Global Journal of Researches in Engineering
Electrical and Electronics Engineering
Volume 12 Issue 7 Version 1.0 July 2012
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Nonlinear Estimation of External Power System Dynamic Equivalent Parameters

By R. Gueddouche & M. Boudour

University of Science and Technology Houari Boumediene

Abstract - Based on the concept of the external power system dynamic equivalent for the study system, this paper proposes a novel evolutionary method for the identification of the equivalent's parameters, comparing the answers of the complete network and its equivalent following the small disturbances which emerged in the study system. The proposed method is demonstrated and compared with the original system using the 10 machines 39 buses New England test system. The comparison shows that the proposed approach can preserve all dynamic properties of the original network.

Keywords : Dynamic equivalents, Dynamic modeling, Genetic algorithm, Nonlinear identification, Multi-machine system, Parameter identification, Power system, Structure preservation.

GJRE-F Classification : *FOR Code: 090607*

NONLINEAR ESTIMATION OF EXTERNAL POWER SYSTEM DYNAMIC EQUIVALENT PARAMETERS

Strictly as per the compliance and regulations of:

© 2012 R. Gueddouche & M. Boudour.This is a research/review paper, distributed under the terms of the Creative Commons Attribution-Noncommercial 3.0 Unported License http://creativecommons.org/licenses/by-nc/3.0/), permitting all non commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Nonlinear Estimation of External Power System Dynamic Equivalent Parameters

R. Gueddouche [α] & M. Boudour [σ]

Abstract - Based on the concept of the external power system dynamic equivalent for the study system, this paper proposes a novel evolutionary method for the identification of the equivalent's parameters, comparing the answers of the complete network and its equivalent following the small disturbances which emerged in the study system. The proposed method is demonstrated and compared with the original system using the 10 machines 39 buses New England test system. The comparison shows that the proposed approach can preserve all dynamic properties of the original network.

Index Terms : Dynamic equivalents, Dynamic modeling, Genetic algorithm, Nonlinear identification, Multi-machine system, Parameter identification, Power system, Structure preservation.

I. Introduction

Electric power systems have long been perceived and exploited like national entities or regional areas. The interconnections between such zones being mainly used with the aim of help in case of failure in a nearby zone. In the new context of the electricity sector, this situation has changed since the interconnections are increasingly used in order to maximize the exchange of electricity through power exchanges recently introduced. This leads the transmission system operators (TSOs) to operate their systems increasingly close to their limits. In an individual way, each TSO is obliged to re-examine its way of doing the usual studies on its own network. In particular, a more refined modeling of the influence of neighboring systems on its own should be considered. Moreover, the process of extension of the synchronous area which continues today, led to a significant increase in the size of dynamical systems to study. Besides the difficulty posed by the size, new structural phenomena occur from this extension as the electromechanical oscillations of low frequency observed between generators remote network.

Many dynamic equivalence techniques have been developed over the years [1]-[9]. More research focused on coherency equivalents and modal equivalents nowadays, however, they need detailed data of the external system which may be difficult to get in the power market environment. Some estimation methods are based on available information from the boundaries nodes and do not require any knowledge detail of the external network. The classical estimation methods are mainly based on the linearization of the system around an operating point with theoretical constraints validity [10] - [12]. Consequently, they are limited by their validity in nonlinear practical applications, offline and online applications. This paper proposes a new evolutionary approach for estimating parameters to determine a dynamic equivalent model of an external power system from synchronized measurements of disturbance occurred in internal system, which obtained by PMUs (Phasor Measurement Units). This approach was applied to 10 machines 39 buses New England test system [13]. Comparing the properties of the equivalent system with ones of the original system, the result shows that the reduced system can represent dynamic behaviors of the original system well, for any kind of disturbance.

