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ScienceDirect

Energy Procedia 5 (2011) 382–386

Energy Procedia

IACEED2010

Hierarchical Control of Complex Ecological-Economic Systems

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Abstract

The paper is devoted to developing methods for control of ecological-economic systems consisting of three hierarchically subordinate subjects of control. In describing the dynamics of a system state, equations in partial derivatives that are solved numerically according to a semi-implicit scheme of the finite-difference method are used. To achieve its main goal, the subject of control of the upper level applies different control methods. Methods of hierarchical control that differ in the direction of action are proposed. At last a comparative analysis of the obtained results is made.

Keywords: Ecological-Economic Systems; industrial enterprises; environment contaminants

1. Introduction

Today, some economic regions are on the verge of an ecological catastrophe. As finance of environmental protection is decreasing, problems of environmental safety are getting more and more acute. This specifies the necessity for forecasting changes of the state of an ecological system, assessments of consequences of made decisions for the environment. Therefore, the development of control mechanisms for complex ecological-economic systems is one of the burning tasks .In the last decades, in analyzing ecological-economic systems is used the notion of hierarchically controlled dynamic systems [1] in whose concept a specific character of control mechanisms for real ecological-economic objects is taken into consideration. The simplest hierarchically controlled dynamic system is a two-level systemstudied in [2-5].

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1876–6102 © 2011 Published by Elsevier Ltd.
doi:10.1016/j.egypro.2011.03.065

This paper analyzing ecological-economic systems are used three-level systems that more exactly describe the structure of modern control systems for ecological-economic systems; methods of hierarchical control that allow achieving a stable development of an ecological subsystem are proposed. The main goal of the study is to define optimal standards of distribution of environmental contamination penalty for the center government among budgets of different levels. The solution to this problem may help justify existing standards or develop new ones.

2. Mathematical formulation of the problem

Let along the river there be N industrial enterprises (IE) that discharge contaminants (C) into the river. Discharged C are for convenience divided into carbon and nitrogen-bearing. IE pay penalties for discharge of contaminants into the waterway. Hierarchical three-level systems of river water quality control that involve sources of action of the upper (center government-CG), intermediate (local government-LG), and lower (enterprise-IE) levels and controlled dynamic system (CDS or waterway). It is assumed that relations between the elements of the system under study are organized as follows: CG acts on LG, LG acts on IE, IE acts on CDS. In the system, the presence of feedback is assumed: information about the current state of CDS comes to all subjects of control. CG must maintain CDS in stable state but cannot act on it directly. The indirect action of CG on CDS is in defining what part of money obtained from IE in the form of payment for discharge of contaminants into the waterway comes to LG. The task of CG is to create conditions under which it would be profitable for LG and IE, maximizing money that they receive, to stick to the fixed standards of quality of river and waste water. beside maintaining CDS in stable state, it tends to define optimal standards of penalty distribution among budgets of different levels, i.e., maximize the objective function of the form

$$
\begin{aligned}
J_{\Phi} = \int_0^{\Delta} \Big\{ -C_{\Phi}(y_c, y_n) + \sum_{i=1}^{N} \Big[F^c(T_i^c) H_i^c(t)(1-P_i^c(t)) W_i^c(t) \\
+ F^n(T_i^n) H_i^n(t)(1-P_i^n(t)) W_i^n(t) \Big] \Big\} \quad dt \to \max(\{H_i^{c,n}\}_{i=1}^N);
\end{aligned}
\tag{2.1}
$$

Here t is a time coordinate; $T_i^m(F_i^m(T_i^m)$ is a size of payment per unit of discharged carbon and nitrogen-bearing ($m=c$ and $m=n$ respectively) C on the i th IE at the instant t; $W_i^m((1-P_i^m(W_i^m)$ is an amount of C discharged into the river by the i th IE before (after) purification of waste water per time unit ($m=n,c$); $P_i^m(t)$ is a share of carbon and nitrogen-bearing ($m=c$ and $m=n$ respectively) C removed on the i th IE in the process of waste water purification; C_{Φ} is an expenditure function of CG on the improvement of river water quality dependent on the total amount of C discharged into the river; Δ is an instant up to which the examination is being made; $H_i^{c,n}(t)$ is a share of payment of TP for discharge of contaminants into the waterway that rest with CG in the budget at the instant t. LC tend to maximize money , their objective function has the form

$$
\begin{aligned}
J_y = \int_0^{\Delta} \Big\{ -C_0(y_c, y_n) + \sum_{i=1}^{N} [F^c(T_i^c)(1-H_i^c(t))(1-P_i^c(t)) W_i^c(t) \\
+ F^n(T_i^n)(1-H_i^n(t))(1-P_i^c(t)) W_i^c(t)] \Big\} \quad dt \to \max(\{T_i^{c,n}, q_i^{c,n}\}_{i=1}^N)
\end{aligned}
\tag{2.2}
$$

where C_0 is an LC expenditure function on the improvement of river water quality; $q_i^m(m=n,c)$ are minimal admissible purification rates of waste water per IE that are among the constraints on IE controls. In the functions C_0 and C_{Φ} are reflected material losses of the society and regions due to contaminated water. The goal of IE is to maximize its profit, i.e.,