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SYSTEM RELIABILITY OPTIMISATION OF COOLING-CUM-CONDENSATE-EXTRACTION SYSTEM

OPTYMALIZACJA NIEZAWODNOŚCI UKŁADU CHŁODZENIA Z SYSTEMEM ODPROWADZANIA SKROPLIN

A novel methodology is presented for condensation in power generation plants; this section is the main intersection of heat loss, typically 40% thermal efficiency of a plant. Condensate section is interfaced with the generating section to enhance the active contribution of the system. Both the cooling section and the condensate section are integrated and interfaced through the low-pressure and high-pressure cycles to attain the improved electrical efficiency, which affects the heat transfer capability of the power generation plants. This paper proposess a Cooling-cum-Condensate-Extraction System (CCES), to dedicate a 36-MW- captive power plant. The paper is dedicated for the design and development of an effective CCES, analyzing its impact over the systems in terms of system reliability optimization, and the role of real-time optimization. The designed model also contributes in discharging lesser amount of flu gases as against existing technologies with its improved active operation hours.

***Keywords**: Cooling-cum-Condensate-Extraction System, Fault Tree Analysis, System Reliability, System Safety, Machine Health Monitoring.*

W artykule przedstawiono nowatorską metodologię procesu skraplania do zastosowania w części kondensacyjnej elektrowni, gdzie dochodzi do największych strat ciepła – przeważnie aż 40% wydajności termicznej elektrowni. W proponowanym rozwiązaniu instalację kondensacyjną sprzężono z częścią prądotwórczą aby zwiększyć aktywny wkład systemu. Część chłodzącą zintegrowano i sprzężono z częścią kondensacyjną poprzez cykle nisko- i wysokociśnieniowe, uzyskując w ten sposób lepszą wydajność elektryczną, co ma wpływ na zdolność wymiany ciepła w elektrowni. W artykule przedstawiono układ chłodzenia z systemem odprowadzania skroplin (CCES) przeznaczony dla elektrowni potrzeb własnych o mocy 36 MW. Pracę poświęcono projektowaniu i konstrukcji efektywnego CCES, analizując jego wpływ na systemy elektrowni w zakresie optymalizacji niezawodności systemów oraz roli optymalizacji w czasie rzeczywistym. Zaprojektowany przez nas model, w porównaniu z istniejącymi technologiami, przyczynia się również do zmniejszenia emisji gazów odlotowych dzięki zoptymalizowanemu czasowi pracy.

***Słowa kluczowe**: układ chłodzenia z odprowadzeniem skroplin, analiza drzewa błędów, niezawodność systemu, bezpieczeństwo systemu, monitorowanie stanu maszyn.*

1. Introduction

1.1. Overview

In case of 100 MW and above size generators, air cooling system (ACS) is found ineffective because of the amount of power cannibalized by the ACS. It also becomes more inefficient when the condensation section of the power plants appears at Heat Recovery Steam Generator (HRSG) section. It is vital to incorporate such a complex process with some supervisory system. In recent past, Biswal et al. presented schemes for the optimal cooling of electrical generators, that is, Level – II (control level) only by improving the reliability at systems' level [3], [4] [8], [15], [16]. However, they did not consider the condensate section in their work, which attains the maximum heat loss around 40% of the total generation capacity of the plant. Biswal et al. done a considerable amount of work on cooling of electrical generators through hydrogen. However, they did not count the condensate section in their introduced schemes [3], [4].

To study the effectiveness of Cooling-cum-Condensate-Extraction System (CCES), the cooling section, the portion of feed-water control section and the condensation sections are clubbed together. The presented model meets the requirements of Level – II (Control level) and the Level – III (that is Supervisory level) of the Supervisory Control And Data Acquisition (SCADA) system. Condensate section is the most inefficient section of any combined cycle power plants. In recent time, role of integration is also increasingly critical to deal with the complexity involved in power systems after entertaining both conventional and sustainable sources of energy [7].

