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Status evaluation of smart substation measurement and control device

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Abstract. In power system, measurement and control device plays an important role in maintaining an ideal level of reliability. Therefore, the reliability of the measurement and control device should be evaluated to fully understand the cause of its failure. A new evaluation model is proposed, which relates the fault of measurement and control system with the four main reasons of device hardware fault, software fault, auxiliary equipment fault and human fault. In addition, the model can also comprehensively consider other aspects of the measurement and control system, such as human error in testing and software upgrade, effectiveness of daily operation monitoring, degree of dependence on self-inspection, local backup and misoperation. These studies have a lot of significance to the reliability of the control system, and also can effectively improve the stability of the system.

1. Introduction

The measurement and control device of substation plays an important role in maintaining the high reliability of power system. For the measurement and control device, there are two sharp problems :operation failure and misoperation. The reliability of measurement and control device includes reliability and safety. Robustness is the ability of a device to function normally. Safety means that the measurement and control device will not send out an error signal or refuse to trip[1]. People have done a lot of work to study all aspects of the measurement and control system. An evaluation method of system robustness is given in [2]. Then, the model was optimized in [3] and [4], the redundant configuration of BCU device, the inspection of BCU operation, the occurrence of common fault reasons and the phenomenon of fault clearance are considered in detail.

The latest development of digital technology has a great influence on the measurement of multi-functional substation and the design of control system. Until recently, the measurement and control function of each bay is implemented by a separate device. Measurement and control devices are now implemented by embedded systems. Multiple functions can be implemented in the same processor or in the same computer with multiple processors. The compatibility of microcomputer technology implementation brings the concept of functional integration: On the hardware platform, multi-bay measurement and control functions are realized in the form of centralized IEC61850 modeling. Thanks to this technology, hardware reduction, connection, and installation time to reduce costs. In addition, functional integration is expected to reduce the service life and operation cost of microcomputer equipment [5].

The self-inspection of the equipment strongly guarantees the reliability of the equipment[6]-[9].In the reliability evaluation of BCU system, considering the influence of self-test, the previous model was modified. The influence between redundant measurement and control devices is studied in [10]-[11]. Markov model is proposed, which takes into account such factors as routine test inspection, monitoring self-inspection, temporary and permanent fault, backup measurement and control system operation and fault trip. Monitoring is usually continuous in the time domain and can be used to detect fault trends. These self-checking mechanisms are used to verify whether the key measurement and control functions are running correctly. The measuring and controlling device can realize the monitoring without exiting the running state, and can eliminate faults during the monitoring and testing. However, in the process of self-test, the equipment will be completely or partially discontinued, resulting in temporary unavailability, leading to [11]. Theoretically, improper self-inspection interval will reduce the reliability of equipment.

There are other factors that can affect the reliability of the measurement control system, apart from the self-examination interval. Literature [12] proposes to determine the following factors according to industry experience: actual operation state of power grid, concept of measurement and control algorithm, new product upgrade, technical change, topological complexity of product, training of operation personnel, requirements of state grid specification, relevant auxiliary equipment, assembly process, installation and debugging environment, electrical environment and maintenance scheme.

From a qualitative perspective view [12], this paper proposes a new considerations for quantitative evaluation of the reliability of modern measurement and control system considering the above factors. In this model, BCU system failure is attributed to follow reasons:

1) Hardware failure: in addition to the measurement and control technology, hardware is also a critical component of BCU, hardware failure will lead to the device out of operation.

2) Software fault: in modern measurement and control equipment, software modules are used to realize complex algorithms. The failure of software modules will lead to the failure of the entire measurement and control system.

3) Auxiliary equipment fault: the reliability of auxiliary equipment of measurement and control device is inseparable from the performance and reliability of the whole system.

2. Demand analysis

The original intention of the model is that there is no effective measurement and control device evaluation method in the existing research. In addition to software and hardware failures. Model in this paper also takes many aspects of the measurement and control system into account, such as daily detection efficiency, operational maintenance differences, and self-inspection in the detection of different types of failure (operational failure and misoperation). The part of case analysis shows the actual effect of the model.

