Effect of Grid Instability on Power Generation System's Reliability

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Authors' contributions

This work was carried out in collaboration between both authors. Author JBB designed the study, performed the statistical analysis and wrote the protocol along with the first draft of the manuscript. Author IFO managed the analysis and literature searches. Both authors read and approved the final manuscript.

ABSTRACT

Aims: Reliability assessment of power generation system may be performed with the concept of system adequacy, security or both. Grid being a major component in the power distribution chain is seen to have some influence on the state of the generation system reliability because of the perturbation that may arise from it. In this study, the generation system reliability is evaluated using both the system adequacy and security concept.

Study Design: To capture the system security problems attributed to grid disturbance, the generation system is structured into two component systems (1 - generation component and 2 - transmission component) with a series arrangement.

Methodology: The reliability indices such as, mean time to failure, mean time to repair, failure rate and repair rate are assessed on component bases and with respect to the entire generation system.

Results: The effect of failure rate of the transmission component on the entire generation system failure rate was evaluated as 66.25%, 55.55%, 33.33%, 55.00% and 35.72% in year 2013, 2014, 2017 2018 and 2019 respectively for FIPL Power Plant and 52.94%, 82.35%, 61.38% and 100%
effect was evaluated in the year 2016, 2017, 2018 and 2019 respectively for GT5 of Omoku Power Plant.

**Conclusion:** These results showed that there is a significant influence of grid disturbances on the reliability state of the two gas turbine power plants in Nigeria. Measures on possible reliability state improvement of the power generation systems were suggested to include training and retraining of technical personnel on the management of major equipment in the generation and transmission stations.

**Keywords:** Gas turbine; power plant; grid; transmission.

1. **INTRODUCTION**

Access to affordable and steady electricity supply is imperative to the growth and development of any nation. As such, the need to adequately plan, design, operate and maintain electric power systems becomes crucial. In assessing electric power systems, reliability technique has gradually become one of the globally acceptable tools to be used. The ability of a power system to consistently perform its intended function, on demand and without degradation or failure is known as reliability [1]. Similarly, [2,3] defined reliability as the ability of an equipment to perform its required function satisfactorily under stated conditions during a given period of time. In addition, power systems are said to be reliable if they perform satisfactorily without failure when in service period.

Modern power systems are complex, highly integrated and very large. In order to meet customers' demand, the system can be divided into appropriately subsystems or functional areas that can be analyzed separately [4,5]. These functional areas are generation, transmission and distribution. Reliability studies are carried out individually and in combinations of the three areas. However, this study seeks to evaluate generation system reliability along with the effect of the transmission system (grid) disturbances to the generation system.

Generation system reliability focuses on the reliability of generators in the whole electric power system where electric power is produced starting from the conversion process of primary energy (fuel) to electricity before transmission. The generation system is an important aspect of the electricity supply chain and it is crucial that enough electricity is generated at every point in time to meet demand [6]. Generation system reliability is divided into adequacy and security [7,8]. System adequacy relates to the existence of sufficient generators within the system to satisfy the customer load demand or system operational constraints. System adequacy is associated with static conditions of the system and do not include system disturbances.

System security on the other hand relates to the ability of the system to respond to disturbances arising within the system. Therefore, system security is associated with the response of the system whatever perturbation or disturbance it is subjected to. In this study, the reliability evaluation will consider the generation system adequacy along with the system security due to grid disturbances.

When a generating unit is removed from service due to failure, such an event is known as outage. These outages can compromise the ability of the system to supply the required load and affect the reliability of the system. An outage may or may not cause an interruption of service depending on the margins of generation provided. Outages also occur when the unit undergoes maintenance or other scheduled work necessary to keep it operating in good condition. A forced outage is an outage that results from emergency conditions, requiring that component be taken out of service immediately. A scheduled or planned outage is an outage that results when a component is deliberately taken out of service, usually for purpose of preventive maintenance or repair [9].

