TELKOMNIKA, Vol.11, No.1, January 2013, pp. 476~483
ISSN: 2302-4046

Research on the AVC Testing Platform for the Regional Grid based on Real-Time Digital Simulator (RTDS)

Lin Xu*[1], Yang Han[2]
[1]Sichuan Electric Power Research Institute, No.24, Qinghua Road, Qingyang District, 610072 Chengdu, China
[2]University of Electronic Science and Technology of China, 611731 Chengdu, China
*Corresponding author, e-mail: xulin198431@hotmail.com, hanyang_facts@hotmail.com

Abstract

The automatic voltage control (AVC) relay provides real-time automatic control for the on-load transformer tap changer (OLTC), which is widely used for power system voltage monitoring and control purposes throughout the world. However, there are no uniform testing standards for the AVC system, and the lack of on-site inspection means has stimulated the introduction of the real-time digital simulator (RTDS)-based testing platform. This paper introduces the testing platform of the AVC controller based on the RTDS. The circuit model of the regional power grid is established, and the OLTC and the reactive power compensation devices are also incorporated. The intermediate data conversion device is utilized for bi-directional data exchange of the remote meter and control signals between the RTDS and the AVC system. The principle of the AVC voltage regulation and the RTDS-based AVC testing platform are introduced, followed by the data flow of the OLTC and capacitor/inductor banks, which formulates the foundation for closed-loop testing of the AVC control system for the electric power system.

Keywords: *RTDS (Real time digital simulation), AVC (Automatic voltage control), data conversion, closed-loop control, testing platform, on-load tap changer (OLTC)*

Copyright © 2013 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

The increasing integration of regional transmission system has stimulated the emerging of inter-connected, trans-continental electric power grid. The security, reliability and supreme quality of the power transmission and distribution are major concern for the electric power engineering societies throughout the world, both in the industry and the academic communities [1-4]. At the same time, the power electronic components are widely used in the power system, such as the high voltage DC transmission (HVDC) or the flexible AC transmission systems (FACTS). The testing of the power electronic devices, as well as the supervision control of the power flow and voltage levels are challenging task, which are indispensible technical requirement for promoting the smart grid (SG) revolution globally [5-7].

The main function of the grid AVC (automatic voltage control) system is to ensure the security and stability operation of the power system, and ensure that the voltage and power factor of the specific buses are within the preset values, and also minimize line reactive transmission, reduce the power loss of the grid due to unnecessary reactive power flow. The AVC relay provides real time automatic control for the on-load transformer tap changer (OLTC). When the transformer's secondary voltage is outside the permitted margin, thus the relay issues a command to change the tap position to restore it to the preset limits [1, 3, 4, 7].

The OLTCs interact with each other whenever there is a voltage deviation on the system. Traditionally, each voltage level is graded with the next, using simple time delays. This ensures that the upstream tap changers take priority over the downstream units and make their tap changes first. This prevents hunting and reverse actions by lower-level tap changers. Unfortunately, the voltage control can become crude and inefficient at small voltage deviations [3, 4]. The new control strategies have been developed to improve the coordination of the AVC relays and hence provide an improved 'quality of supply' for consumers [1, 4, 5, 8-12].

In perspective of network security and convenient maintenance, the AVC and the energy management system (EMS) platforms are normally designed together. The real-time acquisition of data is achieved from PAS network modeling control model and the online

Received September 15, 2012; Revised December 5, 2012; Accepted December 13, 2012

analysis and calculation can be realized. Besides, the unified monitoring, supervision and control of the OLTC as well as the reactive compensation devices are utilized to achieve optimized reactive power and voltage control purposes. The AVC system achieves the ccentralized monitoring and analysis of the reactive power and voltage status of the entire network from a global perspective. By using the optimal control strategies of the wide-area distributed grid reactive power regulation devices, the stability and quality of the system voltage is significantly enhanced. And the economical operational of the electric power system can be easily achieved [1, 5, 7, 13-16].

In order to overcome the difficulty of no uniform testing standards for the AVC system and the lack of on-site inspection means for online state estimation of the electric power grid. The real-time digital simulator (RTDS)-based AVC testing platform is introduced. The circuit model of the regional power grid is established, and the OLTC and the reactive power compensation devices are also incorporated. The intermediate data conversion device (OPEN3000) is utilized for bi-directional data exchange of the remote meter and control signals between the RTDS and the AVC system. The principle of the AVC voltage regulation and the RTDS-based AVC testing platform are introduced, followed by the data flow of the OLTC and capacitor/inductor banks, which formulates the foundation for closed-loop testing of the AVC control system for the electric power system.