II. Dynamic Equivalents

The equivalent is represented by a model with unknown parameters. In operation, the power system is often perturbed by small random disturbances. The estimation of unknown parameters of the equivalent model is operated by comparing the measurements obtained from the real network, and the same measurements made on the equivalent network by minimizing some objective function.

a) Dynamic equivalent model

The basic requirement of the dynamic equivalents is that the response of the equivalent system can fit the original system dynamically and approximately when faults happen in the internal system. In our equivalent system, equivalent generator represents dynamic effect of the external system on the internal system located at the boundary bus (Fig.1). When there are multiple boundary buses connecting the external system with the internal system, multiple generators are adopted to represent dynamic influence of the external system on the internal system, with an equivalent generator located at each boundary bus [14]. Parameters to be estimated are: $X_d, X_q, X'_d, H, D, T'_{do}$, voltage regulator gain K_a and its time constant T_a.

Author α : USTHB, Electrical & Industrial Systems Laboratory-LSEI, BP.32 El-Alia, Bab Ezzouar 16111 Algiers, Algeria.
E-mail : gueddouche.r@gmail.com
Author σ : USTHB, Electrical & Industrial Systems Laboratory-LSEI, BP.32 El-Alia, Bab Ezzouar 16111 Algiers, Algeria.
E-mail : mboudour@ieee.org

© 2012 Global Journals Inc. (US)

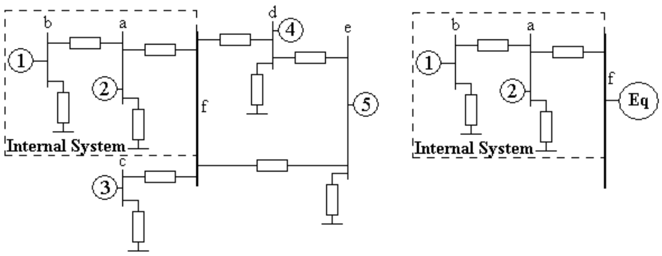

Fig. 1.a : Original System *Fig. 1.b :* Equivalent System

The equivalent generator model can be expressed by the following equations:

$$\dot{\omega} = \frac{1}{2H}\left(T_m - E'_q I_q + \left(X_q - X'_d\right) I_d I_q - D(\Delta\omega - 1)\right) \quad (1)$$

$$\dot{\delta} = \omega_0(\Delta\omega - 1) \quad (2)$$

$$\dot{E}'_q = \frac{1}{T'_{d0}}\left(E_{fd} - (X_d - X'_d) I_d - E'_q\right) \quad (3)$$

$$\dot{E}_{fd} = \frac{1}{T_a}\left(K_a\left(V_{ref} - V_t + V_s\right) - E_{fd}\right) \quad (4)$$

b) Parameter identification of equivalent model

The parameters identification for nonlinear systems includes deterministic and evolutionary methods. Evolutionary methods offer greater ease of adjustment problems and other advantages over deterministic methods because they:

- Require only the calculation of the objective function, without this last being forced to be continuous or differentiable.
- Easily adaptable to multi-objective problems optimization, and complex systems with very important unknown number of parameter.
- Have great theoretical probability to find the global optimum.
- Offer great simplicity of implementation.

An evolutionary approach based on genetic algorithms is presented in this document, to identify the dynamic equivalent model parameters, by minimizing the range of speed variation, electrical power variation and terminal voltage variation produced in all generators of the internal system between the original and the equivalent system.

i. *Error function*

The original system equations are generally written:

$$\Delta\dot{x} = A\Delta x + B\Delta u$$
$$\Delta y = C\Delta x \quad (5)$$

Where:

A= State matrix ($4m\times 4m$).

B = Control matrix ($4m\times 2m$).

C = Output matrix ($2m\times 4m$).

$$\Delta x = \left[\Delta\omega_1 \ldots \Delta\omega_m \ \Delta\delta_1 \ldots \Delta\delta_m \ \Delta E'_{q1} \ldots \Delta E'_{qm} \ \Delta E_{fd1} \ldots \Delta E_{fdm}\right]^T$$

$$\Delta u = [\Delta T_{m1} \ldots \Delta T_{mm} \ \Delta U_{s1} \ldots \Delta U_{sm}]^T$$

$$\Delta y = [\Delta\omega_1 \ldots \Delta\omega_m \ \Delta Pe_1 \ldots \Delta Pe_m \ \Delta V_{t1} \ldots \Delta V_{tm}]^T$$

with :

- $\Delta\delta$ Absolute angle rotor variation (rad. elec/sec).
- $\Delta\omega$ Angular velocity rotor variation (*pu*).
- $\Delta E'q$ Internal voltage variation (*pu*).
- ΔEfd Internal excitation voltage variation (*pu*).
- ΔTm Mechanical torque variation (*pu*).
- ΔUs Order excitation systems variation (*pu*).
- ΔPe Active power variation (*pu*).
- ΔVt Change in terminal voltage generators (*pu*).

