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The Application of a Safety Comparator in the Track Circuit of a Railway Signaling System for Counting Overvoltage

Abstract. *This article presented the application of a safety comparator in the track circuit of a railway signaling system for counting the overvoltage caused by voltage fluctuation resulting in the damage of the BR966F2 relay. Overvoltage counting in the track circuit of the railway signaling system using the safety comparator to detect two voltages in the series circuit and the fault of overvoltage of the track circuit were used for detecting the status of the train in the interlocking system of the railway signaling system, and the digital counter circuit displaying the overvoltage status to monitor and confirm the use of the BR966F2 relay of the railway signaling system that resolved the problem causing the track circuit error, minimized the duration for system maintenance, and maximized the reliable performance of the advanced safety system in the track circuit for the control and command functions of the railway's operations of the State Railway of Thailand.*

Streszczenie. *W artykule przedstawiono zastosowanie układu bezpieczeństwa w obwodzie torowym sygnalizacji kolejowej do zliczania przepięć wywołanych wahaniami napięcia powodującymi uszkodzenie przekaźnika BR966F2. Zliczanie przepięć w obwodzie torowym sygnalizacji kolejowej za pomocą komparatora bezpieczeństwa do wykrycia dwóch napięć w obwodzie szeregowym oraz zwarcia przepięcia obwodu torowego posłużyło do wykrycia stanu pociągu w blokadach systemu sygnalizacji kolejowej oraz obwodu licznika cyfrowego wyświetlającego stan przepięcia w celu monitorowania i potwierdzenia użycia przekaźnika BR966F2.* (***Zastosowanie komparatora bezpieczeństwa w obwodzie torowym systemu sygnalizacji kolejowej do zliczania przepięć***)

Keywords: Safety comparator, train signaling system, track circuit, Failure modes and effects analysis (FMEA).
Słowa kluczowe: obwody trakcji kolejowej, system sygnalizacj, przepięcia

Introduction

A railway signaling system is one of the mechanisms for notifying the route ahead to the engine driver to make a decision to stop, slow down, or redirect the train for a safe, speedy, and efficient operation. The railway signaling system controls and determines the direction and duration for the operation of the trains on joint tracks, as well as the shunt at the station. The functions of the equipment are therefore designed to work mutually to accommodate the engine driver to make a firm decision without confusion over detecting the location, which is very crucial for the train's operation [1] (Fig. 1).

Fig. 1. Railway signaling system.

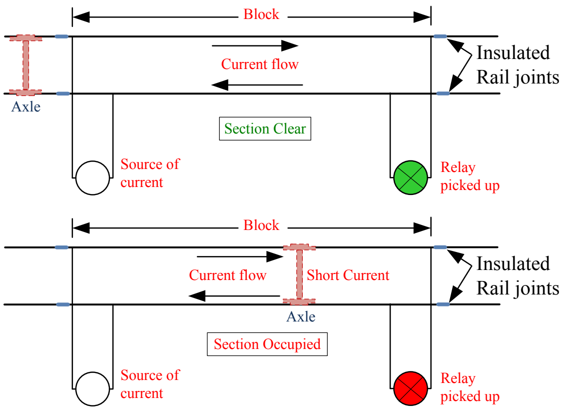

Fig. 2. Fundamental principle of the track circuit.

Fig. 2. Fundamental principle of the track circuit. [1], which is the function of the electrical circuit divided into sections and separated by insulation. One side of the track has the power supply while the other side is the receiver. For the basic principle of the track circuit [2] in a normal condition, the power supply distributes the direct track circuit, approximately 4.356V to the track, which is an effective conductor, to transmit to the receiver and does not require high voltage. If the receiver accepts the signal, there will be no train on the track (clear track) (Fig. 3).

Fig. 3. Voltage drop on the track 4.356V while the track is clear.

In case the train is running between the transmitter and receiver, the voltage on the track would decrease to 4.7 mV because the axles and wheels are steel, so the electrical system would connect or have a short circuit, and the electricity would not be able to be transmitted to the receiver. As a result, this would return to the power supply. Consequently, this would imply that there is a train on the track (occupied track) (Fig. 4).

Fig. 4. Voltage drop 4.7 mV while there is a train.

