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An Optimal Procedure for Identification External System Dynamic Equivalence

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***Abstract*— This paper presents an optimal model order reduction by estimating the parameters of an external system using metaheuristic technique, synchronous generators are represented by second order model for simplicity. However, static exciter along with power stabilizers are included for all generators, phasor measurements units (PMUs) were placed near frontier bus to record important signals employed in the estimation. Time domain simulations are carried using power system analysis toolbox. For validation the method was tested on New England system. Results showes that the reduced system retains the dynamic behaviour of the full system for various disturbances.**

***Keywords*— dynamic equivalent; parameter estimation; model order reduction; differential evolution algorithm; power system analysis toolbox.**

I. INTRODUCTION

Over the years, the electrical network experience an accelerated growth in both size and complexity, analyzing large power system presents a computational burden even with modern technologies. Almost every network is interconnected with its neighbours due to the advantages provides; although the interconnection enhance the reliability of the system even more, contingencies propagation through tie lines cause instability problems to local and neighbour systems. Therefore, local stability studies are required. However, power system software have restricted size limitations. In the last years, new technique refers to as dynamic equivalence is introduced, its target is to reduce a portion of the power system, and thus the computational time. Generally the power system is divided into internal system (study system), external system (system to be reduced) and frontier buses that link the internal with the external system.

Dynamic equivalence can be classified into three categories:

- Model Equivalent [1, 2];
- Coherency Equivalent [3, 4];
- Parameter Estimation Equivalent [5, 6, 7].

The first method is based on linear model of the system, modes are extracted from the linearized state matrix, the method only preserve the slow modes (inter-area modes) that varies typically in the range of 0-2 Hz [8], and neglect the fast ones. Coherency equivalent is done in three stages; identification of coherent groups, aggregation of generators and their control systems, and network reduction. Unlike coherency, parameter estimation evaluate the whole process in one stage only. Furthermore, detailed information on the external system is not needed. These techniques aims to estimate parameters of a model that represents part of the power system by recording important signals when the system is subjected to disturbances (perturbation of any kind). The parameters of the equivalent model are adjusted until the signals measured from the original and reduced system are matched.

Dynamic equivalent using parameter estimation has been used to reduce wind farms with Doubly fed induction generators (DFIG) in [9, 10]. On the other hand, a hybrid technique between parameter estimation and coherency is addressed in [11]. Graph model was used in [12] to identify coherent generator without the need of dynamic parameters. However, their application were limited to small and simple networks, which is not the case in reality.

Classical estimation methods are mainly based on the linearization of the system around an operating point [13], these methods are limited by their validity in nonlinear practical application. Hence, it is more appropriate and to use a nonlinear model to give more confidence of stability at wide range of operating points. In [14], a detailed model estimated by an extended two particle swarm optimization is presented. However, the method appear to be time consuming since the dimension of the problem is too high. The objective of the dynamic equivalent is to preserve the effect of the external system on the study system, and not the behavior of the external system itself. 2nd order model should give faster result than using a detailed model. The results are found to be accurate as will be shown in the result section. In this paper, only frontier nodes are preserved while all nodes in the external system are eliminated, and differential evolution algorithm (DE) will be used to estimate the equivalent model parameters.

The rest of this paper is organized as follows: the problem formulation along with a description of the optimization method used in this work are provided section II. Section III, presents the simulation results, a general conclusion for this work is given in section IV.

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II. METHODOLOGY

A. Generator Model

Nonlinear generator model is used, the equivalent generator model can be of any order [15]. In this article second order model described by the swing equation in (1) was chosen for simplicity.

$$\begin{cases} \dfrac{d\delta_{eqi}}{dt} = \omega_{eqi} - \omega_{s} \\ 2H_{eqi}\dfrac{d\omega_{eqi}}{dt} = P_{m_{eqi}} - P_{e_{eqi}} - D_{eqi}\Delta\omega_{eqi} \end{cases} \tag{1}$$

Where,

- P_m and P_e are the mechanical and electrical power of the equivalent generator, respectively;
- ω is the synchronous angular velocity of the rotor;
- δ is the synchronous machine rotor angle;
- H and D are the inertia constant and damping coefficient of the generator, respectively.

In the first part, static exciter system and PSSs are not included, later on all generators are equipped with static IEEE exciter type I and power stabilizers whose parameters are the same.

