TRANSMISSION COMPANY OF NIGERIA

INDEPENDENT SYSTEM OPERATOR (ISO)

System Adequacy Report

By

Market Operator

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Contents

Definitions of Terms and Acronyms

The acronyms and the main terms are defined below.

ANE	Available Net Energy Represents the electrical energy that is available from the power stations. It includes the capacity restrictions (as in ANGC) as well as energy constraints. It is typically expressed as an average power in MWh/h.
ANGC	Available Net Generation Capacity Represents the available capacity, as recorded in the Daily Operational Reports. It includes the values declared by the generation companies and takes planned and Forced Outages into consideration.
DISCO	Distribution company
ENS	Energy Not Supplied (negative of REM)
Failure Rate	Number of failures per year
Forced Outage	Shutdown of equipment due to failure, normally initiated automatically by protection relay(s).
JICA	Japan International Cooperation Agency
Partial Collapse	Power system disturbances causing at least half of the load to be disconnected.
PTFP	Presidential Task Force on Power
RANGC	Reliably Available Net Generation Capacity Represents the ANGC that is achieved 99% of the time
REM	Remaining Energy Margin (REM) = ANE – Energy Demand.
RM	Remaining Capacity Margin, also called Remaining Margin Excess capacity of reliably available generation, taking into consideration generation constraints, operating reserves and the peak demand.
Urgent Outage	Equipment being taken out of service by operators following short-term planning, normally within hours ahead of the outage

1. Introduction

The system adequacy report is issued by the Market Operator, as required in the Market Rules [1].

The adequacy of the generation and transmission systems is assessed retrospectively for 2015. Subsequently, the adequacy of these systems is projected for the years 2017 - 2027.

This report summarises the findings of the above tasks. Detailed information about the findings of each of the tasks is contained in the following separate documents:

Part 1: Generation Adequacy Report - Retrospective (2015)

Part 2: Transmission Adequacy Report - Retrospective (2015)

Part 3: Demand Forecast Report

Part 4: Generation Adequacy Outlook (2017 – 2027)

Part 5: Transmission Adequacy Outlook (2017 – 2027)

2. Generation Adequacy Retrospective (2015)

The generation adequacy in 2015 is analysed by studying the capability of the generating stations to:

a. adequately supply the load
b. provide ancillary services for power system stability.

Several performance indices are defined to assess the generation adequacy. The full report is appended as Part 1. The most relevant findings are summarised below.

The total installed generation capacity amounted to some 13 GW. After deducting decommissioned or otherwise inactive units, and after deducting auxiliary power and power station internal losses, the active Net Generation Capacity amounted to 10089 MW.

In 2015, on average, some 63% of the Net Generation Capacity was available for production. This is termed Available Net Generation Capacity (ANGC), and amounted to 6376 MW.

On average, generation constraints amounted to 1789 MW. Gas constraints were the most important, amounting to an average 1512 MWh/h.

The Energy Not Supplied (ENS) represents the gap between the supply and demand of electrical energy in the Nigerian power system. The demand is not known accurately since it exceeds the supply. Two values for the Energy Not Supplied are used:

a. Total demand:

   This demand includes on-grid and off-grid demand. The energy demand of the end customers has been calculated based on the estimated peak load of 14630 MW and an assumed load factor of 75%.

b. Unconstrained on-grid demand:

   The demand includes on-grid demand, and is derived from the stress-test project. The latter was managed by the Presidential Task Force on Power (PTFP). Allowance is made for exports to neighbouring countries and transmission losses. A load factor of 75% has been assumed.

The Energy Not Supplied based on total demand amounted to 65 TWh (average power 7443 MWh/h).[1]

The Energy Not Supplied based on unconstrained on-grid demand amounted to 19 TWh (average power 2208 MWh/h).

Both these figures emphasise the severe shortage of electrical energy in Nigeria.

The RM represents the excess in generation capacity, which is reliably available, taking into consideration the generation constraints and required operating reserves. A negative value indicates inadequate generation capacity.

Based on the peak demand of 14630 MW the RM amounted to -9.4 GW. Based on unconstrained on-grid demand the RM amounted to -2.4 GW. Both figures emphasise the

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[1] *Note that in chapter 5 the index Remaining Energy Margin (REM) is used. This is the negative of ENS.*

severe shortage in reliably available generation capacity. This shortage arises due to insufficient installed and active generation capacity, as well as due to poor technical reliability.