1.2. State-of-the-art

Unlike the office environment, power generation and energy management components are expected to handle ruthless situations come across because of surrounding atmosphere and the complexity involved in the process. Even chances of 0.1% failure cause a serious loss, irrespective of significant improvement noticed in component reliability. Emphasis on uninterrupted operation is equally applicable both at system level and considering component(s) of plant as an individual unit. Thus, redundancy is always taken into account as far as any industry applications are concerned [5], [11], [14– 16]. As, there is considerable amount of stress on power stations for generating electricity with unity power factor, and also, its uninterrupted and cost-effective supply to the end-users. System safety is a vital factor in process design and modeling. In the same line, a controller area network based an adaptive fault diagnosis algorithm was discussed by Kelkar and Kamal [12]. Fault Tree Analysis (FTA) is a widely used reliability assessment tool for large and complex engineering systems [13].

Surface condensers followed by the large size electrical generators are the vital components of an Integrated Gasification Combined Cycle (IGCC) power plant. This portion of the closed-loop cycle has experienced the maximum heat to work loss of the Rankine Cycle, which is almost 40% of the total thermal efficiency [6]. Biswal et al. proposed a complete analysis over the reliability aspect of system design for industry applications (power generation area). In their paper, the application area was considered for the cooling of large electrical generators through hydrogen cum water [2], [5]. A condensate heat exchanger is provided for recovering heat from condensate draining from a condensate boiler [9]. Condensate generated from latent water vapor must be collected and discarded to avoid any damage to the heating /cooling unit, and to prevent this contaminant from surrounding environment [6]. Fujita and Machii proposed a condenser design, which includes a plurality of cooling pipes and supporting plates to take care the downstream of condenser [10]. For many years, process C&I was considered as an art rather than science. In recent years, some integrated solutions have been evolved dedicated for optimal operations of the various components power systems using real-time platforms [1]. Objectives of this manuscript are:

To propose a model to improve the efficiency of CCES by enhancing the gain of the model.

To enhance the design of discussed model from system reliability point of view.

2. System specifications of the CCES

This section highlights the role of critical sub-sections of the generating section and the condensate section of the IGCC plants, and their parameters, viz., the C&I; process / physical parameters, WCT (water cooling tower), Cooling Section, and the Condensate Section. Here, both the sections are interfaced through a novel designed close-loop cycle. Suitable transducers, control valves, switches, communication links, a master PLC and the HMI are the integral part of the presented design for the different measurements.

The Control and Instrumentation (C&I) take care of supplying low pressure (LP) and high pressure (HP) water channelized through water cooling tower (WCT); pressurized hydrogen to generating sections of the plant, and actuations of different valves at both the cooling section and condensation section. Further, each input-output (I/O) signal is assigned a unique card and slot number to identify its job by PLC. The database is a must for on-line control, virtual monitoring, and prediction of the system. Descriptions of some of the tags which are governed by PLC of the CCES are summarized in Fig. 1. Performance of the overall power generation can be optimized by ensuring levels and pressures of hydrogen at cooling section, the level of vacuum and pressure inside the condensate section, and the water concentration at WCT.

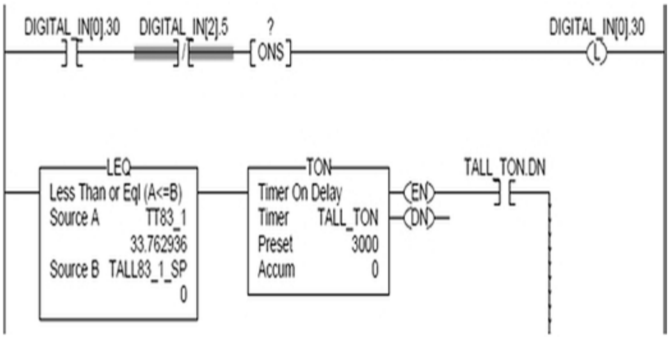

Fig. 1. A segment of ladder-logic program of the CCES

Number of indicators and transmitters are mounted in the design at different location of the CCES for the local monitoring and / or pre-processing of data and further communicating to master controller unit through a balance type communication link. As depicted in Fig. 1, different sub-groups are T, P, F (Temperature, Pressure, and Flow) and L, T (Level, Temperature) across the surface condenser and at both inlet and outlet respectively. Similarly, other set of indicators and transmitters namely, F, T (Flow and Temperature) and only T (Temperature) are mounted at WCT site.