The signal status on the monitor displayed in the control room (Fig. 5) would show the train's operation. When the monitor shows the green line (picked up relay), this would infer that there is no train on the track in this block. On the other hand, if this showed a red line (dropped relay), there would be a train on the track in this block. This is the status of the T50 track circuit at the Chitralada Signal Control Tower, Signal Maintenance Central Region, Signaling and Telecommunication Department, State Railway of Thailand.

Fig. 5. Monitor displaying the train's operation status.

The track circuit is the function of an electrical circuit, which divides the track into sections and separates it with insulation. One side is the power supply while the other side is the receiver with the BR966F2 relay [3], which controls the display of the train's operation status (Fig. 6).

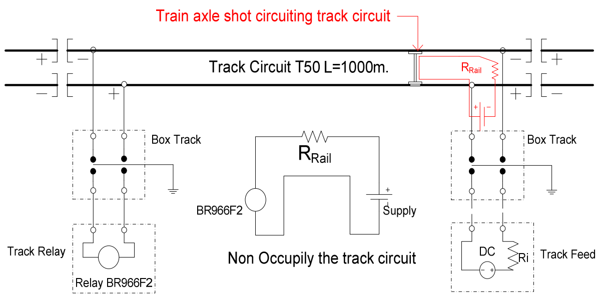

Fig. 6. The BR966F2 relay and non-occupying the track circuit

For the detection of the voltage and light signal transmitted to the BR966F2 relay receiver of the track circuit to detect the train's operation, the BR966F2 relay is operated by the voltage in a normal condition. The initial power is a DC voltage of 1.4V; the normal voltage of the track circuit is a DC voltage of 4-5V, which is the usual status of the track's occupation.

There are various causes for the damage of the BR966F2 relay in the track circuit. Since the railway in Thailand is an open track, it is an external factor causing an error in the track circuit inspection system; such as, a metal object on the track, damaged cable, burning BR966F2 relay due to overvoltage, damaged power supply, and a thunderbolt on the track, which would need time to be inspected and repaired. Consequently, there would be a delay in the command to move the train to the required location [4], as safety would need to be ensured before releasing the train. The BR966F2 relay burns from overvoltage (Fig. 7).

Fig. 7. Installation and burning of the BR966F2 relay from overvoltage.

In the past, there was no overvoltage counting that caused the damage of the BR966F2 relay in the track circuit of the railway signaling system. In order to analyze the frequency of the damage, planning on the substitution and investigation of the cause shortened the time to investigate, and the solution could be processed quickly. The summary on the number of damaged signaling system equipment during 2018-2019 is shown in Fig. 8.

Fig. 8. Statistics of the railway signalling system errors.

This research proposed the application of overvoltage counting using a safety comparator (SC) to detect the two levels of overvoltage in the track circuit of the railway signaling system. Overvoltage counting consists of a signal processing circuit using the transistor SC, the simple circuit that minimizes the number of passive equipment. It is small and compact to detect the abnormality of the DC voltage in the track circuit of the railway signaling system. It is designed to stand-by in a fail-safe mode, so the circuit is stable to control and has a reliable self-diagnostic function while operating the system. With the failure modes and effect analysis (FMEA), the monitoring and commanding the train's operation with an interlocking method has a higher safety integrity level (SIL).

Concept of a safety counter circuit design

The design of an overvoltage counter circuit with the SC of the railway signaling system caused by voltage fluctuation transmitted through the track to the receiver is controlled by the BR966F2 relay to display the occupation status based on the principle and concept of a safety system design [5] in the fail-safe mode, which is very important to be applicable for the track circuit. The safety standard corresponding with the application of the railway signaling system would be crucial for SIL except in the event of a relay error [6], which would comply with IEC 61800-5-2 [7]. In terms of the international safety standard for the track circuit of the railway signaling system, the comparator circuit would generally use two op-amp integrated circuits (IC) and one gate. Fail-safe inspection using IC is difficult to examine, so the design of an overvoltage circuit detection with the SC using the transistor and passive resistor equipment that would have the same mode with the active equipment would facilitate the inspection of the damaged equipment with the FMEA. This would comprise two main parts: the function of the SC with two sets of voltage to compare the circuit to detect the overvoltage of the track circuit and the display set.

Concept of the safety comparator

The voltage comparator that is widely used compares two voltages: the size of the direct current signal from the input to the determined referred signal. Overvoltage from the voltage reference would make the output voltage from the compared circuit to have a high or low logic (Fig. 9).

