

Robust Power System Stabilizer Design Using a Hybrid of ANN and ICA

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ABSTRACT

The steady-state stability limit and the system positive damping can be improved by conventional Power System Stabilizer (PSS). However, in order to have abilities such as the online tuning and optimal real-time damping in the entire operating range, robust design of PSS is required.

A novel robust PSS design using Artificial Neural Network (ANN) and Imperialist Competitive Algorithm (ICA) for damping electromechanical modes of oscillations and improving power system stability is proposed in this paper. The dynamics associated with a single machine connected to infinite bus power system is analyzed in this study. Optimal settings of PSS parameters are achieved by the means of hybrid ICA-ANN.

ANN is used for online PSS parameters tuning. The results of ICA-based PSS (ICA-PSS) are used as training designs of ANN. Eigenvalue analysis and system simulations demonstrate the effectiveness of the proposed method in the damping of electromechanical oscillations and improving the system dynamic stability.

INDEX TERMS— Power System Stabilizer, Imperialist Competitive Algorithm, Artificial Neural Network, Low frequency oscillations.

I. INTRODUCTION

Power system stability is one of the key factors that affects the generation, transmission and distribution as three main segments of power system. There are several factors that can endanger the stability of the system such as sudden load change, fault occurrence and change in generator shaft speed. With the advent of automatic voltage regulators (AVRs) in the late 1950s, AVRs was widely installed on power generating units. However, the high performance of these regulators produced destabilizing problems on the power system; most of which are related to the low frequency oscillation in power systems, especially under deregulated environment [1].

To overcome this problem and to improve the dynamic performance of the system by providing fast damping a supplementary control signal in the excitation of a generating unit can be used. A Power System Stabilizer (PSS) can be then used to provide additional supplementary control signals to the generating unit to damp out low frequency oscillation [2-3]. PSSs are mainly used to damp low frequency oscillations in the range of 0.2Hz to 2.5Hz. Conventional PSS (CPSS) design normally uses classical control theory and is based on lead-lag compensation concepts with two categories of single input [4] and dual inputs [5-6], is mainly planned based on using a linear model and considering one operating point. However, since power systems are highly nonlinear in nature a CPSS cannot guarantee to have the best performance as operating point changes. Therefore, in order to have a reliable design, considering the uncertainties of power system in the design procedure are inevitable. In recent years many studies have been carried out to investigate the optimal parameters of PSSs; various mathematical programming and optimization techniques have been employed to design PSS parameters [7-9]. For the parameter tuning of PSS in a power system two main techniques are used which are sequential tuning and simultaneous tuning. In order to achieve a set of reliable data of the optimal PSS parameters under different operating conditions, the tuning and testing of PSS parameters must be repeated under different operating points of the system. The simultaneous tuning of PSS parameters is generally formulated as a very large scale nonlinear non-differentiable optimization problem which is very difficult to solve by the means of classic differentiable optimization algorithms [1]. Recently, intelligent optimization based methods have been employed to solve this complicated power system problem [10]. Heuristic algorithms have some benefits to solve such a complicated optimization problem and have been widely used in the literature. Different heuristic techniques have been used for this problem like genetic algorithm (GA), Tabu Search (TS), Particle Swarm Optimization (PSO) as well as Simulated Annealing (SA). Artificial Neural Network (ANN) has been used for many years for identification and control of complex systems due to its non-linear mapping properties. A feedforward neural network was used in [11-12] to develop a neural adaptive PSS. A radial basis function network to design PSS parameters was proposed in [13]; the proposed PSS was trained under different operating conditions and system parameter variations.

The aim of this study is proposing a new robust PSS Design by the means of ANN and heuristic methods. To achieve a reliable training pattern Competitive Imperialist Algorithm (ICA) as a powerful optimization method is used. References [14-15] represent the successful implementation of ICA in solving complex and complicated problems. Two eigenvalue-based objective functions are considered to damp system damping of electromechanical modes. The results of ICA-based PSS (ICA-

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PSS) are used as the training patterns of ANN. Then the real-time parameters of PSS under different loading conditions and system configurations are obtained by the means of ANN. The simulation results show the effectiveness of the proposed ANN-ICA-PSS. In the previous studies the proposed method were usually designed for only one configuration and with the change in load they were not able to update the parameters of PSS on a real-time basis [3-5] and those who proposed an algorithm for real-time studies have not considered the ANN-heuristic based optimization model that is proposed in this paper.

