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Real-Time Root Cause Analysis of Governor Control System for Sirikit Hydropower

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Abstract

The existing governor control system of Sirikit Hydropower is designed as a standalone system. It communicates to another system such as the distributed control system (DCS), protection system, and excitation system by hardwiring. Some abnormal events are the group alarms that cause the operator and maintenance team to spend more time on problem-solving. This paper studies real-time root cause analysis of the governor control system for Sirikit Hydropower. This real-time root cause can improve operator and maintenance team performance, especially in case of emergency and ready-to-start events. The real-time root cause analysis system knowledge is based on input/output real-time data of the governor system and DCS, maintenance instruction manual, history events, and drawing of the governor control system. The root cause analysis in this research is a fault tree logic analysis technique for diagnosing alarms and emergency events. Developing a graphical user interface is a real-time troubleshooting guide monitor with user-friendly. This system can help the operator and maintenance team to solve problems of the governor control system more effectively.

Keywords: Diagnostic, Fault Tree Logic Analysis, Governor Control System, Real-Time Root Cause Analysis, Troubleshooting guide.

1. INTRODUCTION

Nowadays, renewable energy plays an important role in generating electricity to provide the greatest environmental benefit. Hydropower plant currently is the largest source of renewable energy in the electricity sector. Sirikit Hydro Power Plant is the largest saddle dam in Thailand, not only help power system fulfill peak demand period but also support power systems in northern Thailand during transmission maintenance, affecting approximately start-stop 3,000 times/year. Therefore, Sirikit Hydro Power Plant always prepares for synchronization systems. One of the important speed and load adjustments is Governor control systems.

The governor control system of Sirikit Hydro Power Plant is an electrical automatic control guide vane and inlet valve consisting of sequence control, power output control, turbine speed control, opening limiter, guide vane position control, and isolated network control. Thus, the system is essential for releasing water and generating electricity of the Sirikit Hydro Power Plant.

Figure 1 shows an overview of a part of the governor control system. The Governor control system is the main controller of the hydraulic turbine, control command, and automation of machines and processes of the proportional valve by the programmable logic controller (PLC). Solenoid valves are electronic devices that transform electrical energy into mechanical force and motion controlled by PLC in multiple control modes such as normal, freezing, emergency shutdown (ESD), quick shutdown (QSD), and manual mode.

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The principle of mechanical systems begins with the governor oil pump building up oil pressure when systems detect that the pressure of the tank drops. As a result, the pressure tank distributes oil pressure to both of proportional control valve and the distributing valve. Then position sensor of the proportional control valve has the role of feedback for controlling the position of the distributing valve by closing or opening the oil pressure. After that, the distributing valve controls the servo motor to close or open the wicket gate. The turbine speed sensor is sensed by the rated speed for the control speed of the turbine. Finally, the output power is controlled by opening a wicket gate to increase the load (MW). On the other hand, the load will decrease if the wicket gate closes.

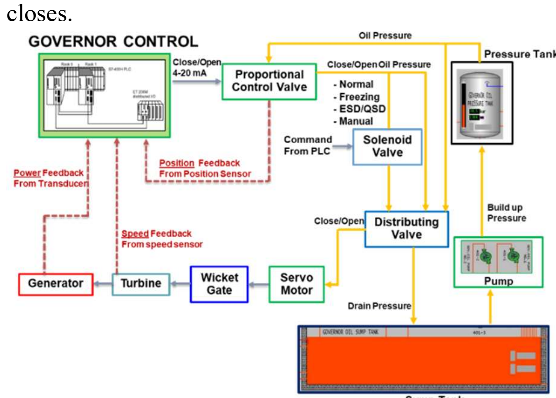


Figure 1 overview a part of the governor control system

The governor control systems interface with the user by programming device is an engineering laptop used together with programmable logic control (PLC) and human-machine interface (HMI) at the operator panel. Limited access and no specific troubleshooting guidance can cause spending more time on problem-solving and loss more availability payment leading to generating power. Reducing working time to resolution requires being able to identify event root causes in minutes or seconds. The Real-Time Root Cause Analysis of the Governor Control System in this paper helps to identify the contributing causal factors associated with adverse events.