The statutory frequency limits were exceeded on every day in 2015. The target level of primary reserves (220 MW) was met on four days in total. In addition, the generators did not regulate the frequency in the power system adequately. It appears that the governor controls (i.e. the primary frequency response) were not active or not tuned correctly on any generating unit. The lack of automatic controls led to a very poor frequency stability and consequently to unplanned generator and load outages.

Six total and four Partial Collapses occurred in 2015, which is very high by international standards.

The full set of performance indices is provided in the separate report, Part 1 of the System Adequacy Report – Retrospective for year 2015. The most important conclusion is that the Nigerian power system is characterised by both an energy and a capacity deficit. In addition, only some 77% of the available electrical energy is utilised due to problems in the entire supply chain, including generation, transmission and distribution.

3. Transmission Adequacy Retrospective (2015)

The transmission adequacy represents the capability of the transmission system to transmit power from the generation stations to the loads reliably. The adequacy is assessed retrospectively for the year 2015.

Several performance indices are defined to assess the transmission adequacy. The full report is appended as Part 2. The most relevant findings are summarised below.

The capability of the transmission system can, in general, be deduced from operational data by considering the times when it was operating at its limit. Such times are characterised by the occurrence of transmission system constraints. However, it was found that most of the constraints affected the south-eastern part of the network and that, at times when these constraints were active, the remainder of the network was operating below its maximum capacity. Therefore, an overall figure for the transmission capacity could not be deduced. It can be stated, however, that the transmission system transferred as much as 4156 MW despite transmission constraints. A calculated value of the future transmission capability will be provided in the adequacy outlook report.

Regional transmission constraints were frequently observed during day-ahead planning and during operation. These included:

1. Limiting power flow between regions coupled by a single line to within the operating reserve. This was the most important constraint, affecting the south-eastern part of the network, which was coupled to the remainder of the power system by a single 330kV line (Alaoji-Onitsha 330kV line).
2. Limiting the power flow to prevent voltage stability problems in case of (n-1) operating conditions (Shiroro-Kaduna 330kV lines).
3. Limiting the power flow through lines that had to be derated due to protection problems (lines outwards of Benin towards the west).

Transmission constraints, which have led to modifications in the day-ahead load allocation, occurred on 174 days of the year. On these days, an average power of 154 MW was reallocated between the DISCOs. The generation was frequently reduced due to transmission constraints, especially at Odukpani and Ibom power plants.

Compared to international experience, the number of Forced Outages of transmission lines during 2015 was high and the availability relatively low. The Failure Rates and the availabilities of the transmission lines were as follows:

Transmission line reliability	330kV	132kV
Failure Rates (average failures / year / line)	7.2	5.0
Failure Rates (average failures / year / 100km)	7.4	11.7
Average availabilities	98.3%	96.3%

Around 60% of all outages were Forced Outages, the remainder being planned and Urgent Outages. Nine 330kV and thirteen 132kV lines were unavailable for long durations (more than one day).

There was a poor correlation between the number of transmission line failures and their lengths, suggesting that many of the failures were not due to typical phenomena (insulator flashovers due to lightning and bird excrement), but rather other factors such as protection maloperation or tower collapse.

The Failure Rates and availabilities of the transformers during 2015 are shown below. As in the case of the transmission lines, these numbers compare unfavourably with international experience.

Transformer reliability	330/132k	132kV/MV
Failure Rates (average failures / year / transformer)	1.7	1.2
Average availabilities	97.5%	97.5%

Most outages were short-term outages (less than one day), suggesting that many outages were not due to typical phenomena (such as tap changer failure, insulation failure, bushing failure), but rather protection maloperation.

The steady-state voltage regulation in the 330kV network was assessed. It was found that the maximum statutory voltage limit was exceeded on 201 days. Most of these incidents occurred at Omotosho. The voltage dropped below the minimum statutory limit, at least at one substation, on every day of the year. Most of these incidents occurred at Kano, Gombe and Yola.

The transmission system losses were found to be 7.3%. The calculation was based on a period 25.11.-17.12.2015, during which the load data of all DISCOs and exports is known. Assuming that the losses during this period are representative in general, the annual transmission losses amounted to 2.43 TWh or, on average, a power of 277 MWh/h.

