Thyristor voltage regulator control algorithm research

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Abstract. The article deals with the development and research of thyristor voltage regulator (TVR) dual-zone control algorithm in the electrical distribution networks 6-20 kV. The TVR control system hardware and software complex based on the algorithm was developed using LabVIEW and NI myRIO controllers. The transverse, longitudinal and longitudinal-transversal voltage regulation modes experimental research was conducted by the TVR prototype. The experimental research results confirmed the developed algorithm and its program realization effectiveness and efficiency.

1. Introduction
The electric energy distribution low efficiency problem in long length distribution networks of medium voltage can be solved by the voltage level automatic control devices [1-7]. We have developed a thyristor voltage regulator (TVR) for 6-20 kV long length distribution networks [8]. The TVR principle of operation based on the joint use of longitudinal and transversal voltage control [9].

The TVR control algorithm research task is set in the article. The TVR control system development scientific and technical solutions are given, the control algorithm is described. The TVR prototype with the control system software and hardware complex was made for research. The control algorithm research results at different TVR operation modes are presented.

2. The thyristor voltage regulator dual-zone alternating control algorithm
We have developed a dual-zone alternating control algorithm for the TVR control system [10-11]. The algorithm block diagram is shown in Figure1.

The line voltage parameters are the input data. The TVR thyristor control pulses implementing various modes of the device are the output data.

The dual-zone alternating control is implemented by α1 and α2 thyristors unlocking angle variation intervals. This algorithm allows to convert TVR into a nonconducting condition if needed.

The thyristor control angles discrete change with a variable step is used to improve the performance and linearize the regulation characteristics of the longitudinal and transversal control modules.

The algorithm represents the following sequence of actions:
1. TVR startup and performance parameters achievement.
2. Readings are taken from the voltage sensors connected to the windings of the TVR parallel transformer.
Figure 1. The TVR dual-zone alternating control algorithm block diagram.

3. The clock generator voltage sensor generates voltage transition through zero signals on its output during the transition of voltage from a negative to a positive value and back. These signals synchronize the RS-trigger operation that is a part of the clock generator. The positive and negative half-cycles signals are formed at the output of the RS-trigger, respectively.

4. Control signal and voltage transition through zero signals generated by the voltage sensor come to the unrelated phase shifting device inputs. The values of the α1 or α2 switching angles are determined by the control signal with a base voltage comparing. Thus, it is possible to regulate the values of the angles α1 and α2 by changing the value of the control signal.

5. Control voltage, base voltage and the signal from the unrelated phase shifting device are the input signals for the related phase shifting device. These signals determine the related phase shifting device operation mode forming "1" or "0" logical signal on the output, which define the operating mode of voltage increase or decrease.

6. The formation of the thyristors control pulses duration is carried out in the thyristors control pulses generator block under the influence of the clock generator, related and unrelated phase shifting devices blocks input signals.

The above mentioned algorithm does not require the use of the current sensor. Therefore the TVR regulating properties are intact during transformer idling condition.

3. The thyristor voltage regulator control system hardware and software complex

The TVR control system hardware and software complex based on the algorithm was developed. The software is implemented by the LabVIEW graphical language with Real-Time and FPGA modules [12]. The hardware represents programmable controller with built-in FPGA programmable logic device NI CompactRIO model. NI myRIO-1900 device was used for program testing and debugging.

Program executables provides controller operation, which generates and transmits the control pulses to the TVR thyristors in the following:
- startup;
- longitudinal regulation;
- transverse regulation;
- longitudinal-transversal voltage regulation.

Generated pulses monitoring is carried out by using the built-in oscilloscopes. The program includes functional blocks intermediate values continuous monitoring in real time, and there is a possibility of step-by-step execution when debugging.

The TVR control system hardware and software complex structural scheme is shown in Figure 2.

**Figure 2.** The TVR control system hardware and software complex structural scheme.

Control actions come to the programmable controller, which passes them to the FPGA programmable logic device. Synchronizing pulses are generated at the FPGA level from the received voltage values of the transformers high voltage winding. These pulses are generated at the time of voltage polarity changing at its zero crossing. TVR thyristors control pulses are generated in the programmable logic device due to the commands received from the programmable controller.

The regulation block designed on this platform contains input/output digital and analog information blocks, synchronization and control parameters calculation, output voltage magnitudes and phase angles convert blocks.

The program consists of the following main modules: regulation logic module, counters module, multiplexer module, comparators module and decoders module. The program also includes a rectangular pulse generators module.

The program works as follows. The regulation logic module generates commands to counters control and forms control signals to them. Counters record the number of these commands and produce an output result for further processing, which affects the thyristors groups control pulses formation. The count pulses formation gated with the signal coming from the voltage sensors. Counting results come to decoders blocks that form a finite number of variables compared with the counting results via comparator module. Variables that are determinant for the decoder are generated as a result. Decoders generate TVR thyristors groups control pulses gated with signals from voltage sensors.
Figure 3. TVR control system regulation block software realization.

TVR control system regulation block program front panel is shown in Figure 4.

4. Results and discussion
The TVR control algorithm research at the in the transversal, longitudinal and longitudinal-transversal voltage regulation modes was conducted using the developed hardware-software complex. Mode selection is carried out remotely using the buttons on the program front panel.

The experimental oscillograms of the input \(u_{in}\) and the output \(u_{out}\) voltages at the researched modes are shown in Figure 5 – 10.
Research results analysis shows that phase shift of the output voltages regarding the input voltages is provided in the range of the angles $\alpha = \pm 15^\circ$ at the transversal voltage control mode (Figure 5, 6). The longitudinal control mode (Figure 7, 8) allows increasing or decreasing the TVR output voltage to $\pm 15\%$. The longitudinal-transverse mode (Figure 9, 10) allows getting the output TVR voltages different from the input voltages in the magnitude and in the phase.
TVR operation modes research results analyses shows that the developed dual-zone alternating control algorithm provides the reliable thyristors switching and the smooth control of the output TVR voltage in the transversal, longitudinal and longitudinal-transverse modes. The use of the current sensor is not required for this algorithm implementation. Therefore the TVR reliable operation is ensured at any phase shift of the load current regarding the supply voltage, as well as at idling condition.

5. Conclusion
The TVR control system conducted research has proven performance and efficiency of the developed dual-zone control algorithm and hardware and software complex created on its basis.

The control system as part of a thyristor voltage regulator allows to automate the voltage level control process in the 6-20 kV distribution networks.

Acknowledgments
This work is supported by the Ministry of Science and Higher Education of the Russian Federation (agreement №14.577.21.0242 for a grant on September 26, 2017). The unique project identifier is RFMEFI57717X0242.

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