2. Principles of the AVC (Automatic Voltage Control) system

2.1The control model of the AVC system

In the perspective of network security and maintenance convenience, the integrated design is adopted for the AVC and EMS platforms. The control model is obtained from PAS network, and the real-time data acquisition is obtained from the SCADA system. The centralized monitoring, unified management, and optimal control of closed-loop operation of the whole network is achieved by using online analysis and calculation of the grid and substation OLTC devices, as well as the reactive power compensation devices [1, 4, 5].

The hierarchical partition-balance principles must be guaranteed to optimize the power system reactive power flow at high voltage level, namely:

(1) It should have sufficient reactive power, thus power system operation in the high voltage level can be ensured;
(2) The grid reactive power balance should be ensured at different voltage levels, in order to avoid excessive reactive power exchange, which will help to improve the power factor of the transmission system;
(3) The long-distance transmission of reactive power should be avoided, reactive power within different voltage levels should be partitioned as much as possible, thus reduce network losses. Besides, it is worth emphasizing that the voltage and reactive power balance on the total amount is insufficient, one must balance the reactive power locally;
(4) The characteristics of local and dispersed reactive power balance indicate that the hierarchical partitioning control must be implemented for the AVC system with space and time decoupled control algorithms, thus the coordinated and effective AVC control can be achieved, and voltage and reactive power fluctuations or oscillations can be eliminated.

2.2 The system control mode of the AVC

The automatic voltage control (AVC) system is based on the optimized control structure of the reactive voltage optimization and the global coordination of the network security and economical aspect. The optimal power flow calculation and online soft partition of the three-level voltage optimization control is adopted. And the centralized decision-making and the coordinated sub-control is utilized for reactive power and voltage optimization control. The constraints of the grid security and the online optimization calculation result in reasonable correction of voltage and reactive power optimization strategies to achieve automatic reactive power and voltage control [1, 5, 7].

Figures 1 and 2 show the schematic diagrams of the overall structure of the AVC system for the three-level voltage control based on soft partition control, respectively. The three-level control is responsible for the reactive power optimization calculation of the global network. The whole network bus voltage optimization is utilized as overall optimized control objectives, and the superior coordination control requirements are used as constraints for the whole network, and the power plants and substations are treated as control targets.

On the other hand, according to the real-time status of the regional power grid, the automatically control zoning partitioning is achieved based on the characteristics of the regional grid partitioning and radiation features. The second-level control is based on the traditional voltage and reactive power correction control, followed by the optimization goals of the third-level voltage control. By using the expert rules, the discrete device control regulations requirements are guaranteed. Meanwhile, the first-level control degrades as an executive agent, mainly responsible for the substation capacitor/reactor switching and transformer tap switching.

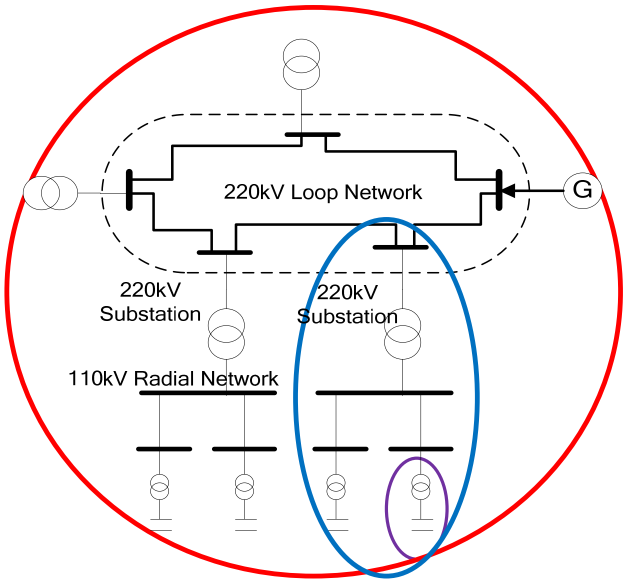

Figure 1. The schematic diagram of the soft-partition-based three-level voltage control

3. The basic composition of the test system

3.1. The RTDS-based AVC test system

Figure 2 shows the overall data flow diagram of the AVC system, the system model of the study area is built in the RTDS platform, the telemetry data (bus voltage, the transformer side active/reactive power, the active/reactive power at the line terminals, transformer tap position), remote signaling data (the controllable capacitor/reactor switch position at each substation) are transmitted to the intermediate data conversion devices. Meanwhile, the remote control commands (sub-closing) of the controllable capacitor/reactor switching are also received.