From the perspective of the causes of transmission system events, China's power grid has appeared for consecutive years [13]. Therefore, the main reasons for the failure of the measurement and control system are as follows: hardware failure of device: hardware failure accounts for 10% of the total failures statistics caused by substation equipment failure. There is no doubt that regardless of the measurement and control technology, hardware is a key part of every device.Any hardware unit failure could lead to a device running out. The hardware failure rate clearly represents the occurrence rate of the Markov model.

Application failure: previous measurement and control technology was based on hall element acquisition. Application is the main component of smart substation measurement and control technology, and the algorithm is realized by software. The failure of measurement and control algorithm will lead to the failure of the entire substation measurement and control system, especially in the cluster measurement and control devicethat can perform multiple tasks and different functions.So the robustness of the software is critical in the device. Therefore, an effective software evaluation mechanism is particularly important. Software reliability needs to be established on the basis of time-domain constraints [14], and the error-free operation probability over a period of time should be assessed. In the Markov model of this paper, the concept of software failure rate has been introduced, so Shooman model that leads to application failure rate is presented here. Shooman model was built upon the following study [15]-[16]:1.The set of program instructions is constant. 2. The number of errors is constant when the entire substation test is started. 3. The concept of residual is the initial error minus the cumulative correction error. The number of misdirection is proportional to the residual error. Based on these upon:

$$e_r(x) = e(0) - e_c(x) \tag{1}$$

Assumes that the failure rate and residual form proportional relationship：

$$\beta_s(t) = H_s e_r(x) \tag{2}$$

The reliability or survival function is expressed as：

$$F(t) = e^{\left[-\int_0^t \beta_s(t)dx\right]} = e^{\left[-\int_0^t H_s e_r(x)dx\right]} \tag{3}$$

In this model, the risk is assumed to be independent, thus leading to a constant failure rate

$$MTTF = 1/\beta_s(t) = 1/H_s e_r(x) \tag{4}$$

To complete the estimation of the model parameters, (1) must be substituted into (4) as shown

$$MTTF = \frac{1}{H_s[e(0) - e_c(x)]} = \frac{1}{H_s[E_0/I - e_c(x)]} \tag{5}$$

There are two variables in formula (5), H_s and E_0, which can be estimated using the moment method:

$$MTTF_i = {OT_i}/{n_i} \tag{6}$$

Consider the two-level debugging process x_1 and x_2, we can get $x_1 < x_2$

$$MTTF_1 = OT_1/n_1 = 1/H_s[e(0) - e_c(x_1)] \tag{7}$$

And

$$MTTF_2 = OT_2/n_2 = 1/H_s[e(0) - e_c(x_2)] \tag{8}$$

From formula (7)and formula (8)

$$E_0 = I[\beta e_c(x_1) - e_c(x_2)]/(\beta - 1) \tag{9}$$

Which

$$\begin{aligned} \beta &= OT_1/OT_2 \\ n_2/n_1 &= MTTF_1/MTTF_2 \end{aligned} \tag{10}$$

From formula (7)

$$H_s = n_1/OT_1[E_0/I - e_c(x_1)] \tag{11}$$

In conclusion, an evaluation model reflecting the software failure rate can be obtained.

3. Model Description

On the basis of the existing model, a new Markov model for reliability evaluation of measurement and control device is proposed to solve the problem that has great influence on system performance. This paper presents a model to distinguish traditional measurement and control technology from modern measurement and control technology.