- Process Parameters: The differential pressure method, which is used to measure the parameters pressure, level and flow rate through vessels are governed by $\Delta P = \rho g h$ ($\because \Delta \mathrm{P} = \mathrm{P}_b - \mathrm{P}_a$). Where, $\Delta \mathrm{P}$ is the differential pressure in $pascal$ (Pa) ; ρ is the density of fluid / gas (in kg/m^3) at the respective section; g is the gravitational force in N/m^2, and h is the vertical height of the chamber in $meters$. Thus, the same scheme can be used for the measurement of two physical quantities viz. inside chamber pressure and the volume of fluid at WCT, hydrogen at cooling section, and vacuum at condensate section respectively, which resultant to be simple and cost-effective. Fluid storage limits such as volume limits, starting and stop volumes are governed as per industry standard and practices. Where, the temperature of the module is directed by $\Delta T_{range} = \{Q_{out}/w_{cool} - C_{Pcool}\} = T_{in} - T_{out}$ [1], [3], [5].
- Cooling and Condensate Sections: With the increasing size of generating plants, more attention is given on the design of the exhaust of the machine / section. Proper safety measures are taken in account to avoid the chances of explosion because of hydrogen leakage as per industry standards. The standard sensors are used for the measurement of respective physical parameter are as follows:

i Temperature: $\pm 1^o C$ .Pressure: $\pm 5\%$ in mercury (Hg) manometer tube.

ii Relative humidity: 5% and 0% at the maximum and the minimum threshold.

iii Vibration tolerance band: $\pm 30\%$ to any random input.

3. Methodology of the CCES

Two decision making points and three other check points are assigned for the execution of the control philosophy of the presented model. The entire integrated system is handled by two lever positions viz., the cooling section and the condensate section. Loops are strategically directed to meet the requirements of HRSG (heat recovery steam generator) section of the captive plant. The line of actions is well depicted in Fig. 2. Further, need and effectiveness of all the check points / assessment points are selected, and assigned their roles. Role of all the decision making and the check points are as follows:

- *Mixer*: injection of hydrogen in cooling section at desired pressure, circulation of fluid to maintain the temperatures of cooling, generator, and condensate sections are taken care.
- *WCT*: (water cooling tower) is responsible for using waste heat, and recycle it through the close-loop cycle (HRSG section) of the power station.
- *CWP*: (cooling water pump) has a major role in injecting treated water to both the cooling section and the condensate section using 3-way plug valve.
- *Plug* valve: this valve bifurcate the low pressure (LP) and the high pressure (HP) line of circulating fluid flow at cooling section and condensate extraction section, respectively.
- *Condensate*: at this stage, the fluid is circulated inside the matrix of shell through the pipes to retain the optimal temperature, flow and desired pressure inside the chamber.