The various method that identifies the root cause of events or system failure condition was proposed in the literature. The reliability assessment can be performed based on quantitative and qualitative analysis. The most used methods are fault tree analysis as shown in the research of Knezevic et al. (2020), Hu et al. (2020), Melani et al. (2018), Wang et al. (2017) and Kemikem et al. (2018) and the other methods are rule and logic trees as shown in Nicolau et al. (2017), simulation method in research of Priambodo et al. (2018) and Dudgeon (2017), Expert system method in research of Buaphan et al. (2017), and the last method is Failure Modes and Effects Criticality Analysis (FMECA) is used in research of Hu et al. (2020), Melani et al. (2018). Our project uses fault tree analysis (FTA) because simple to comprehend the reasoning behind the undesirable state or top event and demonstrate compliance with input system reliability standards.

The FTA is a systematic and deductive procedure for defining the adverse event and determining all possible reasons that could result in the adverse events of the system. The adverse event will be the top event of a fault tree diagram, then takes a top-down approach to assess failure consequences and trouble-shooting root cause failure analysis as presented by Buaphan et al. (2017).

This paper study to develop a real-time root cause analysis of the governor control system for Sirikit Hydropower and create the FTA by using Node-red software based on real-time data as shown in Figure 2.

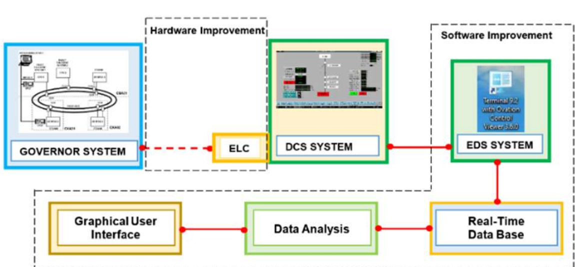


Figure 2 overview improvement diagram

Hardware improvement:

Ethernet Link Controller (ELC) Module to get data interface between governor system and DCS by communication cable (LAN) using Modbus protocol.

Software improvement:

(a) Enterprise Data Server (EDS) is an existing online application of DCS and shows current/historical data.

(b) Real-Time Data Base access data from EDS, this use for knowledge is based on input/output real-time data of the governor system and DCS, maintenance instruction manual, history events, and drawing of the governor control system.

(c) Data Analysis uses fault tree analysis techniques to analyze fault events using information from a knowledge base and a real-time database.

(d) Graphical User Interface is a real-time trouble shooting guide monitor with user-friendly.

2. DESIGN CONCEPT OF REAL-TIME ROOT CAUSE ANALYSIS

To facilitate more effective problem-solving for maintenance & operation staff. This results in reduced financial loss and charges from stopping the machine. the real-time root cause analysis has been developed for problems solving not only electrical failure but also mechanical failure of the governor control system Sirikit Hydro Power Plant in this paper. For example, the Turbine is ready To Start, the governor is quick or emergency shutdown, the temperature turbine guide bearing is too high, and the shaft seal water flow is too low. The flow diagram is shown in Figure 3.

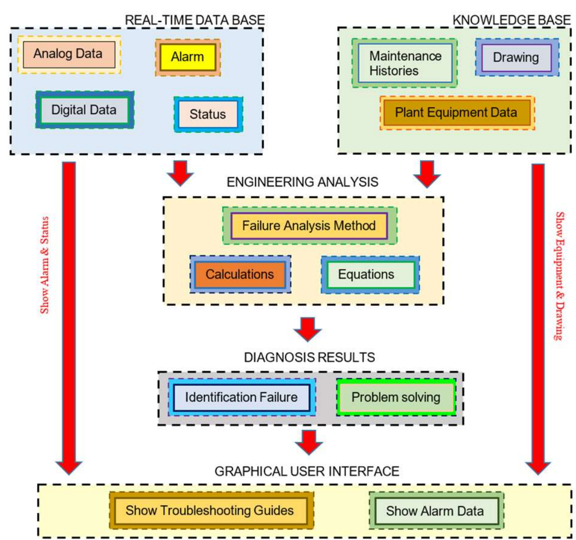


Figure 3 flow diagram of the real-time root cause analysis

The real-time root cause analysis flow diagram displays the program's overall workflow. The first is a knowledge base derived from power plant data and a database containing real-time data from DCS. The second is engineer analysis, which makes use of FTA, equations, and calculations based on the governor control system's parameter settings. The third step involves identifying failures in the diagnosis results and displaying problem-solving techniques. The final graphic user interface shows alarm data and user-friendly suggestions for troubleshooting.