In assessing generation system reliability, system adequacy and system security reliability are treated independently and in combination of the two. Since system adequacy deals with the ability of the system to supply the aggregate electric energy requirements of customers within component ratings and voltage limits when planned and unplanned component outages occur, system security deals with the ability of the power system to withstand disturbances arising from faults or equipment outages which may arise within the generation system or from the transmission system. The security assessment dwells on the system transient
responses and cascading sequences after a disturbance.Transient responses include the fluctuations of both the system frequency and bus voltages [10]. If the fluctuations exceed certain operating limits, cascading sequences, such as line and generator tripping, may occur and persist until the system completely separates or collapses. These effects are usually not accounted for in most adequacy studies but must be captured in security evaluations. In view of this, the transmission system is modeled along with the generation system to account for the effect of its disturbances on the generation system. Here, the structured system is arranged in series as shown in Fig. 1.

2. MATERIALS AND METHODS

Two gas turbine power plants operating in the southern region of Nigeria were considered for the study, which are: A 170 MW unit of First Independent Power Plant (FIPL) Afam, River State and GT5 unit (25 MW) of Omoku Power Plant, Rivers State. A seven (7) year operational data of the power plants were available for consideration. Data collected from these stations include information regarding the number of operating hours for each unit per year, the outage frequency due to grid disturbance as well as the outage frequency due to internal and external factors. Also considered are the outage hours per year due to grid disturbance and the total outage hours caused by both internal and external factors. The internal factors considered here are causes or failures that originate from the Power Generation Plant, e.g., poor or no ventilation in gas turbine compressor, fire gas detector alarm, excitation, low gas inlet pressure, flame monitor failure etc. while the external factors are grid perturbations (high frequency, 132 KV supply line failure etc.) and gas supply constraint. Also to note that some of the parametric terms like Period hour, Service hour and Active period where reported in line with the IEEE std. 762 (2006). Table 1 shows a statistical data base of information obtained from the operational Log Sheet.

From the statistical data shown in Tables 3 and 4, the failure rate and repair rate information were obtained. Operational records of FIPL Afam as shown in Table 3 was not listed for the year 2015, 2016 and part of 2017 because the plant was out of service, awaiting acquisition from new owner (i.e., it was put up for sale by the government) while for the Omoku Power Plant, operational records from year 2013 to 2015 were not available. Thus the available information as shown were used to compute the mean time between failure, mean time to repair, availability, reliability and maintainability of each of the power generating system. In evaluating the reliability of the generating stations, the transmission system was considered as a component in the power generating system. As such, its failure rate was computed, showing its effect on the entire system reliability.

**Mean time between failures (m):** Mean time between failure (MTBF) measures the time between system failures. It is mostly used in reliability evaluation because it is easier to understand than a probability number.

\[ m = \frac{\beta_r}{\varphi_m} = \frac{1}{\lambda} \]  

(1)

where, \( \beta_r \) is the total operating time between maintenance, \( \varphi_m \) is the number of failures between maintenance, and \( \lambda \) is the expected failure rate.

**Mean time to repair (Q):** Mean time to repair (MTTR) is a measure of how long, on average
Table 1. Year 2013 outage frequency of FJPL Afam

