International Journal of Engineering and Applied Physics (IJEAP)
Vol. 2, No. 3, Sept 2022, pp. 492~501
ISSN: 2737-8071

Maintenance strategy focused on the specific consumption of diesel generators in sub-saharan countries: Case of National Electricity Company of Burkina Faso

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Article Info

Article history:

Received Apr 27, 2022
Revised May 11, 2022
Accepted May 27, 2022

Keywords:

Diesel thermal power plant
Specific consumption
predictive maintenance
Burkina Faso

ABSTRACT

Sub-Saharan countries would mainly use thermal power plant whose Specific Consumption (SC) was relatively higher than the reference values provided by the manufacturers, which would contribute to the increase in electricity production costs. The aim of this study would be to propose a maintenance strategy which would aim to keep the SC according to the age of the generator at acceptable proportions according to the reference values provided by the manufacturers. The Ishikawa and Pareto diagrams were used to identify and analyze the causes of the variation in the SC of two large plants of the National Electricity Company of Burkina Faso. The results showed four major causes representing about 20% of the common causes which are 80% of the increase in SC in the thermal power plant of Kossodo and Komsilga, it would be: the poor quality of the fuels, lack of spare parts, inadequate maintenance practice, and poor fuel supply policy.

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1. INTRODUCTION

Sub-saharan countries mainly use thermal power plants equipped with generators consisting of diesel engines and generators for the production of electrical energy [19]. The brands of the generators « Wartsilä, MAN, CATTERPILLAR and DEUTZ» are mainly used in these thermal power plants, because their acquisition and installation costs are accessible to the purchasing power of these countries. However, the operation of these thermal power plants remains costly with the increase in the SC of generating sets [27]. The SC is an indicator of the fuel consumption of a thermal engine as a function of the developed power and time. Maintenance is generally performed, planned maintenance performed according to a schedule established from a predetermined number of units of use and corrective maintenance performed after failure [14]. These types of conventional maintainances often do not effectively anticipate the early wear of a part and, therefore, do not prevent the rise of the SC. Systematic preventive maintenance is time-based and not optimal, as components are replaced before the end of their service life, thus increasing costs [7]. As for conditional preventive maintenance, it is carried out in some thermal power stations to a lesser extent. Its principle is to detect signs of a deviation from a nominal value defined during the design of an equipment or its components, and which may evolve during its life cycle. However, it does not make extrapolated predictions or prognoses of failures or an estimate of the residual life of a component of an equipment, as is the case with predictive maintenance [12].

In Burkina Faso, the National Electricity Company had a total electricity generation capacity of about 600 MW in 2020, including solar and hydro. It has imported more than 60% of its electricity consumption since 2018 from Côte d'Ivoire and Ghana [1]. The National Electricity Company has thermal power plants with a combined nominal capacity of 287 MW, which account for 93% of the national electricity production. The five largest plants representing more than 75% of the thermal production capacity installed in Ouagadougou and Bobo-Dioulasso are [2]:

- OUAGA 2,23.3 MW installed in 1978;
- OUAGA 1,23.3 MW installed in 1991;
- KOSSODO, 51 MW installed in 2000;
- KOMSILGA, 80 MW installed in 2012;
- BOBO 2,57 MW installed in 1988.

Kossodo and Komsilga are the largest thermal power plants in the city of Ouagadougou and will serve as case studies for the analysis of the causes of SC as they provide 82.23% of thermal electricity production. The analysis according to the Ishikawa diagram will be used to understand and explain the problems experienced by all the National Electricity Company thermal power plants.

This work consists in recommending a predictive maintenance strategy focused on monitoring the SC of generators in thermal power plants, based on the average SC of all manufacturers. Thus, on the basis of the results obtained, it is proposed recommendations that are based on the practices of this type of maintenance to lower the SC, having as a trigger indicator, the value of the SC. However, the concept of predictive maintenance is not standardized, but it is often used to characterize maintenance forecasts based on the trend of the detected malfunction and the estimate of the remaining correct operating time [25]. It is a question of proposing an adapted maintenance strategy taking into account the existing maintenance practices, environmental conditions, age, operating conditions and types of generators [29].

