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Application of functional modelling to the solution of electrical power system optimization problems

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Abstract

This paper presents theoretical foundations for the application of the principles of functional modelling (FM) to the electrical power systems optimization problems and concrete algorithms for the solution of such of them as optimal operation and optimal development problems. A FM type algorithm includes operations executed on several levels of analysis: lower (subsystems) levels and higher (system) level. On the lower levels functional characteristics of subsystems and their internal variables are calculated, on the higher level boundary variables are computed. Important advantage of FM algorithms is that results obtained with them on each iteration are identical to those of basic sequential algorithms from which they are derived. It is shown in this paper and elsewhere that application of FM algorithms, especially in their parallel realization, can greatly increase effectiveness of optimization problems solution in electrical power systems. Especially efficient is their application to real time operation control of large power systems.

Keywords: Functional modelling; Power system optimal control; Real time control; Parallel processing; Optimal power flow

1. Introduction

Effective control and development of electrical power systems depend to a high degree on the efficiency of algorithms used for solution of the corresponding optimization problems. The requirements to which these algorithms should match and which of them determine their efficiency are well known. They are: acceptable computer time and memory necessary for problem solution within the whole range of problems to be solved and their ability to take into account all factors having essential influence on the solution to be obtained.

The following features of electrical power systems are of great importance for successful development of optimization algorithms satisfying the above requirements:

1. a large extent in space of the system;
2. high dimensionality of the mathematical models representing power systems;
3. high speed of processes in these systems.

Another important requirement to the development of optimization algorithms is their ability to make use of tremendous opportunities offered by the modern computer, communication and measurement technologies for increasing efficiency of power systems control and development.

This paper is devoted to the theoretical foundations for the application of the functional modelling (FM) method to solution of optimization problems in electrical power systems. This method proved very effective for solution of the steady-state and dynamical modelling problems of electrical power systems [1–3]. Analysis of the above requirements and general features of the large power systems on the one hand and the vast opportunities offered by the FM method on the other hand has shown that it is reasonable to expect that optimization algorithms, based on this method, can essentially increase efficiency of optimization solution in this field.

The main principles of the FM method, presented in Refs. [1,2], are the following:

1. Representation of systems and subsystems by functional characteristics (FC). The FCs are input–output characteristics in which vectors of boundary variables are considered as input and output vectors of the system (subsystem). These characteristics are obtained while meeting all equations and constraints within the system (subsystem).
2. Building of models according to hierarchical principles

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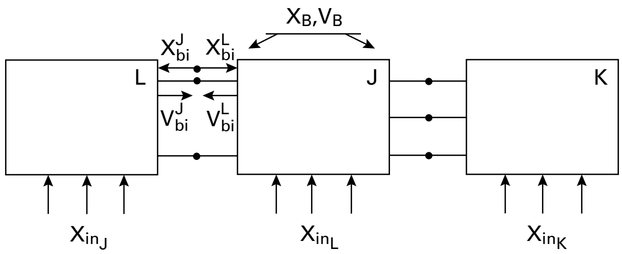

Fig. 1. System presentation in the FM method.

with *n* levels of subsystems and $n + 1$ levels of analysis. On a higher level, each subsystem is regarded as an element of the system, i.e. as a "black box" represented by the functional characteristic. No processes within the subsystems are considered on this level. On lower levels each subsystem is regarded as an open system influenced by the input variables on it's borders. This level is used for determination of FCs and revealing internal processes in those subsystems where it is necessary.

3. Determination of the values of boundary variables on the higher level of the model through formation and solution of the system of connection equations (SCE), comprising equations obtained from Kirchoff's law expressions, pertaining to all boundary nodes.

On the basis of these principles several universal structures of FM algorithms were developed as well as methods of their application to main classes of modelling problems in electrical power systems.

All these theoretical results enable man to develop for any basic modelling algorithm which uses only the notions of "element" and "system" the generalized functional models which use also the supplementary notion of "subsystem" and can have different structures. Owing to this fact it is possible to optimise the structure of the model so that the computation time and memory, as well as human efforts necessary for solution of the problem, were minimal. Subject to optimization in this case are: the number of levels of analysis, the number of subsystems on each level, organization of interaction between the levels and other parameters. The structure of the model obtained by this optimization procedure depends on the characteristics of the system and on the processes studied as well as the purpose of modelling, i.e. what variables of the systems are of interest for the user of the model.

Important feature of the FM method is the possibility to represent some subsystems by their FCs, enabling one to find boundary variables and internal variables of other subsystems without determining internal variables of the former subsystems [1].

The FM method belongs to the large group of methods, which use intermediate transformation of system model in order to facilitate solution of modelling and control problems of large-scale power systems [5,6]. Important advantage of the FM method compared with other methods of this group is that results obtained using the algorithms based on this method, for each iteration, are identical to those of usual one-level algorithms from which hierarchical FM algorithms are derived.

Especially efficient for solution of large-scale power systems problems is the implementation of FM method in the form of parallel algorithms realized on the concentrated and distributed computer systems [3,4].

All these favourable features of the FM method make very attractive the development of optimization algorithms based on this method. This being applied to the solution of control and development problems of electrical power systems, they allow one to overcome many of the difficulties arising from the features of these systems mentioned above.

2. Theoretical foundations for the application of functional modelling to optimization problems

The FM algorithm, in its general form, includes the following steps.

1. Model formation, which can be performed automatically or by an analyst. On this step the structure and parameters of a model are determined in order to make the solution process optimal.
2. Model functioning, subdivided in its turn into steps:

   (a) determination of the FCs of subsystems up to the highest level—upward move;
   (b) building of the highest level model and the solution of the problem at this level, finding in this way the values of boundary variables;
   (c) calculation of the internal variables of subsystems down to the lowest level—downward move.

This general procedure determines the operation of the model on one cycle of interaction between the levels. As shown in Ref. [1] a FM algorithm can be built so that one or several such cycles will be necessary for solution of steady-state or dynamical problem. For instance, the solution of a linear steady-state problem can be obtained by one cycle of interaction, corresponding to one iteration in Newton's method. As to non-linear steady-state problem—for example power flow or transient stability problems—the solution can be obtained from one or several interaction cycles [1].

General approach to solution of optimization problems in the FM method according to Ref. [4] is that they are considered as steady-state modelling problems with supplementary condition of minimization the system objective function. Hence, the general structure of FM algorithm can be applied to these problems provided that optimality constraints are satisfied by these algorithms.

Our goal is to create FM type algorithms intended for solution of power systems optimal operation problems such as economic dispatch including optimal active and reactive power dispatching. Mathematical formulation of these problems is well known. Further, the general structures