B. Objective Function

Estimated parameters are: (a) Inertia H; (b) Transient reactance X_d' and (c) Damping coefficient D. Before that, steady state for the reduced model must be preserve, this is done by (2). The voltage magnitude of frontier node is set to the value of the full model [17].

$$P_{g_i} = P_{l_i} + \sum_{j\in J} P_{ij} \qquad \forall i \in I \tag{2}$$

Where I is the set of frontier nodes, J is the set of nodes in the internal system linked directly to the frontier nodes. P_{gi} and P_{li} are the power generated by the i^{th} equivalent generator and the load of i^{th} bus, respectively. While P_{ij} is the power flowing from i^{th} to the j^{th} node in the study system.

Fig. 1 shows the flow chart of the proposed methodology, the problem is to minimize the error function in (3). Time domain simulations were carried using power system analysis toolbox (PSAT) [16], and measurements are obtained from (PMUs) near frontier bus.

$$Error = \frac{1}{n}\sum_{i=1}^{k}\left(Y_{original}(i) - Y_{equivalent}(i)\right)^2 \tag{3}$$

Where:

Y is a vector of measured signals $[\Delta P, \Delta V, \Delta\omega]^t$;

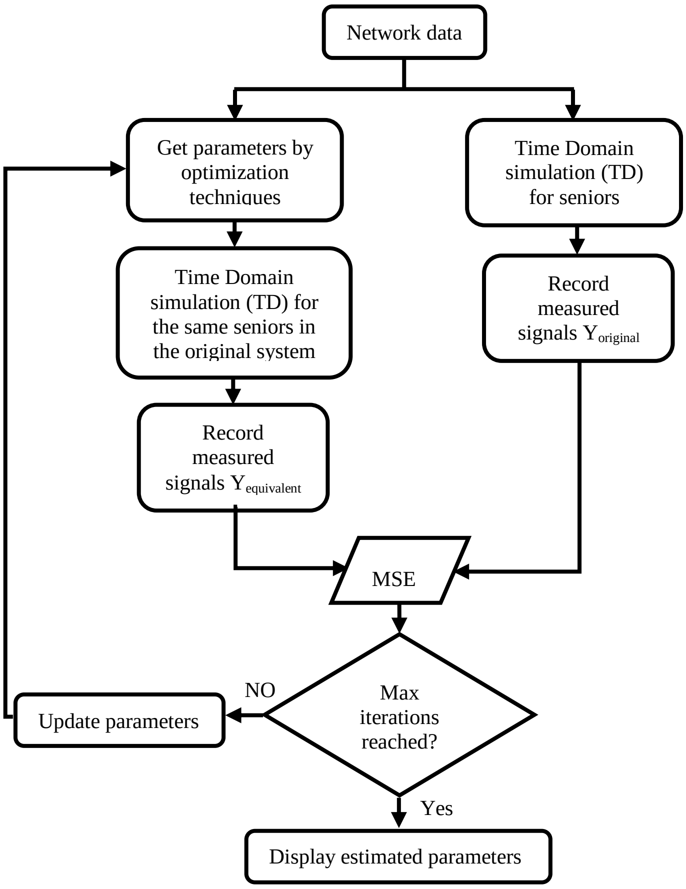


Fig. 1 Flow chart of the proposed methodology

$Y_{original}$ and $Y_{equivalent}$ are signals measured from the original and the equivalent systems, respectively. When both systems are subjected to the same disturbance.

Small signals are given large weighting factor, thus Y could be rewritten $[\rho_1\times\Delta P, \rho_2\times\Delta V, \rho_3\times\Delta\omega]^t$, where $\rho_{1,2,3}$ are the weighting factors, determined after several tests.

C. Differential Evolution

Differential Evolution (DE) is a stochastic population based optimization method. It was introduced in 1995 by Storn and Price [18]. Like Genetic Algorithm (GA), it can handle nonlinear, continuous, noisy, or problem that has many local minima [18, 19]. As illustrated in Fig. 2 the next generation is created through selection, mutation and crossover from the current population.