2. MATERIALS AND METHODS

Kossodo and Komsilga thermal power plants are designed for continuous operation with HFO (Heavy Fuel Oil) and DDO (Distillate Diesel Oil) and have fifteen generators of four different manufacturers. The respective reference SC values of the manufacturers according to the 85% ISO conditions are: CATERPILLAR, 175g/kWh [3], MAN, 185g/kWh [4], Wartsila, 184g/kWh [5] and DEUTZ, 182 g/kWh [6], this corresponds to an average SC of 181.5 g/kWh.The generators are shown in table 1 below:

Table 1. Generators for the Kossodo and Komsilga thermal power stations.

Group type	Manufacturer	Rated power (MW)	Available power (MW)	Year commissioned
Kossodo Thermal Power Plant				
18V28/32H	MAN B & W	3 800	3 000	2000
BV16M 640	DEUTZ	6 460	5 500	2000, rehabilitated in 2017
BV16M 640	DEUTZ	6 460	5 500	2000, rehabilitated in 2017
BV16M 640	DEUTZ	6 460	5 500	2003
BV16M 640	DEUTZ	6 460	5 500	2004
18VW 32	Wartsilä	8 032	6 000	2006, rehabilitated in 2017
18VW 32	Wartsilä	8 032	6 000	2006, rehabilitated in 2017
18V48/60 B	MAN B & W	18 390	16 500	2006

Komsilga Thermal Power Plant				
18V48/60 B	MAN B & W	18 427	16 212	2013
16VM43 C	CATERPILLAR	12 527	10 000	2012
16VM43 C	CATERPILLAR	12 527	10 000	2012
16VM43 C	CATERPILLAR	12 527	10 000	2012
16VM43 C	CATERPILLAR	12 527	10 000	2012
16VM43 C	CATERPILLAR	12 527	10 000	2012
16VM43 C	CATERPILLAR	12 527	10 000	2012

The CATERPILLAR brand is predominant in the fleet of two (02) power plants. The available capacities range from 3 MW to 16.212 MW. The age of the generators varies between 8 and 21 years.
To analyse the causes of the SC variation, each thermal power plant work team composed of six persons, including the plant service manager, the operations division manager, the operations team leader, the plant clerk, the head of the mechanical maintenance division, the head of the electrical maintenance division, the head of the mechanical section, the electrical section leader met respectively to complete the Ichikawa diagram and analyze the causes of the SC after a small training.

2.1.1. Research and analysis of the causes of specific consumption variation in the thermal power plants

The Ishikawa diagram is used to analyze the probable causes of an increase in the SC of the Kossodo and Komsilga power plants. It allows to visualize and link the causes and effects of failures following a brainstorming. The tool branches show scenarios to better explain a failure, event or cause situation. It is in the form of fish bones or a tree classifying the categories of causes inventoried according to the law of the five M (Manpower, Machine, Material, Method, Measurement). It lends itself well to a collective team search, conducted by building a tree structure from the downstream (the defect) to the upstream (the potential causes) [24]. The analysis work took place in 2016, between the months of June and December for two weeks of 08 to 12 hours per day. This work took place as part of a master's degree in industrial engineering (Ilboudo, 2016). The common causes of the SC of thermal power plant are identified and the use of the Pareto diagram has made it possible to highlight the major causes. The development of the Pareto diagram is made possible by Table two (2) below illustrating the cumulative percentages and percentages of causes and the products of the weighted vote weights. It is made by us on the basis of the Excel software. The percentage of a case is calculated by dividing the weight of the case concerned by the total number of weights (m) of all cases, which is then multiplied by 100 (the last value is always 100%), hence the formula:

$$P = \left(\frac{Weight}{m}\right) X\ 100 \qquad (1)$$

The calculation of the cumulative percentage is done, for the first cause by repeating the same values for the percentage and the cumulative percentage. The rest obeys the same logic represented by the following formula:

$$PC\, n = PC(\, n - 1\,) + \,P\, n \qquad (2)$$

For each case, the weight of the weighted votes of a case is calculated on the basis of the following formula:

$$Pp = \ VP1\ X\ VP2 \qquad (3)$$

Legend: *PC : Cumulative Percentage of Cases*
P : Percentage of cases
Pp : Product weight of weighted votes
VP1 : Kossodo Weighted Vote
VP2 : Komsilga Weighted Vote
m : Total weight of all causes

2.1.2. Predictive maintenance based on monitoring specific consumption

One of the greatest needs of thermal power plants is to ensure the maintenance of the generators in order to control their SC and to be able to estimate the life of the components and/or to predict potential failures; This inevitably involves predictive maintenance [14]. Predictive maintenance is based on the analysis of the collected data thanks to intelligent sensors positioned on the generators.

In our case, predictive maintenance is based on the performance indicator of SC and other behavioural indicators such as vibration, noise, oil analysis, thermography, temperature [11-15]. The SC must be less than or equal to the reference value of the generators manufacturers. Moreover, the specific consumption of the best large diesel engines can drop to 160 g/kWh [12].

Several works have been carried out on predictive maintenance, allowing it to be properly implemented and better evaluated. Indeed, according to Murry and Mitchell [30]; Crowder and Lawless [20]; Eti, Ogaji and Probert [21]; Maillart and Pollock [17], there is better control over the operating costs of generators, also according to Grall, Dieulle, Berenguer and Roussignol [8]; Carnero [22]; Carnero [23] optimizes maintenance programs in a thermal power plant. Moreover, in comparison with other types of maintenance strategy, Contreras, Modi and Pennathur [17]; Lu and Jiang [16]; Zhou, Xi, and Lee [31] propose for a permanently monitored system, prone to degradation due to imperfect maintenance, a predictive maintenance policy. They also recommend corrective maintenance for a system that deteriorates slowly and preventive maintenance when its failure rate is high.

3. RESULTS AND DISCUSSION

3.1. Analysis of Thermal Power Plant SA Variances

According to a study conducted by Shopeju and Oyedepo [28], thermal power plants in general have good reliability at the time of first commissioning, but decrease over time due to several factors such as poor maintenance planning, lack of spare parts and poor operational decision-making. Figure 1 below shows the average specific consumption deviations per year from the average SC of 181.5 g/kWh used here as the reference threshold.

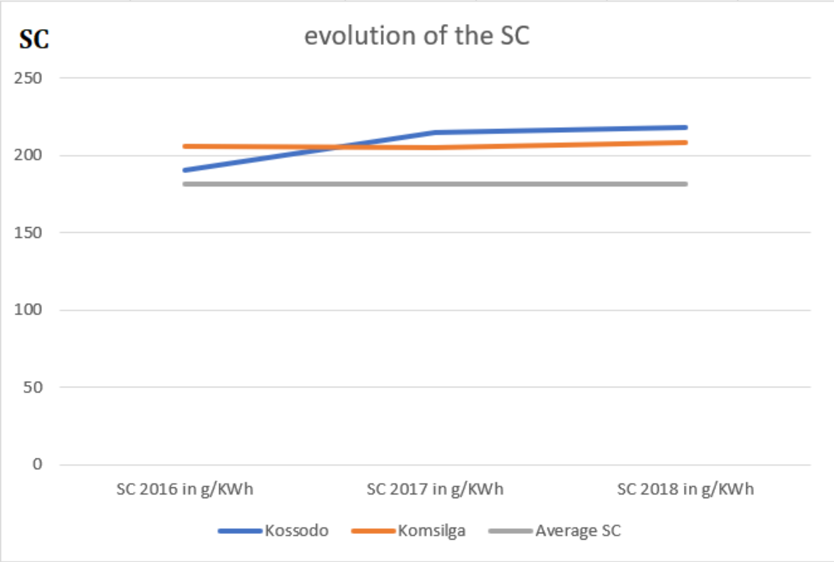

Figure 1. SC of Kossodo and Komsilga thermal power plants as a function of the average SC