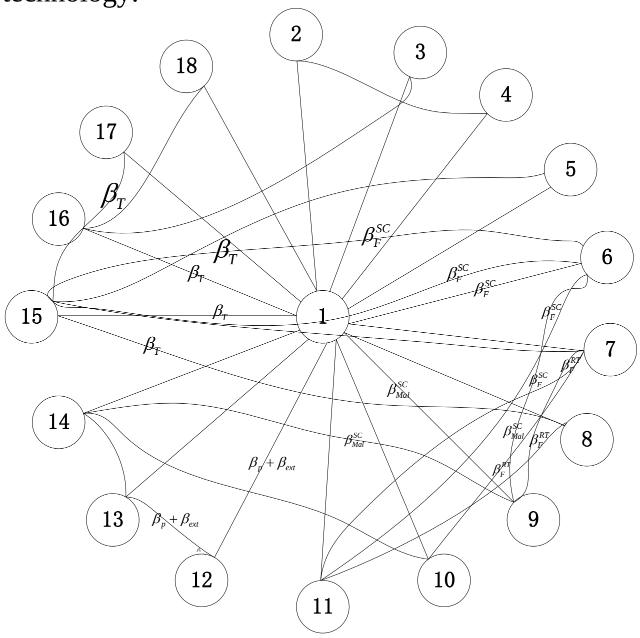

Fig. 1. Proposed Markov model

The reliability model of performance evaluation of measurement and control device is shown in figure 1. The measurement and control device is in state 1 most of the time in its working state. The measurement and control device can complete the measurement and control function as required. If a failure occurs, the model is moved to fault state 2. After the device issues an alarm signal, CB isolates the component in state 3. When fault troubleshooting is completed or the standby measurement and control runs, the model enters state 1. In state 4, the measurement and control device is in the state of software and hardware self-check, and specify that measurement and control device cannot be operate under state 11. When the self-check is complete, the state moves to 1. However, since the device has been out of operation in this state, if the software and hardware self-check does not pass, it will not be able to run, thus the state will slip to state 5, and the checked measurement and control device will exit operation. However, if the device completes the normal check, the model will return to state 1, which is not the only path. In this case, repeated accidents may occur in the measurement and control system without careful verification by the operational monitoring personnel. Negligence by the engineer or the user will cause the device to exit the operation at an accelerated speed, and the failure state will be transferred to state 12. In addition, the wrong application replacement will bring other problems to the device, which may be a hidden trouble or may cause wrong actions, so that state 5 will move to state 7 and state 10. In addition, in state 5, since the device has been out of operation, once the scheduling instruction is received at this time, the device cannot respond, and it is inevitable to switch to state 15. Among state 6, the device is during an unperceived failure state. This failure can be accomplished by self-diagnosis of the device. After the detection, the model is transferred to state 14. Fault indicates that the equipment is being upgraded. In this state, the device stops responding and the fault causes the state transition to 15. It's different from state 6, state 7 is more severe. At this time, the device cannot operate normally or even self-inspect, so it can only pass third-party detection. Status 8 indicates that the device may not be in use and may not be displayed through self-inspection or regular inspection. Therefore, the field analysis is completed by operation record or wave recording. In which case that failure of the device is detect and repaired by switch to state 14.

When the self-diagnostic function of the device perceives the problem of the device, it will automatically switch from state 1 to state 14. In state 14, the measurement and control system completes self-repair, such as software restart, hardware reset. If the remote control command is issued at this time, the measurement and control system will not respond, and if the repair fails, the model will move to state 15. State 15 indicates damage to the primary system. Therefore, it is necessary to use local standby measurement and control system, such as centralized measurement and control device, to switch the model to state 16, complete the isolation of fault device components, and properly exit the equipment. In this state, a transition to state 14 occurs if the device is reenergized or restored to communication before repair, and vice versa. On the other hand, if the local centralized measurement and control device cannot complete the standby input, the upstream equipment of other measurement and control system will undertake the task. After the operation of the local centralized measurement and control device, apart from the normal operation device, all the failed parts within the interval will be isolated. This process is shown as a transition from state 15 to state 18. When the recovery device is manually switched, the state is manually switched to 16.

In initial state 1, if multiple device failures occur simultaneously, such as large-scale communication failures, the model moves from state 1 to state 14. The measurement and control device issues a control command in state 2. However, if the device loops in this state indefinitely, it immediately switches to state 17. If the local redundant backup device replacement fails, the device state will be moved from state 1 to state 14, and when the failed device is isolated, the device will be in state 13.

Monitoring and self-testing devices have efficiency coefficients that indicate how many device faults they detect. In addition, this article first assumes that periodic inspection will miss some equipment faults. This is a reasonable assumption because engineers may not be accurate enough to complete their tasks. At the same time, when multiple device faults are detected, the self-checking mechanism and the ability to perform routine checks are different. Considering the above steps, it can be inferred that the efficiency of normal patrol inspection is greater than that of links that are easily ignored by detection. Therefore, in this article, the values used to detect operation failure or error operation patterns are different for each self-check and general check.