A. Real-time database

The DCS system data will transfer via the EDS system and then send real-time application program interface (API) data including analog data, digital data, sequence of events (SOE), alarm, and status of the governor system. Finally, the software application will receive the data from the API. We chose the Node-red program for our project because it can transfer API data and has a user-friendly Boolean logic flow feature.

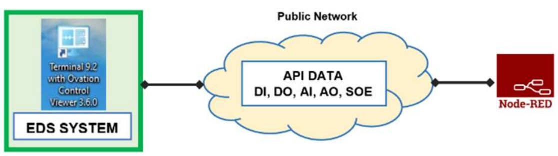


Figure 4 EDS system transfer to Node-Red program

B. Knowledge base

The knowledge base is supporting data to improve root cause analysis more effectively as listed below and the structure is shown in Figure 5.

1) Maintenance histories: corrective & preventive maintenance report, minor inspection report, major overhaul report, and test report.

2) Plant equipment data: instruction manuals.

3) Drawing: control logic and parameter setting.

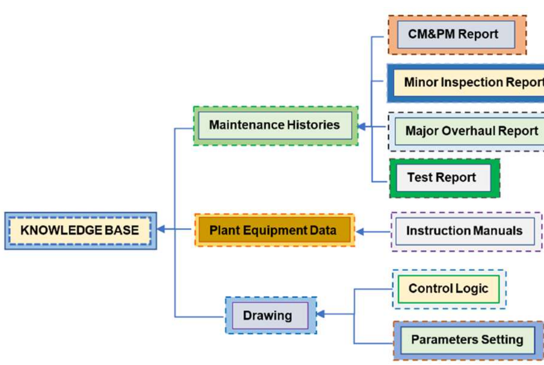


Figure 5 knowledge base structure

C. Engineering analysis

1. Failure Analysis Method

The method of reliability analysis engineering technique is fault tree analysis to understand how systems components can fail, and to identify the best ways to solve emergency case problems of the system, aiming at obtaining optimized results. After that, a summary of failure and transfer data in logic algorithm form. The emergency case problem leading to an emergency shutdown in this project has four types as listed below.

1.1 Lock-out relay 86-1 is an emergency shutdown to instantaneous stop the unit.

1.2 Lock-out relay 86-2 is a quick shutdown. The system decreases load by about 10% of maximum power (12.5 MW) after that stops the unit.

1.3 Lock-out relay 86-3 is a partial shutdown. The system opens the unit circuit breaker, excitation off and down a step from load mode to turbine start mode. The machine runs at the rated speed (125 rpm.).

1.4 Lock-out relay 86-4 is a differential relay. The system instantaneously stops the unit.

If the emergency case of governor control systems happened, systems operate will respond immediately depending on the situation of the emergency case. For instance, as seen in Figure 6, the temperature turbine guide bearing too high (38B21H2) triggers lockout 86-2 as a result of root cause analysis using real-time database and knowledge base data.

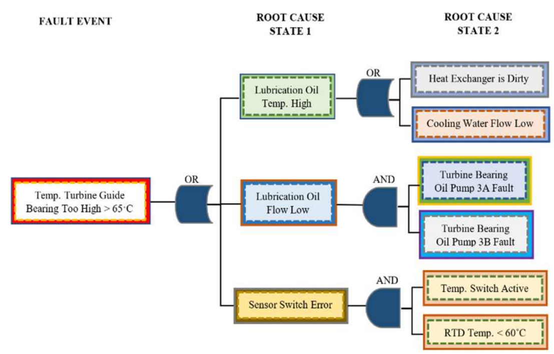


Figure 6 example case “Temperature Turbine Guide Bearing Too High (38B21H2)”

2. Equations and Calculations

Both historian value and testing report data will be analyzed for setting alerts. After that setting alerts notify the operator of first aid this event because the unit is at high risk of emergency shutdown. The alert is helpful for outage planning for preventive maintenance with the maintenance team.

In the example from the knowledge base, Temperature Turbine Guide Bearing Too High (38B21H2) we used a bearing run test report from minor inspection 2017 unit 3 as Figure 7.