4. Demand Forecast (2017-2027)

The demand forecast is a critical input into an assessment of future system adequacy. The demand forecast developed by the Japan International Cooperation Agency (JICA) has been used. JICA forecasted Nigeria's energy demand and peak demand, both nation-wide and for each region, for the period 2015 to 2040. For each forecast, JICA developed three cases representing different GDP growth scenarios: a Base Case with an average annual GDP growth rate of 6.1% over the period, a 'low case' with an average annual GDP growth rate of 4.8%, and a 'high case' with an average annual GDP growth rate of 7.3%.

For 2015, JICA estimated an energy demand of 63.8 TWh, which represents an equivalent continuous power of 7282 MWh/h. The figure below shows the total forecasted energy demand, expressed as average continuous power in MWh/h. Average power is expected to increase to between 15440 MWh/h and 24551 MWh/h in 2027.

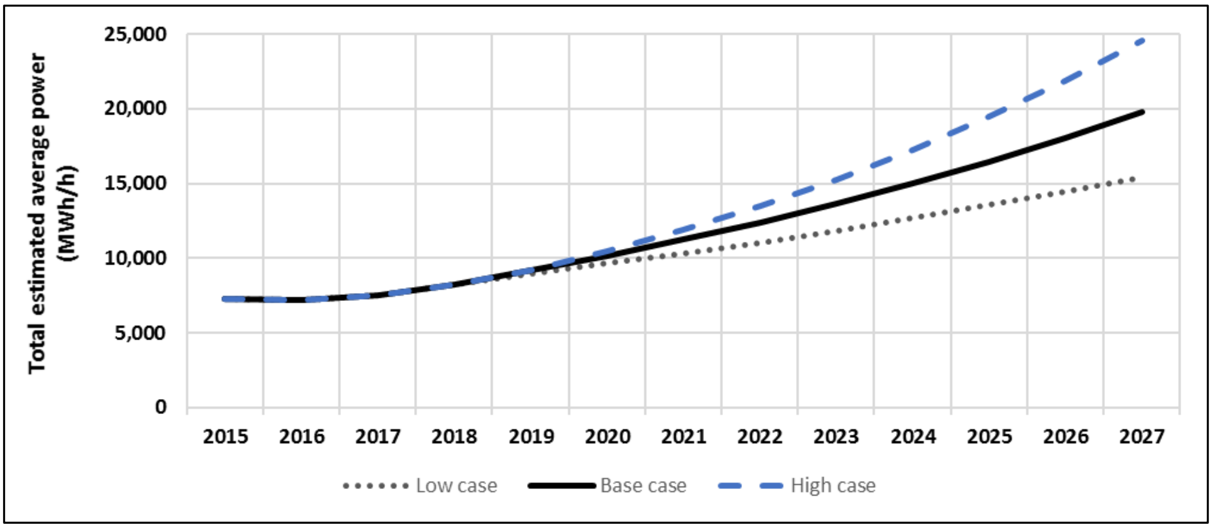

Figure 1 - Forecasted average power demand (on-grid, including exports), 2015-2027

The figure below shows the total forecasted peak demand (in MW) in the low case, Base Case, and high case scenarios. Peak demand is projected to increase from 9499 MW in 2015 to between 21808 MW and 34824 MW in 2027.