The data acquisition and remote data transmission between the AVC SCADA system and the intermediate data conversion devices is achieved by using IEC104. The dynamic partitioning of the study area is realized by the AVC system after the filtered data is obtained, the control mode is automatically selected according to the space distribution of the grid voltage and reactive power status, and the control mode priority is "area voltage control" > "voltage correction control" > "regional reactive power control".

For example, in case of regional low voltage, then “area voltage control” is activated, thus the voltage level is rapidly increased. In case of excessive overvoltage or under-voltage occurs, the "voltage correction control" is activated to ensure the allowable node voltages. In case of qualified node voltages throughout the network, then the economic operation of the network is adopted by using “area reactive power control”. Then, the control commands and alarm latching signals are sent to the remote interface for execution.

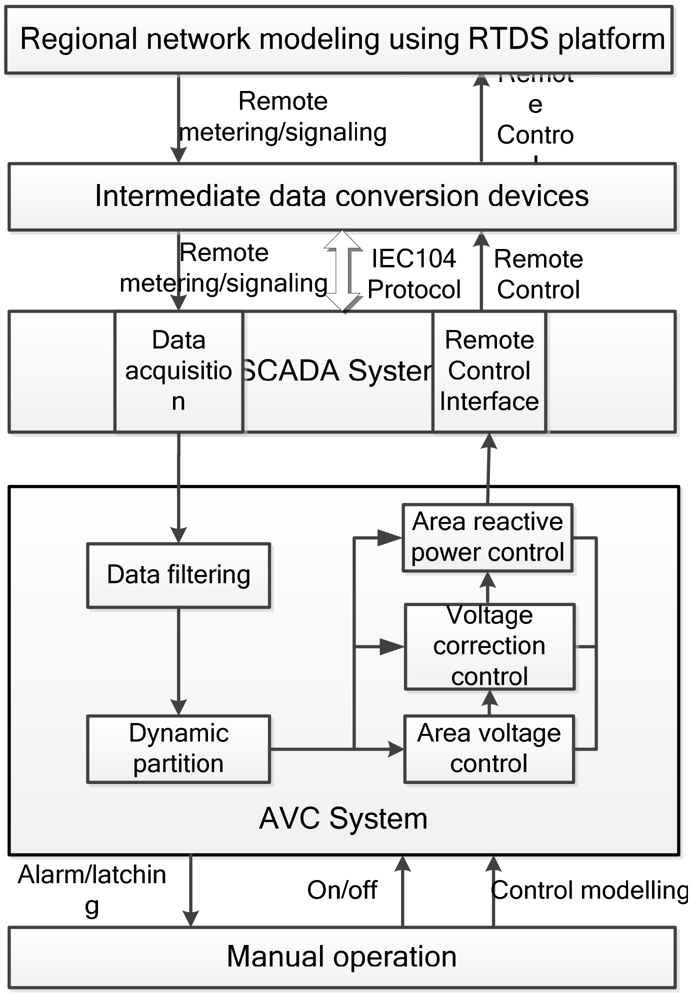

Figure 2. The overall data flowchart of the AVC system

In the initialization process of the AVC system, you need to manually set the "on-off" logic and control models. The hybrid control structure is adopted for the AVC system; hence the closed-loop control automatically coordinates the voltage and reactive power status. For instance, when the AVC system detects a voltage limit violation, the discrete event is formulated to drive the controller, which is sent to the remote interface for execution. Therefore, the system executes the command to form a new steady-state power flow to eliminate the voltage limit violation.

If the grid voltages are within the allowable limits, the "area reactive power optimization control" is activated. The sequential switching mechanism is adopted for the reactive devices, i.e., only one switching adjustment is allowed during one control period. This characteristic is vital to provide sufficient response time for the network to form a new steady-state power flow after the discrete control action is imposed to the network. In the next control period, the AVC controller selects the control mode automatically, thus approaching optimal operation of the network gradually and control overshoot is also effectively avoided.