The equations describing the dynamic equivalent system are expressed similar to those of the original system (5), but with a simplified structure and less parameters.

$$\Delta\dot{\tilde{x}}(\alpha) = \tilde{A}(\alpha)\Delta\tilde{x}(\alpha) + B\Delta u$$
$$\Delta\tilde{y}(\alpha) = \tilde{C}(\alpha)\Delta\tilde{x}(\alpha) \quad (6)$$

$\tilde{A}(\alpha), \tilde{C}(\alpha), \Delta\tilde{x}(\alpha) et \, \Delta\tilde{y}(\alpha)$, are all functions of α, the equivalent system parameter vector to be identified. Therefore, an error function may be defined by:

$$e(\alpha) = \Delta y - \Delta\tilde{y}(\alpha) \quad (7)$$

Where Δy represents the responses of the original system, which are directly measureable.

And $\Delta\tilde{y}(\alpha)$, must be calculated by simulating the equivalent system with the same disturbance.

ii. *Objective function*

The idea is to minimize the error function (7) between the measure and the model output for all machines belonging to the internal network. The mathematical model of the optimization problem is a multi-objective function and can be formulated as follows:

$$\begin{cases} [min] \ \ e(\alpha) = \left[e_1(\alpha), e_2(\alpha), \ldots, e_{3(m-nex)}(\alpha)\right] \\ \qquad \alpha > 0 \end{cases} \quad (8)$$

Where:

$$e_i(\alpha) = \sum_{t=to}^{t_{fin}} \left(|\Delta y_i(t) - \Delta\tilde{y}_i(\alpha, t)|\right); \ i = 1,2, \ldots, 3(m - nex)$$

By weighting the measurements by a weighting factor λi, our objective function becomes:

$$\begin{cases} [min] \ \ e(\alpha) = \sum_{i=1}^{3(m-nex)} \left[\lambda_i \sum_{t=to}^{t_{fin}} \left(|\Delta y_i(t) - \Delta\tilde{y}_i(\alpha, t)|\right)\right] \\ \qquad \alpha > 0 \end{cases} \quad (9)$$

Where:

$$\alpha = [X_d, X_q, X'_d, H, D, T'_{do}, K_a, T_a]$$

© 2012 Global Journals Inc. (US)

$$\Delta y =$$
$$\left[\Delta\omega_1 \dots \Delta\omega_{m-nex} \;\; \Delta Pe_1 \dots \Delta Pe_{m-nex} \;\; \Delta V_{t1} \dots \Delta V_{t(m-nex)}\right]^T$$
$$\Delta\tilde{y} =$$
$$\left[\Delta\tilde{\omega}_1 \dots \Delta\tilde{\omega}_{m-nex} \;\; \Delta\widetilde{Pe}_1 \dots \Delta\widetilde{Pe}_{m-nex} \;\; \Delta\tilde{V}_{t1} \dots \Delta\tilde{V}_{t(m-nex)}\right]^T$$

m = number of machines belonging to the complete system.
$m-nex$= number of machines belonging to the study system (internal system).

iii. *Encoding and initial population*

The encoding of individuals is an important parameter in population research methods. These are represented as a strings (chromosomes) containing characters or genes of a predetermined alphabet. There are different ways to code a solution. In our study, the individual is represented by eight parts of chromosome corresponding to the eight parameters to be estimated, each gene (parameter) is represented by its physical value, which means that, the real coding is adopted (fig.2).

