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Design on the HCB based on IGCT and Neural Network Current Detection

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Abstract

Nowaday, the traditional circuit breaker is which action slow, poor reliability, can not meet large grid interconnection and flexible AC transmission requirements. To address those shortcomings of traditional circuit breaker, an idear is put forward that traditional mechanical circuit breaker combinates of power electronic switch-IGCT to build a new type of hybrid circuit breaker device (Hybrid Circuit Breaker shorted at HCB). Basing on natural converter circuit principles,when grid line failure, the novel device adopts Elman neural network to detect short-circuit fault current, can disconnect quickly by IGCT's rapidity to ensure the safety of the power grid and improve switching speed and service life of the mechanical switch. It has a very important significance in fast switching of power system.

Keywords*: IGCT, HCB, Elman neural network, fault current detection, circuit breaker*

1. Introduction

Due to the rapid development of the power system, the interconnected grid lines come into millions of households, this trend requires line switch having a higher action performance, such as controllability, rapid action, stability etc [1]. Currently, though the traditional mechanical switches be widely used, but its operation speed is slow, and poor consistency action, is difficult to guarantee reliability [2]. As the power electronic circuit breaker having rapidity and good consistency, HCB device building on power electronics on the basis of the conventional mechanical breaker, can overcome disadvantages of the conventional circuit breaker effectively, and become the mainstream direction of the circuit breaker [3].

In the design of hybrid circuit breaker, a class of method is the idea based on the of natural commutation principle and IGBT soft switching, it is mainly to solve problems of the circuit breaker's rapidity and consistency. But the on-off capacity is usually smaller [4-6]. In order to solve the problem of the capacity of the hybrid circuit breaker, another class of method useing control equalizing voltage circuit to achieve better series connection of IGBT and dynamic equalizing voltage. However, the control effect is instable [7-9]. And further more, some equalizing voltage auxiliary circuit is used to ensure IGBT's series and parallel connection smooth realization [10]. But this led to a complex structure and it is uneconomic. Compared with this method which structure is more complex, the other design method is based on the topological structure of the diode's bidirectional quick isolation, and is used to achieve the reliability of shutdown protect, and its structure is simple, better economy [11], but the reaction is slowly and the lack of precision of control and action.

In this paper, neural network services in the short-circuit current fault detection, and basing on the traditional mechanical circuit breakers, the IGCT is used to build hybrid circuit breaker devices, can not only simplify the structure of hybrid circuit breaker and ensure its economy, but also increase the switching speed and action precision effectively, can meet the requirements of the fast switching applications in power systems [12].

2. The Modeling and Dynamic Performance Simulation of IGCT

The power electronic component of HCB's solid part can use integrated gate commutated thyristor (IGCT), which combines the advantages of the GTO and IGBT, that is the

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component is both GTO's high-power characteristics and the IGBT's fast, integrated door gate drive technology. In short, IGCT is a more comprehensive performance and high-power switch, can simplify the structural design of the HCB, to the operation speed, can also achieve the fast breaking requirements of solid-state circuit breaker. To analyze the IGCT characteristics, establishing electrical simulation model of IGCT by ORCAD [13].

IGCT is a bipolar, three-terminal and four story device. The device composes by the PN junction, so it may be a generic model of the diode or transistor as basic constituent unit, according to its structure and principle to constitute corresponding circuit model. So it can be seen as a combination of a PNP (Q1) transistor and NPN (Q2) transistor, thereby forming what is called the "Hu-Ki" model. It is consistent with the traditional equivalent circuit of the IGCT. But in order to correctly describe its characteristics, it needs to define device parameters of the model according to the manual parameters, then adds auxiliary devices according to the structural characteristics of the IGCT, combines with the above characteristic description, using of the ORCAD inherent model, constitute a new model according to the specific needs. The model is shown in Figure 1.

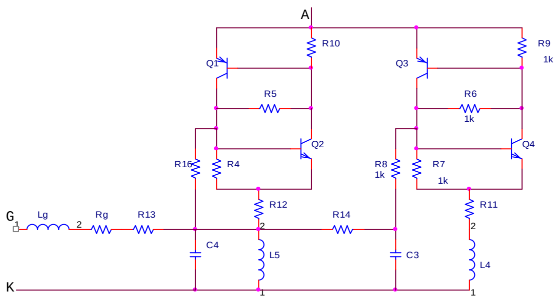

Figure 1. Electricity Model of IGCT

This model is a double-cellular structure, in which Q1 and Q2, Q3 and Q4 as the two pairs of transistors, represent the two sets of unit cell, transmission delay link is composed by R13 and C4, to be used describing the signal transmission delay between the IGCT's layers. The saturate conduction and fast of transistor must need the bias voltage which is provided by the resistors R4, R5 and R10 to meet the Necessary condition of the saturation conduction and disconnection [14]:

$$\begin{cases} \text{turned:} & \alpha_{NPN} + \alpha_{NPN} \geq 1 \quad (1) \\ \text{shut down:} & \alpha_{NPN} + \alpha_{NPN} \leq 1 \quad (2) \end{cases}$$

