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<https://doi.org/10.15866/ireaco.v10i2.11056> 204 Optimal Tuning of PSS Parameter Using
HACDE Based on Equivalent SMIB Model Rusilawati^{1,2}, Dheny Ashari¹, Dimas Fajar
Uman Putra¹, RonySeto Wibowo¹, Adi Soeprijanto¹ Abstract – This paper proposesthe
optimal tuning of PSS parameter using the Hybrid Adaptive Chaotic Differential
Evolution (HACDE) based on equivalent SMIB model in spite of the complex
interconnection multi-machine system.

The interconnection of power systems has some advantages such as the increase in
power system reliability and maximum power transfer but, on the other hand, these
interactions make the systems difficult to analyze because it becomes larger and more
complex. To simplify the analysis, first the multi-machine system is converted into an
equivalent Single Machine to Infinite Bus (SMIB) model which is formed by determining
the equivalent impedance obtained from the network reduction method using the
losses concept based on power flow tracing. This model is fairly enough to represent the
setting of generator control equipment. Afterward, the PSS parameters is tuned using
HACDE optimization methods in the SMIB system.

The HACDE method is able to increase the damping of generator oscillation. The PSS
tuning by using HACDE is compared with the DE and RD-PSO methods. Based on time
domain and ITAE simulation results, the PSS tuned using HACDE gives better damping
than by using the other methods. Copyright © 2017 Praise Worthy Prize S.r.l. - All rights
reserved. Keywords: Hybrid Adaptive Chaotic Differential Evolution (HACDE), Losses
Concept, Network Reduction, Power Flow Tracing, PSS Parameter Tuning Nomenclature
K Contribution factor matrix i Row index of negative element in line sink node as a

reference to start tracing m Row index of positive element that perpendicular with negative element in line sink node n Column index of negative element in line with positive element that will be eliminated j Column index of negative element that contain positive element which will be eliminated NB Number Bus in the system T A matrix that contain power flow due to the ith node through a line j diag (Fj) A diagonal matrix with Fjj elements value equal to the power at the sending end or the receiving end $P - jQ$ The complex power of the observed machine V_i^* The conjugate complex voltage at the observed machine bus I The current of the observed machine Z_{eq} the line equivalent impedance R_{eq} Equivalent resistance X_{eq} Equivalent reactance PL The active power losses QL The reactive power losses J_i Objective function of ith individual j_{th} Real component of ith individual eigenvalue j_{th} Damping ratio of ith individual eigenvalue PSS gain of ith individual PSS Washout time constant of ith individual ... PSS lead lag time constant of ith individual Chaotic number of j_{th} dimension for k_{th} iteration Constant number of logistic chaotic function ($= 4$), New mutation and crossover factor of ith individual for t_{th} generation, Mutation and crossover factor of ith individual for t_{th} generation I. Introduction Modern electrical power systems are connected by interconnection systems not only to provide efficient and low cost power, but also to improve reliability.

Load fluctuation can lead to generator oscillation, which acts as a response generator to overcome load changes. Therefore, load changes can be seen as stability problems [1] – [2]. Although the interconnection system provides efficient and reliable power, stability in the Rusilawati et al. Copyright © 2017 Praise Worthy Prize S.r.l. - All rights reserved International Review of Automatic Control, Vol. 10, N. 2 205 interconnection system becomes more complex and difficult to be analyzed due to the interaction between the generators and control equipment.

Therefore, to simplify the analysis, first the multi-machine system is converted into the Single Machine to Infinite Bus (SMIB) model. This model fairly enough represents the setting of generator control equipment [3]. To convert the multi-machine system into a SMIB model, it is necessary to know the equivalent impedance of the observed generator. Some of the methods that used to change the multi-machine system into SMIB model are described in [4]-[9]. However, all this models are not suitable to analyze the machine because they focus on the system itself. A new alternative method of network reduction is the losses concept method [10].