The GAs requires an initial population to start search process. Applied methods generate randomly a set of solutions belonging to the following area:

$$\alpha_{min} \leq \alpha \leq \alpha_{max} \qquad (10)$$

Where:

$$\alpha_{min}{}^T = \begin{bmatrix} \frac{\sum_{i=1}^{m-nex} X_{di}}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} X_{qi}}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} X'_{di}}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} H_i}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} D_i}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} T'_{doi}}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} K_{ai}}{2(m-nex)} \\ \frac{\sum_{i=1}^{m-nex} T_{ai}}{2(m-nex)} \end{bmatrix} \; ; \quad \alpha_{max}{}^T = \begin{bmatrix} \frac{2\sum_{i=1}^{m-nex} X_{di}}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} X_{qi}}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} X'_{di}}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} H_i}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} D_i}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} T'_{doi}}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} K_{ai}}{(m-nex)} \\ \frac{2\sum_{i=1}^{m-nex} T_{ai}}{(m-nex)} \end{bmatrix}$$

The individuals' number in the initial population is chosen such that:

$$N_{ind} > N_{mes} * (m - nex) \qquad (11)$$

Where:

N_{mes} = Number of measures nature considered (ω, Pe, Vt)=3.

m= Total number of machines belonging to the complete network.

nex= Number of machines belonging to the external system.

A representation of *Nind* individuals (solutions) in an initial population is shown in fig.2.

Initial Population

0.0200 /	0.2300 /	0.4000 /	0013 /	1.000 /	0.1020 /	23.78 /	0.0500	1
0.1201 /	0.0340 /	0.2020 /	0323 /	2.030 /	0.0030 /	10.79 /	0.0410	2
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
0.1500 /	0.0441 /	0.1460 /	0020 /	0.031 /	0.0280 /	104.7 /	0.1001	Nind
Xd /	Xq /	X'd /	H /	D /	T'do /	Ka /	Ta	

Fig. 2 : Organization and coding of individuals in initial population.

iv. *Evaluation mechanism*

With a fitness function or adaptive function the evaluation is done in a closed interval $[t_o, tf_{in}]$ using each time a new dynamic simulation of the equivalent system for each population individuals.

$$f_i(\alpha) = \lambda_i \sum_{t=to}^{tfin} (|\Delta y_i(t) - \Delta\tilde{y}_i(\alpha, t)|) \qquad (12)$$

Where:

$$\lambda_i = \frac{1}{\sum_{t=to}^{tfin} (|\Delta y_i(t)|)} \quad ; \qquad i = 1,2, \dots, N_{mes} * (m - nex)$$

v. *Evolution mechanism*

a. *Parents selection*

Among initial population individuals, we choose:

- A number of individual « $Nmes * m-nex$ »;

To form a group of (*Local parents*), in which each parent *"i"* satisfied the fitness function minimum:

$$parent_i = \min_{j=1..N_{ind}} [f_i(Ind_j)] \qquad (13)$$

Where:

$$i = 1,2, \dots, N_{mes} * (m - nex)$$

– A number of individual « $Nmes$ » ;

To form a group of (***Global parents***), in which each parent *"k"* satisfied the fitness function minimum:

$$parent_k = \min_{j=1..N_{ind}} \left(\sum_{i=1}^{N_{mes}*(m-nex)} f_i(Ind_j)\right) \qquad (14)$$

Where: $\quad k = 1,2, \dots, N_{mes}$

The local parents group includes the favorable solutions for each type of measure that corresponds to each machine belonging to the internal system. However the global parents group includes the favorable solutions for each type of measure that corresponds to all the machines belonging to the internal system. The population called, *"Parents population"* is made up of the two groups (*Global parents & Local parents*).

b. *Multi-parent recombination*

Recombination is used mainly in evolutionary strategies. Contrary to k points crossover operators, which exchange information between two parents, the recombination creates the descendants, by weighting many parents components'. We define three weighting operators:

© 2012 Global Journals Inc. (US)

$$Op_1(chr) = \frac{Pr_1(chr)+Pr_2(chr)}{2}$$

$$Op_2(chr) = max\big(Pr_1(chr), Pr_2(chr)\big) + \frac{|Pr_1(chr)-Pr_2(chr)|}{2}$$

$$Op_3(chr) = min\big(Pr_1(chr), Pr_2(chr)\big) - \frac{|Pr_1(chr)-Pr_2(chr)|}{2}$$

Where:

chr : Integer belonging to [1,8], which represents crossed chromosome order.