The above curves show maximum deviations of the SC of the Komsilga and Kossodo thermal power plants of 26.53 g/kWh and 36.42 g/kWh respectively from the average SC provided by the manufacturers, which means that the respective over-consumption is in the order of 14,61% and 20.06%. Also, we see that the SC of Kossodo grows exponentially, and that of Komsilga in tooth of saw.

Despite the regular application of systematic and curative preventive maintenance, this did not really allow the SC of the power plants to remain packed with SC supplied by the manufacturers. Moreover, the SC of Kossodo is superior to that of Komsilga, because it is ten older.

3.2. Investigation of the causes of the increase in the specific consumption of the thermal power stations of Kossodo and Komsilga with ISHIKAWA

The Kossodo team made it possible to create the first diagram, and that of Komsilga the second all illustrated respectively by figures 2 and 3 below. The common causes for both plants are numbered from 1 to 12 on the two (02) Ishikawa diagrams below. They also correspond to the numbers shown in table 2 below.

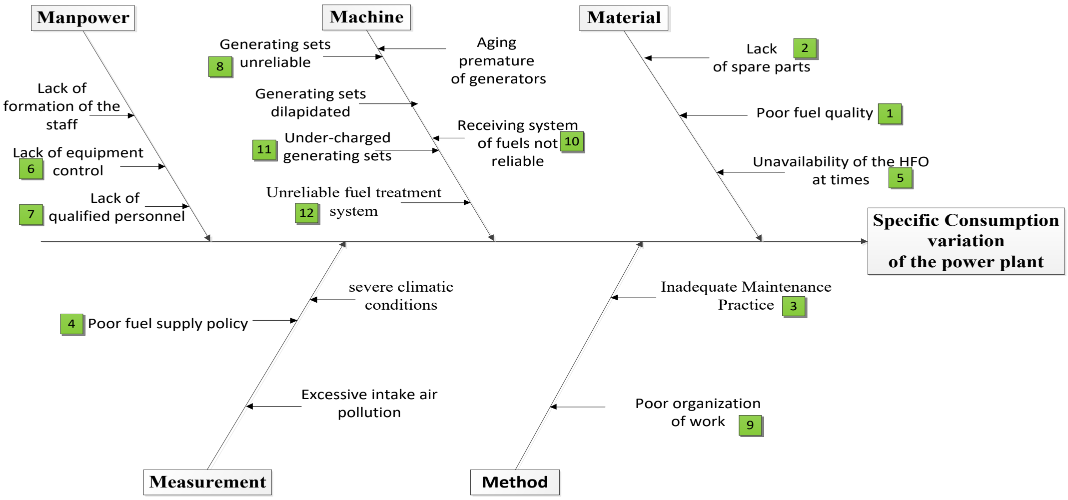

Figure 2. Kossodo cause-effect diagram

The « Machine » business line is related to the obsolescence of the equipment. The « Material » business shows difficulties related to the quality and unavailability of the desired fuel, and the lack of spare parts. The « Measurement » branch illustrates the plant's environmental problems (temperature and dust). The « Manpower » and « Method » branches provide information on the causes of the lack of qualified personnel and the poor organization of maintenance teams respectively. All these problems are related to inadequate maintenance practice, which accelerates the aging of the generators and leads to an increase in the SC of the plant.

