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SIMULATION OF OPTIMAL LOADFLOW CONTROL OF ELECTRIC POWER SYSTEMS USING SCADA

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Abstract. *The paper presents simulation using similarity of optimal states that increases the efficiency of optimal loadflow control of electric power systems. Integration of the simulation model into the system of optimal control provide the means of verification of control software in course of operation and perform testing of automated control of regulating devices aiming at comprehensive evaluation of possible all-system result.*
Keywords: *electric power system, optimum control, simulation model, SCADA-system.*

Introduction

In [1] the problem of optimal loadflow and voltage control in electric power systems (EPS) is presented and the block diagram of automated control system is given. The means of monitoring and control of transformers with on-load tap changers that realize the above-mentioned automated system are presented in [2]. The microprocessor-based automated system controlling loadflow and voltage in EPS provides the realization of control laws derived on the basis of similarity theory and modeling. Operation of the system reduces the energy transmission loss and increase voltage quality in electric networks.
The principles of operation of the simulation model are considered in this paper, the model being an element of the system of optimal loadflow and voltage control in EPS presented in [1, 2, 3]. Simulation of optimal states of EPS is based on their similarity.

Simulation in optimal control of EPS loadflow

The method of optimal loadflow control using a simulation model puts the latter into correspondence with the power system on a certain scale. The main purpose of the model is participation in establishing conditions of self-optimization of EPS states [3]. This determines its inner structure, a number and structure of information provided by the supervisory control and data acquisition complex (SCADA) of EPS, and control messages and commands given via SCADA to regulating devices (RD) that optimize loadflow.
Fig. 1 presents a block diagram of the simulation model that is used for optimal loadflow control in EPS [1, 3].
The simulation of the operation of a complex system consists of the following functions:
- simulation of a certain element of the system;
- simulation of interaction between elements;
- simulation of sequence of system events.

Simulation of operation of a certain element of the system is realized as the adjustment of the model to that element of the system and computer realization of the model of the element.
The simulation of interaction between the elements is determination of the coefficients of mutual influence between certain regulating devices and subsystems of EPS on the basis of the method of experiment planning using the similarity of optimal loadflow states of EPS.