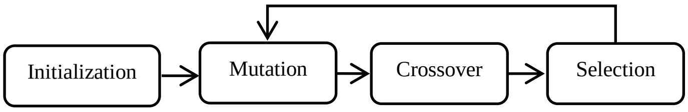


Fig. 2 Differential evolution algorithm flowchart

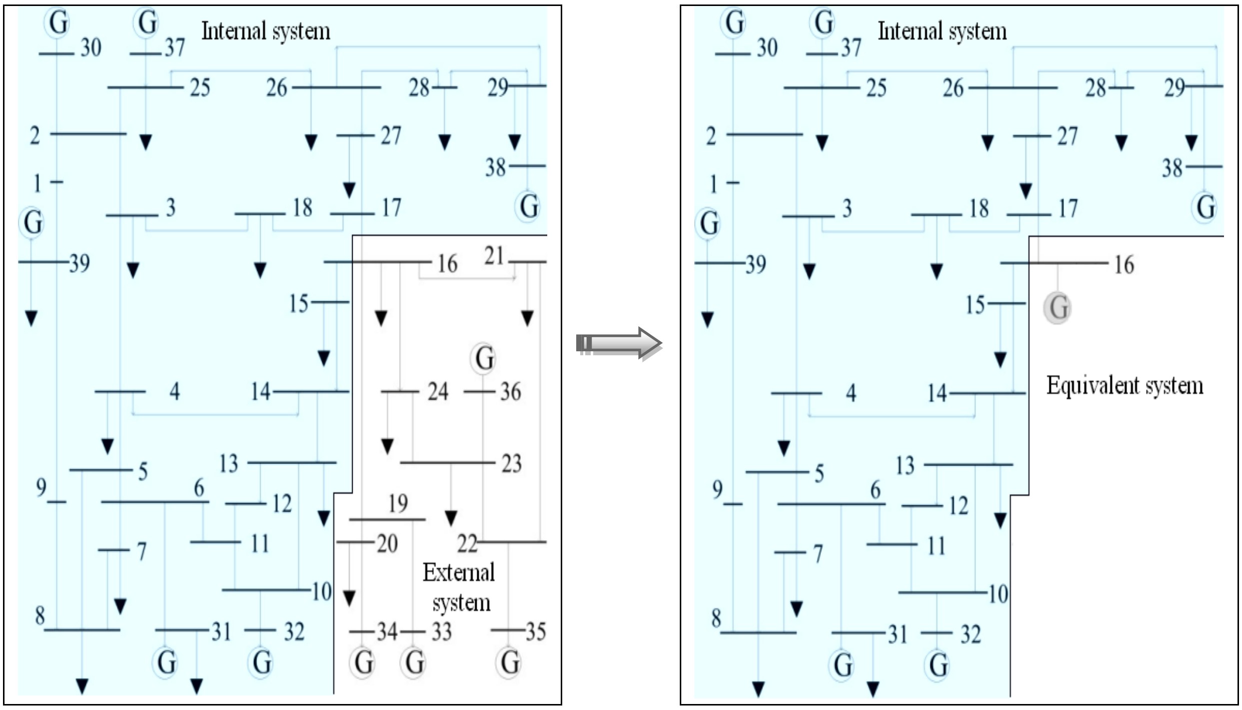


Fig. 3 New England full and reduced system

1) The Mutation: An initial mutant parameter vector, called donor vector $V_{i,G+1}$ is created by choosing randomly three members of the population. The donor vector $V_{i,G+1}$ written in (4) is created by adding the weighted difference of two of the vectors to the third one.

$$V_{i,G+1} = X_{r1,G} + F\left(X_{r2,G} - X_{r3,G}\right) \qquad (4)$$

Where $X_{r1,G}$ represent an individual of g^{th} generation, F is a mutation constant varies between (0, 2) [18].

2) The Crossover: In crossover a trail vector $U_{i,G+1}$ is created as a perturbation of the target vector $X_{i,G}$, and the donor vector $V_{i,G+1}$. The crossover process is introduce to improve the diversity in the search space.

$$U_{j,i,G+1} = \begin{cases} V_{j,i,G+1} & \text{if} \quad \mathrm{r_j} \le CR \quad or\ j = j_{rand} \\ X_{j,i,G} & \text{if} \quad \mathrm{r_j} > CR \end{cases} \qquad (5)$$

In (5) r_j is a uniformly distributed random variable ($0 < r_j < 1$) and j_{rand} is random index ($1 \le j_{rand} \le n$). CR is constant parameter called crossover constant.