This method changes the multimachine system into a single-machine, therefore it is possible to observe the trouble in the machine. However, the equivalence based on the losses concept method conducted in [10] has the disadvantage that the system is modeled into the superposition. Because this model does not represent the original

multimachine state, load is uniformly normalized, sometimes the power flow of superposition does not converge due to the too large impedance line, and requires a lot of adjustments to suit the initial state operating point. Hence, this paper proposes a solution for the equivalence method based on the losses concept by changing the superposition approach into power flow tracing.

The SMIB system is formed by determining the equivalent impedance obtained from the network reduction method using the losses concept based on power flow tracing. The Power flow tracing method is widely used for interconnection systems deregulation due to the energy market competition [11]-[15]. The power flow tracing method is able to determine the losses that the observed generator contributed to. In this paper, the generator linear model [16]-[17] has been selected to represent the synchronous generator model with an addition of control components such as the governor and AVR. Thus, in this paper the generator is modeled as a modified SMIB.

Generator control systems such as AVR have a role in the generator oscillation [18]. The most suitable solution to provide the generator oscillation damping is additional equipment such as a power system stabilizer (PSS). However, to obtain the optimal damping, PSS parameters need to be tuned first. The optimization methods commonly used to obtain optimal value, such as genetic algorithms (GA), Particle Swarm Optimization (PSO), Random-Drift PSO (RD-PSO), Differential Evolution (DE), etc.

The conventional methods have some drawbacks such as premature convergence, trap on local optima, or lack of diversity. New modified methods are developed to improve their performance, such as IHSA [19] and BFO-PSOTVAC-DE [20]. Those optimization methods are based on the gradient free technique. It makes those techniques easily applied to the various problems, such as in [21] and also to the optimal tuning PSS problem. This paper proposed the modification of the DE method called HACDE method.

This method is inspired and adapted from the chaotic equation in DE optimization method that is capable to cover wide areas of search and is able to obtain the optimal value better than DE and RD-PSO methods [22]. To get optimal and fast damping value, the objective function based on eigenvalue is used to tune the PSS parameters. Besides using the eigenvalue to demonstrate the advantages of HACDE performance, the generator responses are also simulated in the time domain.

The evaluation parameters in the time domain using Integral Time Absolute Error (ITAE) also show that HACDE has better performance than ED and RD-PSO methods. II. Proposed Method II.1. Proposed Method This paper proposes the network reduction using the losses concept to get the values of R_{eq} and X_{eq} . These values will be used to

calculate K1-K6 inside the SMIB model, as developed by [16] – [17]. In the system, power is naturally distributed through a network transmission which has losses. Line losses are obtained from the power flow tracing process to which the generator contributes.

Based on the losses concept, the calculation of Req and Xeq for single-machine is more simple. Fig. 1 shows the flowchart of the proposed method. The steps of the proposed method will be described in the following section. II.2. The Multimachine into the SMIB System with Network Reduction using the Losses Concept The network reduction process using the losses concept for each machine unit can be described as follows [10]: A. Perform the interconnection system power flow in a multi-machine system. B. Based on the multimachine system power flow results, the power flow tracing can be performed.

The concept of power flow tracing starts since the deregulation of power systems due to the open competition in the energy market. The maintenance cost of the transmission line is divided in a fair, transparent and convincing manner to all the system users [17]. The Power flow tracing method used in this paper refers to paper [17]. The Power flow tracing algorithm is divided into two components, namely downstream and upstream tracing. Downstream tracing (DST) is useful to seek the power generator contributions to the system.

Upstream tracing (UST) is used to look for the extraction of load power on the system. In this method, the node type can be divided into: 1. The source node: the bus in which all the connected lines send power out of the bus. 2. The generation node: the bus in which some connected lines send power out, some of the lines receive power and net positive power injection. 3. The load node: the bus in which several connected lines send power out, some of the lines receive power and net negative power injection. 4. The sink node: the bus in which all the connected lines receive power. Fig. 1.