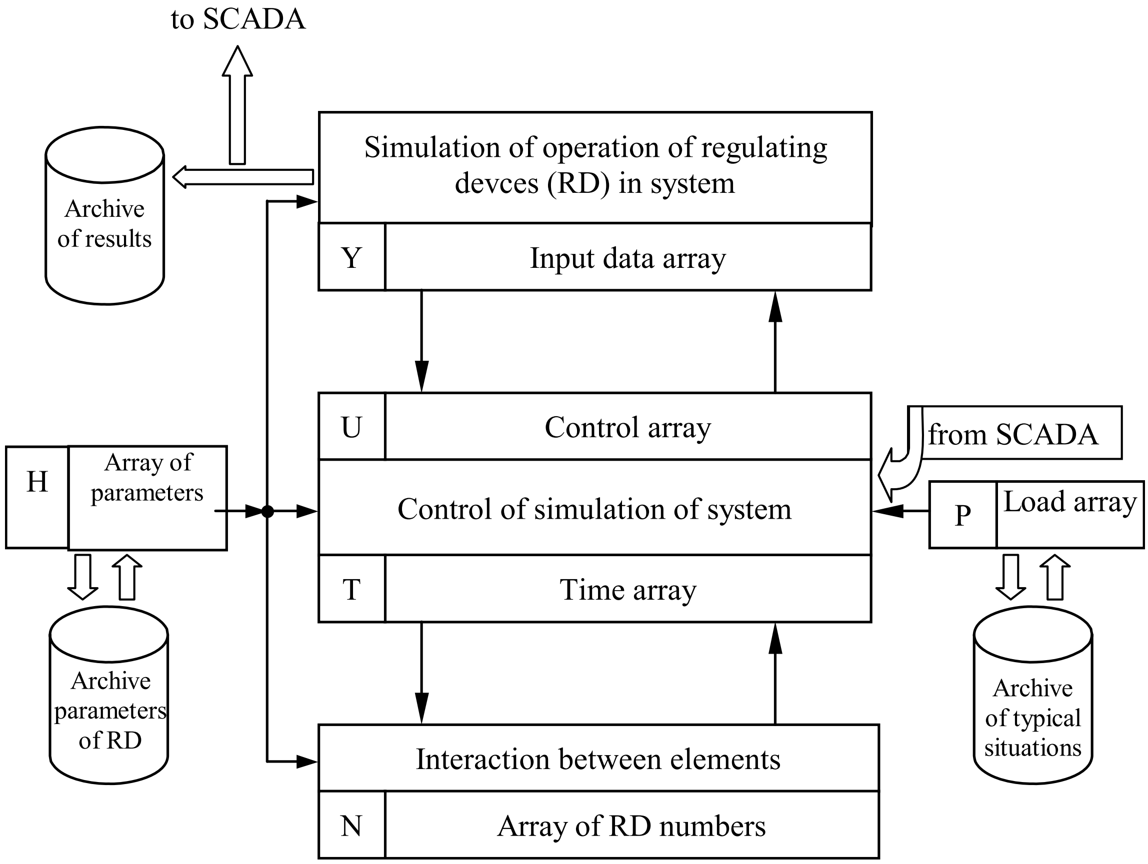

Fig. 1. Block diagram of simulation model

The control of the model is realized as determination of the sequence of system events, which take place in the course of simulation. It is carried out using the simulator of the process that forms an array of arguments, which are measured by the telemetering system, namely the observation array y* (t). In order to take into account specific character of each state of EPS, the array y*(t) is formed based on the data obtained from the archive of typical situations, and from the results of telemetering. The array y*(t) is obtained by the approximation of each i-th component on j-th time interval by the following posinomial function:

$$y_{*ij} = a_{ij}\tau^{\alpha_{ij}} + b_{ij}\tau^{\beta_{ij}}, \qquad (1)$$

where a_{ij}, b_{ij}, , α_{ij} , β_{ij} are the spline coefficients. All this corresponds to the simulation process because information on the real-time state of the system is used.. Thus, the complex system being simulated is divided into subsystems. Each subsystem is a correction zone of a certain regulating device that realizes an optimum control law [1]:

$$u_*(t) = -\pi y_*(t), \qquad (2)$$

$$u_*(t) \in \delta u_* \qquad (3)$$

where u*(t) is the control array; π is the feedback array, which elements are similarity criteria by their physical significance; δu^* is the optimality zone (deadzone), which upper u_*^+ and lower u_*^- limits are evaluated and set for a certain time interval on the basis of analysis of specific states of EPS [1].

In (2) - (3) the parameters are given in relative units. Thus, the parameters of RD, which determine the optimization, are calculated in relative units $u_{*i}=u_i/u_{io}$ (as the basis values u_{io} the optimal values are accepted). All other parameters in (2) - (3) are given in relative units as well.

The problem of optimal loadflow control in EPS is to keep the value of optimality criterion F_* within the established optimality area δF_*. When the criterion leaves the area, the controlling influences are performed by means of regulating devices. As the result the decrease of the optimality criterion from the actual value to the optimum is achieved. Monitoring of optimality criterion, as well as observation of the state parameters of EPS are carried out on the time interval τ.

Simulation model in TRACE MODE system

The simulation model of the automated system of loadflow and voltage control is developed on the basis of TRACE MODE SCADA-system. The given model consists of the elements of different hierarchical levels based on the ideology of distributed control systems in SCADA and SoftLogic industrial automation tools [4].

The development environment of TRACE MODE provides design of several types of monitors (work stations) with certain functions and means according to the type of the process being automated.

The considered simulation model is a part of automated loadflow control system. Functions of data acquisition and execution of process control of the latter is carried out by programmable logic controllers (PLC). TRACE MODE provides the monitors of PLC level that sample transducers and organize data transfer with operator stations, which control on-load tap changers control. It is necessary to provide information on currents and voltage of power transformers of the substation and the currents of transmission lines that connect the control substation (correction node) with neighboring substations (nodes of the correction zone) where voltage directly depends on the voltage in the correction node regulated by on-load tap changer. Values of voltage and currents are obtained from instrument voltage transformers and current transformers of the substation. The PLC level of control system consists of the Micro RTM (real-time monitors) provided in TRACE MODE for data acquisition and realization of control commands by PLC. Such monitors are not supported with graphical interface, but their software organization is similar to that of operator work stations and have means to operate with controllers. This PLC level is organized by the complex system of data acquisition being the part of the automated control system, and it provides the simulation model with necessary information from subsystems of EPS. The simulation model operates not the subsystems of EPS but the models of those subsystems, which state is determined by control actions of the model.

The development of simulation model in SCADA-environment TRACE MODE system requires implementation of control software for each correction zone on the substation level (the part of EPS, where a single regulating device is operated that determines loadflow of the whole subsystem, namely the set of substations of that subsystem); thus, the type of real-time monitor (RTM) of TRACE MODE development system is used for each correction zone as well as the central Supervisor monitor on the administrative level with necessary archive database, data exchange protocols and documentation means (event logging, summary reports, etc).

