York: Marcel & Dekker Publishers; 2004.

[2] Monticelli A. Electric power system state estimation, Proc. IEEE 88 2000: 262-282.

[3] Castillo MRM, London JBA, Bretas NG, Lefebvre S, Prevost J, Lambert B. Off-line detection, identification and correction of branch parameter errors based on several snapshots. IEEE Trans Power Syst 2011; 26: 870-77.

[4] Zarco P, Exposito AG. Power system parameter estimation: A survey. IEEE Trans Power Syst 2000; 15: 216-22.

[5] Zhu J, Liu F, Mei S. Branch parameter error identification and estimation in power systems. First International Conference on PCSPA, Beijing, China, pp. 504-507.

[6] Zhu J, Abur A. Improvement in network parameter error identification via synchronized phasors. IEEE Trans Power Syst 2010; 25: 44-50.

[7] Lefebvre S, Prevost J, Horisberger H, Lambert B, Mili L. On the accuracy of state estimation. In Proceeding Power and Energy Society General Meeting 2006.

[8] Castillo MRM, London JBA, Bretas NG. Network branch parameter validation based on a decoupled state/parameter estimation and historical data. IEEE Bucharest Power Technology Conference, Bucharest, Romania 2009: 1-7.

[9] Bretas NG, Bretas AS, Pierreti SA. Innovation concept for measurement gross error detection and identification in power system state estimation. IET Gener Transm Distrib 2011; 5: 603-608.

[10] Korres G. A robust algorithm for power system state estimation with equality constraints. IEEE Trans Power Syst 2010; 25: 1531-1541.

[11] Zhu J, Abur A. Identification of errors in power flow controller parameters, 9th International Conference on Probabilistic Methods Applied to Power Systems, Stockholm, Sweden 2006: 1-6.

[12] Rakpenthai C, Premrudeepreechacharn S, Uatrongjit S. Power system with multi-type FACTS devices states estimation based on predictor-corrector interior point. Electr Power Energy Syst 2009; 31: 160-166.

[13] Singh SK, Sharma J. A Hopfield neural network based approach for state estimation of power systems embedded with FACTS devices. In IEEE Power India Conference 2006.

[14] Cardenas AZ, Esquivel CRF. State estimation of power systems containing FACTS controllers. Electr. Power Syst Res 2011; 81: 995-1002.

[15] Qiang SG, Nong WZ. Power system state estimation with unified power flow controller. 3th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies. 2008: 775-778.

[16] Xu B, Abur A. State estimation of systems with UPFCs using the interior point method. IEEE Trans Power Syst 2004; 19: 1635-1641.

[17] Lusting I, Marsten R, ShannoD. On the implementing mehrotra's predictor corrector interior point method for linear programming, SIAM J. Opt. 2 1992: 435-449.

[18] Filho MBC, Souza JCS, Meza EBM. Off-line validation of power network branch parameters, IET Gener. Transm. Distrib. 2008; 2: 892-905.

[19] Kannan S, Jayaram S, Salama M. Real and reactive power coordination foe a unified power flow controller. IEEE Trans Power Syst 2004; 19: 1454-1461.

[20] Vural A, Tumay M. Mathematical modeling and analysis of a unified power flow controller: a comparison of two approaches in power flow studies and effects of UPFC location. Electr. Power Energy Syst. 2007; 29: 617-629.

[21] Tarafdar M, Ahmadi M. A robust method for state estimation of power system with UPFC. Turk. J. Elec. Eng. & Comp. Sci. 2010; 18: 571-582.

[22] Minguez R, Conejo A. State estimation sensitivity analysis. IEEE Trans Power Syst 2007; 22: 1080-1091.

[23] Zhu J, Abur A. Identification of network parameter errors. IEEE Trans Power Syst 2006; 21: 586-92.

[24] Power System Test Case Achieve: University of Washington [Online]. Available: htpp: //www.ee.washington.edu/research/pstca.

[25] Asadzadeh B, Asadzadeh V, Hosseini H, Gharehpetian G. Allocation of UPFC in North-west grid of Iran to increase power system security. IEEE PES, New Orleans, USA 2010: 1-8.