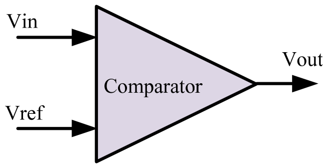

Fig. 9. Voltage comparator.

The voltage comparator wave is shown in Fig. 10.

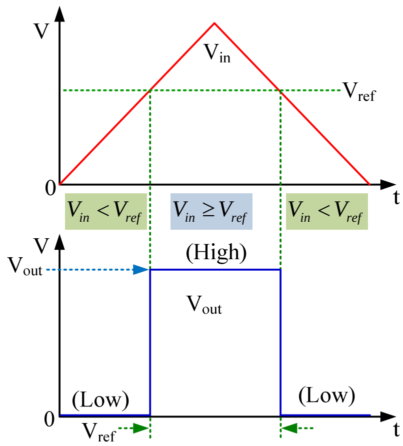

Fig. 10. Voltage comparator wave.

When the input signal is lower than the voltage reference (V_{ref}), the output signal from the comparator would show logic 0 (low) (Equation 1).

(1) $$V_{in} < V_{ref} = 0$$

When the input signal is equal or higher than the voltage reference (V_{ref}) the output signal from the comparator would be logic 1 (high) (Equation 2).

(2) $$V_{in} \geq V_{ref} = 1$$

Design of the voltage comparator circuit

The voltage comparator circuit detects the different levels of the input voltage and voltage reference (V_{ref}). If the input voltage is equal to or higher than the voltage reference, the output signal of the comparator would be logic 1. However, if it is lower than the voltage reference, the output signal of the comparator would be logic 0. In order to design the voltage comparator, three transistors, Q_1 Q_2 and Q_3 which were the oscillator circuits, were used [8-10]. These could set the V_{out}. The voltage reference could be calculated from the determination of R_1 and R_2 that would be connected in the voltage divider circuit with the base-emitter voltage V_{EB} of transistor Q_1 to determine the level of the voltage reference [11-13] (Fig. 11).

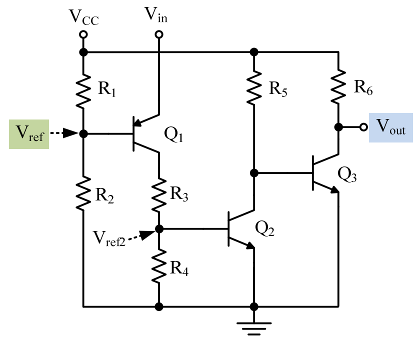

Fig. 11. Voltage comparator circuit.

For the function of the Q_3 transistor, biasing the transistor to the cut-off condition, which is the switch operation, and to the saturation condition is to set it as the same condition of the switch. As a result, there would be more current flow through the transistor as the output voltage level would be logic 0 and 1.

To calculate V_{ref}, V_{CC} would be determined as the stand-by current where resistors R_1 and R_2 would be connected as the voltage divider circuit. The calculation of the voltage reference is shown in Equation 3.

(3) $$V_{ref} = \left(\frac{R_2}{R_1 + R_2}\right) \times V_{CC}$$

The input voltage signal V_{in} would make the voltage drop at transistor Q_1. The voltage at the collector (V_{CEQ1}) is the output voltage reference for biasing transistor Q_2, which would have the resistors R_1 and R_2 connected to the voltage divider circuit. V_{ref2} is shown in Equation 4.

(4) $$V_{ref2} = \left(\frac{R_4}{R_3 + R_4}\right) \times (V_{CEQ1})$$

Therefore, at the voltage function, the changing point of the voltage comparator circuit would have the lowest voltage of V_{ref2} at 0.5V (Fig. 12). If V_{in} was higher than V_{ref}, the level of V_{ref2} would increase to 0.6V, which would be sufficient for the $I_{B(Q2)}$ to flow through the transistor (Q_2) and function as the switch. Consequently, the output signal would be logic 1.

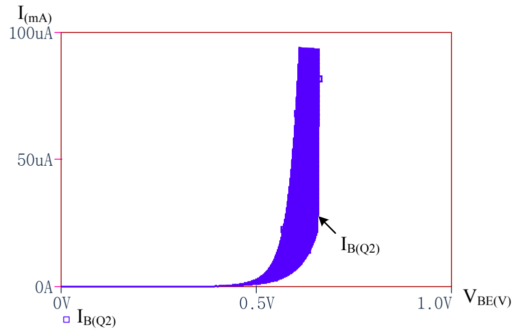

Fig. 12. Graph showing the characteristic of the voltage at connector B of transistor Q_2.