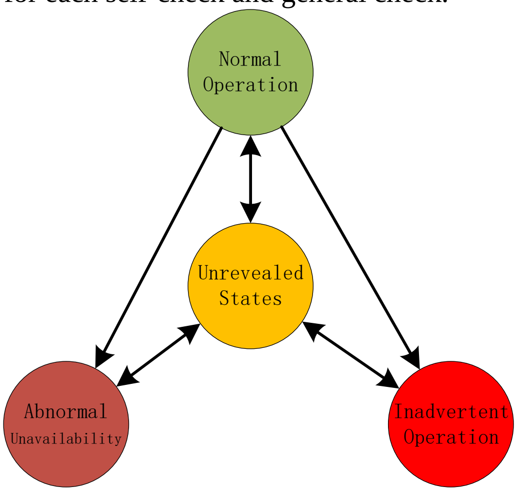

Fig. 2. Example of mode switching

Assume that the failure of the measurement and control system is the sum of the above types:

$$\beta_{\mathrm{p}} = \beta_{HW} + \beta_{SW} + \beta_{AE} + \beta_{H} \tag{12}$$

Therefore, the different occurrence probabilities of the model can be defined as:

$$\beta_{\mathrm{pmn}} = (1-\eta)\beta_p MNE \tag{13}$$

$$\beta_F^{SC} = (1-\eta)\beta_p (SCE_F - MNE) \tag{14}$$

$$\beta_F^{RT} = (1-\eta)\beta_p (RTE_F - SCE_F) \tag{15}$$

$$\beta_F^{UN} = (1-\eta)\beta_p(1-RTE_F) \tag{16}$$

$$\beta_{Mal}^{SC} = \eta\beta_p SCE_M \tag{17}$$

$$\beta_{Mal}^{RT} = \eta\beta_p(RTE_M - SCE_M) \tag{18}$$

$$\beta_{Mal}^{UN} = \eta\beta_p(1-RTE_M) \tag{19}$$

Depending on the state, the description model can be divided into four categories, as shown in fig 2. The first set is a normal state of the control system. Group III includes what is called an exit state (where the device is not ready when needed), and a fourth group includes states associated with a pattern of operational failures (human failures) in the measurement and control system. The second group includes the condition that the measurement and control device is unavailable or has failed, but no fault backtracking data is formed. Therefore, specify that this group does not display state. According to Markov theory, the probability of each state is calculated, and the classification definition is as follows:

$$\mathrm{P(I)} = p_1 + p_2 + p_3 \tag{20}$$

$$\mathrm{P(II)} = p_4 + p_5 + p_6 + p_7 + p_8 + p_9 + p_{10} + p_{11} + p_{14} \tag{21}$$

$$\mathrm{P(III)} = p_{15} + p_{16} + p_{17} + p_{18} \tag{22}$$

$$\mathrm{P(IV)} = p_{12} + p_{13} + p_{19} \tag{23}$$

4. The simulation

In order to study the measurement and control system with the proposed model, a case study is carried out. The study used matlab software package for simulation analysis. The following conversion rates are assumed to be considered in this study. Most of the values are extracted from references [8] and [11], and a few are random values:

$\beta_T = 0.9 f/yr$

$\mu_T = 25rep/yr$

$\beta_{AE} = 0.001 f/yr$

$\mu_p = 0.5rep/hr$

$\beta_{sc} = 0.05/hr$

$\mu_{sc} = 800/hr$

$\beta_H^i = \beta_H/8$

$\mathrm{RTE}_{f,m} = 95\%$

$\beta_{CB} = 0.005 f/yr$

$\beta_{Mal}^{BP} = 0.005 f/yr$

$SM = 45000sw/yr$

$S_{RB} = 6000sw/yr$

$\beta_{HW} = 0.005 f/yr$

$\beta_{sw} = 0.005 f/yr$

$\beta_H = 0.002error/yr$

$\beta_{ext} = 0.001 f/yr$

$\beta_{RT} = 0.0002/hr$

$\mu_{RT} = 1/hr$

$MNE = 20\%$

$SCE_{f,m} = 80\%$

$\beta_{BP} = 0.0025/yr$

$\beta_{TP} = 0.005 f/yr$

$S_{LB} = 22500sw/yr$

$S_{man} = 0.5sw/yr$

$\eta = 5\%$

Fig. 3 shows the relationship between P(I) and β_{HW}, Traditional redundancy solutions can reduce hardware failure rate and improve system robustness. No digitization equipment does not have self-inspection equipment; However, intelligent centralized measurement and control does have this ability. It can be seen that regardless of the failure rate of the measurement and control device P(I), the performance of the measurement and control system is ideal for equipment with self-inspection ability. Therefore, although the measurement and control scheme is implemented by multiple interval measurement and control, the centralized measurement and control device is highly integrated with functions and the IEC61850 model fusion, which has good redundancy and reliability. If a functional device is also a digital device, then the priority of using centralized measurement and control devices is that they need less space to install, reducing the cost of equipment.