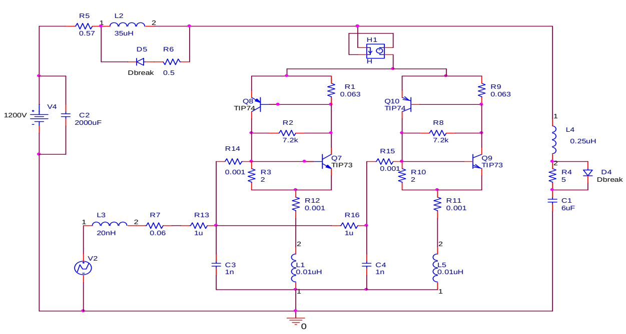

Figure 2. Characteristic Simulation Circuit

The connection relationship between the cathode and the gate of IGCT is described by resistors R4, R5 and R10. R11 and R12 are cathode resistance, Rg is connection resistance of

IGCT integrated gate, Lg is the equivalent inductance of IGCT integrated gate. The IGCT's anode, cathode and the gate are A, K and G. Analyzing characteristics of the model, the simulation circuit is shown as Figure 2.

The model is shutdown at 300μs, and its operation characteristics are shown in Figure 3 to 6. The simulation results show that the operating characteristics of the model is consistent with the measured operating characteristics, so the model can be used in the operating characteristics simulation of the IGCT.

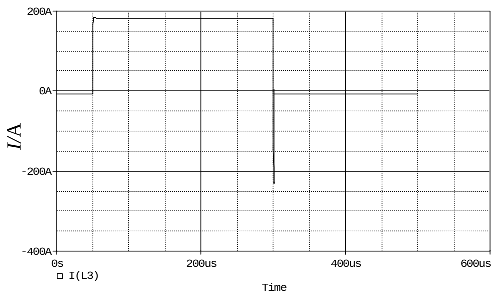

Figure 3. Turn Off Process Waveform of Grid Current

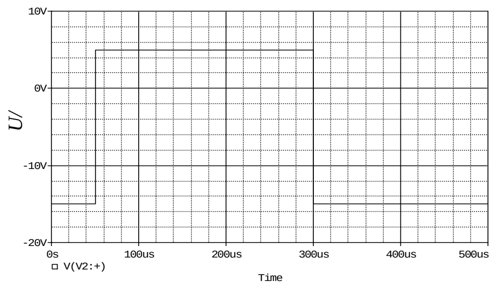

Figure 4. Turn Off Process Waveform of Grid Voltage

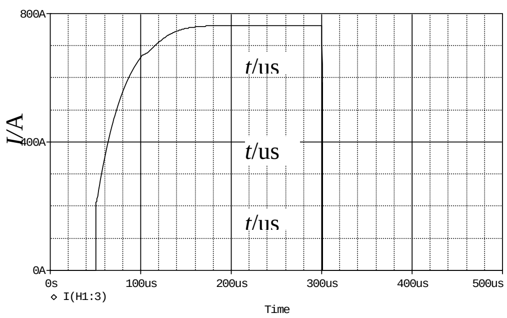

Figure 5. Turn Off Process Waveform of Anode-cathode Current

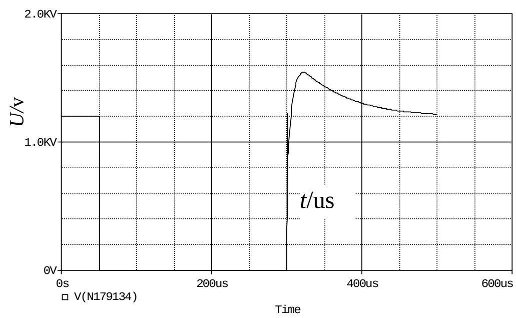

Figure 6. Turn Off Process Waveform of Anode-cathode Voltage

3. The Structural Design of HCB

The HCB apparatus of this study is based on the principle of natural commutation, combinates of a bridge circuit, its structure is shown as Figure 7. The device uses a parallel structure of mechanical switch and solid state switch, mechanical switch is as the main switch, IGCT with the bridge circuit compose a commutation circuit, the combining circuit with the voltage clamping and di/dt absorption can achieve IGCT’s safe action [15].