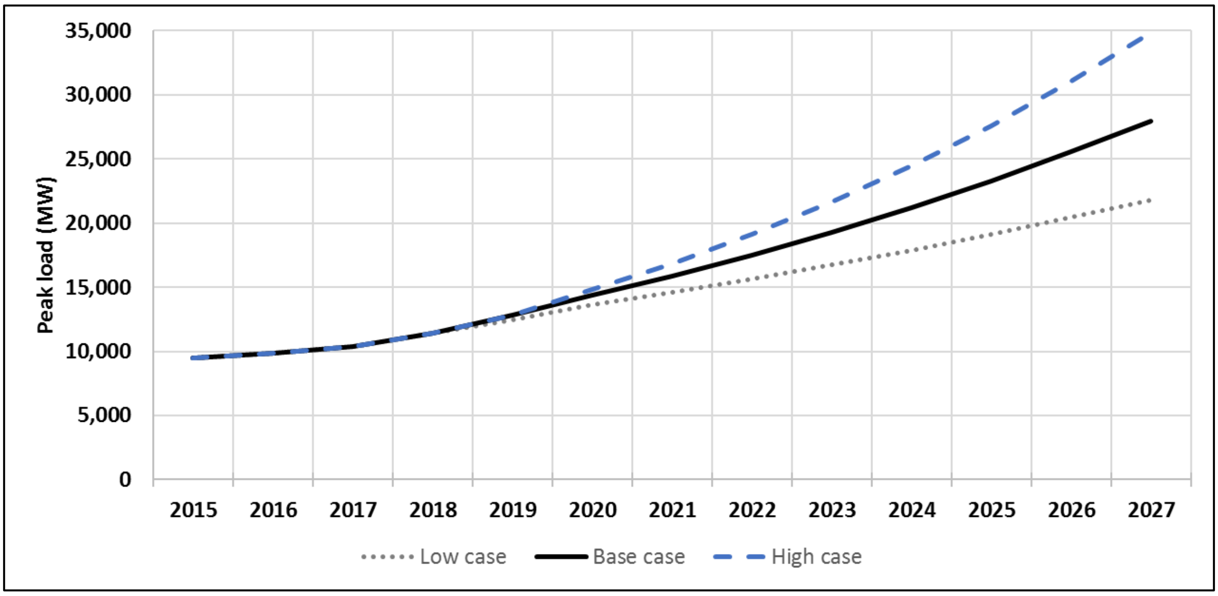

Figure 2 - Total estimated peak demand (on-grid, including exports), 2015-2027

5. Generation Adequacy Outlook (2017-2027)

Generation adequacy is a measure of whether the capability of generation meets the demand reliably, without considering transmission or distribution constraints.

Part 5 of the system adequacy report provides an outlook into generation adequacy from 2017 to 2027 in terms of energy and capacity margins. It considers the most recent demand forecast from JICA, the currently planned generation expansion, the technical availability of power plants and constraints of primary energy (gas and water).

Generation is adequate if it is sufficient to supply the energy demand of all customers and meet the required power demand at all times[2]. It is, therefore, useful to assess the adequacy of generation distinctly in terms of energy and power, as in the case of the retrospective analysis of generation adequacy (Part 1). Generation adequacy is quantified using two main indices: Remaining Energy Margin (REM) and the Remaining Capacity Margin (RM).

The retrospective analysis of generation adequacy (Part 1) shows that the Nigerian power system has both an energy deficit and a capacity deficit, i.e. REM and RM are both negative.

The REM and RM indices are initially determined for a Base Case scenario. This scenario is defined by the following:

1. Demand as per Base Case in JICA's demand forecast (see chapter 4).
2. Gas supply as per gas outlook report by OG Analysis.[3]
3. Water supply estimated using long-term history from TCN as well as publicly available data.
4. Generation projects as per a list from TCN.
5. PV projects as per list of committed projects from TCN.
6. Generation reliability estimated using performance of generation fleet in 2015 and 2016.

In addition to the Base Case, additional scenarios are defined to estimate impact of uncertainty in water supply, the impact of delays in the commissioning of new plant and the impact of improved reliability of generating units.

The REM of the Base Case (in MWh/h), and the variation due to the abovementioned factors, is shown in Figure 3. It is also shown as a percentage of Base Case demand in Figure 4. The latter figure shows that, in the Base Case, the REM remains at approximately 40% of demand.

The Nigerian power system will suffer from a severe energy deficit within the next 10 years. Even under most optimistic assumptions (high technical availability, high rainfalls, low demand growth), this energy deficit will remain at a level of around 3000 MWh/h.

In the Base Case scenario of this outlook the energy deficit will even increase to around 9000 MWh/h by 2027.

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[2] *In addition, the available generation must be able to provide sufficient Operating Reserves to ensure frequency stability.*

[3] *OG Analysis is an international provider of research and consulting services to oil and gas companies.*