Pr_1, Pr_2 : Two individuals of local parents group.

We generate $Nind$ individuals for construct the new population (generation) from the two groups' "*local parents*" and "*global parents*", with the following steps:

1. We reproduce the same individuals in the global parents group for construct, N_{ind} individuals of the new population (Fig. 3).

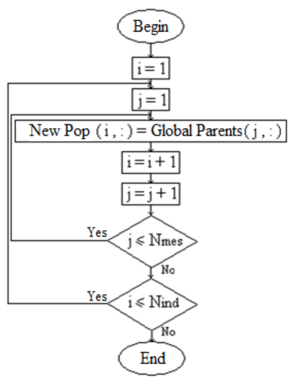

Fig. 3 : New population from the group Global Parents

2. For each individual "/ " belonging to the new population:

- A random integer number of weighted point "k" is generated between 1 and $8*T_{div}$.
- In each weightings j=1,2…,k :
  - we choose a random pair of individuals from the local parents group.
  - a crossed chromosome is chosen randomly « chr ».
  - a random real number, "h", is generated between 0 and 1, to select the weighting operator (Fig. 4).

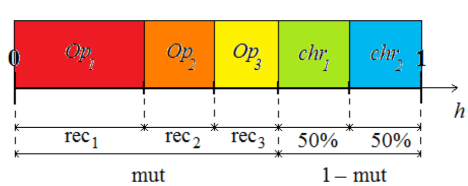

Fig. 4 : Recombination operator distribution's

- the value obtained by the weighting operator is assigned to the individual's chromosome "i(chr)" of the new population, if this value satisfies the constraint:

$$\alpha > 0 \qquad (15)$$

- we move to the next individual "i +1" when the number of weighting point "k" of the individual "i" is complete.

3. Accordance with the procedure for selection of parents, the best individuals evaluated by the fitness function (12) between *parents population* and this *new population*, construct the *new parents population* and clear the *old parents population* for the next generation *(elitist strategy)*.

III. Algorithm

The complete algorithm of the proposed method is given below:

Step1 : Introduction of static and dynamic data of the complete system.

Step2 : Power flow calculation, linearization, disturbance choice and network dynamic simulation.

Step3 : Border node choice and equivalent system linear model construction from results of the power flow.

Step4 : Generating the initial population according to the procedure specified in subsection *(III.B.3)*.

Step5 : Run equivalent system dynamic simulation and evaluate all individuals by fitness function (12).

Step6 : Construct the population of parents following the procedure described in paragraph *(III.B.5.a)*, with equations (13,14).

Step7 : While the number of generation has not reached the maximum number N_{gen}:

Step7.1 : Generate the new population using described procedure in paragraph (III.B.5.b).

Step7.2 : Run equivalent system dynamic simulation and evaluate all individuals by fitness function (12).

Step7.3 : Select the new individuals in parents population following described procedure in paragraph (III.B.5.b.3).

Step8 : End while.

Step9 : Select best individuals in parents population with the objective function (9), and display the results.

Table.I, represents the most significant parameters that characterize this algorithm.

Table I : Control Parameters

Control parameters	Definition
N_{ind}	Number of individual in a population
N_{gen}	Maximum number of generation
T_{div}	Weighting rate
rec_1, rec_2, rec_3	Recombination rate
Op_1, Op_2, Op_3	Recombination operator

IV. Application

To validate the proposed approach, developed algorithm was used to build the dynamic equivalent of transmission network IEEE New-England 39 bus [13]. It represents a simplified New England transmission network (northeastern United States) that is part of real U.S. network. This network consists of 10 generators (PGtotal= 6.19 GW, QGtotal= 1.28 GVAr) and 39 bus with 19 load bus. The original system structure is as Fig.5.