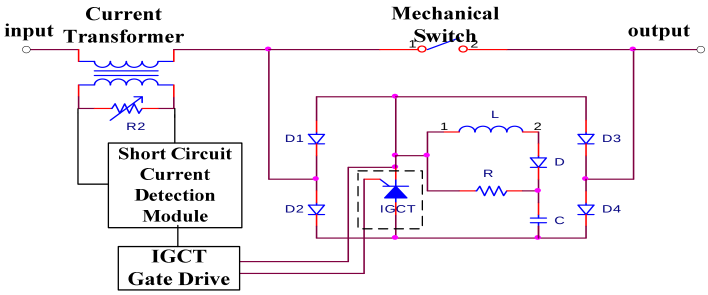

Figure 7. Structure of HCB

In the structure, the short-circuit current detection use dynamic neural network method. Movement coordinate performance of HCB's solid part and the mechanical part is related to whether HCB is able to isolate fault effectively, which depends on the current detected speed and reliability. Now, artificial neural network has been widely used in the power system fault detection. The historical memory effect of feedback neural network is in order to achieve effective fault detection and to predict the signal compare, the neural network can be used. The network can quickly reflect the current dynamic changes, and then make predictions based on changing data, and if there is a greater measured deviation between the current value and the neural network predictive value, that is abnormal circuit, the principle shown in Figure 8.

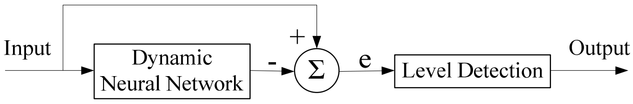

Figure 8. The Detection Theory based on Neural Network

The HCB protection process is as follows: During the grid normal operation, mechanical switch of HCB is conducting, solid state switch is shutdown, then the electrical characteristics of HCB is the characteristics of mechanical switch conduction. As the IGCT is integrated gate driver, so can be turned on immediately and fast commutated, the mechanical switch is turned, then IGCT is off, so that defective part is separated from the grid, grid is protected.

4. HCB Operating Characteristics Simulation and Analysis

4.1. Operating Characteristics Simulation and Analysis of the Short-circuit Current Detection Module

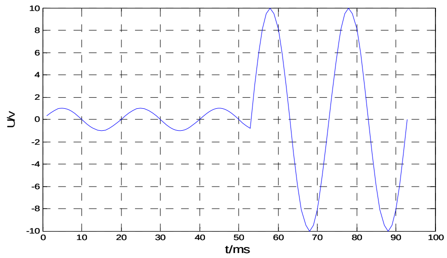

Figure 9. Simulation on of Fault Signal

Using MATLAB simulation, input signal and the output signal of the training samples is a sine wave of from 1V to 5V, when training sample quantity exceeds 200, after 300 convergence, target accuracy of two networks can achieve below 0.005. Setting level detection threshold value is positive 1V or negative 1V.

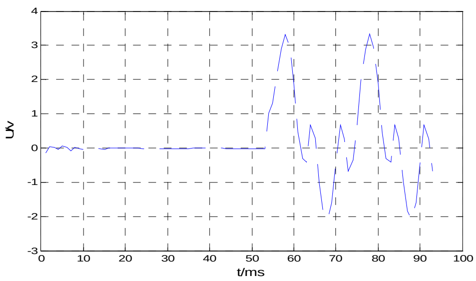

Figure 10. Network Output Error

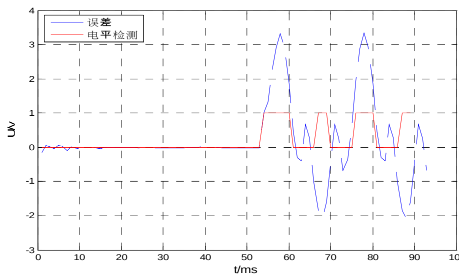

Figure 11. Result of Voltage Level Detection

From those figures, when grid is normal, predictive value of neural network is consistent with actual value of the signal, that is the error detection results shall be zero approximately. When abnormal signal emerged (53ms), the input signal mutated, then the measured current value greater than the prediction value of neural network, the error detection result of neural network increases suddenly. When the result is not in the threshold value range of the level detection (Approximately 54ms), the detection circuit will be able to issue a fault signal in time.

In this process, the moment of the abnormal occurrence is different, the phase angle in the moment is different, then operation time of the detected abnormality signal is also different, the experimental results of Elman neural network are shown in Table 1 below. It can be seen that the Elman neural network can detect fault condition in 2.29ms. Detecting other types of abnormality signa, the results have shown that this method can quickly detect the abnormality signal in the grid within 2.9ms.