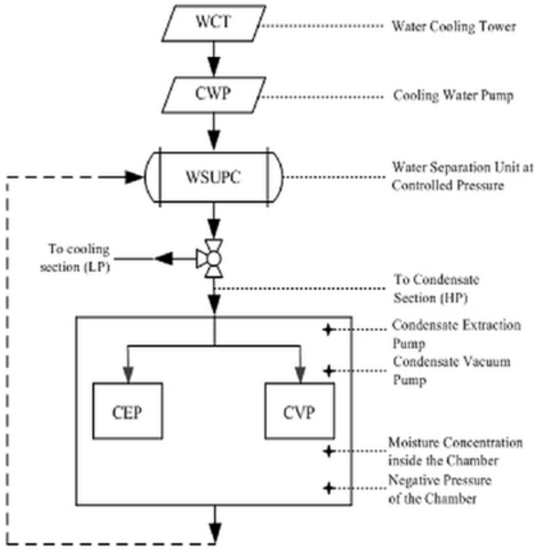

Fig. 2. The control philosophy of the proposed CCES

4. System reliability and failure modeling

Prediction of system's reliability is very much essential as the system (in this paper, CCES) is a collection of different components, assembly lines, and married of close-loop control in a specific pattern in order to identify the desired mathematical model with utmost efficiency and reliability. It is observed from industry standard and practices, fault avoidance methods [5], [13] are overall expansive because of increasing costs (both commissioning and operation costs) versus the linear improvement in reliable life of the system. For the first time, the three parameter Weibull distribution function is used for evaluating the effectiveness of the C&I model at the supervisory level of the SCADA system. This mathematical model is also considered the location of the fault if it occurs. All the symbols referred in Eq. (1) and (2) have standard nomenclatures:

$$\begin{aligned} \Re(T) = e^{-(T-\gamma/\eta)^{\beta}} \ for\, \lambda(t) \geq 0, T \geq 0, and\ T \geq \gamma \\ or\ \gamma, \beta, > 0, \eta > 0, -\infty < \gamma < \infty. \end{aligned} \quad (1)$$

$$\Re_s(t) = \sum_{i=0}^{k} \{\int_0^t \lambda(t)dt\}^i e^{-\int_0^t \lambda(t)dt} (i!)^{-1} = \sum_{i=0}^{k} \frac{(\lambda \cdot t)^i e^{-\lambda t}}{i!} \quad (2)$$

For CCES (Cooling-cum-Condensate Extraction System), Water Separation Unit at Controlled Pressure (WSUPC), 3-way Valve, WCT, CWP, CEP, CVP, the cumulative distribution function for the removal of random variable selected is the three-parameter Weibull distribution, given by:

$$\left. \begin{aligned} \lambda(t) = (\beta/\eta) \cdot (T-\gamma/\eta)^{\beta-1}\ for\, T \geq \gamma \\ and\, \lambda(t, \beta, \gamma, \lambda) = 0\ for\ T < \gamma \end{aligned} \right\}. \quad (3)$$

$$\left. \therefore f(t) = 1 - e^{-(T-\gamma/\eta)^{\beta}} \right\} \quad (4)$$

It is also noted that after burn-in period T_o, considering $\gamma = 0, T_o = 200$ days, if $t = 100$ days that is, taking the double of the operation duration. For, fixed β, η changes as the mean (MTTF/MTBF), the median, and the mode (modal life), and standard deviation, all models / systems are different as is different for all. η, considers a maximum operation hour is equal to 365 days.

$$\Re\left(\frac{t}{T_o}\right) = e^{-(t+T_o/\eta)^{\beta} + (T_o/\eta)^{\beta}} \ for\, \lambda(t) \geq 0, T \geq 0, and\ T \geq \gamma. \quad (5)$$

The reliability factors of the different components are categorized into following sections: (i) reliability factors of converters, reservoirs R_{TX}, R_{TY}, R_{iv}, R_v, and R_{ov} (ii) reliability factors of all the heat exchangers $R_{HEx/z/1A...5B}$, (iii) reliability factor of insulated chamber and vacuum lines R_C or R_S. In terms of system reliability, equivalent models of all the methods discussed in section 4.1– 4.4 are worked out as per specifications of IEEE 1413-2010. From Section 3 and onwards, the method anticipated in this paper (Active CCES) is represented by $S4$, while $S1$ represents Farrell and Billett scheme [9], $S2$ represents Currier system [6], and $S3$ represented Fujita and Machii model [10].