The unified software platform is adopted for the AVC and SCADA system. The control model is obtained from PAS network, and the real-time data acquisition is obtained from the SCADA system. The centralized monitoring, unified management, and optimal control of closed-loop operation of the whole network is achieved by using online analysis and calculation of the grid and substation OLTC devices, as well as the reactive power compensation devices. The data flow diagram of the AVC system modeling is shown in Figure 3.

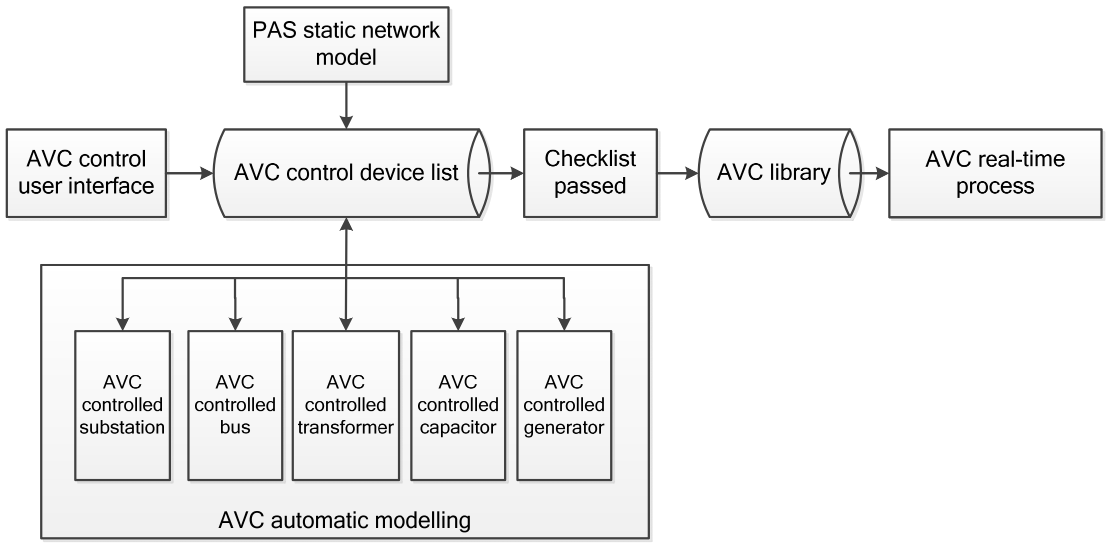

Figure 3. The data flowchart of the AVC automatic modeling

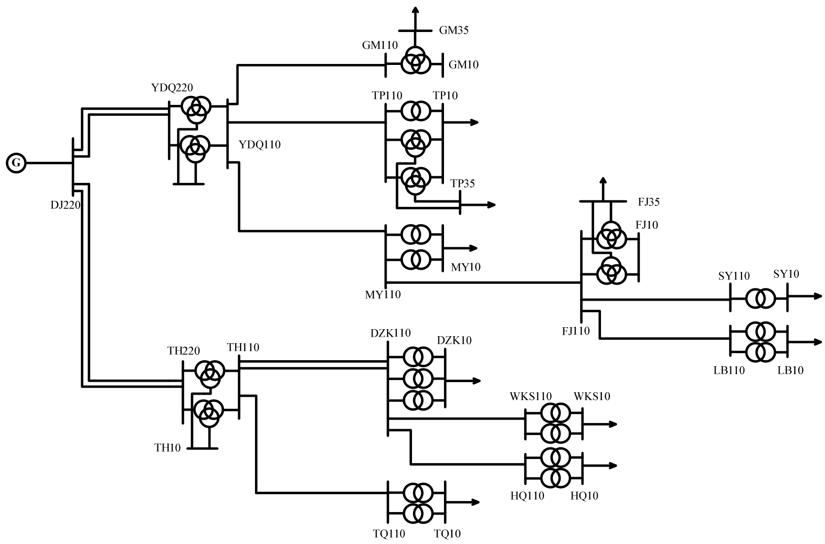

Figure 4. The topology of the study area of the AVC system

3.2. System modeling and control strategy based on the RTDS platform

Figure 4 shows the topology map of the study area of the AVC, which consists of two 220kV substations and ten 110kV substations, the remote networks are represented by the equivalent generators. Figure 5 shows the system model of the RTDS research area, which consists of the main circuit, control circuit and input-output channel configuration. The control subsystem contains the active/reactive power control loop, the transformer tap control, the controllable capacitor/reactor switching logic control. The input and output channel configuration send the analog signals to the analog output channels (AO), such as the bus voltages, transformer active/reactive powers, the active/reactive powers at both ends of the line, as well as the transformer tap positions. Besides, the switch position signals are sent via the digital output channels (DO). And the opening and closing of the switch and the on-load transformer “up/down” signals are sent to RTDS system via digital input channels (DI). The schematic diagram for detailed configuration is shown in Figure 6, which can also be referred in the RTDS manual configuration instructions.