The model's local level for a correction zone uses RTM, which is a workstation of the operating personnel, where it is possible to perform control within the subsystem. The automation of OLTC control requires mathematical environment to simulate optimal loadflow control in EPS at this level. On the basis of obtained data of loadflow parameters in the subsystem the software estimates optimal transformation ratioes according to the control law and generates control actions to switch taps of OLTC. A subsystem's RTM of the model stores data in local archive and provides the operator with parameters of control via graphical interface.

In case of several subsystems of optimal control connected by information channels it is necessary to develop the administrative level of the model, which monitors the whole EPS loadflow and RD, and summarizes the operation results. The type of Supervisor monitor is necessary, which is a station for graphical representation and analysis of the process. The Supervisor is connected with local RTMs.

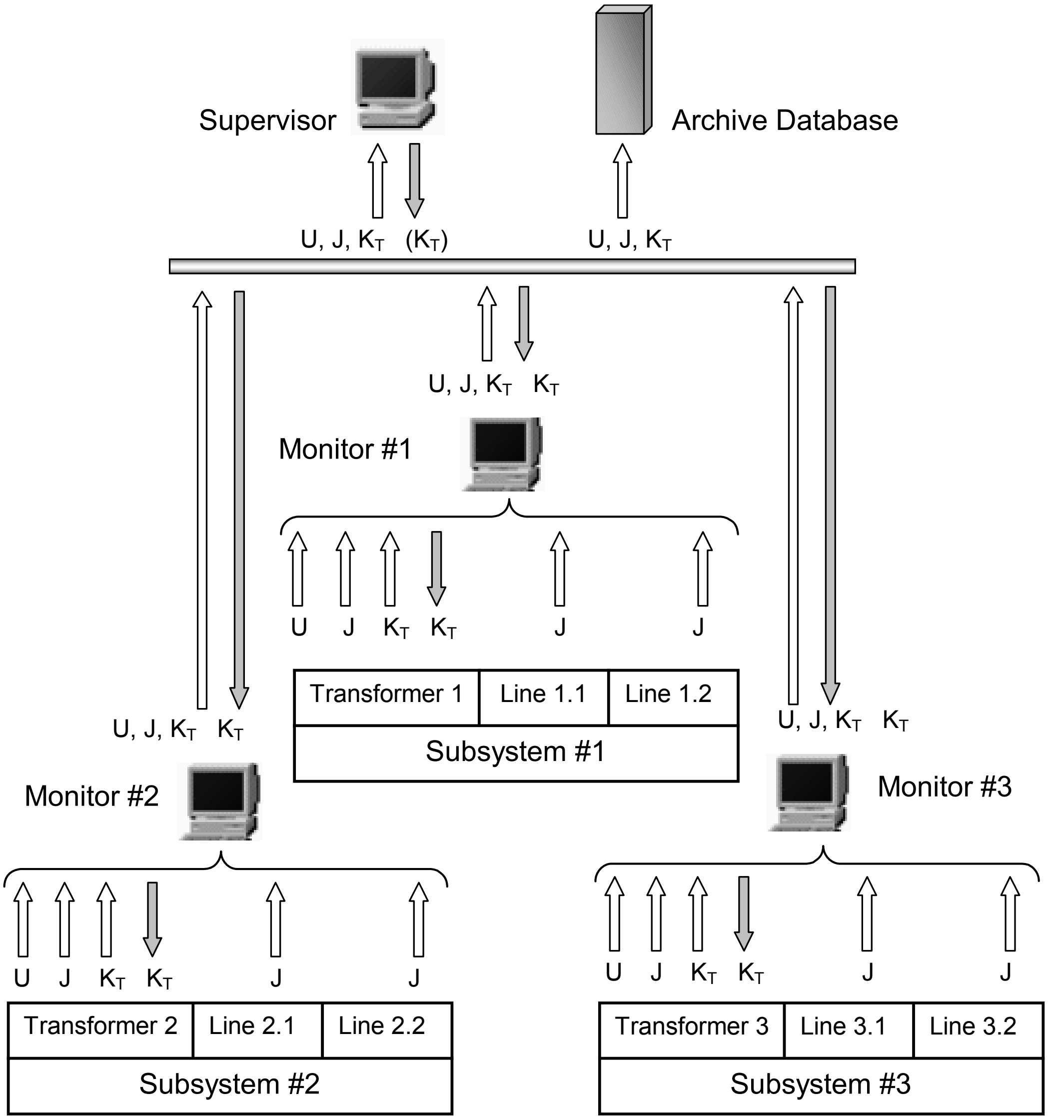

Fig. 2. Block diagram of simulation model using TRACE MODE

Fig. 2 presents the block diagram of the proposed simulation model of loadflow and voltage control realized in TRACE MODE development system, which consists of three subsystems (correction zones). The substation that is a correction node is provided with necessary channels of local loadflow parameters (current and voltage of power transformers with on-load tap changers and transmission lines that connect the correction node with other substations, which load influences the optimality of loadflow within the correction zone.). The tap number of tap changer that is the transformation ratio is also monitored. All parameters are transferred to the local RTM level of the model, where optimal transformation ratios are calculated and the commands of switching taps are simulated for the regulating device. Realization of the switchover is controlled by the change of tap number of OLTC. Simultaneously, the information on switchover and loadflow parameters and parameters of OLTC are transmitted to the SUPERVISOR and the archive server of the model. In case of central optimal control the optimal transformation ratios of operating RD are calculated on the administrative level of the model and transmitted to RTMs of regulating devices for further realization in the substation models.

