REVIEW OF OPERATING MODELS FOR THE DESIGN OF TURNAROUND MAINTENANCE OF TURBO GENERATORS

SUNDAY OKEREKEHE OKPIGHE[1]*; JAMES EJENIKE OGAGAROJO OVRI[2]; CHARLES MONYE[3].

1. DEPARTMENT OF PROJECT MANAGEMENT TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA.

2. DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA.

3. MANAGER, BOILER/TURBINE SHOP, THERMAL POWER PLANT AND TURBO-BLOWER STATION, (TPP-TBS), AJAOKUTA STEEL COMPANY, AJAOKUTA, NIGERIA.

* CORRESPONDING AUTHOR (eloziconsultants@yahoo.com, +2348023235323)

ABSTRACT

Review of operating models for the design of turnaround maintenance of turbo-generators is reported. The operating status and militating constraints to effective and efficient power generation were identified. Information on series of operating models and new turnaround maintenance strategy were obtained. The reviewed operating models when synchronized to drive the new turnaround maintenance strategy for the turbo-generators is likely to drastically improve the performance efficiency of the turbo-generators, hence the National grid.

KEY WORDS: Operating Models, Turnaround Maintenance, Turbo-Generators, Design.

INTRODUCTION

The Nigerian power sector with an installed capacity of 13,308 MW had only 6 158 MW operational in 2014. Of this 6158MW, only 3000 MW to 4 500 MW were actually being generated due to unavailability of gas, breakdowns, water shortage and grid constraints. The poor performance of the power plants has led to acute shortage of power across the country. Altogether, up to 2 700 MW of power generation capabilities are regularly lost due to gas constraints in a country with one of the largest natural gas deposit in the world.[1]

Up to 500 MW are lost due to water management, while several hundred megawatts are regularly lost due to line constraints. Industry, commerce and private households are suffering from a severe shortfall in electricity generation. With the intention of incentivising private-sector investment in the power sector, the government has privatised the generation and distribution sections in two waves. The proceeds are sensibly being dedicated to infrastructure expansion and, in the case of the second wave, a large part of the revenue has been earmarked for expansion of the country's array of hydropower plants.[1] However, the process of privatisation is still ongoing. At present it is impossible to say with any certainty whether the independent power producers who now form the backbone of the Nigerian power sector will be commercially viable. As part of the process, however, the government has started to encourage investments in both renewable energy and energy efficiency. [1]. According to [2] One hundred million Nigerians, representing 60% of the country's population, have no access to grid electricity. Those who do have grid access experience extremely unreliable supply. Efforts are underway to accelerate the transition to an adequate electricity generation capacity that can meet the current and future demand of Nigerian citizens and their businesses. However, there is as yet no clear vision of what Nigeria's future electricity generation mix can and should be, nor is there a concept of how to align such a vision with the country's sustainable development, industrialisation and climate protection goals. According to [3] There are currently two main types of **power plants operating in Nigeria:** (1) hydroelectric and (2) thermal or fossil fuel power plants. With a total installed capacity of 8457.6MW (81 percent of total) in early 2014, thermal power plants (gas-fired plants) dominates the Nigerian power supply mix[1]. Electricity production from hydroelectric sources (% of total) in Nigeria was reported at 17.59 % in 2014, according to the World Bank collection of development indicators, compiled from officially recognized sources. There have been two main types of fossil fuel/thermal power plants in the country: (i) coal-fired and (ii) natural gas-fired. The power plants are classified, based on ownership, as either:

1. Fully owned by the Federal Government of Nigeria (FGN). There is a plan to privatize these power plants.
2. Owned by the Niger Delta Power Holding Company (NDPHC). The NDPHC is owned by the three tiers of government in Nigeria (Federal, State and Local). These power plants are referred to as being part of the National Integrated Power Project (NIPP).
3. Wholly owned by state governments and/or private companies/individuals. Such a power plant is referred to as being an Independent Power Producer (IPP). Also, [4] reported that

- Many turnarounds lack focus, planning and leadership
- More than 90% failed to meet turnaround goals
- Eight out of 10 grew beyond the original cost and scope
- Three out of every four turnarounds abandoned the original plan/schedule in the first week

In a similar vein, [5] posits that Turnaround maintenance (TAM) is an essential activity in process industry. It plays an important role in maintaining consistent productive capacity. It is a major project that requires sound planning, execution and control. According to [6], Shutdowns for maintenance occur for three main reasons, namely:

- **Efficiency recovery.** Heat exchangers, air-coolers, and other equipment progressively lose efficiency and must be cleaned to recover their functionality.