<table>
<thead>
<tr>
<th>Year 2013</th>
<th>Outage frequency due to grid disturbance</th>
<th>Outage hours due to grid disturbance</th>
<th>Total outage frequency</th>
<th>Total outage hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>294.22</td>
</tr>
<tr>
<td>February</td>
<td>4</td>
<td>38.43</td>
<td>4</td>
<td>38.43</td>
</tr>
<tr>
<td>March</td>
<td>5</td>
<td>8.65</td>
<td>5</td>
<td>8.65</td>
</tr>
<tr>
<td>April</td>
<td>5</td>
<td>36.98</td>
<td>6</td>
<td>50.58</td>
</tr>
<tr>
<td>May</td>
<td>6</td>
<td>37.28</td>
<td>9</td>
<td>40.38</td>
</tr>
<tr>
<td>June</td>
<td>5</td>
<td>28.10</td>
<td>9</td>
<td>128.03</td>
</tr>
<tr>
<td>July</td>
<td>2</td>
<td>19.10</td>
<td>5</td>
<td>547.92</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>16.65</td>
<td>9</td>
<td>232.92</td>
</tr>
<tr>
<td>September</td>
<td>3</td>
<td>28.18</td>
<td>6</td>
<td>286.58</td>
</tr>
<tr>
<td>October</td>
<td>10</td>
<td>69.73</td>
<td>13</td>
<td>95.27</td>
</tr>
<tr>
<td>November</td>
<td>3</td>
<td>29.28</td>
<td>4</td>
<td>175.28</td>
</tr>
<tr>
<td>December</td>
<td>7</td>
<td>20.38</td>
<td>9</td>
<td>66.52</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>332.78</td>
<td>80</td>
<td>1964.78</td>
</tr>
</tbody>
</table>

Where, 
- Total outage freq. = outage freq. due to grid disturbance + sum of outage freq. due to other factors
- Total outage hours = outage hours due to grid disturbance + sum of outage hours due to other factor

The system is repaired and brought back to normal serviceability when it fails.

\[ \zeta = \frac{\psi_t}{\phi_n} = \frac{1}{\mu} \quad (2) \]

where, \( \psi_t \) is the total outage hours per year, \( \phi_n \) is the number of failures per year, and \( \mu \) is the expected repair rate. When the parameters in equations (1) and (2) are known for a given system or component, then its availability (\( \psi \)) and unavailability (\( U \)) can be determined.

**Availability (\( \psi \)):** It is a measure of the percentage of time that a system is capable of producing its end product at some specified acceptable level. A power plant is also available if it can operate without being demanded for the operation. Most power plants use the index proposed by IEEE std. 762 (2006) to define availability. That index represents the percentage of a given period of time in hours for which the unit is in service [11]. For a gas turbine power plant, availability is a measure of the duration for which the plant is capable of generating the nominal power output whether it is demanded for or not.

\[ \psi = \frac{\mu}{(\lambda + \mu)} = \frac{m}{(m + \zeta)} \quad (3) \]

And,

\[ U = \frac{\zeta}{(\lambda + \mu)} = \frac{\psi_t}{(m + \zeta)} \quad (4) \]

**Reliability \( R(t) \):** It is regarded as the ability of an equipment to perform its required function satisfactorily under stated conditions during a given period of time (Ireson et al., 1996; Smith and Hinchcliffe, 2004). In order words, reliability is a probability that the equipment is operating without failure in the time period \( t \).

\[ R(t) = e^{-\frac{t}{\mu}} = e^{-\lambda t} \quad (5) \]

For a system with series arrangement of components, reliability of a system in series \( R_s(t) \) is:

\[ R_s(t) = R_1 R_2 R_3 \ldots \ldots R_n \quad (6) \]

where, \( R_i \) is the unit \( i \) reliability for \( i = 1, 2, 3, \ldots, n \).

For unit \( i \) failure rate at period \( t \), \( \lambda_i(t) = \lambda_i \), thus unit \( i \) reliability may be expressed as

\[ R_i(t) = e^{-\lambda_i t} \quad (7) \]

where, \( R_i \) is the reliability of unit \( i \) at time \( t \).

Putting eqn. (7) in (6) we have

\[ R_s(t) = e^{-\sum_{i=1}^{n} \lambda_i t} \quad (8) \]

where, \( R_s(t) \) is the series system reliability at time \( t \).