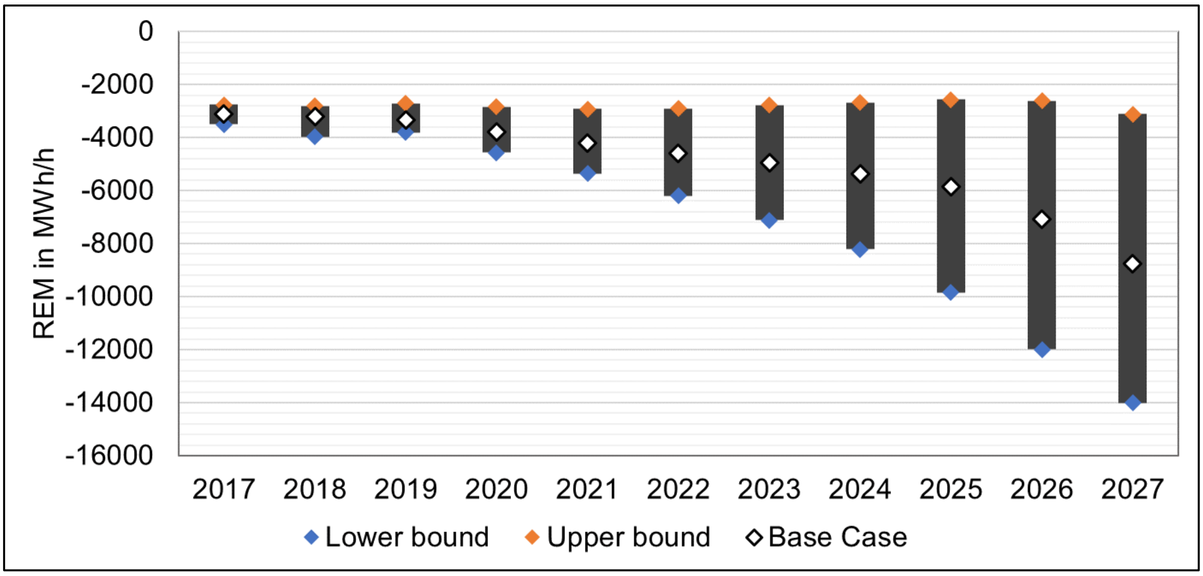

Figure 3 - Total range of REM in MWh/h

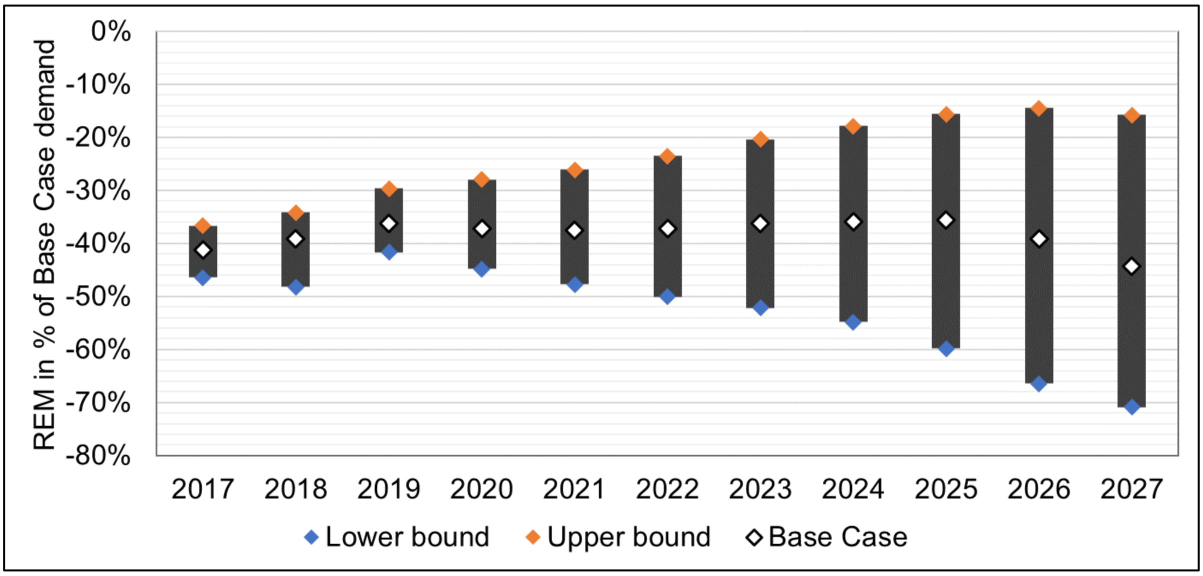

Figure 4 - Total range of REM as percentage of Base Case demand

The differences in the upper and lower bounds compared to the Base Case are mostly due to the different demand estimates. The results are not very sensitive to realistic changes in hydro generation, as most generation is from gas-fired plants. Also, the results are not very sensitive to realistic changes in the generation expansion or their reliability, as the energy from these plants is limited mostly by gas constraints.