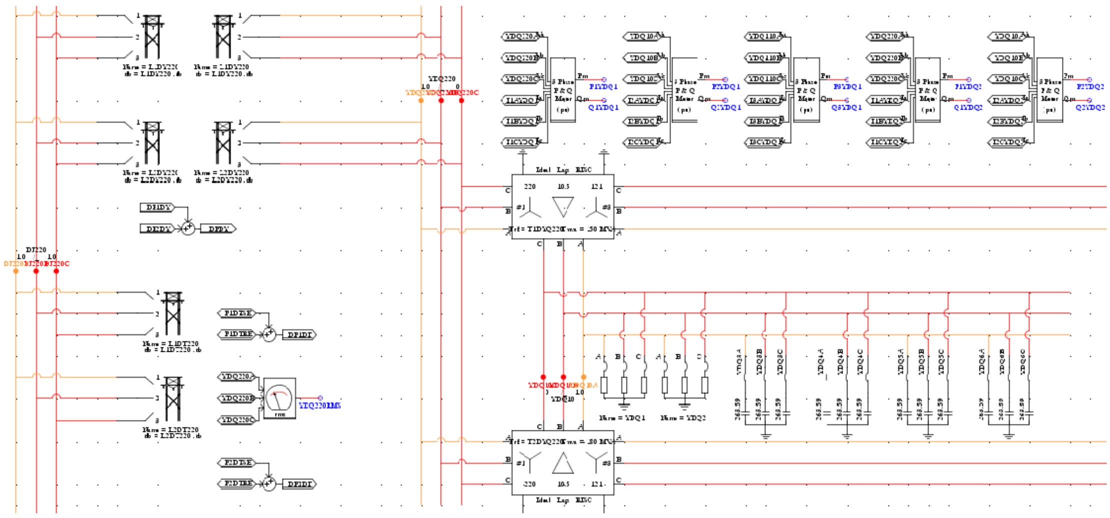

Figure 5. The system model of the study area of the RTDS system

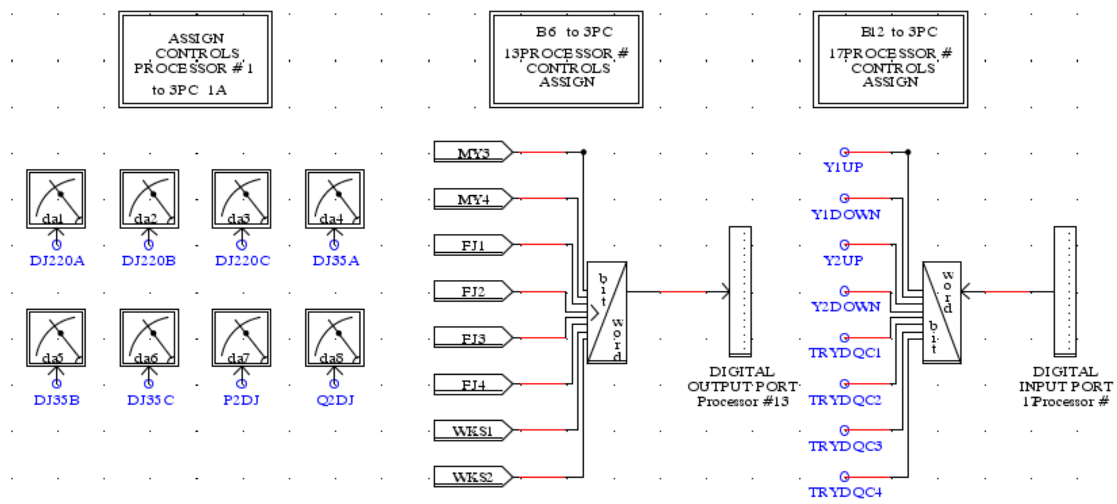

Figure 6. The analog output and switch input / output configuration of RTDS

Figures 7 and 8 show the on-load transformer tap-changer control and logic control block diagram of the capacitor banks, respectively. As shown in Figure 7, the “UP” and “DOWN” denote the up-shifting and down-shifting commands of the AVC system, “TAP0” denotes the initial tap position of the transformer, “DW” denotes the real-time tap position of the transformer. When there is no need for changing the tap positions, the voltage levels of “UP” and “DOWN” are low. When the tap position needs to be adjusted, a rising edge of the trigger pulse is generated for “UP” and “DOWN”. A corresponding increase or decrease of the tap position would be executed when the rising edge of the trigger pulse is detected.

As shown in Figure 8, “TRYDQC1” denotes the capacitor on/off signal generated by the AVC system, “YDQ1” denotes the capacitor switch position signal, “SH” and “ST” denotes the switch on and switch off signal of the manual switch, respectively, to facilitate logic testing for the switch position signals. The relationships of the four signals “TRYDQC1”, “YDQ1”, “ST” and “SH” are shown in Table 1.

Table 1. The relationships between the capacitor switching signal and switch position signal

SH	ST	TRYDQC1	YDQ1
0	0	0	Remain unchanged
0→1（↑）	0	0	1
0	0→1（↑）	0	0
0	0	0→1（↑）	reversed，1→0，0→1

When “SH”, “ST”, “TRYDQC1” are low, “YDQ1” remains unchanged. When a rising edge of the trigger pulse is detected by the signal “SH”, “YDQ1” is set to 1 and the capacitor is switched on. When a rising edge of the trigger pulse is detected by the signal “ST”, “YDQ1” is set to 0 and the capacitor is tripped. When the trigger pulse is detected by the signal “TRYDQC1”, the signal “YDQ1” set to the opposite state (from 0 to 1 or from 1 to 0).