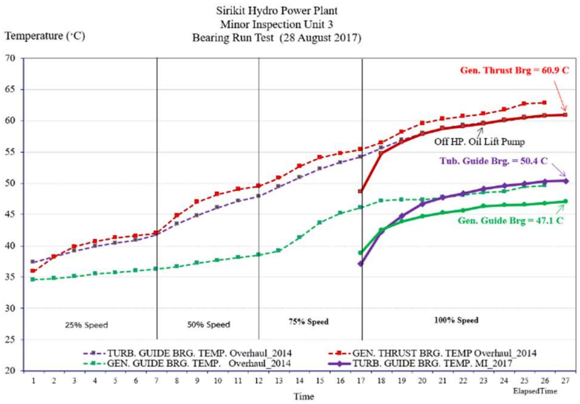


Figure 7 Unit 3 bearing run test report

This report shows the turbine guide bearing temperature needs a time of approximately 30 minutes to be saturate at 50.4 ˚C. The parameter setting of turbine guide bearing temperature alarm and trip at 60 ˚C and 65 ˚C respectively. In this case, we alert at temperature 58 ˚C and notify to operator for planning with the maintenance team to clean the turbine oil cooler heat exchanger.

From a historical value, the governor oil pump normally runs about 30 seconds each time during the mechanic run as Figure 8. When the governor oil pump appears to be something wrong. for example, if the governor oil pump runs overtime, the temperature of the governor oil sump tank will increase at the point of alarm is 65 ˚C and trip at 70 ˚C. So, the set-up alert time of the governor oil pump working is more than 3 minutes. The systems will alert and notify operators then operators have to check the governor oil pump working and the governor oil sump tank temperature.

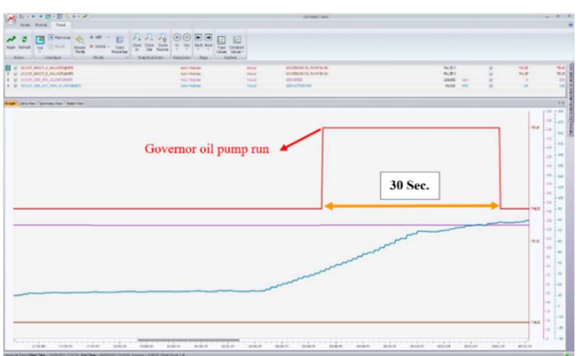


Figure 8 Governor oil pump run of historian

D. Diagnosis result

We collect 24 emergency failure occurrences in the governor system. All problem was identified and the failure cause and was solved by gathering information from engineer analysis, history of event, and experienced maintenance & operation staff of Sirikit Hydro Power Plant from the corrective maintenance report. Then, Information data and problem-solving steps are analyzed to a summary of troubleshooting guide details shown in three examples of emergency failure cases in Sirikit Hydro Power Plant as Table 1 and listed below.

1. Fault Events: Name of an emergency case.
2. Default reaction: The affected machine such as unit trip lockout 86-2.
3. Root Cause State 1: First state of root cause analysis for identify possible main cause of fault event.
4. Root Cause State 2: Second state of root cause analysis for identifying the underlying possible cause from root cause state 1 of fault event in more detailed.
5. Possible Reason: The gathering information from manual of equipment, drawing and experience maintenance & operation staff.
6. Recommend Inspection: The solution recommends for solve and check of each problem that different depend on an emergency case cause.

Subsequently, both engineering analysis and diagnosis result process are important data for creating real-time root cause analysis via Boolean logic that each component has input data then the data can be evaluated as true or false, or 1 or 0 in the node-red program.

For example, in analysis case 38B12H2 - Temp. Generator Thrust Bearing Too High, we analyze how low lubricating oil flow in condition 1 and the generator bearing oil pump A (88QBM1) and B (88QBM2) in root cause state 2 are the main causes of the thrust bearing temperature too high. In the node-red software, we use the AND Boolean operator between the generator-bearing oil pumps A and B failures when the lubricating oil flow is low, as shown in Figure 9.

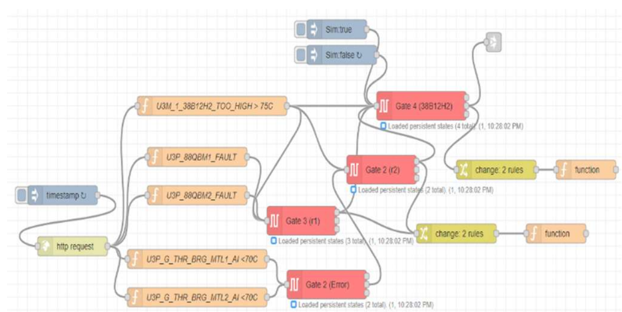


Figure 9 Example create logic flow of 38B12H2 - Temp. Gen. Thrust Bearing Too High at node-red program.