When the input voltage is higher than the voltage reference (V_{in}>V_{ref}), the output voltage of the voltage comparator circuit would be logic 1 or equal to the voltage of V_{CC}. If the input voltage was lower than the voltage reference (V_{in}<V_{ref}), the output voltage would be logic 0 or equal to 0V. The graph of the voltage characteristic of the voltage comparator circuit at different points is shown in Fig. 13.

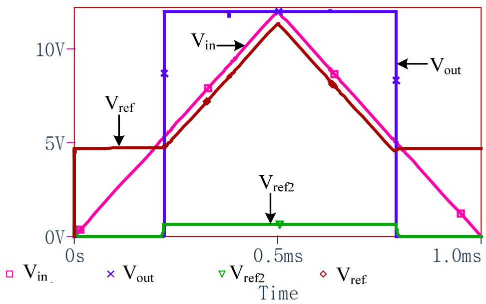

Fig. 13 Graph showing the characteristic of the voltage comparator circuit at different points.

The design of the voltage comparator circuit would be in the safety mode to prevent any possible error to the circuit resulting from undesired reasons. For this reason, the voltage comparator circuit would be a designed series transistor comprising two sets of voltage comparator, which the level of the voltage reference would show a difference of 1V to prevent any error from the noise. Both output signals would be in the series connection as logic AND Gate [11] (Fig. 14).

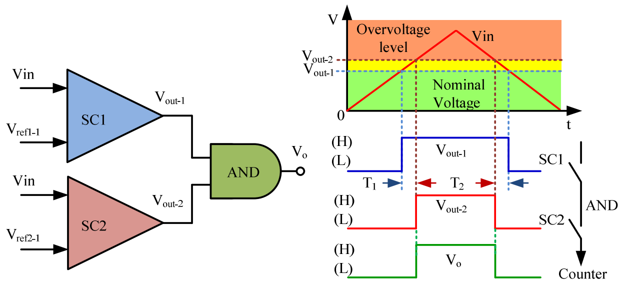

Fig. 14. Signal of the series safety comparator.

The designed circuit would detect the overvoltage at two levels in the track circuit of the railway signaling system and the SC with the series transistor. The SC with the series transistor would have two sets comprising transistors Q_1-Q_3. The first set (SC_1) would have the transistors Q_4-Q_6 as the second safety comparator (SC_2) while transistors Q_7 and Q_8 would be the series circuit AND Gate with a transistor (Fig. 15).

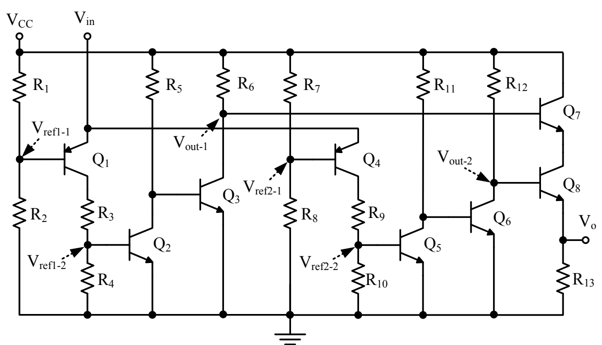

Fig. 15. Safety comparator with the series transistor.

The graph that displays the characteristic of the safety comparator circuit at different points is shown in Fig. 16.

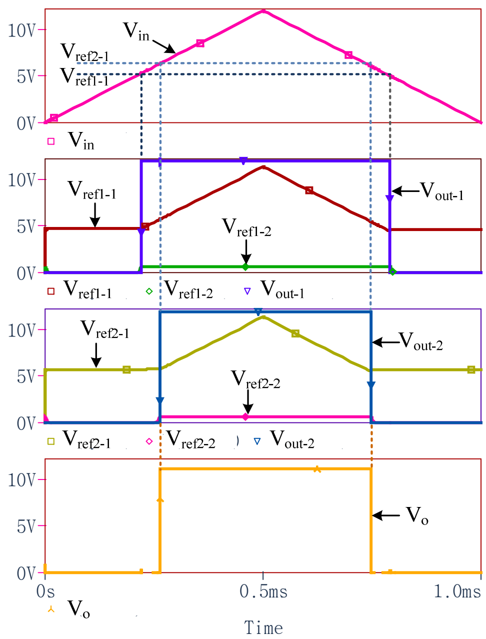

Fig. 16. Graph showing the characteristic of the voltage comparator circuit at different points.