For several values of \( \lambda_i \) where \( i = 1,2,3,\ldots,n \), the mean time between failure for a system in series \( (m_s) \) may be expressed as:

\[ m_s = \int_0^t e^{-\sum_{i=1}^{n} \lambda_i t} dt = \frac{1}{\sum_{i=1}^{n} \lambda_i} \quad (9) \]
Table 2. Classification of outage duration for year 2013 (FIPL Afam)

<table>
<thead>
<tr>
<th>Reason(s) for Tripp</th>
<th>Frequency</th>
<th>Outage Hours (OH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips due to grid disturbance</td>
<td>53</td>
<td>332.78</td>
</tr>
<tr>
<td>Trips due to other factors</td>
<td>27</td>
<td>1632</td>
</tr>
<tr>
<td>Trips due to both internal and external factors</td>
<td>80</td>
<td>1964.78</td>
</tr>
</tbody>
</table>

**Planned outages:** Duration = 0 hrs; Freq. = 0

**Unplanned outages:** Duration = 1964.78 hrs; Freq. = 80

Where, Freq. due to both internal and external factors = Freq. due to grid disturbance + sum of freq. due to other factors

OH due to both internal and external factor = OH due to grid disturbance + sum of OH due to other factors

Table 3. Seven year outage frequency data for FIPL, Afam

<table>
<thead>
<tr>
<th>Year</th>
<th>Outage frequency due to grid disturbances</th>
<th>Total outage freq.</th>
<th>Outage hours due to grid disturbances</th>
<th>Total outage hours</th>
<th>Period hours</th>
<th>Service hours</th>
<th>Active period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>53</td>
<td>80</td>
<td>332.78</td>
<td>1964.78</td>
<td>8760</td>
<td>6795.22</td>
<td>Jan-Dec</td>
</tr>
<tr>
<td>2014</td>
<td>28</td>
<td>63</td>
<td>232.67</td>
<td>2039.90</td>
<td>8760</td>
<td>6720.10</td>
<td>Jan-Dec</td>
</tr>
<tr>
<td>2015</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2016</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2017</td>
<td>1</td>
<td>3</td>
<td>3.97</td>
<td>480.22</td>
<td>744</td>
<td>263.78</td>
<td>Dec</td>
</tr>
<tr>
<td>2018</td>
<td>55</td>
<td>100</td>
<td>645.2</td>
<td>2924.82</td>
<td>8760</td>
<td>5835.18</td>
<td>Jan-Dec</td>
</tr>
<tr>
<td>2019</td>
<td>10</td>
<td>28</td>
<td>204.3</td>
<td>824.17</td>
<td>2160</td>
<td>1335.83</td>
<td>Jan-March</td>
</tr>
</tbody>
</table>

Table 4. Seven year outage frequency data for Omoku Power Plant

<table>
<thead>
<tr>
<th>Year</th>
<th>Outage frequency due to grid disturbances</th>
<th>Total outage freq.</th>
<th>Outage hours due to grid disturbances (hrs)</th>
<th>Total outage hours (hrs)</th>
<th>Period hours (hrs)</th>
<th>Service hours (hrs)</th>
<th>Active period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td>2014</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td>2015</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>N/A</td>
</tr>
<tr>
<td>2016</td>
<td>99</td>
<td>119</td>
<td>346.85</td>
<td>440.58</td>
<td>8760</td>
<td>8319.42</td>
<td>Jan-Dec</td>
</tr>
<tr>
<td>2017</td>
<td>83</td>
<td>89</td>
<td>288.12</td>
<td>340.28</td>
<td>8760</td>
<td>8419.72</td>
<td>Jan-Dec</td>
</tr>
<tr>
<td>2018</td>
<td>119</td>
<td>137</td>
<td>404.88</td>
<td>619.43</td>
<td>8760</td>
<td>8140.57</td>
<td>Jan-Dec</td>
</tr>
<tr>
<td>2019</td>
<td>6</td>
<td>6</td>
<td>5.73</td>
<td>5.73</td>
<td>90</td>
<td>84.27</td>
<td>Jan-March</td>
</tr>
</tbody>
</table>