In this paper a novel ANN-ICA-PSS method is proposed to optimally determine the design of PSS on real-time basis. The contributions of this paper are listed below:

1. Real-time tuning of PSS by the means of hybrid ICA and ANN.
2. The Usage of ICA optimization method as a tool for solving the complex problem of real-time PSS design.

The rest of this paper is organized as follows: section II describes the problem statement. Section III gives an overview of ICA algorithm. Simulation results are conducted in section V. Finally, conclusions are given in section VI.

II. PROBLEM EXPLANATION

A. Power System Model and PSS Structure

Figure 1 depicts the line diagram of single machine connected to infinite bus. A power system can be modeled by a set of nonlinear differential equations as follows:

$$\dot{X} = f(X, U) \quad (1)$$

Where, X is the vector of the state variables, and U is the vector of input variables. The linearized incremental models around an equilibrium point are usually employed in the design of PSSs. As a result, the state equation of a power system with machines and stabilizers can be written as (2).

$$\Delta \dot{X} = A \Delta X + B U \quad (2)$$

While A is $4n \times 4n$ matrix and is equal to $\partial f / \partial X$ B is $4n \times 4n_{PSS}$ matrix and is equal to $\partial f / \partial U$. On the other hand ΔX is $4n \times 1$ state vector, and U is $n_{PSS} \times 1$ input vector.

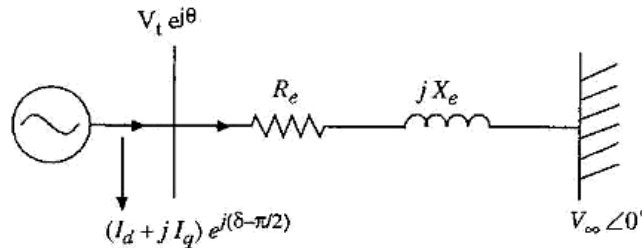


Fig. 1. Line diagram of single machine connected to infinite bus.

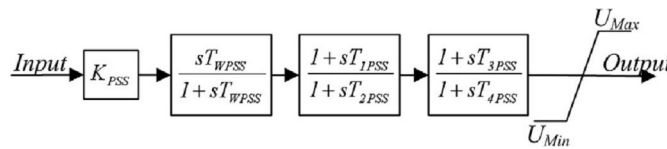


Fig. 2. Power System Stabilizer (PSS) Structure.

The structure of PSS is shown in Fig. 2. A conventional lead-lag PSS is considered in this study. It can be formulated as the following:

$$U_i = K_i \frac{sT_\omega (1+sT_{1i})(1+sT_{3i})}{1+sT_\omega (1+sT_{2i})(1+sT_{4i})} \Delta\omega_i \quad (3)$$

Where, T_ω is washout time constant, U_i is PSS output signal at the i th machine and $\Delta\omega_i$ is i th machine speed deviation from the synchronous speed. While T_ω , T_2 and T_4 , the time constants, are typically pre-specified [16].

There are three remained parameters that are aimed to be obtained; the stabilizer gain K_i and time constants T_1 and T_3 .

There are three assumptions over the full order model that converts it into simplified third order model of synchronous generator that is connected to infinite bus via a transmission line with the resistance R_e and reactance X_e :

- Stator winding resistance is neglected.
- Damper winding effect is neglected.
- Balancing conditions are assumed and saturation effects are neglected.

From the above assumption the linear equation of stator voltage can be written as (4) [17].

$$\Delta E'_q = \frac{K_3}{1 + K_3 \tau'_{d0} s} \Delta E_{FD} - \frac{K_3 K_4}{1 + K_3 \tau'_{d0} s} \Delta \delta \quad (4)$$

Where, E_{FD} is the rms value of E'_q and τ'_{d0} is the direct-axis transient time constant.

The incremental electrical torque is calculated using the following equations:

$$\Delta T_e = K_1 \Delta \delta + K_2 \Delta E'_q \quad (5)$$

$$E'_q = E + (x_d - x'_d) I_d \quad (6)$$

Where, E represents the stator air gap rms voltage. The linearized terminal voltage of synchronous generator (ΔV_t) is computed as follows:

$$\Delta V_t = K_5 \Delta \delta + K_6 \Delta E' \quad (7)$$

It should be noted that the constants K_1 to K_6 are dependent on system parameter and operation conditions and are usually positive. Only if R_e be high the K_4 will be negative and in case of low and medium loading and external impedance K_5 will be negative.