Table 1. Response Time of Detecting by Different Angle

Fault time (ms)	**Phase Angle** (°)	**Operation Time (ms)**
80	0	1.73
81	18	1.95
82	36	2.21
83	54	2.29
84	72	2.25
85	90	2.21
86	108	2.22
87	126	2.17
88	144	2.09
89	162	2.96

There are often various of harmonics signal in the grid, so the current is often not normal sinusoidal signal, shown as Figure 12. In this case, the trained network can be used to detect the current, and also obtain results which respective error compare with threshold value, shown as Figure 13.

That is when there are harmonic signals in the grid, through this method, the abnormality signal can quickly be detected within 5ms. Because of predictive function of neural network, it does not affect the trial outcome even if there is a certain harmonic pollution in the grid.

Further expanding the neural network training samples and number, the neural network can get a better approximation. When training the neural network, training different precision network can be according to the different needs, can also combine static network with dynamic network and coordinate with use, so that not only can detect harmonic pollution and filtering but also can detect other types of failure detection. Detection effect can be achieved better.

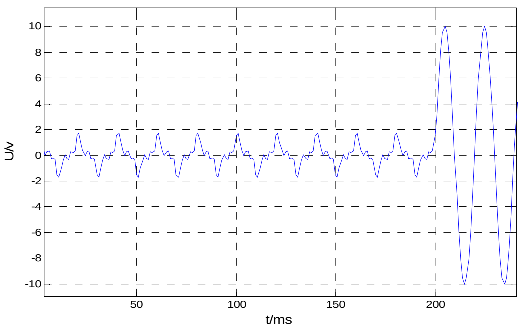

Figure 12. Signal Waveform of Including Harmony

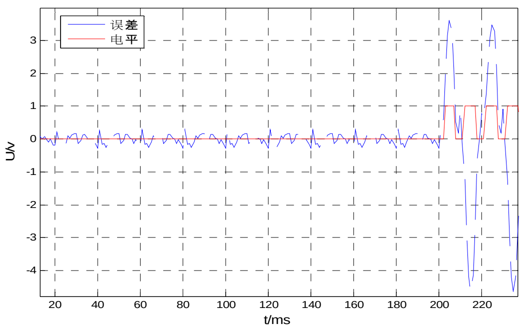

Figure 13. Output error and result of electric level detection

4.2. Operating Characteristics Simulation and Analysis of HCB

For observing HCB's superior performance, the simulation analysis of HCB's characteristics is operated, the circuit is shown as Figure 14. Despite the circuit failure is diverse, the performance of short-circuit is different, but all of the short-circuit may eventually naturalized as Figure 14 shown. In Figure 14, R1 and L1 are equivalent impedance of the grid, R2 and L2 is load of the grid. If circuit breaker parallel to the load is conducting, then the load is short-circuited and generates a short circuit current, then the operation characteristics simulation of HCB is carried out.

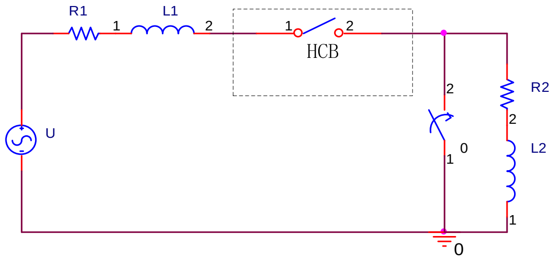

Figure 14. Equivalent Short Circuit

(1) Closing characteristic of HCB

Before closing, the mechanical switch and IGCT are disconnecting. When closing signal is issued, because of integrated gate drive itself, the IGCT turned on quickly and produce a current, Load current(*I*l) equal to mechanical switch current(*I*m) plus solid-state switch current(*I*s), that is:

$$I\text{l}= I\text{m}+I\text{s} \qquad (3)$$

Therefore the current yields immediately. When the mechanical switch is in closed state, the IGCT is short-circuited completely. According to the principle of natural commutation, *I*l flow from IGCT to the mechanical switch, then *I*s equal to zero approximately. When closing signal is completed, IGCT is on off. In this process, experimental waveforms of the mechanical switch voltage (*U*m), mechanical switch current (*I*m) and solid-state switch current (*I*s) are shown respectively as the Figure 15, 16 and 17.