- **Reliability.** Corrosion due to chemical elements such as sulphur or mechanical-creep cracking can disrupt unit equipment operations.
- **Regulatory.** All inspections required by law,

and that Reducing the complexity of maintenance turnarounds was key to improving the turnaround strategy because it is the main method for coping with recent trends in the engineering, procurement, and construction (EPC) industry of higher costs and less available manpower. Lowering the complexity of turnarounds also helps in larger refineries that have many sophisticated conversion units. Furthermore, [6], posits that the new turnaround strategy consists of four major factors:

- De-clustering process units.
- Using distributed maintenance for process-related shutdowns.
- Increasing the intervals between turnarounds.
- Optimizing the critical maintenance path.

And [6] further postulates that this reduced the number of external contractors involved in a given turnaround, while increasing their efficiency thereby allowing us to:

- Overcome the limited availability of skilled workers.
- Limit interference among maintenance workers by limiting concurrent work on adjacent units. This also decreased idle time due to lack of physical space, safety requirements, and the use of such shared resources as cranes.
- Increase the internal maintenance team’s supervision level of maintenance operations, allowing better
- control especially for unexpected work such as unplanned work discovered during the turnaround.

Consequent on the foregoing, Increased turnaround efficiency allowed us to reduce maintenance direct costs and to lessen unit downtime (recovery of lost production margin). The new strategy was implemented as a pilot project in the Sannazzaro refinery, which is Eni's top performing refinery in terms of maintenance costs. It is in the top end of the first quartile in Solomon benchmarking. In a similar vein, [7] asserts that Plant turnaround maintenance is a fundamental asset management in capital intensive process based industries. The successful implementation of turnaround maintenance among others depends on the appropriate provision of institution and organization for the governance of the event. Also [8] postulates that if project management practice and involvement of external experts and parties are allowed in the maintenance projects, then issues in maintenance projects can be addressed more clearly and the cost and schedule for such a maintenance project can also be optimized. The use of information technology in the whole process can be facilitated not only during the planning phase, but also during the execution and review process.

As a consequence of the identified inadequacies highlighted above, it might be imperative to formulate/ adopt an operating model for the effective management of the Turnaround maintenance of the turbo generators of the national grid. Operating Model is defined by [9] as the operational design that makes it possible to deliver the business strategy. Operational design follows strategy, but the relationship also works the other way around, which means that ideas for operating model improvements can lead to changes in business strategy. The operating model defines how the organization will deliver the capabilities and financial outcomes required by the strategy.

The origin of the term Operating Model in a business context is not clear and is likely to have been coined in a commercial organisation and thus not publicly available. An early example of a similar term can be found in Linder and Cantrell in their work in the year2000 when they used the term 'operating business model' as the operational manifestation of the business model, they provide examples of different operating business models and also provide an emphasis on how organisations change and keep up to date their business model.[10] However, the first user of the term in an academic source is probably Jeanne Ross from Massachusett Institute of Technology (MIT) who in 2005 stated “To make IT a proactive – rather than reactive – force in creating business value, companies should define an operating model”.[10] In her paper Ross goes on to define four alternative Operating Models based on the level of standardization and integration. This derives four categories of model: diversification (low standardization, low integration); unification (high standardization, high integration); coordination (low standardization, high integration) and replication (high standardization, low integration). By standardization and integration Ross can be taken to mean standardization/integration of the IT requirements of operations rather than standardization/integration of actual operations. [10] Also, proactive maintenance of main equipment on power plant demand the monitoring and technical diagnostics on power plants[11]. On the other hand, [12] posits that through the use of the 'Simple System Life Cycle' and the 'V-Diagram of the Simple Life Cycle,' effective and efficient project delivery could be assured. While the Simple System Life Cycle's emphasis is on review, change and feedback on each activity of the project, the emphasis of the V-Diagram of the Simple System Life Cycle is on verification and validation of each activity of the project.

According to [13], Capital repair also referred to as Turnaround Maintenance (TAM) of thermal power plants entails turbines and boilers as main equipment while the auxiliary equipment include: i) Cooling tower ii) Oil system iii) Air system i v) Regenerating system v)System pipelines (dry steam) vi) Steam air fittings vii) Feeding pumps viii) Condensate pumps ix) Circulation pumps x) Low pressure and high pressure heaters.

ORGANIZATION, FORMAL PREPARATION AND FULFILMENT OF CAPITAL REPAIRS.