In addition to insufficient generation capacity, constraints in the gas supplies will remain very important. Given the expected available generation capacity, gas constraints will continue to limit the available energy until 2025.

The development of the Remaining Capacity Margin (RM), as depicted in Figure 5, shows that the capacity deficit will increase significantly by 2027.

Under most optimistic assumptions the capacity deficit (negative of the RM) will increase from a level of around 4000 MW in 2017 to around 11000 MW in 2027.

In the Base Case scenario, the capacity deficit (negative of the RM) will increase from around 5000 MW to around 19000 MW in 2027.

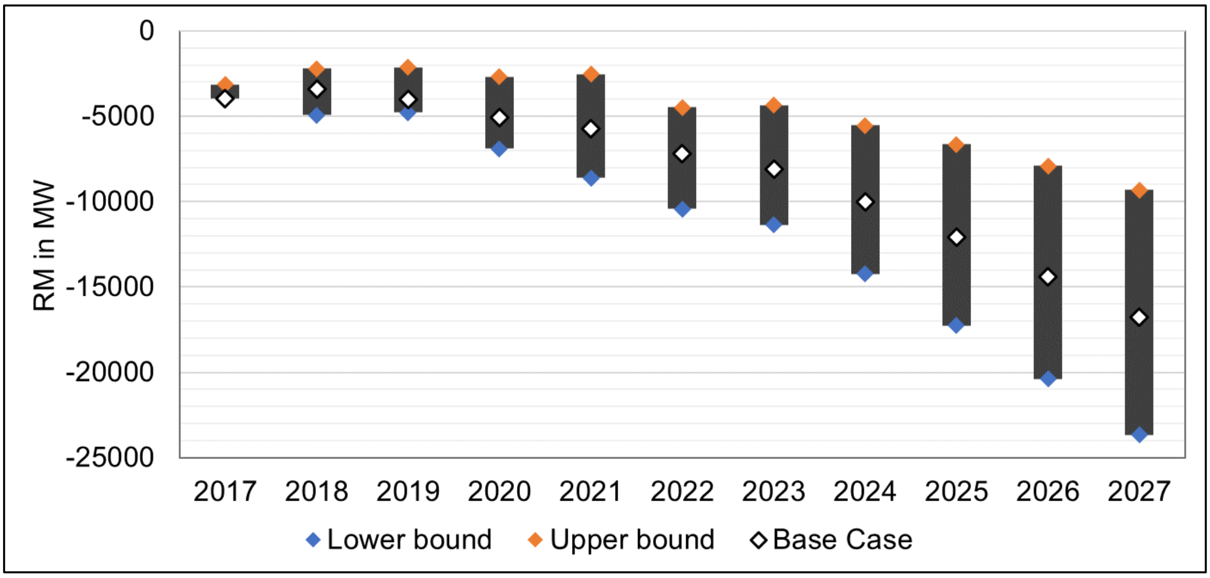

Figure 5 - Total range of RM in MW

6. Transmission Adequacy Outlook (2017-2027)

The capability of the transmission network was calculated under the conditions of all active generators in service and the load distributed according to the MYTO allocation. It is noted that the actual capability varies continuously depending on the generation dispatch and the availability of transmission equipment. It can be higher or lower than the calculated values.

Both the thermal and the voltage stability-constrained capabilities of the 330kV and the 132kV networks have been calculated. When considering these constraints as well as the thermal capabilities of transmission lines, the capability of the 330kV network will be as follows:

Year	Capability limited by line [MW]		Thermal or voltage-stability constraint		Limiting component or boundary
	(n-0)	(n-1)	(n-0)	(n-1)	(n-1)
2017	6200	4700	Voltage stability	Voltage stability	Kaduna import
2018	6200	6200	Voltage stability	Voltage stability	Yola import
2019	7000	7000	Voltage stability	Voltage stability	Yola import
2020	7000	6900	Voltage stability	Thermal	Kaduna-Shiroro
2021	7000	7000	Voltage stability	Voltage stability	Yola import
2022	8000	7400	Voltage stability	Thermal	Kaduna-Shiroro
2023	8000	8000	Voltage stability	Thermal	Kaduna-Shiroro
2024	8000	8000	Voltage stability	Thermal	Kaduna-Shiroro
2025	8000	6200	Voltage stability	Thermal	Benin-Omotosho
2026	8000	6200	Voltage stability	Thermal	Benin-Omotosho
2027	8000	6200	Voltage stability	Thermal	Benin-Omotosho

Under (n-1)-conditions, the capability will be limited by voltage constraints throughout the considered time period.