Table 1 The example of trouble shooting guides

No.	Fault Events	Default Reaction	Root Cause State 1	Root Cause State 2	Possible Reason	Recommend Inspection
1	Temperature turbine guide bearing too high (38B21H2)	Unit trip lockout 86-2	1. Lubrication oil temperature high	1.1 heat Exchanger is dirty	- Lubrication oil is contaminated - Cooling water is dirty	- Inspection and clean heat exchanger
				1.2 Cooling water flow low	- Electrical flow sensor switch is bad - Cooling water valve is not fully opened	- Check electrical flow sensor switch - Check status cooling water valve
			2. Lubrication oil flow low	2.1 Turbine bearing oil pump A, B fault	- Motor overcurrent	- Check overload relay - Check status lubrication oil valve - Pump A, B inspection
			3. Temperature detector is error	3.1 Temperature switch is active and RTD temperature is lower than 65 ˚C	- Wiring connection is loose - Temperature detector is Bad	- Check annunciator - Check relay K902 - Check wiring connection at terminal
2	Temperature governor oil sump tank too high (23QTTH2)	Unit trip lockout 86-2	1. Oil circulation at governor oil sump tank	1.1 Governor oil pump A run overtime or 1.2 Governor oil pump B run overtime	- Pressure relief valve mechanical "ON"	- Check pressure at governor pressure tank - Inspection governor oil pump A, B - Check unloading valve
					- Electrical pressure switch malfunction	- Check pressure switch - Logic function check
3	Shaft seal water flow too low (80FPTL)	Unit trip lockout 86-2	1. Orifice valve is dirty	1.1 Main strainer is dirty	- Cooling water is dirty	Inspection & clean main strainer
				1.2 Shaft seal strainer is dirty	- Cooling water is dirty	Inspection & clean shaft seal strainer
			2. Flow sensor is error	-	- Wiring connection is loose - Flow sensor switch is bad	- Check flow sensor - Check relay K1130 - Check wiring connection at Terminal

E. Graphical user interface

A graphical user interface is a computer program that enables a person to interact with a computer through the graphical components. This shows the overall status of the system and makes with user-friendly, simple, and easy to use. The graphic was created by the node-red dashboard program. In this paper, the graphic working separate in two parts.

Part 1: Ready to start checker of governor system as Figure 11. This is importance part because the machine was started-stopped many times/years. If start-up failure happens, effect to available payment of the power purchase agreement and key performance index of hydro power plant.

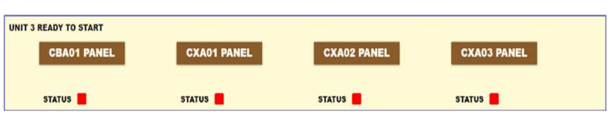


Figure 11 Graphic unit 3 ready to start

Part 2: Emergency Cases of the governor system that divided into 6 groups as Figure 12 and list below.

Group 1: External Trip is the governor system that cannot detect fault. So, other equipment such as the generator protection relay or excitation system can detect faults and then will send a trip command to the governor system.

Group 2: Emergency push button on every panel of the governor system. The button has 2 types.

Type 1: Emergency shutdown is instantaneous stop.

Type 2: Quick shutdown is decrease about 10% load of maximum power (12.5 MW) after that stop the unit.

Group 3: Speed device is detected overspeed from electrical and mechanical and need 2 failures of 3 speed sensor failures.

Group 4: Inlet Valve System is detected hydraulic control of the inlet valve such as the pressure or level of the inlet valve pressure tank.

Group 5: Turbine System is detected hydraulic control and shaft sealing water of the turbine.

Group 6: Temperature is detected oil temperature such as lubrication oil temperature at the guide bearing and thrust bearing of the machine, oil temperature of the control actuator.

3. RESULTS AND DISCUSSION

Case Study, The generator can’t control power in load mode status. So, that effect to load (MW) swing and unit trip lockout 86-2 detected temperature too high. The system sends the trip signal from the temperature governor oil sump tank that is too high temperature (23QTTH2) as Figure 12.