According to [13], the necessary steps entailed are: i) Compiling of the schedule of the repair and a list of the deeds and volume of works to be done. ii) Technical graph (CPM, Gantt chart) of repairs. iii) Carrying out of preparatory works. iv) Heading of the repairs and instruction of the personnel before repairs. v) Checking and control test of the turbine before its stoppage for repairs. vi) Preparation of the shutdown turbine for repair. vii) Dismantling, repair and assembly of the turbine unit. xiii) commissioning of the unit after repair. x) Documentation on the repair.

SUMMARY OF REVIEW

1. The Nigerian power sector has installed capacity of 13,308 MW but recently generating only 3000 - 4500 MW. Militating factors against power generation have been identified as : unavailability of gas, breakdowns, water shortage and grid constraints.

2. One million Nigerians have no access to grid electricity.

3. The main types of plants operating in Nigeria are Hydro electric and Thermal power plants.

4. Power Plants are classified based on ownership thus: i) fully owned by the Federal Government. ii) Owned by the Niger Delta Power Holding Company (NDPHC), a tripartite holding consisting Federal, State and Local Government. This is also referred to as being part of the National Integrated Power Projects (NIPP). iii) Wholly owned by State Governments and /or private companies/individuals. Also referred to as Independent Power Producers (IPP).

5. Turnaround Maintenance (TAM) is an essential activity in process industry that maintain consistent productive capacity.

6. Shut down for maintenance occur for the purpose of Efficiency Recovery, Reliability and Regulatory.

7. The new turnaround strategy consists of four major factors, namely: i) De- clustering process units, ii) Using distributed maintenance for process shut downs, iii) Increasing the intervals between turnarounds, iv) Optimizing the critical maintenance path.

8. Operational design drives strategy and it is possible that strategy drives operational design.

9. The operating model defines how the organization will deliver the capabilities and financial outcomes required by the strategy.

10. Use of the simple System Life Cycle and the V- Diagram of the simple System Life Cycle can lead to effective and efficient project delivery.

11. Operating Models reviewed are : i) OEE Consulting ii) Boeing in Dupont iii) Campbell et al (POLISM) iv) Bain in Cooper et al v) SOMS vi) EY and vii) Simple System Life Cycle in Stevens et al (1998).

DISCUSSIONS

From point 1 above, the current power generation output of 3000 - 4500MW is a mismatch with the installed capacity of 13,308MW as enumerated by capital power assets in Table 1. The factors listed as militating against power generation can be addressed proactively through the process of thinking out-of-the-box. The problem of breakdown and grid constraint can be eliminated through Risk Based Inspection (RBI) and Reliability Centred Maintenance (RCM).

From point 2 above, that one hundred million Nigerians have no access to grid electricity is a direct fallout from point 1 above. IT is impossible to share/distribute a value that does not exist. When plans fail to support power generation, plans are rife for failure in distribution.

From point 3 above, the choice of hydroelectric generation is in good faith and in line with judicious use of the country's endowment factors of rivers and waterfalls/rapids. Also the choice of thermal power plants is line with the judicious use of the nation's abundant reserve of crude oil and natural gas.

From point 4 above ,the ownership of the power plants range from Federal Government, State Government , Local Government and Private companies/individuals. That the problem of inefficiency in power generation persists, it implies that the owners/managers of these power plants need to be more proactive in operations of these plants in order to step up the much needed power generation/distribution efficiency.

From points 5 and 6 above, an effective and efficient turnaround maintenance will lead to consistent productive capacity and will also allow efficiency recovery, reliability and meet regulatory requirements..

From point 7 above, the new turnaround strategy could be an invaluable tool of change for the Nigerian power plants operations if effectively and efficiently adopted.

From points 8, 9, 10 and 11 above, operational design drives strategy and it is possible that strategy drives operational design. Hence the operating models reviewed, namely: OEE Consulting, Boeing in DUpont, Cmpbell et al (Polism), Bain in Cooper et al, SOMS, EY and Simple System Life Cycle when synchronized to drive the new turnaround maintenance strategy, may likely lead to improved efficiency in power generation.

CONCLUSION

Nigeria's current power generation is about 33% of its installed capacity. Factors militating against effective and efficient power generation have been enumerated as unavailability of gas, breakdowns, water shortage and grid constraints. Operating Models such as OEE Consulting, Boeing in Dupont, Campbell et al(Polism), Bain in Cooper et al, SOMS, EY and Simple System Life Cycle , if synchronized to drive the new turnaround maintenance strategy for the turbo generators of the Nigerian power plant, may lead to improved efficiency.