Flowchart of proposed method The Power flow tracing algorithm can be explained as follows: 1. As an initial input, forming a power flow matrix, based on power flow calculations and state estimation. The matrix power flow can be formed separately from the active power (P) and reactive power (Q). 2. Calculate the net injection and flow passing on each node. 3. Establish a contribution factor matrix (for generation) and extraction (for load). 4. Perform power flow tracing using each tracing equation for each contribution factor and extraction matrix: $K_{in} = K_{in} + K_{ij}K_{mj} \quad i = 1, NB \quad i \neq j \quad (1) \quad C.$

Calculate the power contribution and extraction on the system with each matrix using

the following equation: $T = K \cdot \text{diag}(F_j)$ (2) with: T_{ij} = power flow due to the i th node through a line j , $\text{diag}(F_j)$ = a diagonal matrix with F_{jj} elements value equal to the power at the sending end or the receiving end. D. Get the active power (P), reactive power (Q), active power losses (PL), and reactive power losses (QL). E. Calculate the current value of the observed machine using the following equation: $I = (P - jQ) / (\sqrt{3} \cdot V_i^*)$ (3) with: I = The current of the observed machine, $P - jQ$ = The complex power of the observed machine, V_i^* = The conjugate complex voltage in the observed machine bus. F. Calculate R_{eq} and X_{eq} values through the losses concept using the following equation: $R_{eq} = \frac{PL}{3I^2}$, $X_{eq} = \frac{QL}{3I^2}$ (4) with: PL = the active power losses, QL = the reactive power losses, Z_{eq} = the line equivalent impedance. G.

The values of R_{eq} and X_{eq} will be used to calculate K_1 - K_6 inside of the SMIB model, as developed by [16]- [17]. H. Modelling the SMIB system as the Synchronous Machine Linear The synchronous machine linear model used in this paper is a Heffron-Phillips model [16] and deMello-Concordia [17] with the addition of some control components as the IEEE ST4B AVR, IEEE G1 Governor, and IEEE 1A PSS to approach the machine model of the 150kV transmission system of the Pacitan steam power plant in Central Java. I.

Power System Stabilizer Parameter Setting The IEEE 1A PSS models with rotor speed changes as the input signal is used in the Pacitan steam power plant 150kV transmission system in Central Java. For simplification, the Pacitan PSS steam power plant optimization model is approached with PSS conventional model. I.1. Objective Function to Increase the PSS Parameter Damping Rusilawati et al. Copyright © 2017 Praise Worthy Prize S.r.l. - All rights reserved International Review of Automatic Control, Vol. 10, N.

2 207 In this paper, the objective function used to increase the machine oscillation damping analysis is a multi-objective eigenvalue [23]: $J = \sum_{i=1}^n \sum_{j=1}^m \frac{1}{\zeta_{ij}}$ (5) with: ζ_{ij} = the damping ratio of the i th individual in the group and j th eigenvalue of electromechanical oscillation mode. The objective function above aims at maximizing J to increase the electromechanical oscillation damping. The objective function based on the eigenvalue is chosen besides being able to represent the dynamic stability, but also shorten the optimization time compared to the time domain objective function I.2.

Constraints The optimization problem in this paper can be formulated as: $h(6) = (7) = (8) = (9) = (10) = (11) = (12)$ The PSS parameter optimization typical range is [0001-50] for K_i , [0.06-1.5] to T_{1i} and T_{3i} , [0.01-0.1] for T_{2i} and T_{4i} , and [4.5-5] for T_{wi} [24]. This paper used the HACDE approach to find the optimal value of PSS parameters and to obtain a sufficient oscillations damping value for the machine. J. PSS Parameter

Damping Optimization using HACDE J.1. Chaotic Function In nature, chaos is a nonlinear phenomenon that is ergodic, random, and sensitive to initial values [25]. The iterative chaotic function used in this paper is a logistic function with $\mu = 1 - \mu$, $\mu = 1, 2, \dots$? (0,1), ? 0.25, 0.5, 0.75, and 1 (13) The chaotic iterative function has a high probability on the boundaries regions, so to avoid the too early convergence it can be used as a carrier operator on the optimization method [26]. J.2.

