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Method for Analyzing and Optimizing the Topologic Observability of Cognitive Maps of Complex Spatially Distributed Systems

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***Abstract* — The work offers a new method for analyzing and optimizing the topologic observability of cognitive maps of complex spatially distributed systems in terms of various approaches to setting the optimization problems. Such method is based on a new criterion of optimal level of its observability. The method has been elaborated on the basis of the well-known topologic observability analysis technique applicable to complex spatially distributed systems which are formalized in their geoinformation space of parameters. The work demonstrates an example of application of proposed method.**

***Keywords* — cognitive map; topologic observability; observability optimization; complex spatially distributed system; GIS**

I. Introduction

A great number of modern complex systems belong to the category of spatially distributed systems, e.g. electric energy and electric systems, pipeline and transport systems, river systems, etc. [1, 2]. An optimum control over the processes and parameters of such systems is achievable through the use of cognitive maps (CM) [3-5]. Moreover, great importance in solving the problem of optimization of certain object is attached to the ability to visualize and standardize solution of its problem with CM. For this purpose, CMs are effectively used. A cognitive map is a result of cognitive modeling, carried out by a team of relevant experts. Generally speaking, such cognitive modeling consists in describing certain processes within a given system and the internal events occurring therein.

One of the key attributes of controllability of a system is the observability of such system. Four kinds of observability algorithms are used in state estimators; algebraic, numerical, topological and hybrid. Algebraic observability is defined as the ability of system model to be solved for a state estimate [6]. According to the control theory, a dynamic system is observable if at a finite time interval $t=[t_0,t_1]$, based on the system's output at the end of such interval $y(t_1)$ and using the known control (input) variables $u(t_0)$ it is possible to define all state variable values $x(t_0)$ [1]. The topological algorithms use graph theory and determine network observability strictly based on the type and location of the measurements in the entire system. Consequently, topological algorithms are strictly faster than algebraic ones [6].

There are multiple approaches to determining the observability for cognitive maps, yet they mostly consider the algebraic observability analysis methods [7, 8]. However, such methods are not universal for many types of cognitive maps; they require much effort and time and are hard to computerize in practice.

Topologic observability is applicable to optimizing electric energy systems (EES). Such topologic observability is determined based on special bichromatic graph (BG) of a system: if there is a match where every variable that describes the state of the system corresponds to a strong edge, i.e. the edge which belongs to the maximum matching, then the system is deemed fully topologically observable. Here, it is worth mentioning such scholars well known in the field of topologic observability of complex spatially distributed systems (CSDSs), including EESs, as Clements K.A., Krumpholz G.R., Shahraeini M. A., Gamm A. Z. and others [9-11]. However, the works of the said scholars do not consider the process formalization specifics in such CSDSs with the use of CMs.

The aim of this paper is to develop a method for analyzing and optimizing the topologic observability of cognitive maps of complex spatially distributed systems. The rest of this paper is organized as follows: In Section II, classical formulation of topologic observability will be investigated and famous technology of topologic observability analyzes a complex spatially distributed system will be described. A new method for analyzing and optimizing the topologic observability of cognitive maps of complex spatially distributed systems and an example of its application will be introduced in Sections III and IV, respectively. Finally, this paper will end with some concluding remarks and future perspective in Section V.

II. A known technology of topwologic observability analysis

A. Classical definition of topologic observability

Topologic observability is determined on the bichromatic graph basis. Such graph is a graph comprising two types of nodes: the nodes representing the variables $y_i(i=\overline{1,5})$ and the