REFERENCES

1. *Nigerian Energy Support Programme (NESP) (2015), The Nigerian Energy Sector An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification 2nd Edition, June 2015 .* NESP is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and funded by the European Union and the German Federal Ministry for Economic Cooperation and Development (BMZ).*

2. *The Nigerian Economic Summit Group and Heinrich Böll Stiftung Nigeria.(2017), Comparison of Costs of Electricity Generation in Nigeria Abuja, June 2017. *The Lead Author is Maria Yetano Roche supported by Nnanna Ude and Ikenna Donald Ofoegbu, with inputs from stakeholders in the Nigerian power sector. Report was reviewer: Dr. Felix Matthes (Oeko Institute, Berlin) and Hans Verolme (Climate Advisers Network, Berlin).*

3. *Wikipedia* *(2018) List of power stations in Nigeria*

4. *Peter Armato (2018),* ***Plant Turnarounds, Maintenance Shutdowns Require Planning and Know-How*** *. H. Brown Inc. January 2018. Sourced from Bobby Singh "World-Class Turnaround Management: Business Driven and Reliability Focused," , President of Shutdowns & Turnarounds at Project Assurance consultancy.*

5. OGFJ (2017), Turnaround Projects. Vol. 14. 1ssue 10. 23 October 2017.

www.ogfj.com

6. . Italian refiner lowers turnaround maintenance complexity, costs

01/12/2009

7. Ghazali, Zulkipli & Halib, Mohammed. (2018). The Organization of Plant Turnaround Maintenance in Process-Based Industries: Analytical Framework and Generic Processes.

*8. **Shaligram Pokharel**, (2008), Turn-around maintenance management in a processing industry: A case study in Journal of Quality in Maintenance Engineering14(2):109-122 · May 2008with325 Reads DOI: 10.1108/13552510810*

Available from: https://www.researchgate.net/publication/235290737_Turn-around_maintenance_management_in_a_processing_industry_A_case_study [accessed Apr 29 2018].

9. Hult (2018) Designing Operating Models | Specialized Programs |

www.hult.edu/en/executive-education/open-programs/.../designing-operating-models/

10. BATEMAN, N., (2017). Operating model: an exploration of the concept. Loughborough University: Loughborough, UK, 13pp. Additional Information: • This report was commissioned and funded by OEE Consulting. Metadata Record: https://dspace.lboro.ac.uk/2134/26654 Version: Published. Publisher: c Loughborough University Rights:

11. Zdravko N. Milovanovic, Aleksandar N. Milasinovic, Darko M. Knezevic, Jovan B. Skundric, Svetlana R. Dumonjic-Milovanovic. Evaluation and Monitoring of Condition of Turbo Generator on the Example of Thermal Power Plant Ugljevik 1x300 MW. American

Journal of Mechanical and Industrial Engineering. Vol. 1, No. 3, 2016, pp. 50-57. doi: 10.11648/j.ajmie.20160103.13

12. Stevens R., Brook P., Jackson K. and Arnold S. (198). Systems Engineering: Coping With Complexity. PreticeHall Europe. London. ISBN 0-13-095085-8

13. Avhachov, Alexander Pavlovich (1983): Manual for the Turnaround Maintenance of Thermal Power Plant and Turbo Blower Station (TPP-TBS).. Novo-Lipetsk Metallurgical Plant, Lipetsk, Russia.

TABLES AND FIGURES

TABLE 1: Fossil fuel power stations (SOURCE: [3])

Natural gas

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
AES Barge (IPP)	Egbin	6°33′33″N 3°36′54″E	Simple cycle gas turbine	270 MW	Non-operational	2001	Escravos–Lagos Pipeline System
Aba Power Station (IPP)[3]	Aba Abia State	5°09′11″N 7°18′38″E	Simple cycle gas turbine	140 MW		2012	
Afam IV-V Power Station (FGN)	Afam Rivers State	4°51′05″N 7°15′17″E	Simple cycle gas turbine	726 MW (Afam IV -6 x 75 MW (GT 13-18), Afam V -2 x 138 MW (GT 19-20))	Non-operational	1982 (Afam IV)- 2002 (Afam V)	Okoloma gas plant