4.1. Scheme of Farrell and Billett

Authors introduced a scheme of utilizing heat flow between condensate section and boiler section. It has a typical matrix (2x6) of the devices inside the heat exchanger which may be placed in the boiler flue gas flow bath. The system model is given by (6):

$$\left. \begin{aligned} S1 = \Re_{FB}(t) = R_{iv} * R_{TX} * R_{TY} * R_{ov} \\ \because R_{TX} = R_{HEx} \,\|\, R_{ov}, 1 \leq x \end{aligned} \right\} \quad (6)$$

4.2. System of Currier

Currier introduced a condensate pump that provides an efficient expel system for the exit of warm air from the surrounding of a pump-motor. The pump has married of a motor-driven fan, an enclose (cover), and an opening which allow air flow. The system is expressed by (7):

$$\left. S2 = \Re_C(t) = R_{HEx} * R_v * R_{HEz}\ for\ 1 \leq x, z \leq 1 \right\} \quad (7)$$

4.3. Fujita and Machii model

Fujita and Machii proposed a condenser which includes plurality of cooling pipes, and further cooling water used for exchange of heat with steam flows. Overall, the model is dedicated to improve the condensate performance. The reliability model is expressed as:

$$\left. \begin{aligned} S3 = \Re_{FM}(t) = R_{TX} * R_{HEx} * R_{\gamma} * R_v * R_{HEz} \\ \because R_{\gamma} = R_{HEx} \,\|\, R_{HEy}, 1 \leq x, y \leq 2 \\ \Rightarrow S3 = \Re_{FM}(t) = R_{HEx} * R_{SI} * R_v * R_{HEz} \end{aligned} \right\} \quad (8)$$

4.4. Proposed method: Active-CCES

The proposed model presents an Active – CCES, which is reliable and cost-effective for the plant capacity of 36-MW generation units. Here, typical hazard rate of $s-out-of-t$ is considered for designing the CCES based on steps shown in (9) and (10):

$$
\begin{gathered}
R_Y = R_{HE1A} \parallel R_{HE1B},\ R_Z = R_{HE2A} \parallel R_{HE2B},\ \therefore R_Y = R_Z \\
\Rightarrow R_S = R_{TB} * R_Y = R_Z = R_O,\ \because R_O = R_{HE3A} \parallel R_{HE3B}; \\
R_\beta = R_{HE4A} \parallel R_{HE4B} = R_\gamma\ ; \Re_{S^3RS}(t) = R_{X'} * R_\alpha * R_\beta * R_\gamma
\end{gathered} \tag{9}
$$

$$
\therefore S4 = \Re_{S^3RS} * (R_m \parallel R_{SC'}),\ \because R_{SC'} = R_{SC} * (R_a \parallel R_b) \tag{10}
$$

$R_{SC'}$, R_{S^3RS}, and R_m are connected serially in forward direction. Fig. 3a-3b and Table 1, shows proportion perfection of $S4$ versus the system reliability of $S1$, $S2$, and $S3$. Respective data are also highlighted in Table 1, which shows performance of presented system, $S4$ as against the existing models.

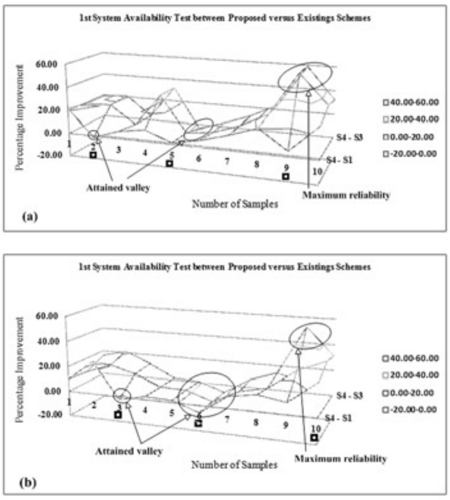

Fig. 3. System availability analysis between of proposed model, S4 as against existing schemes S1, S2, and S3

Table 1. System Availability: Proposed Method (S4) as against systems S1, S2, and S3