The calculation of the voltage reference V_{ref1-1} to determine the status of the output signal of SC_1 is shown in Equation 5.

$$V_{ref1-1} = \left[\frac{R_2}{R_1 + R_2} \right] \times V_{in} \tag{5}$$

The calculation of the voltage reference V_{ref2-1} to determine the status of the output signal of SC_2 is shown in Equation 6.

$$V_{ref2-1} = \left[\frac{R_8}{R_7 + R_8} \right] \times V_{in} \tag{6}$$

The design of the safety comparator with the series transistor in AND Gate is resistor-transistor logic (RTL). Both transistors are the series connection where output signal V_o would be logic 1 or high when the output signal of V_{out-1} and V_{out-2} would be logic 1 or high only. The determination of output V_o of the series AND Gate circuit is shown in Equation 7, and the graph of the output signal of the safety comparator is shown in Fig. 17.

$$V_o = V_{out-1} \times V_{out-2} \tag{7}$$

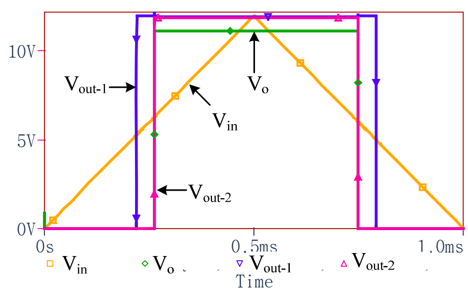

Fig. 17. Graph showing output signal of the safety comparator.

Counter circuit testing for the voltage level with the safety comparator

The performance of the overvoltage counter circuit with the series safety comparator was tested (Fig. 18).

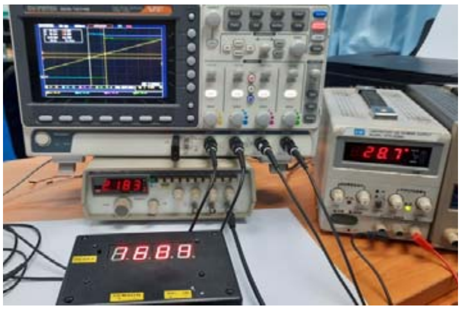

Fig. 18. Safety comparator performance testing.

The wave of testing the performance of the safety comparator in the designed safety comparator circuit for overvoltage detection set the voltage reference at 20% higher than the normal voltage level or 5.28V to prevent any error from the noise. Determining the voltage reference for both sets of the comparator to be different at 1V is shown in Fig. 19.

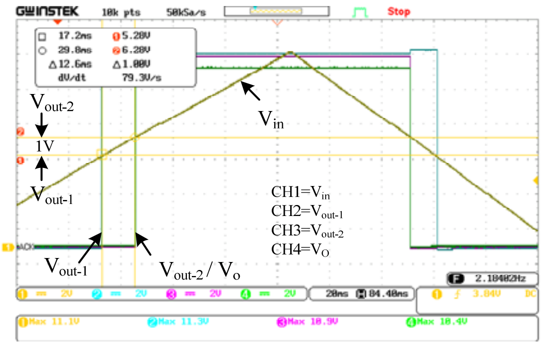

Fig. 19. Voltage reference is higher than normal voltage by 20%.

When the voltage reference of both comparators is set at a difference of 1V, the signal wave of the safety comparator of 1V would have the output signal V_{out-1} at 5.28V and the signal wave of the safety comparator SC_2 would have the output signal V_{out-2} at 6.28V, which was designed as shown in Fig. 20.

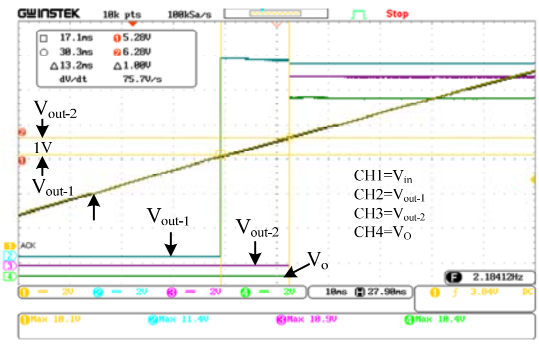

Fig. 20. Signal wave of the safety comparator SC_1 and SC_2.