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
Afam VI Power Station (IPP)	Afam Rivers State	4°50′58″N 7°15′24″E	Combined cycle gas turbine	624 MW	Partially operational	2009 (Gas turbines) 2010 (Steam turbines)	Okoloma gas plant
Alaoji Power Station (NIPP)	Abia state	5°04′00″N 7°19′24″E	Combined cycle gas turbine	1074 MW	Partially operational	2012-2015	Norten Option Gas Pipeline from Obigbo gas plant
Calabar Power Station(NIPP)	Calabar	5°11′21″N 8°16′25″E	Simple cycle gas turbine	561 MW	Non-operational	2014	UQUO gas plant(planned)
Egbema Power Station(NIPP)	Imo State	5°33′56″N 6°44′18″E	Simple cycle gas turbine	338 MW	Non-operational	2012-2013	Gbarain Ubie gas plant(planned)
Egbin Thermal Power Station(FGN but Privatized)	Egbin	6°33′47″N 3°36′55″E	Gas-fired steam turbine	1320 MW (six 220-MW units)Egbin - Thermal Power Station in Egbin, Nigeria	Partially operational (1000 MW	1985-1986	Escravos–Lagos Pipeline System
Geregu I Power Station-Privatized	Geregu Kogi State		Simple cycle gas turbine	414 MW	Partially operational	2007	Oben-Geregu pileline, Oben gas plant

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
Geregu II Power Station(NIPP)	Geregu Kogi State		Simple cycle gas turbine	434 MW	Partially operational	2012	Oben-Geregu pileline, Oben gas plant
Ibom Power Station (IPP)	Ikot Abasi	4°33′53″N 7°34′06″E	Simple cycle gas turbine	190 MW	Partially operational (90 MW)	2009	
Ihovbor Power Station(NIPP)	Benin City	6°24′20″N 5°41′00″E	Simple cycle gas turbine	450 MW [22]	Partially operational	2012-2013	Escravos–Lagos Pipeline System
Okpai Power Station (IPP)	Okpai		Combined cycle gas turbine	480 MW	Operational	2005	Obiafu-Obrikom(Ob-Ob) gas plant
Olorunsogo Power Station	Olorunsogo	6°52′55″N 3°18′52″E	Simple cycle gas turbine	336 MW, (8 x 42 MW	Partially operational	2007	Escravos–Lagos Pipeline System
Olorunsogo II Power Station(NIPP)	Olorunsogo	6°53′08″N 3°18′56″E	Combined cycle gas turbine	675 MW [28]NDPHC (4x112.5 MW and 2x112.5 MW steam turbines.) Working below capacity due to gas supply	Partially operational	2012	Escravos–Lagos Pipeline System

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
				issues.			
Omoku Power Station (IPP)	Omoku		Simple cycle gas turbine	150 MW (6 x 25 MW gas turbines)[32]Rocksonengineering.	operational	2005	Agip (Obiafu-Obrikom(Ob-Ob) gas plant)
Omoku II Power Station(NIPP)	Omoku		Simple cycle gas turbine	225 MW (2 x 112.5 MW gas turbines)	Non-operational	Incomplete	
Omotosho I Power Station (FGN-Privatized)	Omotosho	6°44′09″N 4°42′39″E	Simple cycle gas turbine	336 MW [35]; (8 x 42 MW)	Partially operational	2005	Escravos–Lagos Pipeline System
Omotosho II Power Station(NIPP)	Omotosho		Simple cycle gas turbine	450 MW, (4x112.5 MW)	Partially operational	2012	Escravos–Lagos Pipeline System
Sapele Power Station-Privatized	Sapele	5°55′31″N 5°38′44″E	Gas-fired steam turbine and Simple cycle gas turbine	1020 MW (Phase I: 1978-1980 6 x 120 MW Gas-fired steam turbines, phase II: 1981 4 x 75 MW gas turbines)	Partially operational (135 MW)	1978 - 1981	Escravos–Lagos Pipeline System
Sapele Power	Sapele	5°55′40″N	Simple cycle	450 MW (4x112.5 MW	Partially	2012	Escravos–Lagos

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
Station (NIPP)		5°38′41″E	gas turbine		operational		Pipeline System
Transcorp Ughelli Power Station (privatised)known also as Delta power station.	Ughelli, Delta State	5°32′28″N 5°54′56″E	Simple cycle gas turbine	900 MW	Partially Operational (465 MW)	1966-1990 Plant was built in 4 phases. I: 1966 (decommissioned), II: 1975 6 x 25 MW, III: 1978 6 x 25 MW, IV: 1990 6 x 100 MW	Utorogu, Ugheli East gas plant
Ibom Power Plant	Template:Ikot Abasi		Combined cycle gas turbine Ibom Power Plant presently consist of two GE Frame 6B and one	191MW	Operational Since 2009	2010→	Uquo CPF by Frontier Oil Limited / 7E JV}

Power station	**Community**	**Coordinates**	**Type**	**Capacity**	**Status**	**Year completed**	**Gas supply source**
			Frame 9E turbine generators installed in a simple cycle configuration, using the conventional open cycle gas turbine (OCGT) technology. These three gas turbines are: GTG 1(Model PG 6551B), GTG 2(Model PG 6561B), and GTG3				

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
			(Model PG 9171E) combined to give an installed capacity of 191MW.				