B. Objective Function

In order to increase the system damping to electromechanical modes, two different eigenvalue-based objective functions are considered as follows:

$$J_1 = \text{Max} \{ \text{real}(\lambda_i); \lambda_i \in \text{electromechanical modes} \} \quad (8)$$

$$J_2 = \text{Min} \{ \xi_i; \xi_i \in \xi \text{s of electromechanical modes} \} \quad (9)$$

Where, $\text{real}(\lambda_i)$ and ξ_i are the real part and the damping ratio of the i th electromechanical mode eigenvalue, respectively.

The objective of the optimization process is to minimize J_1 to shift the poorly damped eigenvalues to the left in s -plane and to maximize J_2 in order to increase the damping of electromechanical modes. The problem constraints are those related the optimization parameter bounds and can be formulated as the following:

$$K_i^{\text{Min}} \leq K_i \leq K_i^{\text{Max}} \quad (10)$$

$$T_{li}^{\text{Min}} \leq T_{li} \leq T_{li}^{\text{Max}} \quad (11)$$

$$T_{3i}^{\text{Min}} \leq T_{3i} \leq T_{3i}^{\text{Max}} \quad (12)$$

Typical ranges of the optimization parameters are (0.001–50) for K_i and (0.06–1.0) for T_{li} and T_{3i} [16]. The time constants T_ω , T_2 and T_4 are considered to be 5, 0.05, and 0.05s, respectively based on [18].

III. COMPETITIVE IMPERIALIST ALGORITHM

All evolutionary optimization methods are similar in on aspect that the move from one solution to another is done using rules based upon human reasoning, so the called intelligent. Heuristic algorithms may search for a solution only inside a subspace of the total search region. They are not limited by the search space characteristics like existence of derivative of the objective function and continuity. These algorithms are generally inspired by modeling the natural processes and other aspects of species evolution, especially human evolution. But Imperialist Competitive Algorithm has been conceptualized from socio-political evolution of human as a source of inspiration for developing a strong optimization strategy. ICA is a relatively new evolutionary optimization algorithm.

Imperialism is the policy of extending the control of an imperialist beyond its boundaries. It may try to dominate other countries by direct rule or via controlling of markets for goods. ICA is a novel global search heuristic that uses imperialistic competition process as a source of inspiration [19].

This algorithm starts with an initial population (a number of randomly produced solutions). Each solution in the population is called country. Considering the value of objective function as the measure, some of the best countries in the population selected to be the imperialists and the rest form the colonies of these imperialists. In this algorithm the more powerful imperialist, have more colonies. As the competition starts, imperialists try to achieve more colonies and the colonies start to move toward their imperialists. So during the competition the powerful imperialists will be improved and the weak ones will be collapsed. At the end of algorithm just one imperialist will remain. In this stage the position of imperialist and its colonies will be the same. The algorithm steps are summarized as follows. More details about this algorithm can be found in [20-25].

1. *Generating Initial Empires*: The goal of optimization is to find an optimal solution in terms of the variables of the problem. An array of optimization variable values is called “country”. The cost of a country is found by evaluating the objective function for this country. To start the optimization algorithm we generate the initial population of size N_{country} . N_{imp} of the

most powerful countries are selected to form the empires. Other countries will be the colonies each of which belongs to an empire.

2. Moving the Colonies of an Empire toward the Imperialist:

After assimilation policy, the imperialist states try to absorb their colonies and make them a part of themselves. More precisely, the imperialist states force their colonies to move toward themselves along different socio-political axis such as culture, language and religion [19]. In the ICA, this process is modeled by moving all of the colonies toward the imperialist along different optimization axis. Imperialist countries start to improve their colonies. This has been modeled by moving all the colonies in this empire toward the imperialist. It means that a new country will be generated based on the position of each country in the empire and the distance of this country and imperialist. Assimilating the colonies by the imperialist states does not lead in direct movement of the colonies toward the imperialist. The direction of movement is not essentially a vector from colony to the imperialist. In order to model this fact and to increase the ability of searching more area around the imperialist, a random amount of deviation is added to the direction of movement [19].