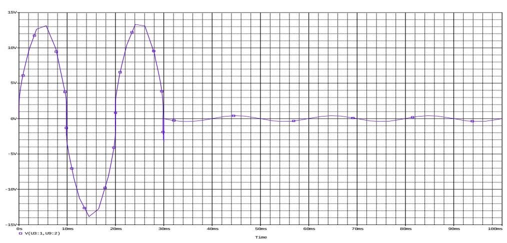

Figure 15. Voltage Waveform of both sides Mechanical Switch

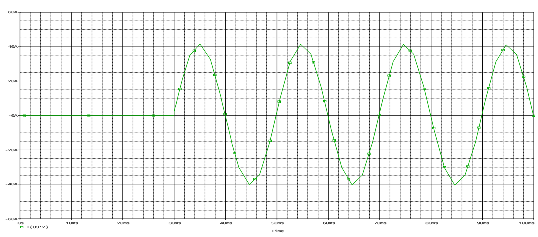

Figure 16. Current Waveform of both sides Mechanical Switch

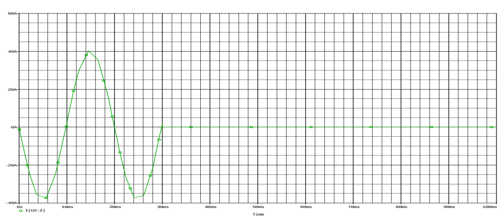

Figure 17. Current Waveform of IGCT

Therefore the current yields immediately. When the mechanical switch is in closed state, the IGCT is short-circuited completely. According to the principle of natural commutation, *I*l flow from IGCT to the mechanical switch, then *I*s equal to zero approximately. When closing signal is completed, IGCT is on off. In this process, experimental waveforms of the mechanical switch voltage (*U*m), mechanical switch current (*I*m) and solid-state switch current (*I*s) are shown respectively as the Figure 15, 16 and 17.

(2) Opening characteristics of HCB

Before opening, the mechanical switch is on normal working state, IGCT is on off state, the load current flows through the mechanical switch. When opening, the opening signal is sent to the mechanical switch and conducting signal is transmitted to IGCT. The mechanical switch state breaking after a period of mechanical delay, it leads to forward voltage drop of the IGCT is greater than zero. The conducting signal fully conduct the IGCT, according to the principle of natural commutation, *I*l commutate to IGCT. After the mechanical switch disconnected completely, IGCT is disconnected too, the opening process is finished. During the process, the voltage of both ends of mechanical switch is always clamp very low by IGCT, it restricts voltage generating. By the arc principle, the mechanical switch has not arc. In this process, experimental waveforms of *U*m, *I*m and *I*s are shown respectively as the Figure 18, 19 and 20.

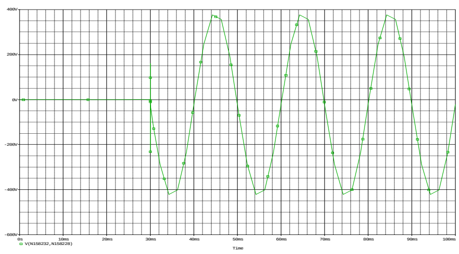

Figure 18. Voltage Waveform of both sides Mechanical Switch

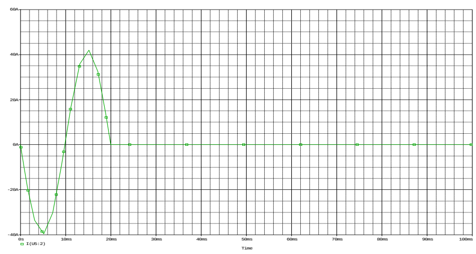

Figure 19. Current Waveform of both sides Mechanical Switch

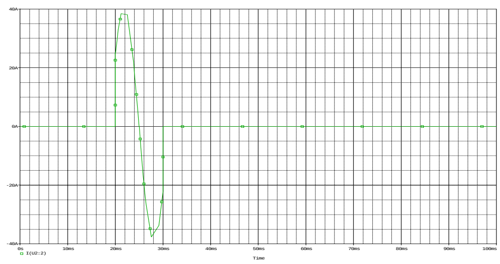

Figure 20. Current Waveform of IGCT

5. Conclusion

Through the above analysis can be drawn that using Elman neural network to detect fault current, the HCB device by mechanical breaker combines with solid-state circuit breaker can achieve fast protection of the grid. Which electrical simulation model of IGCT in this paper, through simulation analysis, is proved that its operating characteristics is consistent with IGCT measured characteristics, can be used for action analysis of the new type HCB device. The fault current detection method based on Elman neural network can detect failure signals of the line in 2.3ms, HCB can act timely, so that the fault lines can be quickly breaken by IGCT's fast features, and ensure the security of the grid.

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3. "New type of device for fault current detection", University Students' Innovative Undertaking Training Program of Harbin University of Science and Technology in 2012.

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