Proposed natural gas power plants(SOURCE: [3])

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Gas supply source
Azura Thermal Power Station(IPP)	Benin City		Simple cycle gas turbine	1,500 MW	In development[4]	TBD	

Coal (SOURCE: [3]

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Additional description
Itobe Power	Itobe Kog		Circulating	1200	Planne	2015-2018 (first	The first phase

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Additional description
Plant	i State		Fluidized Bed technology	MW	d	phase 600 MW)	consists of four 150 MW units. Actual effort is focused on development mining to establish additional coal resources. [5] The project is actually a 1200 MW power plant to be divided into 4 phases of 2 units each. The project has almost achieved financial close and execution of construction

Power station	Community	Coordinates	Type	Capacity	Status	Year completed	Additional description
							agreement.

The Oji River Thermal Power Plant was a coal-fired power plant. It is no longer operational. **(SOURCE: [3]**)

Hydroelectric (SOURCE: [3])

In service

Hydroelectric station	Community	Coordinates	Type	Capacity (MW)	Year completed	Name of reservoir	River
Kainji Power Station			Reservoir	800	1968[6]	Kainji Lake	Niger River
Jebba Power Station			Reservoir	540	1985	Lake Jebba	Niger River
Shiroro Power Station			Reservoir	600	1990	Lake Shiroro	Kaduna River
Zamfara Power Station			Reservoir	100	2012[7]	Gotowa Lake	Bunsuru River

Under construction or proposed (SOURCE: [3])

Hydroelectric station	**Community**	**Coordinates**	**Type**	**Capacity (MW)**	**Year completed**	**Name of reservoir**	**River**
Kano Power Station			Reservoir	100	2015[8]		Hadejia River
Zamfara Power Station			Reservoir	100	2012[9]	Gotowa Lake	Bunsuru River
Dadin Kowa Power Station			Reservoir	40	2018		Benue River
Mambilla Power Station	Taraba State	6°41′46″N11°09′16″E	Reservoir	3050	2018 [44]	Gembu, Sum Sum and Nghu Lake	Donga River

SOURCE: [3]

TABLE 2: SUMMARY OF ELEMENTS OF OPERATING MODELS (SOURCE: [10])

<table>
<tr><th></th><th>OEE Consulting (2017²)</th><th colspan="2">Boeing In DuPont (2104)</th><th>Campbell et al. (2017) POLISM</th><th>Bain in Cooper et al. (2012)</th><th>SOMS (2017³)</th><th>EY (2016) Core other</th></tr>
<tr><td rowspan="9">Core elements of Operating model</td><td>Service proposition (SP)</td><td colspan="2">Channels</td><td rowspan="2">Value propositions</td><td></td><td>Customer experience (CE)</td><td>service delivery</td></tr>
<tr><td>Journey and process (J&P)</td><td colspan="2">key activities</td><td></td><td>Delivery (D)</td><td>process</td></tr>
<tr><td rowspan="2">Management framework (MF)</td><td colspan="2" rowspan="2">Organisation</td><td rowspan="2">Management system</td><td>Key strategic metrics</td><td rowspan="2">Performance Management and improvement (PM&I)</td><td rowspan="2">performance management,</td></tr>
<tr><td>Accountability</td></tr>
<tr><td>Technology and infrastructure (T&I)</td><td rowspan="2">business capa-bilities</td><td rowspan="2">key re-sources</td><td>Information</td><td>Super-structure</td><td>Process context (PC)</td><td>IT</td></tr>
<tr><td rowspan="2">People, culture and organisation (P,C &O)</td><td>Organisation</td><td rowspan="2">Governance</td><td rowspan="2">Strategy governance and leadership (S,G&L)</td><td rowspan="3">Governance, Org design and structure,</td></tr>
<tr><td colspan="2" rowspan="3">key partnerships</td><td>Suppliers</td></tr>
<tr><td rowspan="2">Location, function and teams (LF&T)</td><td rowspan="2">Locations</td><td>Behavioural expectations</td><td rowspan="2">People capability (PC)</td></tr>
<tr><td>Talent requirements</td><td>culture and values</td></tr>
<tr><td rowspan="2">Other elements</td><td></td><td colspan="2">cost structure</td><td></td><td></td><td>Demand and capacity management (D&CM)</td><td>design principles</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td><td></td><td>risk</td></tr>
</table>

SOURCE: [10]