Fig. 21. which displays the performance test result of the overvoltage detection of the safety comparator circuit explains that when allowing overvoltage from the input to the level of the voltage reference of the voltage comparator SC_1, the output status of SC_1 would be high. If the input voltage continued to increase to the level of the voltage reference of SC_2, the output status of SC_2 would be high. Thus, if the status of the output signal of the voltage comparators SC_1 and SC_2 were high, the output signal status of V_o would be high to function as a trigger to the counter circuit to count the overvoltage in the track circuit of the railway signaling system for maintenance purposes.

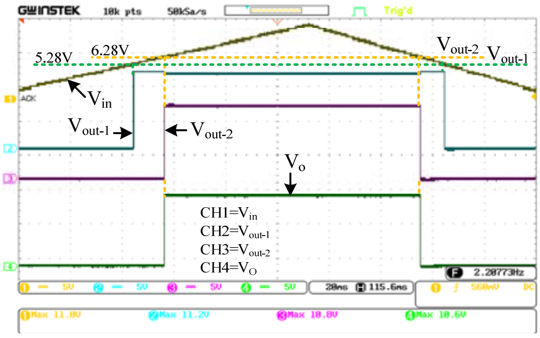

Fig. 21. Output signal wave of the series safety comparator.

After the installation of the overvoltage counter equipment in the track circuit of the railway signaling system, the display monitor showed the number of the overvoltage in the track circuit (Fig. 22).

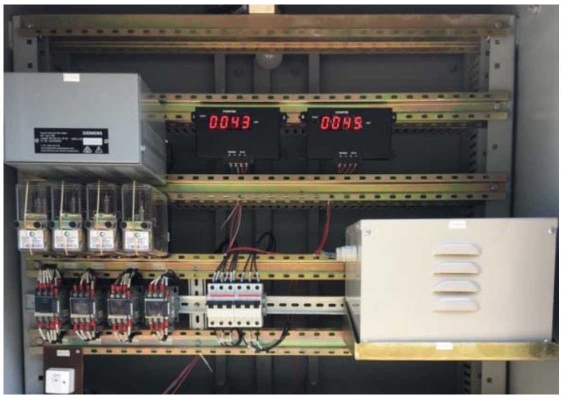

Fig. 22. Installation of the overvoltage counter in the track circuit of the railway signalling system.

Table 1. Results of failure modes and effects analysis (FMEA).

Devices	Failure Mode	Effect of the Comparator	Effect of the Failure	Effect of the Counter Circuit
R_1	Open circuit	Change of the circuit's characteristic.	2	O
	Short circuit	No output signal.	2	O
	R_1*2	Change of the circuit's characteristic.	2	O
	R_1*0.5	Change of the circuit's characteristic.	2	O
R_2	Open circuit	No output signal.	2	O
	Short circuit	No output signal.	3	O
	R_2*2	Change of circuit's characteristic.	2	O
	R_2*0.5	Change of the circuit's characteristic.	2	O
Q_1	Open circuit	Normal circuit.	3	O
	Short circuit	No output signal.	2	O
Q_2	Open circuit	Normal circuit.	3	O
	Short circuit	No output signal.	2	O

Notes: (*0.5) and (*2) refer to the standard valuesof IEC 61496-1:
(1) Normal output.
(2) Abnormal output; detectable.
(3) No output signal.
O No effect on the counter circuit.
Δ Have an effect on the counter circuit and is a dangerous situation.

Failure modes and effects analysis

The failure modes and effects analysis (FMEA) [14-17] is a tool for measuring the analysis of the safety comparator circuit failure leading to the prevention of damage. The analysis concept is set in IEC 61496-1. The analysis result would ensure that if there is a failure to the safety comparator circuit, the system would function in the fail-safe mode and prevent any failure to the entire system (Table 1).

Conclusion

This research proposed the application of a safety comparator in the track circuit of the railway signaling system for counting the overvoltage caused by failure; such as, a metal object on the track, damaged cable, overvoltage in the system, damaged power supply, and the thunderbolt on the track. Such causes might damage the BR966F2 relay. Overvoltage counting comprised the signal processing circuit with a transistor, which was the simple circuit in an impact size, for detecting DC voltage abnormality in the track circuit of the railway signaling system. This was designed to be in a fail-safe mode to allow for the system's stability and reliability in the control and command functions for the trains' operation of the State Railway of Thailand.

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