3. *Finding the Total Power of an Empire:* The total power of an empire is mostly affected by the power of its imperialist. However, the power of its colonies of an empire has an effect, on the total power of empire. The mean value of the cost function of other countries in the empire will be added to the value of objective function for the imperialistic with a small coefficient to form the power of each empire.
4. *Imperialistic Competition:* each empire tries to take the control and ownership of colonies of other empires. This competition brings about a decrease in the power of weaker empires and an increase in the power of more powerful ones slowly. The competition is modeled by choosing a number of weakest colonies of the weakest empires and allow for the empires to compete for acquiring the chosen colonies.
5. After a number of iterations only the most powerful empire will remain and all the countries will be controlled by this imperialist which is the optimum solution of the problem.

IV. SIMULATION RESULTS

In this section we present the test system and the results obtained from the proposed method. The proposed algorithm based on ICA for the PSS robust design problem was implemented using MATLAB R2011a.

In order to evaluate the effectiveness and robustness of the proposed ICA-PSS a test system is employed for simulations in this section. The electromechanical-mode eigenvalues and corresponding damping ratios for CPSS and ICA-PSS are studied.

The performance of single machine connected to infinite bus (Fig. 1) is simulated and investigated under different operating condition. The dynamic system response is analyzed for the system without PSS, with CPSS and the system with the proposed ICA-PSS.

Root-Locus analysis is a graphical tool to show how the roots of a system change with variation of an individual parameter of the system, usually a gain within a feedback system. The Root-Locus of the closed loop system for the system without PSS and with the proposed PSS design are shown in Figs. 3 and 4. As shown in these pictures the application of PSS can effectively improve the stability of the system based on Root-Locus of the closed loop system.

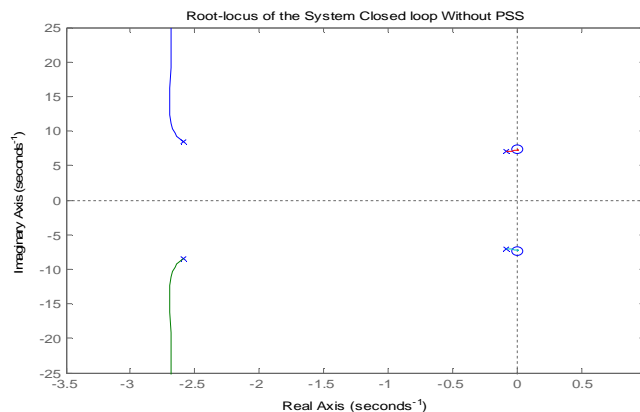


Fig. 3. Root-Locus of the closed loop system without PSS

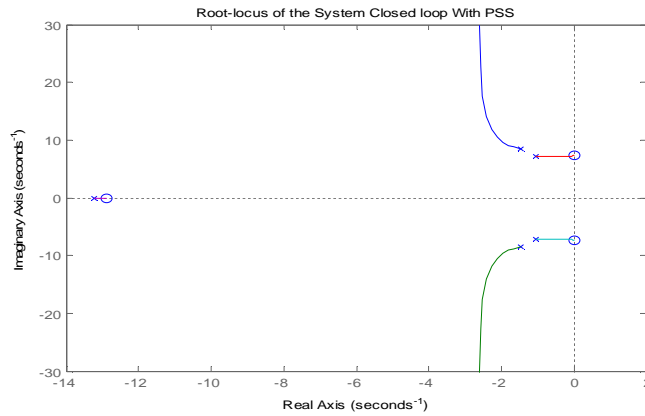


Fig. 4. Root-Locus of the closed loop system for the proposed PSS design

Figure 5 compares V_t response to increase in V_{ref} of system without PSS, CPSS and proposed ICA-PSS. It can be seen that the proposed ICA-PSS has a better performance than CPSS and damp the oscillations more quickly. Comparison of ω response under the same condition is depicted in Fig. 6. The prominent performance of proposed ICA-PSS in comparison with CPSS is more noticeable in this figure.