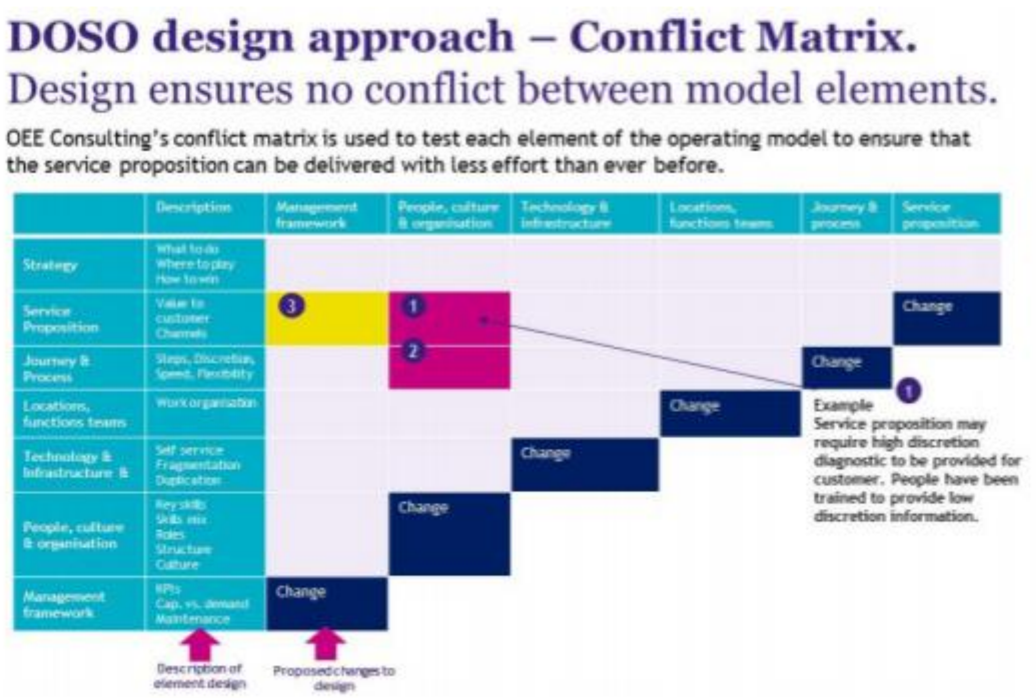

FIG. 1: DOSO DESIGN APPROACH - CONFLICT MATRIX. SOURCE: [10]