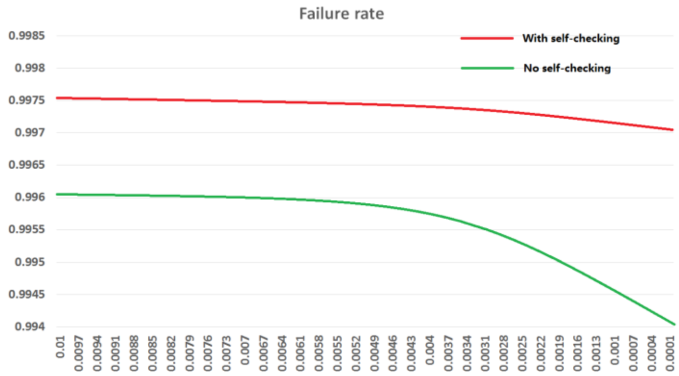

Fig. 3. failure rate

5. Conclusion

In summary, the perfect self-inspection function of the device can effectively warn the device failure and improve the stability of the measurement and control device. Finally, it should be noted in this paper that even in redundant measurement and control design, consideration not only depends on a device, but also needs to introduce the concept of cluster measurement and control. Generally speaking, the measurement and control schemes using multifunctional devices are not less reliable than the traditional similar schemes. On the other hand, economic performance indicators are also very good. Its reliability far surpasses the traditional similar equipment.

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References

[1] A. Ghaderi, H. Mohammadpour, H. Ginn, and Y.-J. Shin, “High impedance fault detection in the distribution network using the time frequency-based algorithm,” *IEEE Trans. Power Del.*, vol. 30, no. 3.

[2] W.-H. Chen, C.-W. Liu, and M.-S. Tsai, “On-line fault diagnosis of istribution substations using hybrid cause-effect network and fuzzy rule-based method,” *IEEE Trans. Power Del.*, vol. 15, no. 2, pp. 710–717, Apr. 2000.

[3] FAN Chen, NI Yi min, DOU Ren hui . Interpretation of relevant specifications of integrated supervision and control systems in smart substations *J*. *Automation of Electric Power Systems*,2012 36(19) 1-5.

[4] ZHANG Hai dong, CHEN Ailin ,NI Yi min,etal． Online state assessment and dynamicre configuration of intelligent electronic devices in smart substation *J*. *Automation of Electric Power Systems*,2014,38(5) 122-126.

[5] XIONG Jian, LIU Chen xin ,DENG Feng． Centralized protection and monitoring devices of smart substation *J*. *Automation of Electric Power Systems*,2013,37(12),100-103.

[6] FAN Chen, NI Yi min, DOU Ren hui, etal．Analysis of network scheme for process layer in smart substation *J．Automation of Electric Power Systems*,2011,35(18),67-71.

[7] IEEE Test Systems. [Online]. Available: www2.ee.washington.edu/ research/pstca/pf14/pgtca14bus.htm, Accessed on: Apr. 2018.

[8] M. Sanaye-Pasand and P. Jafarian, "An adaptive decision logic to enhance distance protection of transmission lines," *IEEE Trans. Power Del.*, vol. 26,no. 4, pp. 2134–2144, Oct. 2011.

[9] N. Mahadevan, A. Dubey, A. Chhokra, H. Guo, and G. Karsai, "Using temporal causal models to isolate failures in power system protection devices," *IEEE Instrum. Meas. Mag.*, vol. 18, no. 4, pp. 28–39, Aug. 2015.

[10] G. Cardoso, J. Rolim, and H. Zurn, "Identifying the primary fault section after contingencies in bulk power systems," *IEEE Trans. Power Del.*, vol. 23, no. 3, pp. 1335–1342, Jul. 2008.