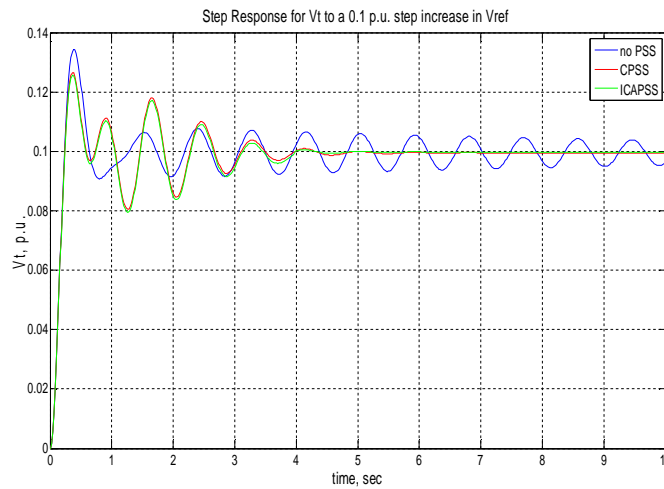


Fig. 5. Comparison of V_t Response to Increase in V_{ref} for system without PSS, CPSS and ICA-PSS

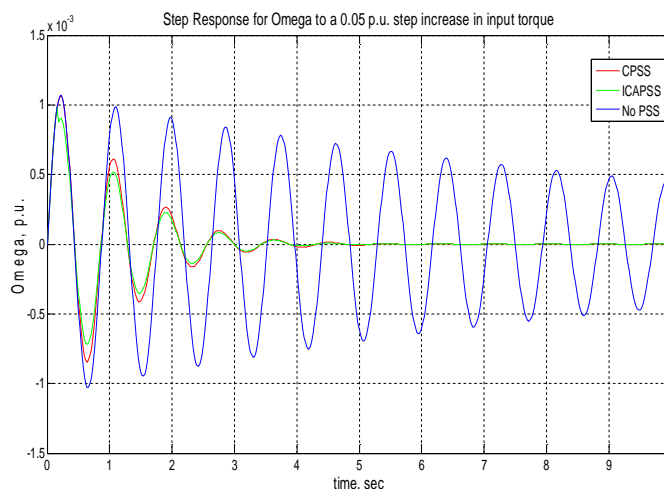


Fig. 6. Comparison of ω Response to Increase in V_{ref} for system without PSS, CPSS and ICA-PSS

As demonstrated by the simulation results, the performance of the proposed ICA-PSS is significantly better than CPSS. The results also show that the proposed ICA-PSS is capable of finding the optimal setting of PSS to enhance the system response to disturbances.

V. CONCLUSION

In this paper the dynamics performance of a single machine connected to infinite bus power system has been analyzed. In order to determine the optimal settings of PSS parameters an ICA-PSS design has been proposed in this study. Two eigenvalue-based objective functions have been proposed to improve damping characteristic of electromechanical modes.

The obtained results demonstrate the effectiveness of the proposed ICA-PSS design to enhance system damping's characteristic of electromechanical modes. They also show that the proposed method is more capable of enhancing dynamic response of the system in comparison with CPSS.