Following the installation of PV in 2019, the voltage constraints in the northern part of the grid improve, leading to an increase in the transmission capability. After 2022, the capability is limited by thermal constraints. The capability under (n-1)-conditions drops significantly in 2025 following the decommissioning of the Egbin generators.

There are around 60 individual 132kV networks. Their thermal capabilities and voltage constraints were analysed separately for the networks as at December 2017 and December 2018. It was found that, in both years, the capabilities of about half of these networks were limited by voltage stability constraints. The voltage stability constraints occur mainly in the northern and north-eastern parts of the power system, where the short-circuit levels are very low.

Furthermore, despite the expansion of many 132kV grids in 2017 and 2018, the sum of the capacities of all 132kV grids did not increase significantly by 2018, as shown in the summary below. Many of the 132kV networks are not (n-1) secure, i.e. the failure of a single component leads to a loss of supply.

Year	Sum of capabilities [MW]	
	Non-Secure (n-0)	Secure (n-1)
2017	11352	6785
2018	12478	7157

In summary, there are both significant thermal and voltage constraints in the 330kV and the 132kV networks. Despite numerous transmission and generation projects, the transmission capacity will remain well below the projected power demand (see also Part 4 – Generation Adequacy Report: Outlook for 2017-2027).

7. Summary

System Adequacy - Retrospective (2015)

The adequacy of the generation and transmission systems in 2015 is summarised as follows:

Nigeria suffered from a severe shortage of electrical energy. Based on an estimated demand of on-grid loads[4], the Energy Not Supplied (ENS) amounted to 19.3 TWh, which represents a continuous average power of 2208 MWh/h.

The energy shortage was largely due to constraints in the gas-supply chain. These shortages led to an average deficit of 1512 MWh/h.

Only some 77% of the available energy from the power plants is utilised. The remaining 23% is not utilised due to problems in the entire supply chain, including generation, transmission and distribution.

In addition to the energy shortage, there was a severe shortage in reliably available generation capacity (RANGC). RANGC represents the amount of generation that is available for 99% of the time, irrespective of any gas and water constraints. It amounted to 5495 MW. The gap between RANGC and peak demand amounted to some 2375 MW, when using the same demand estimate as above. The shortage was not only due to insufficient installed generation capacity, but also due to poor availability of the generators.

The primary frequency regulation of the power generating plants was not working in 2015, causing the statutory frequency limits to be exceeded every day.

Six total and four Partial Collapses occurred, which is very high by international standards.

Transmission constraints frequently limited the power flows in the network. Generation in the south-east frequently had to be reduced due to local transmission constraints and due to constraints in the lines from the Benin towards Lagos areas. Whenever the availability of generation was high, the flow from Shiroro to Kaduna had to be limited to ensure that voltage stability would be maintained in operation. As a result, the power allocated to the northern DISCOs (according to MYTO) could frequently not be met. Furthermore, a redistribution of power to the southern DISCOs often failed, ultimately requiring the generation in the south-eastern network to be reduced.

Compared to international experience, the number of Forced Outages of transmission lines at all voltage levels was high and the availability relatively low. The same applied to transformers. The available data suggests that many of the trips of transmission lines and transformers were due to protection maloperation.

In 2015 the steady-state voltages in the 330kV network could generally not be held within the statutory limits. The maximum statutory voltage limit was exceeded on 201 days. Most of these incidents occurred at Omotosho. The voltage dropped below the minimum statutory limit at one or more substation on every day of the year. Low voltage problems frequently occurred at Kano, Gombe and Yola.

[4] *The estimate was done by the Presidential Task Force on Power as part of the stress-test programme.*

System Adequacy Outlook (2017-2027)

For 2015, JICA estimated an energy demand of 63.8 TWh, which represents an equivalent continuous power of 7282 MWh/h. The total forecasted energy demand, expressed as average continuous power in MWh/h. Average power is expected to increase to between 15440 MWh/h and 24551 MWh/h in 2027.