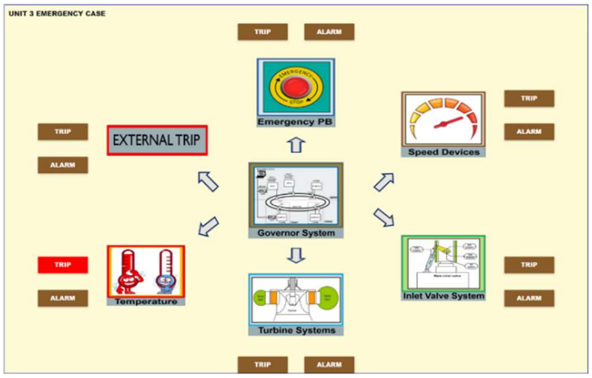


Figure 12 Detected temperature high trip

The program's real-time root cause analysis will show a troubleshooting guide as listed below and in Figure 13.

Fault Events: Temperature governor oil sump tank too high (23QTTH2)

Default Reaction: Unit trip lockout 86-2

Root Cause State 1: Oil circulation at governor oil sump tank

Root Cause State 2: 1.1 Governor oil pump A run overtime or
1.2 Governor oil pump B run overtime

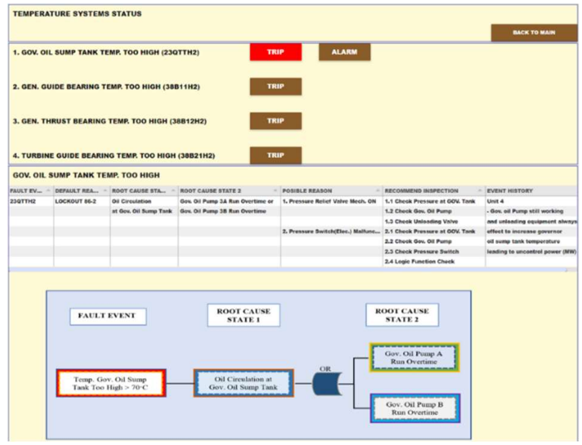
Possible Reason: 1. Pressure relief valve mechanical "ON"

Recommend Inspection: - Check pressure at governor pressure tank
- Inspection governor oil pump A, B
- Check unloading valve

Possible Reason: 2. Electrical pressure switch malfunction

Recommend Inspection: - Check pressure switch
- Logic function check

Event History: Unit 4
- Gov. oil Pump still working and unloading equipment always on, effect to increase governor oil sump tank temperature leading to uncontrol power (MW)



FAULT EV...	DEFAULT REA...	ROOT CAUSE STA...	ROOT CAUSE STATE 2	POSIBLE REASON	RECOMMEND INSPECTION	EVENT HISTORY
23QTTH2	LOCKOUT 86-2	Oil Circulation	Gov. Oil Pump 3A Run Overtime or	1. Pressure Relief Valve Mech. ON	1.1 Check Pressure at GOV. Tank	Unit 4
		at Gov. Oil Sump Tank	Gov. Oil Pump 3B Run Overtime		1.2 Check Gov. Oil Pump	- Gov. oil Pump still working
					1.3 Check Unloading Valve	and unloading equipment always
				2. Pressure Switch(Elec.) Malfunc...	2.1 Check Pressure at GOV. Tank	effect to increase governor
					2.2 Check Gov. Oil Pump	oil sump tank temperature
					2.3 Check Pressure Switch	leading to uncontrol power (MW)
					2.4 Logic Function Check	

Figure 13 Trouble shooting guide of “Temperature governor oil sump tank too high (23QTTH2)”

If the oil sump tank temperature is high before synchronizing mode, it will be hard to synchronize to the grid. Because difficult control speed relates to frequency before synchronizing into the power grid and effect start-up unit failure.

Typically, we solve fault events by depending on the expertise of the operation and maintenance personnel. After that, we use the real-time root cause analysis system which helps to reduce the time for deification fault events and has a guide dance to solve the problem.

4. CONCLUSION

The real-time root cause analysis of the governor control system can help maintenance & operation staff reduce the time for solving problems by using a troubleshooting guide from the dashboard of the node-red program. This system can reduce financial loss and charges from stopping the machine. In addition, the maintenance managers can choose the best way to decision solve the problem or plan to shut down the machine when major or minor trouble happens and decide to shut down at a suitable time. Gained a great benefit for the Sirikit hydropower plant by applying a real-time root cause analysis system to diagnose fault events.

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