**Maintainability** $M(t)$: Maintainability deals with the duration of maintenance outages or how long it takes to achieve (ease and speed) the maintenance actions compared to a datum. The datum includes maintenance (all actions necessary for retaining an item in, or restoring an item to, a specified, good condition) as performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance. Mathematically, maintainability is expressed as:

$$M(t) = 1 - e^{-t} = 1 - e^{-\frac{t}{\mu}}$$

where, $\mu$ is the repair rate

3. RESULTS AND DISCUSSION

The result of reliability indices for FIPL Power Plant from year 2013 to 2019 is presented in Tables 5A to 5C. Fifty-three (53) failures due to grid disturbances were recorded in the year 2013 compare to a total of 80 failures recorded in the system. This resulted to about 66.25% failure due grid disturbances in 2013 which was recorded as the highest across the periods under review. The least grid effect failure across the periods was in 2017 where one (1) grid failure was recorded against a total system failure of three (3), accounting for about 33.33% of the total grid failure. This shows that the generating system failed more due to the grid effect in 2013.
and failed less due to the grid effect in 2017. However the corresponding downtime effect of grid instability was seen to be less across the study periods regarding the overall plant downtime for each year.

The highest grid availability of 0.99 was recorded in year 2017 followed by 0.974 in 2014, while the highest generating system availability was in year 2013 and 2014 with a value of 0.8168 and 0.8111 respectively. These values are close when compared with the IEEE standard of grid availability of 0.99 and generating system availability of 0.99.

Similar results were obtained for GT5 of the Omoku Power Plant as shown in Table 6A and 6B. Seventy four (74) failures due to grid disturbances were recorded in year 2017 compare to a total of 89 failures recorded for the entire system. This resulted to about 83.15% failure due to grid disturbances in 2017, representing the highest value across the periods except for year 2019. The last grid effect failure across the periods was in 2016 where sixty three (63) grid failures were recorded against 119 total failures. Here, the grid percentage failure was 52.94%. This shows that the generating system failed more due to grid effect in 2019 and failed less due to grid effect in 2016. However the corresponding downtime effect of grid instability compared to the total generation system downtime stood at 100% and 70.32% in 2016 and 2018. The grid downtime was also high compare to the overall generation system downtime for each year. The highest grid availability of 0.997 was recorded in year 2019 followed by 0.977 in 2016 which is close to the IEEE standard of 0.99 for grid availability while the highest generating system availability was in year 2019 and 2017 with a value of 0.997 and 0.963 respectively. Comparing these values with the EEE standard of 0.99 shows that the generating system availabilities are very close to the IEEE standard.

Table 5A. Reliability indices of FIPL Afam for year 2013 and 2014

<table>
<thead>
<tr>
<th>FIPL Afam</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trans. comp. (S₁)</td>
<td>Gen. comp. (S₂)</td>
</tr>
<tr>
<td>Number of Failures</td>
<td>53</td>
<td>27</td>
</tr>
<tr>
<td>Downtime (h)</td>
<td>332.78</td>
<td>1631.99</td>
</tr>
<tr>
<td>MTBF</td>
<td>165.28</td>
<td>324.44</td>
</tr>
<tr>
<td>MTTR</td>
<td>6.2789</td>
<td>60.4442</td>
</tr>
<tr>
<td>Repair rate</td>
<td>0.159264</td>
<td>0.016544</td>
</tr>
<tr>
<td>Availability</td>
<td>0.963402</td>
<td>0.842957</td>
</tr>
<tr>
<td>Unavailability</td>
<td>0.036598</td>
<td>0.157043</td>
</tr>
<tr>
<td>Maintainability @ 24hrs</td>
<td>0.978123</td>
<td>0.327706</td>
</tr>
</tbody>
</table>