REFERENCES

- [1] M. Eslami, H. Shareef, A. Mohamed, and M. Khajehzadeh, "An efficient particle swarm optimization technique with chaotic sequence for optimal tuning and placement of PSS in power systems," *Electrical Power and Energy Systems*, Vol. 43, pp. 1467–1478, 2012.
- [2] A. S. Al-Hinai, and S. M. Al-Hinai, "Dynamic Stability Enhancement using Particle Swarm Optimization Power System Stabilizer," *In Proc. 2nd International Conference on Adaptive Science & Technology*, ICAST 2009.
- [3] T. K. Das, G. K. Venayagamoorthy, "Optimal design of power system stabilizers using a small population based PSO," *IEEE Power Engineering Society General Meeting*, 2006, pp. 1–7.
- [4] Mostafa HE, El-Sharkawy MA, Emary AA, Yassin K. Design and allocation of power system stabilizers using the particle swarm optimization technique for an interconnected power system. *Int J Electr Power Energy Syst.*, 2012; Vol. 34, pp. 57–65.
- [5] Avdhesh S, Kothari ML. Intelligent dual input power system stabilizer. *Electric Power Syst Res* 2003;64:257–67.
- [6] Zbigniew L. Dual input quasi-optimal PSS for generating unit with static excitation system. In: Westwick David, editor. *Power plants and power systems control*. Oxford: Elsevier Science Ltd.; 2007. p. 267–72.
- [7] P. Kundur, M. Klein, G. J. Rogers, and M. S. Zywno, "Application of power system stabilizers for enhancement of overall system stability," *IEEE Trans. on Power Systems*, vol. PAS-108, 1989, pp. 614–626.
- [8] C. L. Chen and Y. Y. Hsu, "Coordinated synthesis of multimachine power system stabilizer using an efficient decentralized model control (DMC) Algorithm," *IEEE Trans. on Power System*, vol. 2 no. 3, pp. 543–551, 1987.
- [9] C. Y. Chung, K. W. Wang, C. T. Tse, X. Y. Bian and A. K. David, "Probabilistic eigenvalue sensitivity analysis and PSS design in multimachine systems", *IEEE Trans. on Power System*, Vol. 18, No. 4, 2003, pp.1439 - 1445.
- [10] Mostafa HE, El-Sharkawy MA, Emary AA, Yassin K. Design and allocation of power system stabilizers using the particle swarm optimization technique for an interconnected power system. *Int J Electr Power Energy Syst.*, Vol. 34, pp. 57–65, 2011.
- [11] N. Hosseinzadeh, and A. Kalam, "A hierarchical neural network adaptive power system stabilizer", *International Journal of Power and Energy Systems*, vol. 19, no. 1, 1999.
- [12] P. Shamsollahi, and O.P. Malik, "Design of a neural adaptive power system stabilizer using dynamic back propagation method," *Electrical Power and Energy Systems*, vol. 22, pp.29- 34, 2000.
- [13] Segal, R.; Kothari, M.L.; Madnaui, S., "Radial basis function (RBF) network adaptive power system stabilizer," *IEEE Power Engineering Society Winter Meeting*, 2000.
- [14] Ali Yaghoubi, Maghsoud Amiri, "Proposing a Model to Predict Efficiency and Related Risk by Using Stochastic Data Envelopment Analysis Technique and the Imperialist Competitive Algorithm," *J. Basic. Appl. Sci. Res.*, 2(12)12542-12555, 2012.
- [15] Hossein Towsyfyhan, Seyed Adnan Adnani Salehi, "Optimization of Bead Geometry in Submerged Arc Welding Process Using Imperialist Competitive Algorithm," *J. Basic. Appl. Sci. Res.*, 2(12)12582-12589, 2012.
- [16] M. A. Abido, "Optimal Design of Power-System Stabilizers Using Particle Swarm Optimization," *IEEE Trans. on Energy Conv.*, Vol. 17, No. 3, pp.406 – 413, 2003.
- [17] A. S. Al-Hinai, Member, IEEE, and S. M. Al-Hinai, "Dynamic Stability Enhancement using Particle Swarm Optimization Power System Stabilizer," *In Proc. 2nd International Conference on Adaptive Science & Technology*, ICAST, pp. 117-119, 2009.

- [18] Y. L. Abdel-Magid, M. A. Abido, S. Al-Baiyat, and A. H. Mantawy, "Simultaneous stabilization of multimachine power systems via genetic algorithms," *IEEE Trans. Power Syst.*, vol. 14, pp. 1428–1439, Nov. 1999.
- [19] Atashpaz-Gargari, E., Lucas, C., "Imperialist Competitive Algorithm: An algorithm for optimization inspired by imperialistic competition". *IEEE Congress on Evolutionary Computation*, (2007), 7. pp. 4661–4666.
- [20] Ceylan, H., Ozturk, H.K., 2004. "Estimating energy demand of Turkey based on economic indicators using genetic algorithm approach. *Energy Conversion and Management* 45 (15–16), 2525-2537.
- [21] Dincer, I., Dost, S., 1996. "Energy intensities for Canada". *Applied Energy* 53, 283-298.
- [22] Ebohon, O.J., 1996. "Energy, economic growth and causality in developing countries: a case study of Tanzania and Nigeria". *Energy Policy* 24 (5), 447-453.
- [23] Haldenbilen, S., Ceylan, S., 2005. "Genetic algorithm approach to estimate transport energy demand in Turkey". *Energy Policy* 33 (18), 89-98.
- [24] Hepbasli, A., Utlu, Z., Akdeniz, R.C., 2007. "Energetic and exegetic aspects of cotton stalk production in establishing energy policies". *Energy Policy* 35 (5), 3015–3024.
- [25] Kavrakoglu, I., 1983. "Modeling energy–economy interactions", *European Journal of Operational Research* 13 (1), 29–40.