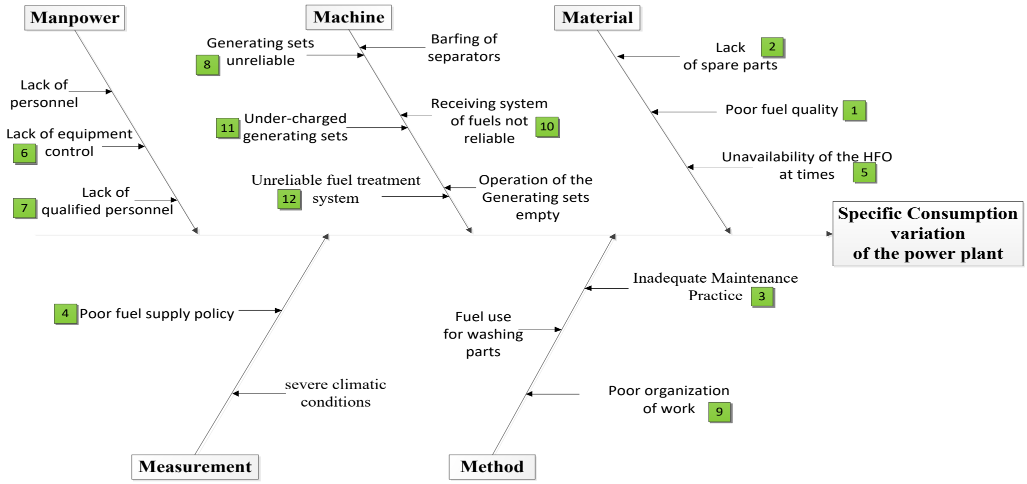

Figure 3. Komsilga cause-effect diagram

The « Machine » business shows cause related to operating deficiencies and recurrence of equipment failures. The « Material » business identifies issues related to the quality and unavailability of the desired fuel and spare parts. The "Method" branch indicates poor organization of the maintenance teams and a lack of consumables for maintenance. The « Manpower » and « Measurement » branches have, respectively, deficiencies related to shortages of qualified personnel and an environmental impact.

All these difficulties are related to the maintenance of the equipment and lead to an increase in the SC of the plant.

The common causes numbered on the figures above are the most numerous, the most relevant and take into account all the causes related to the increase in the SC of thermal power plants. The specific causes of each plant do not allow to build an overall analysis to arrive at solutions allowing to control the SC, which is why they will not be taken into account in the rest of the study. A weighted vote was taken to rank the cases in order of importance and priority. This analysis is done in a cross-tabulated table (table 2 below) in which opinions are placed in a row header and voters in a column header. The table values then represent the score given by each voter. The result of the vote is weighted in table 5 below and gives more precision to our analysis. After defining the number of common cases, a point (from 0 to 5) is assigned to the cases listed in Kossodo and Komsilga. It is a question for each plant to give a higher point, as the cause seems more interesting. It is a simple weighted vote, already used to lower the costs of a company [27]. The results of the centrally weighted votes, as well as the calculation of the cumulative percentages and percentages, are shown in table 2 below, using the formulas (1), (2) and (3) mentioned above.

Table 2. Single weighted vote, percentage and cumulative percentage.

$N°$	$Causes$	$P\ (\%)$	$CP\ (\%)$	T_{pp}		Pp	$Rank$
				$VP1$	$VP2$		
1	Poor fuel quality	20,66115702	20,66115702	5	5	25	1st
2	Lack of spare parts	20,66115702	41,32231405	5	5	25	2nd
3	Inadequate Maintenance Practice	20,66115702	61,98347107	5	5	25	3rd
4	Poor fuel supply policy	7,438016529	69,4214876	3	3	9	4th
5	Unavailability of the HFO at times	7,438016529	76,85950413	3	3	9	5th
6	Lack of equipment control	4,958677686	81,81818182	3	2	6	6th
7	Lack of qualified personnel	4,958677686	86,7768595	3	2	6	7th
8	Generators sets unreliable	3,305785124	90,08264463	2	2	4	8th
9	Poor organization of work	3,305785124	93,38842975	2	2	4	9th
10	Receiving system of fuels not reliable	3,305785124	96,69421488	2	2	4	10th
11	Under-charged generating sets	1,652892562	98,34710744	1	2	2	11th
12	Unreliable fuel treatment system	1,652892562	100	1	2	2	12th
					m	121	

Thermal power plant : Tpp

The above table has shown for each cause its weight on the increase of the SC of the thermal power plants of Kossodo and Komsilga.