3) The Selection: Finally, better individual are selected by simply replacing the original individual with the obtained new individual if it has a better fitness. (6) gives this process.

$$X_{j,G+1} = \begin{cases} U_{i,G+1} & \text{if} \quad \mathrm{f}(U_{i,G}) \le \mathrm{f}(X_{i,G}) \\ X_{i,G} & \text{if} \quad \mathrm{f}(U_{i,G}) > \mathrm{f}(X_{i,G}) \end{cases} \qquad (6)$$

With $i \in [1, N_p]$.

DE is simple algorithm, operates under few controlled parameters, strong optimizing capability, and ease of use [19]. Considering all these advantages, DE was chosen in this work to estimate the equivalent model's parameters.

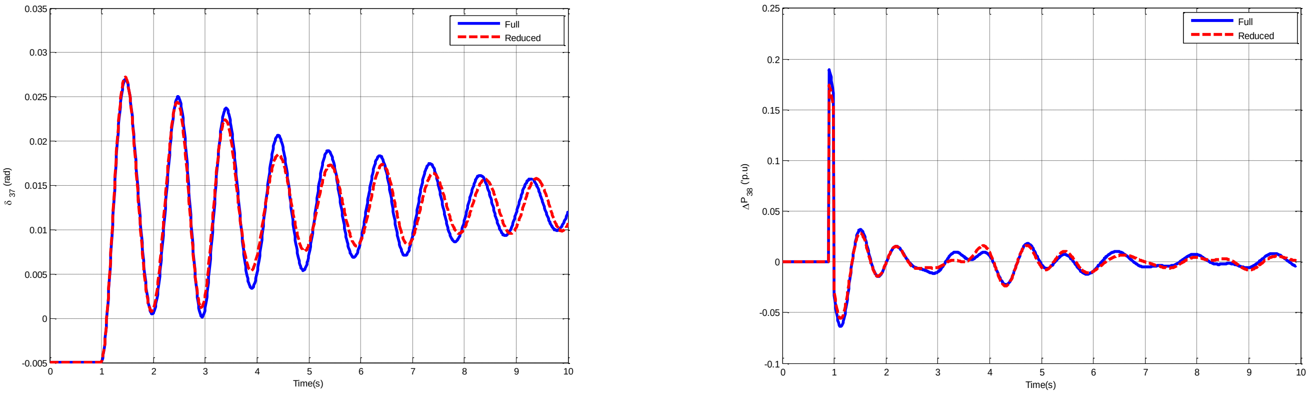
III. SIMULATION RESULTS

39-bus commonly known as New England power system, it contain 10 generators (P_{Gtotal}=6.14 GW, Q_{Gtotal}=1.36 GVAr), the system has 19 loads, 46 branches, and 12 transformers. Fig. 3 shows the full and reduced system, respectively. The shaded area represent the study system, while the rest is the system to be reduced. There are one frontier node (bus 16) and two tie lines (16-15 and 16-17) link the external system with the study system. On the right the reduce system with a fictitious generator who parameters are to be optimized is placed at the frontier bus. The model was built in PSAT.

Small disturbances were applied to bus 7 and 8 in the internal system, from time domain simulations, signals were compared over 10 s window. The optimized parameters of the fictitious generator are given in Table 1. Fig. 4 shows responses of the full and reduced system for small disturbances. It can be seen that measurement from the reduced model are in agreement with those of the full system. To confirm the validity of the estimated parameters, large disturbance (3 phase short circuit) was applied to bus 9 at t=1s, the fault lasts for 6 cycles. The results demonstrate that the equivalent can imitate the influence of the external system on internal system even for large disturbances (see Fig. 5). The equivalent model was also test by other disturbance such as loss of important transmission line and other faults in the internal system.