System's Availability in Run–mode					
R_S(t) of Test I (Proposed – Existing)			R_S(t) of Test II (Proposed – Existing)		
S4–S1	*S4–S2*	*S4–S3*	*S4–S1*	*S4–S2*	*S4–S3*
21.65	18.99	19.00	9.92	8.68	16.00
–1.17	19.41	21.28	25.89	16.32	21.29
6.44	3.97	3.97	–2.14	10.71	12.27
9.85	31.85	31.85	2.45	1.99	1.79
1.33	1.06	–3.52	1.56	1.51	0.79
5.80	3.78	3.78	–5.80	–5.58	–6.18
12.48	11.74	12.37	9.32	4.87	6.59
20.43	23.72	24.05	12.70	9.62	14.17
4.55	59.05	59.05	9.17	25.05	52.60
26.92	34.93	32.33	26.12	34.13	31.53

4.5. System Failure Mode: Active-CCES

The system failure mode is presented the reverse philosophy of the analysis addressed in sub-section IV A–D that is, called the 'chances of survival' of active-CCES (sub-section 4.4) than that of all the schemes (sub-section 4.1 – 4.3):

$$
\left.\begin{aligned}
&\therefore F(t) = F_{CS} + F_{SHXE} + F_{3-wV} = F4 \\
&= F_{S^3RS} + (F_m * F_{SC'}) - (F_{S^3RS} * F_m * F_{SC'}) \\
&\because F_{SC'} = F_{SC} + (F_a * F_b) - (F_{SC} * F_a * F_b) \\
&F_{SHXE} = F_q + F_{CEP} - (F_r * F_{CEP}) = F_r
\end{aligned}\right\} \tag{11}
$$

$$
\left.\begin{aligned}
&\because F_q = F_p + F_{CVP} - (F_p * F_{CVP}) \\
&\because F_p = F_{BV} + F_{OOV} - (F_{BV} * F_{OOV}) \\
&F_s(t)_{OR} = F_s(t)_+ = F_1 + F_2 - (F_1 * F_2) \\
&F_s(t)_{AND} = F_s(t)_* = F_1 * F_2
\end{aligned}\right\} \tag{12}
$$

Eqs. (11) – (12) have formulated the mathematical statements of the 'chances of survival of $F4 = 1 - S4$ as compared to $F1, F2$, and $F3$. As shown in Fig. 4, the proposed CCES only fails if the cooling section, surface condenser, and 3-way valve section fail collectively which is the combination of ten source points.

Thus, the chances of survival of active – CCES, that is of $S4$ is very high as compared to existing schemes as the statistics framed in Table 1 and Table 2. Further analysis and discussions of this section is done in Section 5.2 based on Fig. 3, Fig. 4, Table 1, and Table 2.

Table 2. System Failure: (S4) as against systems S1, S2, and S3

System's Failure in Run-mode (= 1– Availability)					
F_S(t) of Test III (Proposed – Existing)			F_S(t) of Test IV (Proposed – Existing)		
F1–F4	*F2–F4*	*F3–F4*	*F1–F4*	*F2–F4*	*F3–F4*
78.35	81.01	81.00	87.01	89.36	84.29
71.17	80.59	78.72	98.98	102.90	101.07
93.56	96.03	96.03	101.46	85.18	78.62
90.15	68.15	68.15	76.96	76.00	74.82
98.67	94.94	83.52	88.97	92.39	88.75
94.20	96.22	96.22	96.28	93.80	93.80
87.52	88.26	87.63	95.49	97.38	97.38
79.57	76.28	75.95	95.83	96.17	96.14
125.45	70.95	70.95	81.62	86.29	85.89
73.98	65.97	65.97	73.98	65.97	67.68

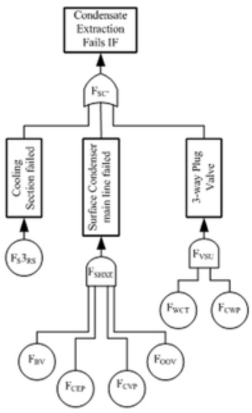

Fig. 4. Static fault tree analysis of the proposed CCES model.

5. Results and Discussions

5.1. Virtual platform of the CCES

Fig. 5 (a)-and-(b) depicts PLC based the project tree of the proposed CCES, and the network view which is used to link the PLC with the HMI of the system. The HMI is the virtual base from where the performance and operation of the entire system (CCES) is continuously observed in real-time. It acts as a virtual plant. Real-time observations of the different parameters of the plant/ process are vital to implement an efficient and reliable system.