The adequacy in generation was assessed from the demand forecast, the planned changes to the generation system, the availability of the generators, and the gas- and water constraints.

Nigeria will continue to suffer from a severe deficit in electrical energy from the main supply grid in the next 10 years. Even under most optimistic assumptions (high technical availability, high rainfalls, low demand growth), this energy deficit will remain at a level of around 3000 MWh/h.

In addition to insufficient generation capacity, constraints in the gas supplies will remain very important. Given the expected available generation capacity, gas constraints will continue to limit the available energy until 2025.

The capability of the transmission network was calculated under the conditions of all active generators in service and the load distributed according to the MYTO allocation[5]. The planned generation and transmission projects were considered.

The capability of the 330kV network is limited by thermal as well as voltage stability constraints. When considering the thermal capabilities of transmission lines, voltage stability, and the (n-1)-operating conditions within the secure part of the grid, will be as follows:

Year	Capability limited by line [MW]		Thermal or voltage-stability constraint	
	(n-0)	(n-1)	(n-0)	(n-1)
2017	6200	4700	Voltage stability	Voltage stability
2018	6200	6200	Voltage stability	Voltage stability
2019	7000	7000	Voltage stability	Voltage stability
2020	7000	6900	Voltage stability	Thermal
2021	7000	7000	Voltage stability	Voltage stability
2022	8000	7400	Voltage stability	Thermal
2023	8000	8000	Voltage stability	Thermal
2024	8000	8000	Voltage stability	Thermal
2025	8000	6200	Voltage stability	Thermal
2026	8000	6200	Voltage stability	Thermal
2027	8000	6200	Voltage stability	Thermal

Under (n-0)-conditions the capability is always limited by voltage constraints. The capability is significantly higher than under (n-1)-conditions in most years.

The capability increases in 2018 following the strengthening of the Benin-Osogbo link. It increases in 2019 due to the installation of PV plants, which improves especially the voltage constraint at Yola. It increases again in 2022 following a number of network modifications,

[5] *It is noted that the actual capability varies continuously depending on the generation dispatch and the availability of transmission equipment. It can be higher or lower than the calculated values.*

which redistribute the load. A significant drop in the capability occurs in 2025 following the decommissioning of generators at Egbin, and increased power flow from the Benin to the Lagos areas.

Numerous 330kV circuits will continue not to be (n-1)-secure, even by 2027. These include the 330kV link to Kainji and the lines eastwards of Jos. The same applies to numerous 330/132kV transformers.

Despite the expansion of many 132kV grids in 2017 and 2018, the sum of the capacities of all 132kV grids did not increase significantly by 2018, as shown in the summary below. Many of the 132kV networks are not (n-1) secure, i.e. the failure of a single component leads to a loss of supply.

Year	Sum of capabilities [MW]	
	Non-Secure (n-0)	Secure (n-1)
2017	11352	6785
2018	12478	7157

In summary, there are both significant thermal and voltage constraints in the 330kV and the 132kV networks. Despite numerous transmission and generation projects, the transmission capacity will remain well below the projected power demand (see also Part 4 – Generation Adequacy Report: Outlook 2017-2027).

Closing remarks

The System Adequacy Report quantifies deficiencies in the generation and transmission systems. The information can be used as a basis for developing solutions.

The energy deficit could only be resolved with a massive addition of more power plants as considered by the generation expansion plan of this study. However, this will be difficult to achieve within the analysed time frame. If the expansion of gas-fired plants were to be accelerated to meet the demand, then the supply of gas would likewise have to increase.

Adding more PV power plants, which can be realised in much shorter time frames than conventional power plants, help to limit the energy problem. PV generation does not reduce the capacity deficit, because there is no PV production during full-load hours, which are assumed to be in the evening in Nigeria. However, as long as there is an energy deficit in the system, the energy deficit is much more important than the capacity deficit.

It may be possible to improve the gas supplies to power stations in the short- and medium-term, i.e. within the next five years. This would improve the supply of electrical energy significantly.

Extensive modifications to the transmission grid would be required to increase its capability. Significant improvements can be achieved by installing series capacitors and/or voltage-stabilising devices at critical locations.

Some short-term relief could be achieved by improving the availability of transmission equipment. The risk of widespread blackouts, when operating at high power levels under (n-0)-conditions, would then be reduced.

This report was prepared by the Market Operator with support from the Nigerian Energy Support Programme (NESP).