© 2012 Global Journals Inc. (US)

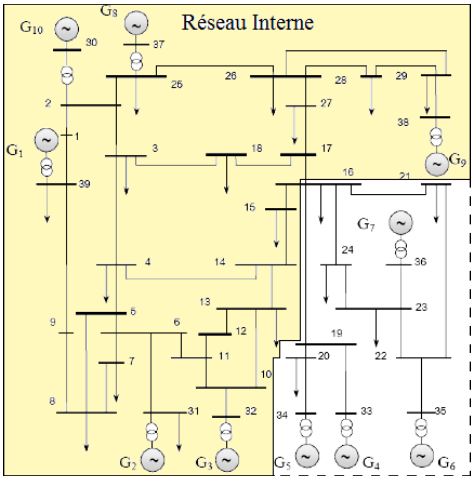

Fig.5 : Original system IEEE-39 bus

In Fig. 5, the shaded part is the internal system and the rest is the external system to be reduced. There are a boundary bus 16 and two tie lines 16-15 and 16-17 between the internal and the external systems. Fig. 6 is the sketch of the equivalent system.

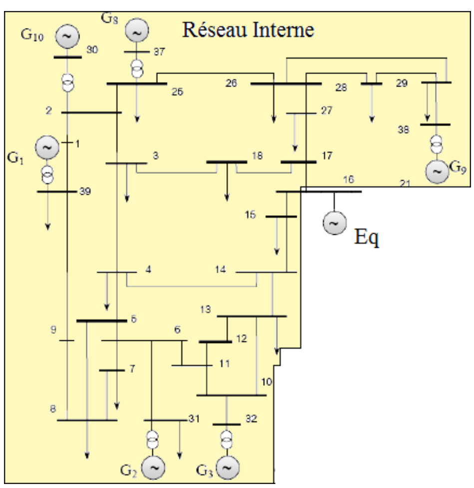

Fig. 6 : Equivalents system

a) Simulation

The network linear model is used by the algorithm for solutions evaluation in estimation procedure. The proposed algorithm programming and dynamic linear model simulation was implemented in Matlab.V7 environment. The algorithm control parameters are summarized in Table II. These parameters were obtained after several tests with an appropriate adjustment.

Table II : Control Parameter Values

Control parameters	Values
N_{ind}	80
N_{gen}	60
T_{div}(%)	100
rec_1, rec_2, rec_3	0.5 , 0.25 , 0.25

To allow a better parameters estimation, different disturbances were applied in different parts of the internal system. Each proposed disturbance has a period of 10s. An event is generated each time to the first second of the simulation. The algorithm verifies the equivalents behavior in period of 10s, by comparing its response with the response of the original system. If the equivalent response exceeds some level relatively to the original systems response in a new disturbance, the equivalent generator parameters are recalculated and updated. Each solution obtained by applying the previous disturbances must be part of the initial population of the next estimation procedure. The estimated parameters of the equivalent generator are presented in Table III.

b) Validation

A small perturbation represented by disconnecting the line 3-18 is applied to bus18 of the equivalent system and the original system respectively at time, t=2s and lasted for about 12 cycles. Time domain dynamic simulations were performed both on the two systems.

Table III : Equivalent Generator Parameters

Dist.	Parameter							
	X_d	X_q	X'_d	H	D	T'_{do}	K_a	T_a
3	0.4718	0.0438	0.0603	135.09	$2.5 \cdot 10^{-5}$	7.8986	155.08	0.0685

Dynamic responses are shown in fig. 7 to fig. 9. The boundary node voltage is shown by fig. 7, The angle of the machine n°10 is shown in fig. 8 and angular velocity of the machine n°8 in fig. 9.