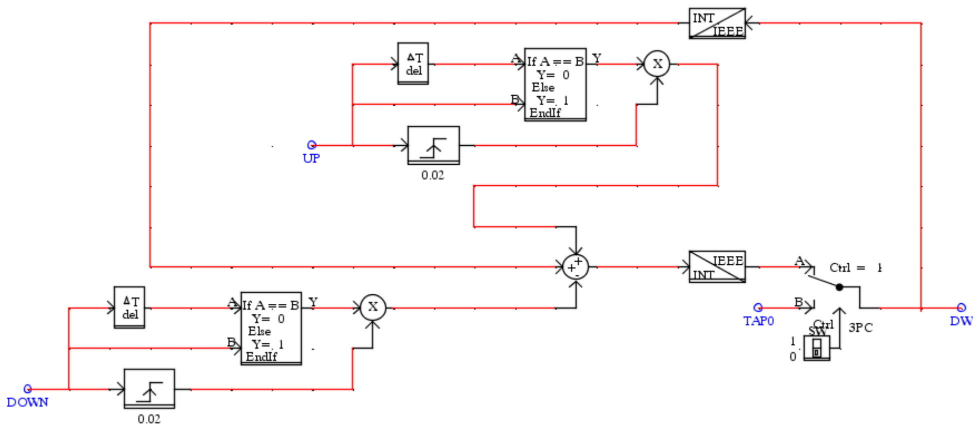

Figure 7. The control block diagram of the on-load transformer

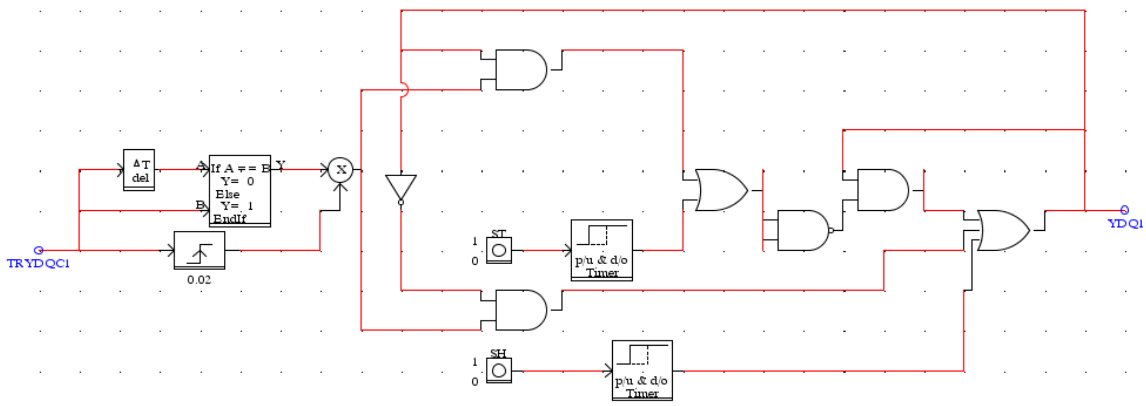

Figure 8. The switch logic control block diagram of capacitor banks

4. Conclusion

The real-time digital simulator (RTDS)-based automatic voltage control (AVC) testing platform is introduced in this paper. The circuit model of the regional power grid is established, and the OLTC and the reactive power compensation devices are also incorporated. The intermediate data conversion device (OPEN3000) is utilized for bi-directional data exchange of the remote meter and control signals (the active-, reactive powers and voltages at the transformer, bus voltages, shunt-connected capacitors or inductor banks) between the RTDS and the AVC system.

The principle of the AVC voltage regulation and the RTDS-based AVC testing platform are introduced, followed by the data flow of the OLTC and capacitor/inductor banks, which formulates the foundation for closed-loop testing of the AVC control system for the electric power system. Due to the space limitation, the results of real-time state estimation and the test result of the AVC control strategies would be reported in the forthcoming papers.

References

[1] P Kundur. Power System Stability and Control. New York: Mc-Graw-Hill. 1994.
[2] N Mohan, TM Undeland and WP Robbins. Power Electronics: Converters, Applications, and Design. New York: Wiley. 1995.
[3] PM Anderson. Power System Protection. Piscataway, NJ: *IEEE Press*. 1999.
[4] M Ilic and J Zaborszky. Dynamics and control of large electric power systems. New York: Wiley. 2000.
[5] LL Grigsby. Electric Power Generation. *Transmission and Distribution.* Boca Raton, FL: CRC Press-Taylor & Francis Group. 2006.
[6] MH Rashid. *Power Electronics Handbook*. San Diego, CA: Academic Press-Elsevier. 2007.
[7] R Marconato. *Electric Power Systems*. Milan, Italy: CEI. 2008; 2.