Operation of simulation model

According to the considered block diagram of simulation model the following operating modes of the model are proposed.

1. The mode of operation in parallel with the basic control circuit when the model receives the data from substations via existing information channels, when the model monitors the main control system and compares the results of the control system with its own control actions. Thus, it provides the verification of operating control system under the condition of the same parameter settings of the model and the control system. That parallel control channel allows to supervise the operation of the basic control channel.

The model is constructed with the loadflow data acquisition in real time, when the data from subsystems is first transferred to the level of monitors of correction zones, while the latter provide the data to the monitor of administrative level. This data organization makes it possible to simulate the model operation in both centralized control mode, when there is complete loadflow data in EPS, and in local control mode, when decisions are made on the subsystem level [3]. It permits to simulate the information uncertainty with some information channels unavailable.

Realization of the simulation model in TRACE MODE SCADA-system provides the means to control basic commercial and engineering performance of the control system. Implementation of SCADA provides not only the development of robust and flexible technological algorithms but also protocols with operation events, emergency messages, a local archive of parameters being controlled.

The interaction of model elements is carried out as follows.

Monitors of the operating control level of the model that operate in the correction nodes (the centers of correction zones) receive the loadflow parameters (currents in power transmission lines and transformers, voltage in the nodes of the correction zone). Provided the parallel additional communication channels between the dispatcher center of the electric power system and substations, the model can get the information directly from the correction nodes. In this case the monitors installed in correction nodes that regulate voltage level in nearby nodes (the latter together with the correction node form the correction zone) send information to the control system and the model in parallel channels, which provide reservation of data channels for the main control circuit. At the same time the Supervisor monitor that is the central core of the model processes the loadflow information of all correction zones, determines optimal setting of regulating devices, and compares them with the parameters obtained by the main control system. In case those prove different the Supervisor disables the main control circuit until the reason of unbalance is determined. This can be caused by software failure, data channel loss, etc. However, this variant of interaction is possible provided developed data acquisition and communication system is operated in the EPS.

In case of failure of the main control circuit the model can send the command to switch on the local control scheme on the level of correction zones according to [3]. Thus, the regulating devices of on-load tap changers will be controlled locally by the monitors of correction zones.

2. A testing mode when the main control system is disabled for test purposes. The model receives the retrospective data from the loadflow archive database and performs testing of the main control system by providing the latter with the archive data with further analysis of its response and failure diagnostics if it occurs.

Except for the operation in the retrospective mode, the testing of the operation algorithm of the main control system can be realized using dynamic simulation of loadflow variation by the model. For example, this mode is used for testing short-term load variation selectivity or failure diagnostics of on-load tap changer drive with determination of time response when realizing switchover of OLTC tap directly at the substation.

3. Modeling of operation of EPS aimed at analysis of control system operation in certain loading conditions for the network using average and forecast load curves. This mode can be a tool for estimation of loadflow control strategy, operation under state constraints, evaluation of commercial and engineering results of loadflow regulation, modeling of optimal variant of network configuration. This requires development of software packages that can be realized in TRACE MODE system using built-in object-oriented algorithmic languages and provided graphical user interface [5].

Conclusions

1. Application of simulation in optimal loadflow control of electric power systems allows to adapt the latter to actual operating conditions of EPS, use the control range of regulating devices more effectively in reaching all-system results, and make the process of optimization more efficient. Development of the simulation model as the element of the automated loadflow control system in EPS provide for verification of software means in actual operating conditions, and test the automated control system of regulating devices in the effect of the latter in reaching all-system results.
2. Application of the methods of similarity theory in the simulation improves its performance due to significant reduction of computational routines and their resource requirements. This is achieved by using of similarity of optimal loadflow in EPS and the computational results are generalized and are used for all loadflow states of EPS being analyzed.
3. Use of intelligent TRACE MODE SCADA-system in simulation process allows to simplify the process of simulation and development of the projects of automation rather considerably due to the powerful means of data acquisition and processing, built-in algorithmic programming languages, developed graphical interface. This increases the overall efficiency of optimal loadflow control in EPS.

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