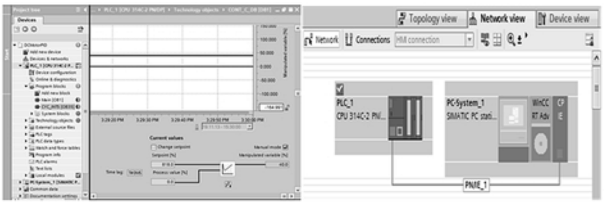

Fig. 5. (a) PLC project tree module of the CCES. (b) Communication interface of the PLC with the HMI

As shown in Fig. 5(b), the network view of the CCES is implemented using wireless HART (IEEE 802.15.4) based protocol which is highly reliable for industrial / robust environment applications. At the same time, cost-effective network/ communication interface is established because of multi-drop configuration. All the sensors/ actuators are mounted over the filed are treated as slaves (RTUs) while the controller is hold the master position. Since there are multiple buses are lying on the same line, only digital communication mode (Bell – 202, FSK standard) is referred for increased reliability. Bell – 202 is referred to interface all the RTUs with controller, and enabling the bidirectional flow of data.

The presented system is also facilitated the trend and the diagnosis modules. These modules are easy the jobs of 'operation and health monitoring of section(s) in real-time', and the diagnosis of any unhealthy signature of a component in auto mode. Thus, the CCES is endowed with the facility of 'bump-less restart', which enable to switch the system (CCES) from manual-to-auto mode and vice –versa without any delay. The model presented in Fig. 5 satisfies the specifications discussed in Section 2.

Fig. 6(a)-and-(b) shows the elements of the programming of the controller (PLC) of the system. Snaps depicted in Fig. 6(a) are in edit-mode, which is ultimately the brain of the system. Further, the activation of the PID (one of the sub-controller of the PLC) followed by the threshold limit of the process variables are depicted in Fig. 6(b). Algorithm is developed to interface the field sensors, the controller (PLC), and the HMI through a balanced type communication link. Aforementioned features of the designed platform helps to realize an integrated automation platform which improves the availability of the CCES (the last sections of CCPPs and the first close-loop component of the HRSG) in operation mode as against the existing schemes. Further sub-sections 5.2 is demonstrated the performance of the CCES (S4) in terms of performance supervision and the system reliability / availability of the process.

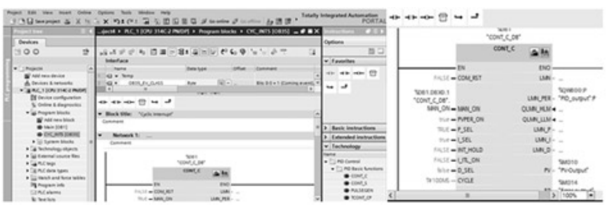

Fig. 6. (a) PLC's Ladder Logic Rungs in Edit Mode. (b) Snap-shot of the Ladder Logic design of the CCES

5.2. System availability and failure of the S4

As shown in Fig. 3(a)-(b) and Table 1, two different tests have been conducted viz., Test I and Test II. Observations are segregated into three domains in terms of the worst case, healthy case/ status, and the optimal availability. Different test events are used to analyze the performances of all the schemes, existing and the proposed one in terms of the worst case (the minimum reliability), healthy state (the average reliability), and the best-fit case (that is optimal availability). Respective data of both the test are fetched in Table 1. The abscissa represents different events / samples collected at different instant of time, varies from the minimum to the verge of the reliability of the individual components. Here, first row of Table 1 indicates the numbers of samples are collected. The second column of the second row shows Test 1, which indicates the performance of S4 versus the existing systems, S1, S2, and S3 in terms of system reliability $R_S(t)$. Similarly, data of Test II is referred from the fourth, fifth and the sixth lines of the row respectively. It is recognized clearly that for the most of the events S4 is performed superior than that of S1, S2, and S3.