[8] JS Thorp, M Ilic-Spong and M Varghese. "An optimal secondary voltage-var control technique". *Automatica*. 1986; 22(2): 217–222,.
[9] Kuffel, J Giesbrecht, T Maguire, RP Wierckx, PA Forsyth and PG Mclaren. "RTDS- A Fully Digital Power Simulator Operating in Real Time". *1995 WESCANEX Conference Proceedings on Communications, Power, and Computing*. 1995; 300 – 305.
[10] R Kuffel, J Giesbrecht, T Maguire, RP Wierckx, PA Forsyth and PG Mclaren. "A Fully Digital Real-Time Simulator for Protective Relay Testing". 1997 Developments in Power System Protection, *Sixth International Conference*. 1997: 147-150.
[11] P Forsyth, R Kuffel. "Utility Applications of a RTDS Simulator". *2007 IPEC International Power Engineering Conference*. 2008; 112-117.
[12] Real Time Digital Simulator Power System and Control User Manual. *RTDS Technologies*. 2009.
[13] Corsi S, Pozzi M, Sforna M, Dell'Olio G. The coordinated automatic voltage control of the Italian transmission Grid-part II: control apparatuses and field performance of the consolidated hierarchical system. *IEEE Transactions on Power Systems*. 2004; 19(4): 1733-1741.
[14] Corsi S, Pozzi M, Sabelli C, Serrani A. The coordinated automatic voltage control of the Italian transmission Grid-part I: reasons of the choice and overview of the consolidated hierarchical system. *IEEE Transactions on Power Systems*. 2004; 19(4): 1723-1732,.
[15] Gao C, Redfern MA. Automatic Compensation Voltage Control strategy for on-load tap changer transformers with distributed generations. *2011 International Conference on Advanced Power System Automation and Protection (APAP)*. 2011; 1: 737-741.
[16] Li Miao, Sun Jian Bo, Li Xiao Ping, Hu Wei, Xu Fei, Dynamic Hybrid Automatic Voltage Control of the power system. *2011 International Conference on Advanced Power System Automation and Protection (APAP)*. 2011; 3: 1918-1924.