Mutation Factors and the Adaptive Crossover DE control parameter settings greatly affect performance optimization, adaptive parameter mechanism intended to DE efficiency [27]. The adaptive mechanism is inspired from paper [28], in which each individual has a mutation and crossover parameters. During the initialization, the parameter mutation () is set at 0.5 and crossover () is set at 0.9. Generally, **the normal distribution with the mean** is 0.5 and the standard deviation is 0.3, as of the effective adaptive parameter approach [29].

However, to avoid too early convergence, Cauchy distribution is more promising on the mutation factor diversity [30]. Thus, the iteration of each individual has different mutation possibilities and crossover parameters (NF and NC) 0.1. The adaptive **mutation and crossover operation** will replace vector trial operations: $= (0.5, 0.3)$, $(0, 1) < 0.1$, $h = (0, 1)$, $(0, 1) < 0.1$, h (14) The knowledge selection process of the superior individual must be maintained and passed on to the next generations. Therefore, the next individual has a greater survival probability [29]. Thus, the selection process mutation and crossover factor value must be renewed for the next generation: $= , () ()$, $h = , () ()$, h (15) J.3.

Hybrid **Adaptive Chaotic Differential Evolution (HACDE)** HACDE is a modification optimization method of the conventional DE with the mutation factor (F) and the crossover factor (C) adaptive parameters for each generation, as well as inspired by chaotic function to expand the exploration area [27], [32]-[33]. To demonstrate the HACDE performance, this paper will be compared to some DE optimization methods results and Random-Drift PSO. Besides, to show the eigenvalue objective function, the performance of HACDE test damping is also simulated in the time domain. III. Simulation and Data Analysis III.1.

Equivalent Impedance Calculation This paper used the Central Java 50Hz 150kV transmission system, with Pacitan steam power plant as the observed machine. The 150 kV system is a fairly complicated interconnection system comprising 77 buses and 103 lines. Based on the Appendix and using the steps Rusilawati et al. **Copyright © 2017 Praise Worthy Prize S.r.l. - All rights reserved International Review of Automatic Control, Vol. 10, N. 2** 208 of the network losses concept reduction [10], the equivalent impedance calculation can be described as follows: 1. From the results of power flow tracing, the

active power losses (PL) and reactive power losses (QL) are $0.10052 + j0.49569$ p.u. 2.

Calculating the current value of the observed machine using equation (3), the result is $I = 1.66713 + j0.33369$ p.u. 3. Calculating the value of R_{eq} and X_{eq} using the losses concept in equation (4), the result is $Z_{eq} = 0.01159 + j0.05716$ p.u. III.2. Comparison of Optimization HACDE Results To obtain the optimal oscillation damping, PSS parameters are tuned first. Table I shows the value of each PSS parameter. To observe the optimal tuning of PSS parameter value performance using HACDE optimization, this method is compared to other optimization methods, such as the conventional ED and RD-PSO.

The objective function of multi-objective is shown in equation (5) using eigenvalue, the greater fitness value is the more optimal. Fig. 2 shows that the convergent value obtained by HACDE is excellent when compared with ED and RD-PSO. III.3. Time Domain Simulation Beside optimization using eigenvalue, the time domain simulation will be demonstrated by the oscillation damping performance of each optimization method. Fig. 3 shows the existing oscillation of rotor speed, Fig. 4 shows the response of rotor speed with PSS, Fig. 5 shows the existing oscillation of rotor angle and Fig. 6 shows the response of rotor angle with PSS, respectively. TABLE I THE PSS PARAMETER

	K_{pss}	T_w	T_1	T_2	T_3	T_4	DE	RD-PSO
Existing	3.47	4.94	0.118	0.0118	0.833	0.010	4.39	4.99
HACDE	3.76	4.87	0.103	0.0105	0.896	0.010	4.39	4.99

Fig. 2. Convergent curve of HACDE, DE, and RDPSO Fig. 3. Existing oscillation of rotor speed Fig. 4. Response of rotor speed with PSS Fig. 5.

Existing oscillation of rotor angle Fig. 6. Response of rotor angle with PSS

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