As depicted in Fig. 3 and Table 1, at the best fit conditions, S4 has performed 64.6%, 62.12%, and 61.83% enhancement in availability in operation/ active mode as against of S1, S2, and S3 respectively. On the other hand, at the worst –fit conditions S4 has attained negative growth from 0.4% to 25.45%. This is experienced by S4 because of the level of complexity and the higher level of integration involved with the system. Therefore, at the healthy state (average performance), it is observed that S4 has shown 22.51% and 26.02% improvement as compared to S1, while S4 has reflected 34.03% average improvement than that of S2 and S3. Generally, it occurs due to same type of components shared in the P&I (Piping and Instrumentation) diagram of the model. It is also analyzed that the S4 has the least chances of failures versus the existing systems because of increased amount of availability.

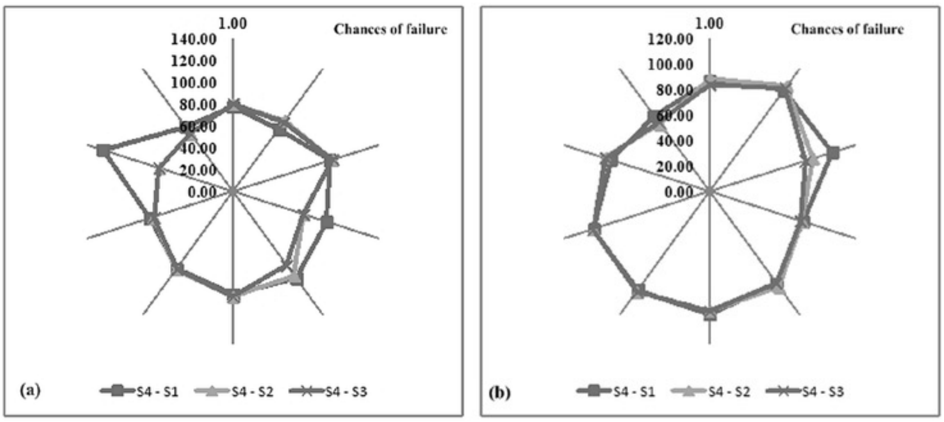

Fig. 7. (a)- (b). System safety analysis of CCES as against the available schemes.

A quantitative analysis is conducted based on Fig. 2 to identify the strength of the proposed design in terms of fault tree analysis (FTA). FTA is considered to be a top-down approach by which each level of fault is expanded to its input from the down. In order to guarantee the reliability of the proposed design (CCES), probability of safety is also evaluated, and the results are depicted in Table 2 and Fig. 7(a)-and-(b).

At this stage, two different sample tests, Test III and Test IV are conducted to judge the effectiveness of CCES. It is noticed that the chances of failure of F4 (1 – S4) has been drop-down from 65.97% to 98.98% as compared to F1 (1 – S1), F2 (1 – S2), and F3 (1 – S3). Data are having more than 100% values are the indices of complexity of the CCES (S4) in contrast to the design of S1, S2, and S3. In some odd cases as reflected from Table 2 and Fig. 7, S4 is reported inferior by more than 1% to 25% than the counterparts. In contrast, the overall availability of S4 is measured in between 26% to 32%. Therefore, it can be recapitulated that the CCES model proves advantage over all others in terms of system reliability.

6. Conclusion

The model CCES is designed and analyzed for the optimal performance of the sizes of 36-MW generation capacity, particularly for the married of cooling cum condensate extraction sections of the power stations. The CCES has publicized (25.89% to 59.05%) significant enhancement not only in terms of the availability but also in terms of system safety (that is, the least chance of failure) of the system in active mode. Active mode is the reflection of the increased electrical gain of the system. S4 has been attained the maximum amount of availability, and framed the highest degree of the safety module. Thus, from the bidirectional analysis, it can be establish that proposed CCES model is on upper hand side than that of all the counterparts. This improved model (CCES) is finally implemented by injecting a methodology for the optimization of a dedicated size process (surface condensation). Process supervision model is designed for the captive power plant to meet the requirement of specific environment in real-time.

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