ST - Transmission Component; S2 - Generation Component; S - Generation System

Table 5B. Reliability indices of FIPL Afam for year 2017 and 2018

<table>
<thead>
<tr>
<th>FIPL Afam</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trans. comp. (S₁)</td>
<td>Gen. comp. (S₂)</td>
</tr>
<tr>
<td>Number of Failures</td>
<td>1.00</td>
<td>2</td>
</tr>
<tr>
<td>Downtime (h)</td>
<td>3.97</td>
<td>476.25</td>
</tr>
<tr>
<td>MTBF</td>
<td>744.00</td>
<td>372.00</td>
</tr>
<tr>
<td>MTTR</td>
<td>3.9700</td>
<td>238.1250</td>
</tr>
<tr>
<td>Repair rate</td>
<td>0.251889</td>
<td>0.004199</td>
</tr>
<tr>
<td>Availability</td>
<td>0.994692</td>
<td>0.095874</td>
</tr>
<tr>
<td>Unavailability</td>
<td>0.005308</td>
<td>0.327706</td>
</tr>
</tbody>
</table>
Table 5C. Reliability indices of FIPL Afam for year 2019

<table>
<thead>
<tr>
<th>FIPL Afam</th>
<th>2019</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trans. Comp (S₁)</td>
<td>Gen. Comp (S₂)</td>
</tr>
<tr>
<td>Number of Failures</td>
<td>10.00</td>
<td>18</td>
</tr>
<tr>
<td>Downtime (h)</td>
<td>204.30</td>
<td>619.87</td>
</tr>
<tr>
<td>MTBF (h/fault)</td>
<td>216.00</td>
<td>120.00</td>
</tr>
<tr>
<td>MTTR (h/fault)</td>
<td>20.4300</td>
<td>34.4372</td>
</tr>
<tr>
<td>Repair rate (fault/h)</td>
<td>0.048948</td>
<td>0.029038</td>
</tr>
<tr>
<td>Availability</td>
<td>0.913590</td>
<td>0.777015</td>
</tr>
<tr>
<td>Unavailability</td>
<td>0.086410</td>
<td>0.222985</td>
</tr>
<tr>
<td>Maintainability</td>
<td>0.691101</td>
<td>0.501883</td>
</tr>
</tbody>
</table>

Table 6A. Reliability indices of Omoku Power Plant for year 2016 and 2017

<table>
<thead>
<tr>
<th>Omoku GT5</th>
<th>2016</th>
<th>2017</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trans. comp. (S₁)</td>
<td>Gen. comp. (S₂)</td>
<td>Gen. system (S)</td>
</tr>
<tr>
<td>Number of Failures</td>
<td>63</td>
<td>56</td>
<td>119</td>
</tr>
<tr>
<td>Downtime (h)</td>
<td>203.85</td>
<td>236.73</td>
<td>440.58</td>
</tr>
<tr>
<td>MTBF (h/fault)</td>
<td>139.05</td>
<td>156.43</td>
<td>73.61</td>
</tr>
<tr>
<td>MTTR (h/fault)</td>
<td>3.235714</td>
<td>4.227321</td>
<td>3.702353</td>
</tr>
<tr>
<td>Repair rate (fault/h)</td>
<td>0.309051</td>
<td>0.236556</td>
<td>0.270099</td>
</tr>
<tr>
<td>Availability</td>
<td>0.977259</td>
<td>0.973687</td>
<td>0.952114</td>
</tr>
<tr>
<td>Unavailability</td>
<td>0.022741</td>
<td>0.026313</td>
<td>0.047886</td>
</tr>
<tr>
<td>Maintainability</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 6B. Reliability indices of Omoku power plant for year 2018 and 2019