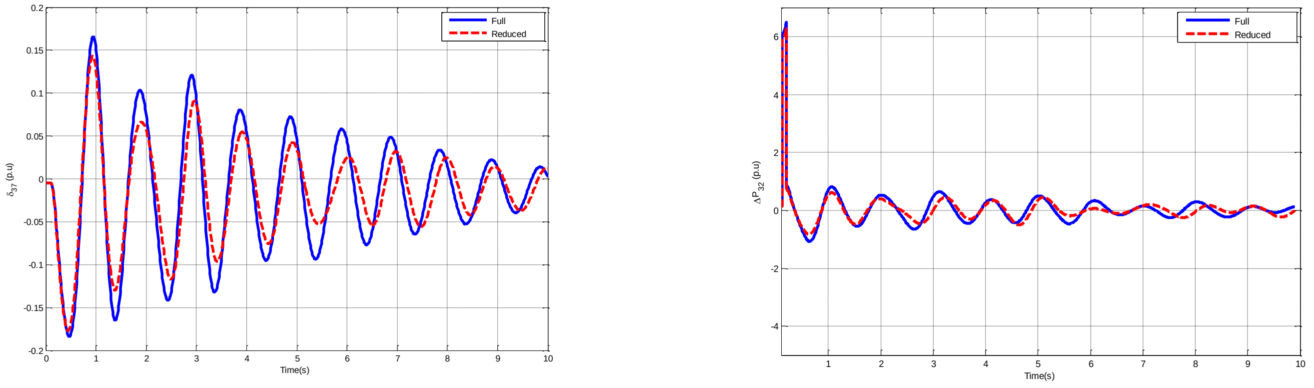
TABLE I. ESTIMATED PARAMETER OF THE EQUIVALENT GENERATOR

	Estimated Parameters		
	H (s)	***X_d' (p.u)***	***D (p.u)***
G_{equiv}	82.9967	0.0603	5



(a) (b)

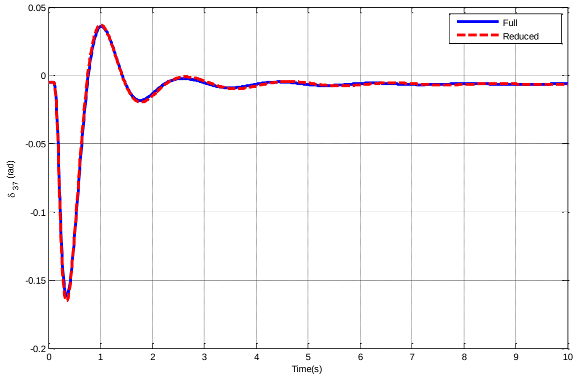
Fig. 4 (a) Angle of generator 37; (b) Power varition of generator 38 for a small distrubance.



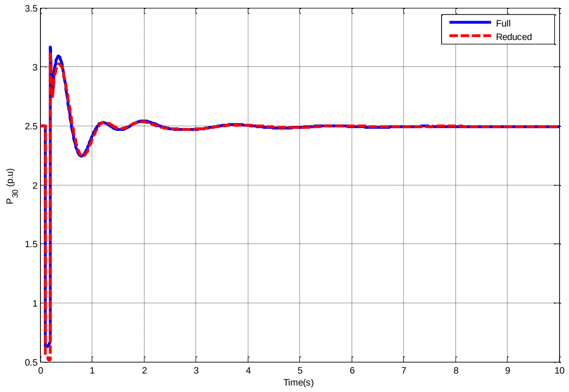
(a) (b)

Fig. 5 (a) Angle of generator 38; (b) Power varition of generator 32 for a short circuit at bus 9.

Including PSSs for all generators. Fig. 6 shows the rotor angle of generator 37, power output of generator 30 and the voltage of bus 15. It can be seen the responses of the reduced system are in total agreement with the full system.



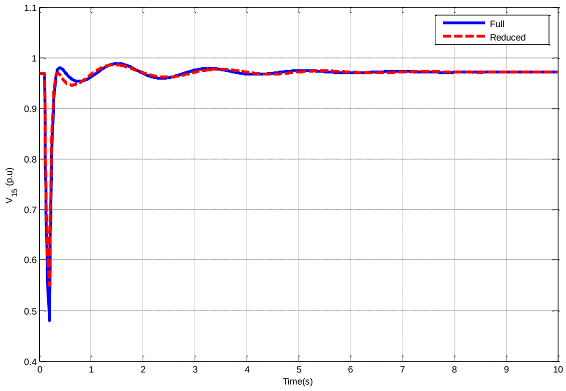
(a)



(b)

IV. CONCLUSION

An optimal reduced model using parameter estimation was presented in this paper, static exciter and power stabilizers are included for all generators, variety of disturbances were applied in the internal system to prove the validity of the estimated parameters. The estimated model offers high accuracy; signals measured from both systems are in perfect agreement.



(c)

Fig. 6 (a) Angle of generator 37 ; (b) Power generatation of generator 30; (c) Voltage at bus 15 ; for a sourt circuit at bus 14.

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