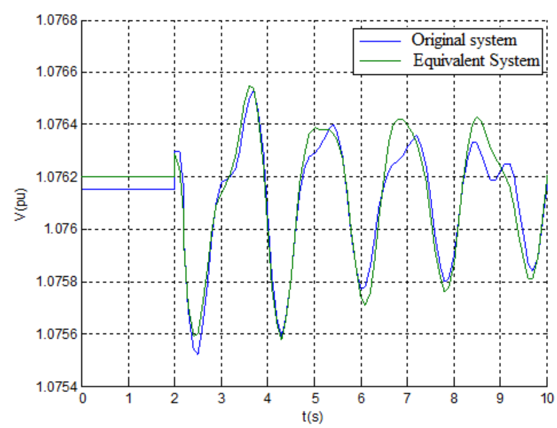

Fig. 7 : Voltage variation at bus 16

© 2012 Global Journals Inc. (US)

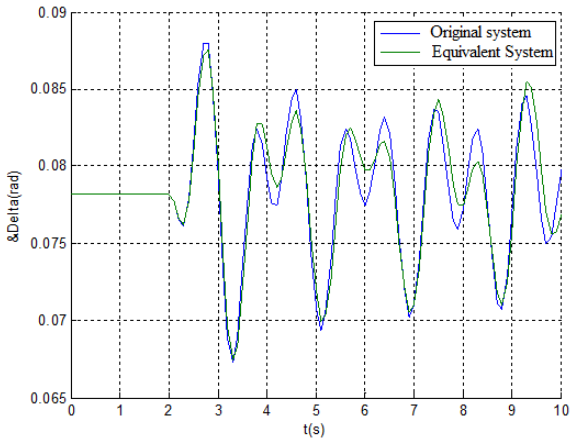

Fig. 8 : Angle of the machine 10

In order to verify the performance of the proposed dynamic equivalent approach in the case of the large disturbances, three-phase fault was applied to bus 30 of the equivalent system and the original system respectively at time t=2s, and the fault lasted for about 3 cycles. Time domain dynamic simulations were carried out on the original system and the equivalent system, and dynamic responses are shown in fig. 10 and fig. 11. The angle of the machine n°10 is shown in fig. 10 and angular velocity of the machine n°8 in fig. 11.

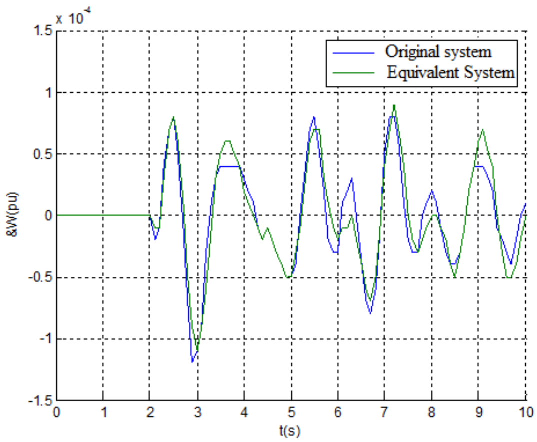

Fig. 9 : Angular velocity rotor variation of machine 8

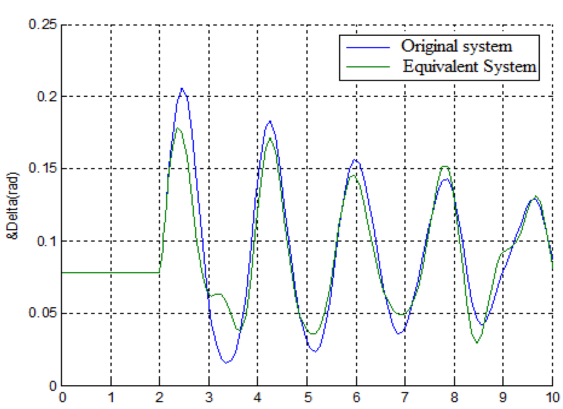

Fig. 10 : Angle of the machine 10

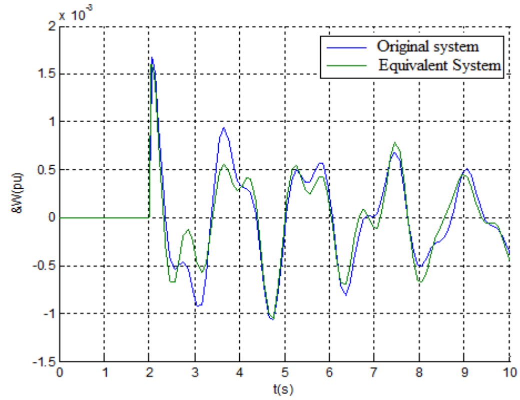

Fig. 11 : Angular velocity rotor variation of machine 8

The simulation results of equivalent system with estimated parameters are encouraging and show the effectiveness of the developed algorithm and the ability of the estimated equivalent to reproduce the influence of the external system on internal system for small and severe disturbances.