<table>
<thead>
<tr>
<th>Omoku GT5</th>
<th>2018</th>
<th>2019</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trans. comp. (S₁)</td>
<td>Gen. comp. (S₂)</td>
<td>Gen. system (S)</td>
</tr>
<tr>
<td>Number of Failures</td>
<td>84</td>
<td>53</td>
<td>137</td>
</tr>
<tr>
<td>Downtime (h)</td>
<td>256.13</td>
<td>363.30</td>
<td>619.43</td>
</tr>
<tr>
<td>MTBF (h/fault)</td>
<td>104.29</td>
<td>165.28</td>
<td>63.94</td>
</tr>
<tr>
<td>MTTR (h/fault)</td>
<td>3.0492</td>
<td>6.8547</td>
<td>4.521387</td>
</tr>
<tr>
<td>Repair rate (fault/h)</td>
<td>0.3280</td>
<td>0.1459</td>
<td>0.221171</td>
</tr>
<tr>
<td>Availability</td>
<td>0.9716</td>
<td>0.9602</td>
<td>0.933959</td>
</tr>
<tr>
<td>Unavailability</td>
<td>0.0284</td>
<td>0.0398</td>
<td>0.066041</td>
</tr>
<tr>
<td>Maintainability</td>
<td>1.00</td>
<td>0.97</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Fig. 2. Failure rate of FIPL Afam
Fig. 3. Availability of FIPL Afam

Fig. 4. Reliability index of FIPL Afam

Fig. 5. Failure rate of GT5 unit of Omoku Power Plant
The failure rate (\(\lambda\)) measures the durability of a power system and also indicates the economic effectiveness of repairs. Grid failure effect on the failure rate of the generation system is seen in Figs. 2 and 5 for Afam and Omoku Power Plants respectively. In Fig. 3, the transmission component (grid) availability was higher across the years than the generation component availability, thus, depicting more grid availability despite its high failure rate. In Fig. 6, the availability of both transmission component and generation component were considerably high across the periods except for 2019 where the availability of the generation component was unity (1) signifying no failure or downtime. The reliability of the generation system was computed at 100 hours. The result as shown in Fig. 4 indicated reliability values of 0.4012, 0.4871, 0.6682, 0.3193 and 0.2735 for year 2013, 2014, 2017, 2018 and 2019 respectively. This low reliability values were partly caused by the high failure rates of the transmission component (grid) accounting for 66.25%, 55.55%, 33.33%, 55.00% and 35.72% of the total failure rate of the generation system in Afam, while in Fig. 7 the reliability values of 0.2571, 0.3620, 0.2093 and 0.7575 at 100 hours were recorded for year 2016, 2017, 2018 and 2019 respectively. The low reliability values observed were also partly caused by the high failure rates of the transmission component (grid), accounting for about 52.94%, 82.35%, 61.38% and 100% of the

4. CONCLUSION

The reliability state of two gas turbine power plants in Nigeria was explored. The analyses revealed that the transmission component significantly affects the reliability of the generation system. More of this effect was seen on GT5 of the Omoku Power Plant across the periods of the study. These results are indications that a reliable and stable electricity supply to the grid by the generation companies does not translate to reliable electricity supply to the customers if the transmission component is unreliable and unstable. Also, with grid instabilities, the generation companies are handicapped in ensuring stable power supply to the grid. Poor and unstable grid increases maintenance cost on the part of generation companies whose power generation systems are gas turbine driven. This is so because, according to the maintenance requirement of gas turbine system, a sudden single trip of gas turbine on load increases the equivalent operating hours (EOH) by 18. Thus this draws planned maintenance action closer than expected which in turn increases the overall maintenance cost of the plant.

5. RECOMMENDATIONS

1. With these anomalies seen in the transmission component (grid), there is need to improve the grid networks that evacuate the generated power from power generation stations for onward transmission to the distribution stations.
2. Adequate spinning reserve capacity need to be deployed to keep the grid system stable.
3. The existing EMS-SCADA system should be upgraded to optimize the performance of the grid.
4. Control mechanism like the AGC from the EMS need to be installed and used to control the frequency.
5. Transmission companies should be compelled to pay risk penalties to the generation companies in instances where significant damages are done on generation systems as a result of transmission system failure. With this, the transmission company will be more proactive in ensuring a stable grid so as to avoid being fined.
6. Lastly, protection mechanism such as free governor should be installed by generation companies to safe guard their systems from frequency perturbations [12].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES


12. APGC Nigeria, assessing the challenges in operating a GENCO, given the current market consideration. Gencos Heartbeat. 2019;3(1).

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