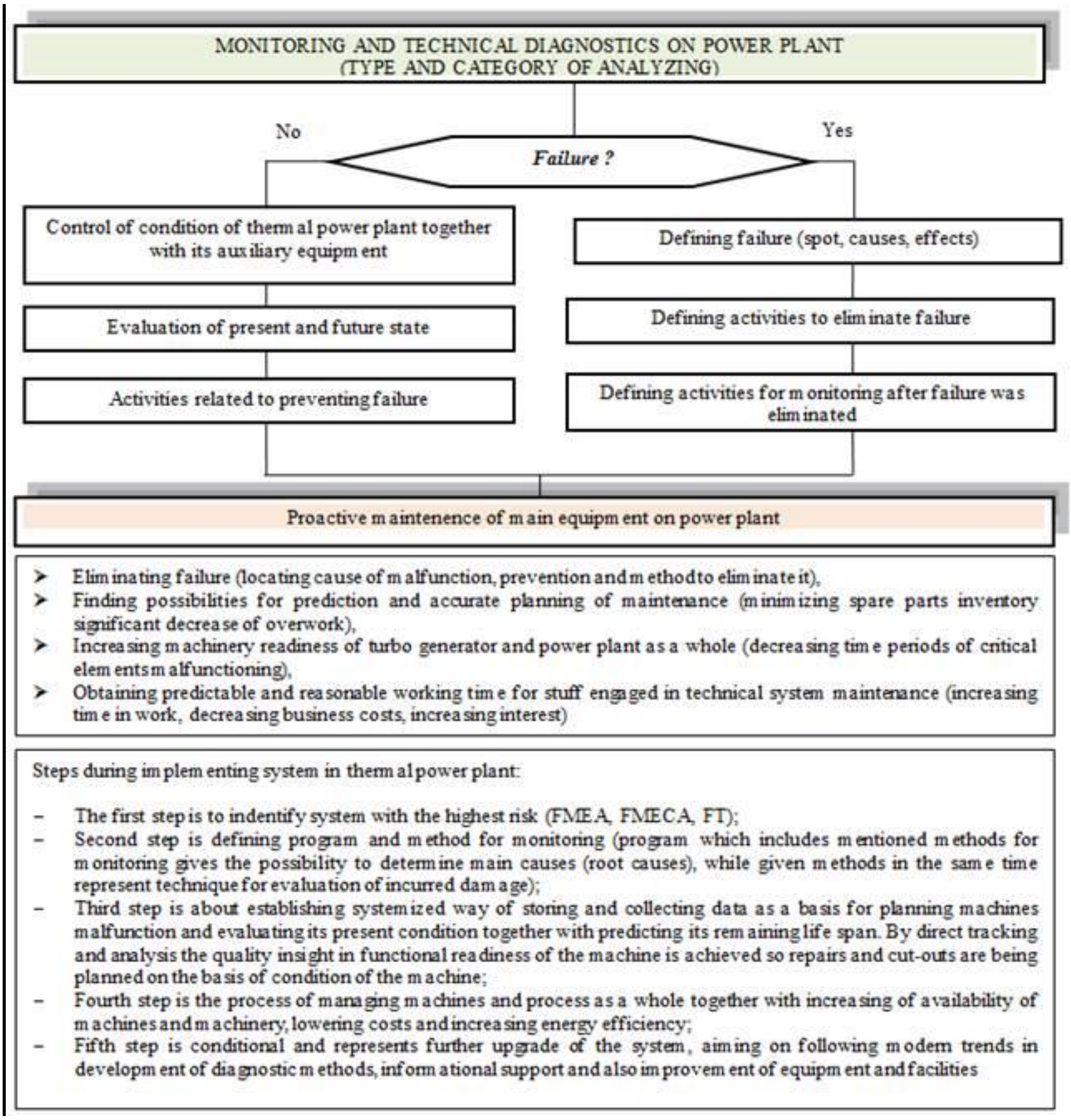

FIG.2. FUNCTIONS OF TECHNICAL DIAGNOSIS AND MONITORING RELATED TO CONDITION OF CERTAIN PARTS OF THERMAL POWER PLANT OR OF THE POWER PLANT AS A WHOLE. (SOURCE: [11])

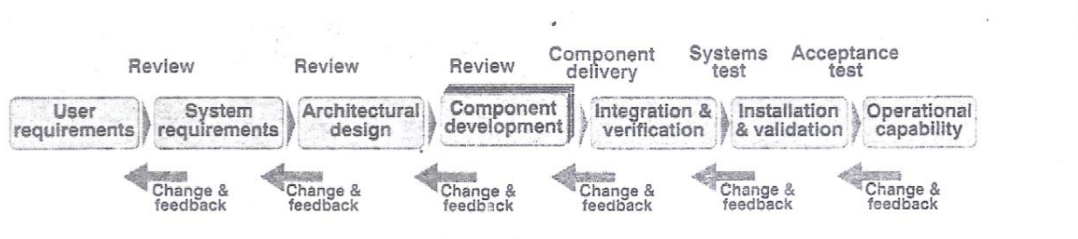

FIG.3 THE SIMPLE SYSTEM LIFE CYCLE SOURCE: [12]

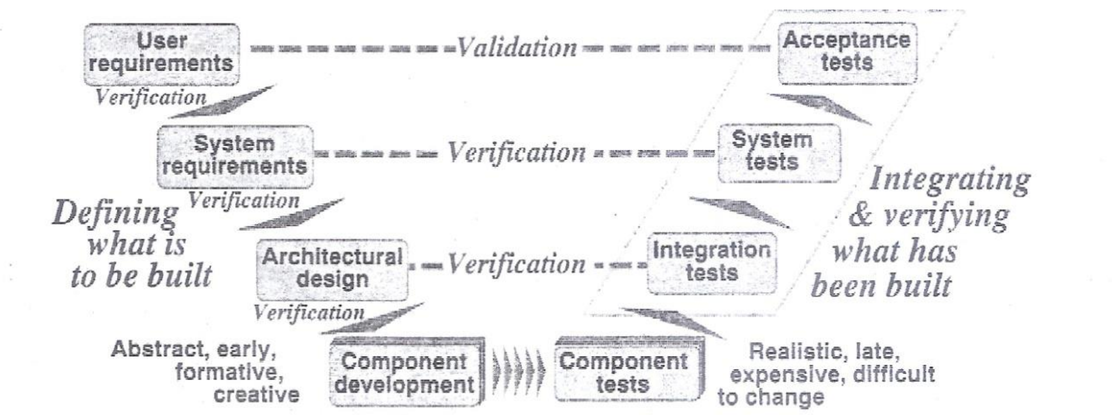

FIG.4 THE V- FORM OF THE SYSTEM LIFE CYCLE. SOURCE: [12].