V. Conclusion

In this study, we proposed a nonlinear estimation method for parameters, based on an evolutionary algorithm. In order to obtain the external system dynamic equivalent, several dynamic simulation disturbances were applied to increase the accuracy of the model estimated by the developed algorithm. The proposed approach does not require data of external system. This approach requires only configuration information, settings and operating status of the internal system. Dynamic simulation was performed on both the original system and the equivalent system under different operating conditions, and the results show that the obtained equivalent system can represent the main dynamic characteristics of the original system well. Thus, the approach proposed is proved to be feasible and has potential for tackling the complex practical application in power system.

References Références Referencias

1. Wang Lei, M. Klein, S. Yirga, and P. Kundurl, "Dynamic reduction of large power systems for stability studies," IEEE Trans. Power Systems, vol. 12, no. 2, pp. 889-895, 1997.
2. M. L. Ourari, L. A. Dessaint, and D. Van-Que, "Dynamic equivalent modeling of large power systems using structure preservation technique, " IEEE Trans on Power Systems, vol. 21, no. 3, pp. 1284-1295, 2006.
3. Sung-Kwan Joo, Liu Chen-Ching, L. E. Jones and Jong-Woong Choe, "Coherency and aggregation techniques incorporating rotor and voltage dynamics," IEEE Trans. Power Systems, vol. 19, no. 2, pp. 1068-1075, 2004.
4. W. W. Price, E. M. Gulachensk, "Testing of the modal dynamic equivalents technique," IEEE Trans.

© 2012 Global Journals Inc. (US)

Power Apparatus and Systems, , vol. PAS-97, no. 4, pp. 1366-1372, 1978.
5. K. Nojiri, S. Suzaki, K. Takenaka and M. Goto, "Modal reduced dynamic equivalent model for analog type power system simulator," IEEE Trans. Power Systems, vol. 12, no. 4, pp. 1518-1523, 1997.
6. Yu Yaonan, M. A. El-Sharkawi, "Estimation of external dynamic equivalents of a thirteen system," IEEE Trans. Power Apparatus and Systems, vol. PAS-100, no. 3, pp. 1324-1332, 1981.
7. W. W. Price, D. N. Ewart, E. M. Gulachenski and R. F. Silva, "Dynamic equivalents from on-line measurements," IEEE Trans on Power Apparatus and Systems, vol. 94, no. 4, pp. 1349-1357, 1975.
8. J. M. Ramfirez, R. G. Valle, "A technique to reduce power systems electromechanical models," IEEE Transa on Energy Conversion, vol. 19, no. 2, pp. 456-458, 2004.
9. Yang Jingping, Xu Zheng. "Application of Dynamic Equivalents Based on Identificaiton of Coherent Generator Group in Engineering," Power System Techonology, vol. 29, no. 17, pp. 68-71, 2005.
10. IBRAHIM M A H, MOSTAFA O M, EI-ABIAD A H. "Dynamic Equivalent Using Operating Data and Stochastic Modeling". IEEE PAS, 1976, 95(5):1713-1722.
11. ALVARADO F L. "Real Time External Equivalents for Static Security Analysis". IEEE TPAS, 1979, 98: 505-507.
12. YU Y. N. "Power System Dynamics. Academic Press", 1983.
13. J.E. Fagan."Synchronous Machine Modeling Mechanization and System Performance Study". Thèse de doctorat, The University of Texas at Arlington, mai 1977.
14. J. M. Ramirez Arredondo. "Obtaining dynamic equivalents through the minimization of a line flows function". International Journal of Electrical Power & Energy Systems, vol. 21: 365-373, (1999).

© 2012 Global Journals Inc. (US)