[11] Q/GDW679-2011Technical specification for construction of intelligent substation integrated monitoring system *S*2011.

[12] Q/GDW678-2011Technical specification for construction of intelligent substation integrated monitoring system *S*2011.

[13] Q/GDW396-2009 IEC61850 project relay protection application model *S*．2009．

[14] L. Wang, Z. Q. Bo, Y. K. Zhao, X. W. Ma, M. Q. Yu, and F. R. Wei, "Hierarchy of distribution centralized substation area protection system based on all-in-one devices," *in 2015 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), Changsha. China*, Nov. 2015, pp. 903–906.

[15] Y. Q. Liu, H. L. Gao, X. Wei, N. Y. Li, and M. J. Xiang, Design of IED with integrated functions of process level and bay level in intelligent substation *J Automation of Electric Power Systems*, vol. 35, no. 21, pp. 58–62, Nov. 2011. (in Chinese)

[16] Y. Q. Liu, H. L. Gao, W. C. Gao, and F. Peng, "Development of a substation-area backup protective relay for smart substation," *IEEE Transactions on Smart Grid*, vol. PP, no. 99, pp. 1–10, Feb. 2016.

[17] L. Chen, K. J. Zhang, Y. J. Xia, and G. Hu, "Study on the substation area backup protection in smart substation," in *Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Shanghai, China, Mar. 2012, pp. 1–4.

[18] A. P. S. Meliopoulos, G. J. Cokkinides, and G. Stefopoulos, "Symbolic integration of dynamical systems by collocation methods," in *Proc. IEEE PES Power Syst. Conf. Expo.*, 2006, pp. 362–367.

[19] Q. B. Dam, S. Mohagheghi, R. H. Alaileh, G. K. Stefopoulos, G. J. Cokkinides, andA. P. S.Meliopoulos, "Alaboratory setup for relay and GPS-synchronized equipment transient testing," in *Proc. IEEE PES General Meeting*, 2008, pp. 1–8.

[20] S. Choi, B. Kim, G. Cokkinides, and A. P. S. Meliopoulos, "Autonomous state estimation for the smart grid—laboratory implementation," in *Proc. IEEE PES Transm. Distrib. Conf.*, 2010, pp. 1–8.

[21] M. Sanaye-Pasand and P. Jafarian, "An adaptive decision logic to enhance distance protection of transmission lines," *IEEE Trans. Power Del.*, vol. 26, no. 4, pp. 2134–2144, Oct. 2011.

[22] Watanabe H，Fujimura S，Nakadaira A．Blockchain contract： Securing a blockchain applied to smart contracts.*Proceedings of the IEEE International Conference on Consumer Electronics (ICCE)*．Las Vegas， NV，USA：IEEE，2016：467-468.

[23] Fan Jie，Yi Letian，Shu Ji wu．Research on the technologies of byzantine system *J．Journal of Software*，2013，24(6)： 1346-1360(in Chinese)

[24] X. L. Zhou, Protection and measuring-control devices in smart substation *J, Electric Power Automation Equipment*, vol. 30, no. 8, pp. 128–133, Aug. 2010. (in Chinese)

[25] C. Xue, C. B. Li, X. Q. Huang, S. W. Tang, and Y. Liu, Application of intelligent substation information integration *J, Electric Power Automation Equipment*, vol. 31, no. 7, pp. 110–114, Jul. 2011. (in Chinese)

[26] J. J. Zhang, C. X. Guo, Y. J. Cao, M. Sun, J. B. Xin, W. Z. Qian, and J. Yang, Substation equipment condition monitoring system and IEC model coordination *J, Automation of Electric Power Systems*, vol. 33, no. 20, pp. 67–72, Oct. 2019. (in Chinese)

[27] S. Jing, Q. Huang, J. Wu, and W. Zhen, "A novel whole-view test approach for onsite commissioning in smart substation," *IEEE Transactions on Power Delivery*, vol. 28, no. 3, pp. 1715–1722, Jul. 2013.

[28] Z. X. Zhang and Z. H. Huo, Research and application of video surveillance for substation sequence control *J, Journal of International Council on Electrical Engineering*, vol. 4, no. 3, pp. 211–215, Sep. 2014.