In order to target the dysfunctional study, a Pareto analysis is associated with it, based on the 80/20 principle (20% of causes at the origin of 80% on the increase in SC). An analysis of a set of observed phenomena (causes) shows the main causes of a problem and gives them a hierarchy [29]. The Pareto diagram allows to act on a minimum of causes in order to control the SC of the generators.

Using the data in table 2 above, we trace the Pareto diagram represented by figure 4 below.

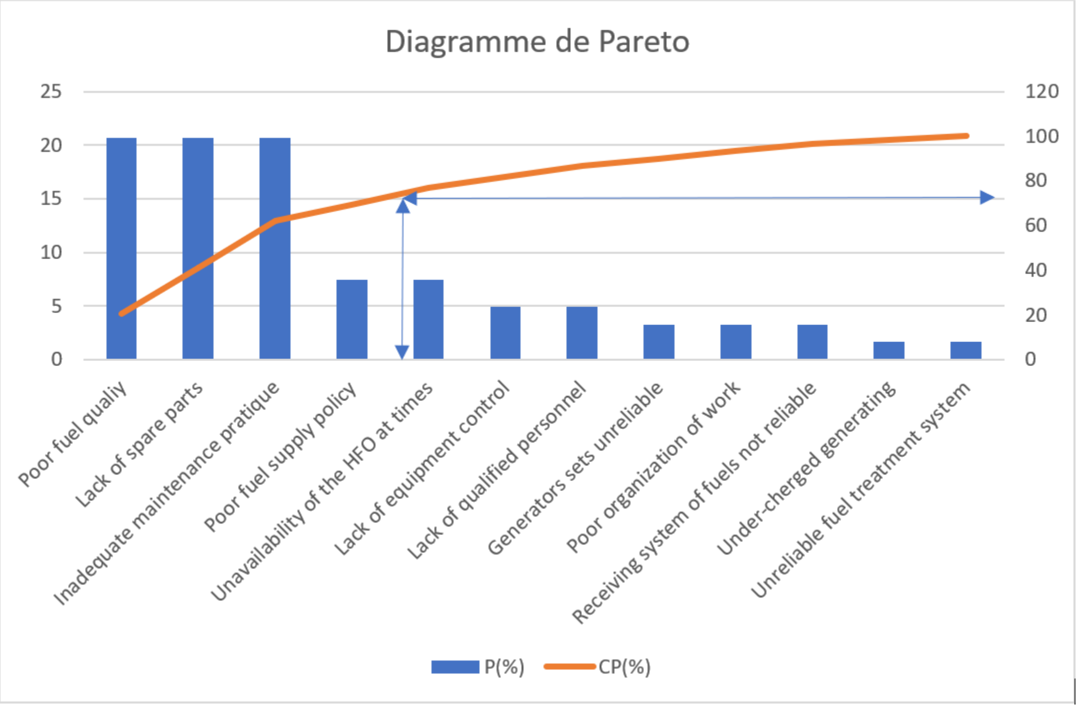

Figure 4. Pareto diagram of the causes of increased SC.

The Pareto diagram shows that four (04) major causes accounting for about 20% of the common causes account for 80% of the increase in SC in the Kossodo and Komsilga thermal power plants, including:

- The poor quality of the fuels was noted by the working teams who expressed reservations about the quality of the fuels used by National Electricity Company. However, there have been no technical reports made available confirming what the teams said.
- Lack of spare parts because worn parts are not always replaced on time due to supply disruptions, which can be attributed to red tape (contracting).
- Inadequate maintenance practice is reported as not taking into account the variation in SA in the analysis of maintenance practices.
- The poor fuel supply policy, because SONABEL often uses DDO instead of HFO, and that increases CS, because the viscosity of DDO 6 Cst is lower than that of HFO which is in the order of 180 Cst. The supply is totally dependent on the type of fuel (HFO and LFO) available at the National Hydrocarbons Society of Burkina.

Moreover, beyond these causes, it should be noted that environmental factors are also at the root of the increase in the specific consumption of generators [9]. Indeed, generators are generally designed to operate effectively at sea level under standard reference conditions. These conditions are specified in ISO 3046-1-2002 as follow :

- an atmospheric pressure of 100kPa,
- an ambient air temperature of 25°C,
- a relative humidity of 30%,
- 25°C coolant charge air temperature.

However, the reality of thermal power plants in Burkina Faso is quite different, because temperatures as high as 35-45°C can impact and reduce the lifespan of mechanical and electrical parts, and cause early failures affecting the SC thresholds of power plants.

Also, high temperatures are associated with low air density which can result in ignition failures similar to that of insufficient air supply, hence the increase in SC. Humidifiers can be used after a thorough study.

Thermal power plants must have a plan for the decommissioning of generating sets whose SCs exceed the maximum proposed above after 25 years of operation. They must also ensure strict adherence to the established plan.

3.3. Recommendations for addressing common causes

- **Poor fuel quality**: strictly comply with supply, acceptance and quality control procedures at all levels, in order to avoid the use of bad fuels in generators.
- **Lack of spare parts**: To simplify the procedures for acquiring spare parts in favour of thermal power plants, by allowing them to access quality parts in desired quantity from the generators manufacturers.
- **Inadequate maintenance practice**: It's about integrating SC-based predictive maintenance into the current maintenance policy. This involves anticipating future equipment failures. Concretely, it is a question of anticipating a breakdown or a malfunction thanks to the accumulation of a data set [26].

The specific consumption is calculated on the basis of the readings made on the daily fuel tanks and on the meters of the various generating sets of the plant. The fuel circuit from the pump to the diesel engine combustion chamber is followed to avoid losses.

The approach to predictive maintenance results in the detection of parameter deviation under surveillance, diagnosis, prognosis and prognosis after the completion of maintenance tasks [13].

Predictive analysis may not take into account contextual information, such as the age of the equipment or weather conditions [10].

- **Poor fuel supply policy**: diversifying sources of supply and facilitating the acquisition of desired fuels: strictly observe the acceptance and quality control in order to obtain the fuels expected in quality and in sufficient quantity.

The analyses were based solely on observations made by technical teams during Ishikawa's analysis of the causes. Thus, the Kossodo power plant, given the age of the generators, will have to continue its rehabilitation plan.

In 2017 the average SC of the power plant decreased by 53.15% thanks to a rehabilitation (overhaul of the coupling and electrical parts) of 50% of generators over 15 years old. However, the average SC is still higher than that of Komsilga.

4. CONCLUSION

The generator is the means of production used in the large thermal power plants in Burkina Faso and in the sub-Saharan countries. These generators operate with fluctuating loads and in a generally severe climate environment. Humidifiers can be used after a thorough study, in order to have a temperature recommended by the generators manufacturers.

The proposed maintenance strategy reinforces National Electricity Company's legacy maintenance practices and will reduce operating costs.

The study made it possible to identify exhaustively all the major causes common to thermal power plants that could lead to an increase in specific consumption. Thus, it was possible to understand that the increase in the specific consumption of the generators of the two (02) power plants is due to more than 80% to the four (04) major causes found. In addition to the proposed maintenance strategy, recommendations have also been made for these causes.

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