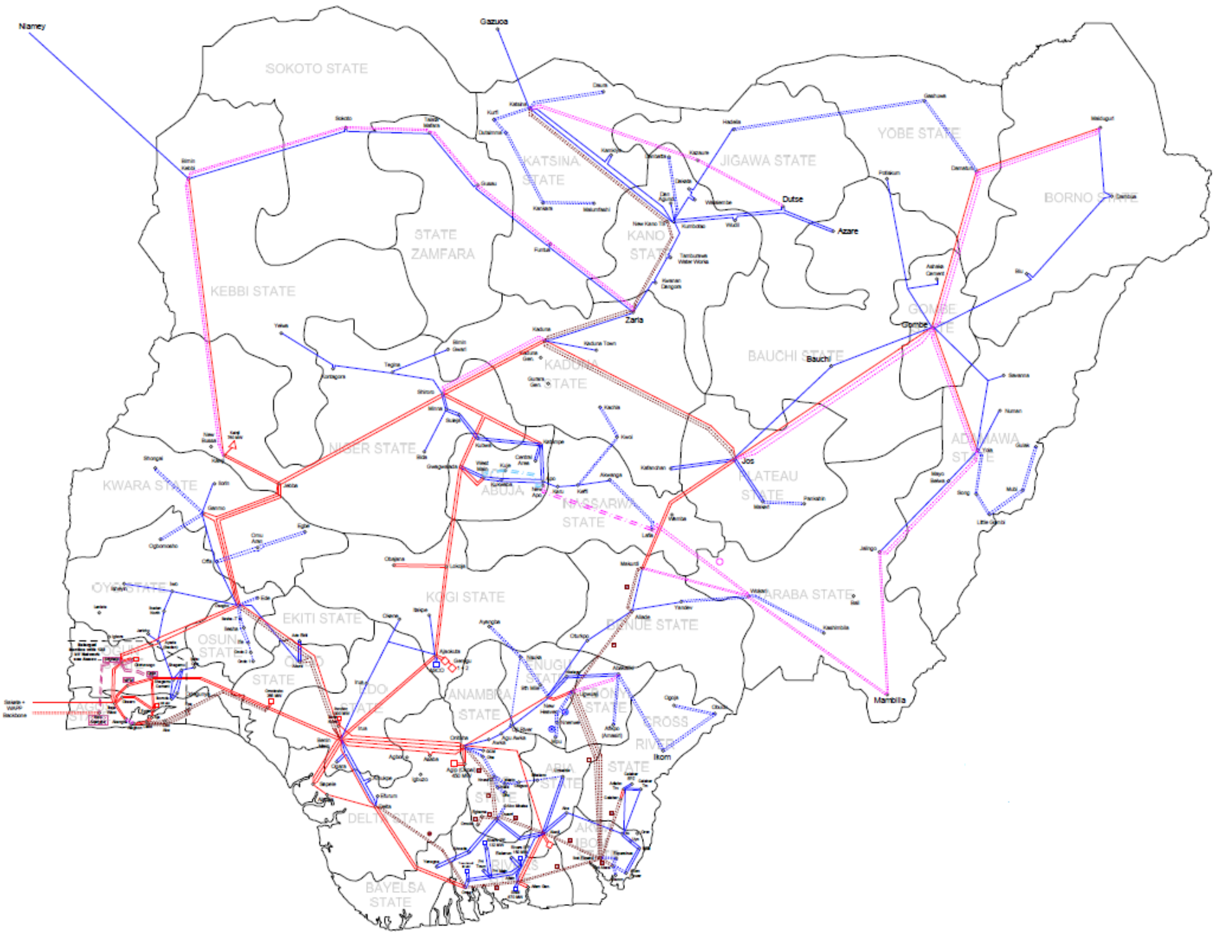
Nigeria Electricity and
Gas Improvement Project
February 2018

Transmission Expansion Plan

Development of Power System Master Plan for the Transmission Company of Nigeria



Synopsis of the Final Report

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2				

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Abbreviations	Declaration
AC	Alternating Current
AFD	Agence Française de Développement- French Development Agency -
AFDB	African Development Bank
DC	Double Circuit
e.g.	Latin: for example
EHV	Extra High Voltage
et. al.	Latin: and others
ENTSO-E	European Network of Transmission System Operators for Electricity
FIRR	Financial Internal Rate of Return
GTMax	Generation and Transmission Maximization Tool
GWh	Gigawatt Hours
HPP	Hydro Power Plant
HV	High Voltage
i.e.	Latin: it/that is
IDB	Islamic Development Bank
JICA	Japan International Cooperation Agency
kg	kilogram
km	kilometer
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hours
LEC	Levelized Electricity Cost
LNG	Liquefied Natural Gas
LV	Low Voltage
MW	megawatt
MWh	megawatt-hours
NERC	Nigerian Electricity Regulatory Commission
No.	number
NPV	Net Present Value
OHL	Overhead Transmission Line

Abbreviations	Declaration
p.	page
SC	Single Circuit
S/S	Substation
SVC	Static Var Compensation
US$	The national currency of the United States of America
TCN	Transmission Company of Nigeria
WACC	Weighted Average Cost of Capital
WB	World Bank

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Transmission Expansion Plan
Development of Power System Master Plan for the Transmission Company of Nigeria (TCN)

Synopsis of the Final Report

1. General

Transmission Company of Nigeria (TCN) owns the high voltage transmission network in Nigeria and is one of the 18 companies which have evolved from the restructuring of the formerly state-owned vertically integrated power utility. The TCN has interconnections with the neighbouring countries and is a member of the West African Power Pool WAPP. At presently, Nigeria is not fully interconnected with other WAPP countries but full integration is anticipated.

The need for development of a Power System Master Plan (PSMP) arised from the new situation in the power sector in Nigeria. The Power System Master Plan for the transmission network development is one of the key instruments needed by Transmission Company of Nigeria, which should support the large expansion program. This synopsis presents in a concentrated form the main results of the studies carried out by the Consultant for the development of a Power System Master Plan for the Transmission Company of Nigeria covering the period 2020 to 2037. The studies have addressed a wide range of topics, including demand forecast, the projection of existing generation capacities availability, future generation candidates to be considered in the transmission and generation optimization studies, least cost generation and transmission analysis, power system analysis to confirm the transmission system expansion (load flow, fault analysis and dynamics simulations), cost estimations for establishment of an investment plan, financial analysis and environmental impact scoping.

2. Power Sector Assessment

The electric power system of Nigeria has for many years been suffering from lack of generation capacity which requires permanent load shedding. Furthermore, frequent transmission and distribution system disturbances contribute to the unreliability of the power system.

TCN has created eight Transmission Planning Regions, which allow a more efficient planning. The actual regions under field and maintenance services sector are shown in **Figure** 2-1.

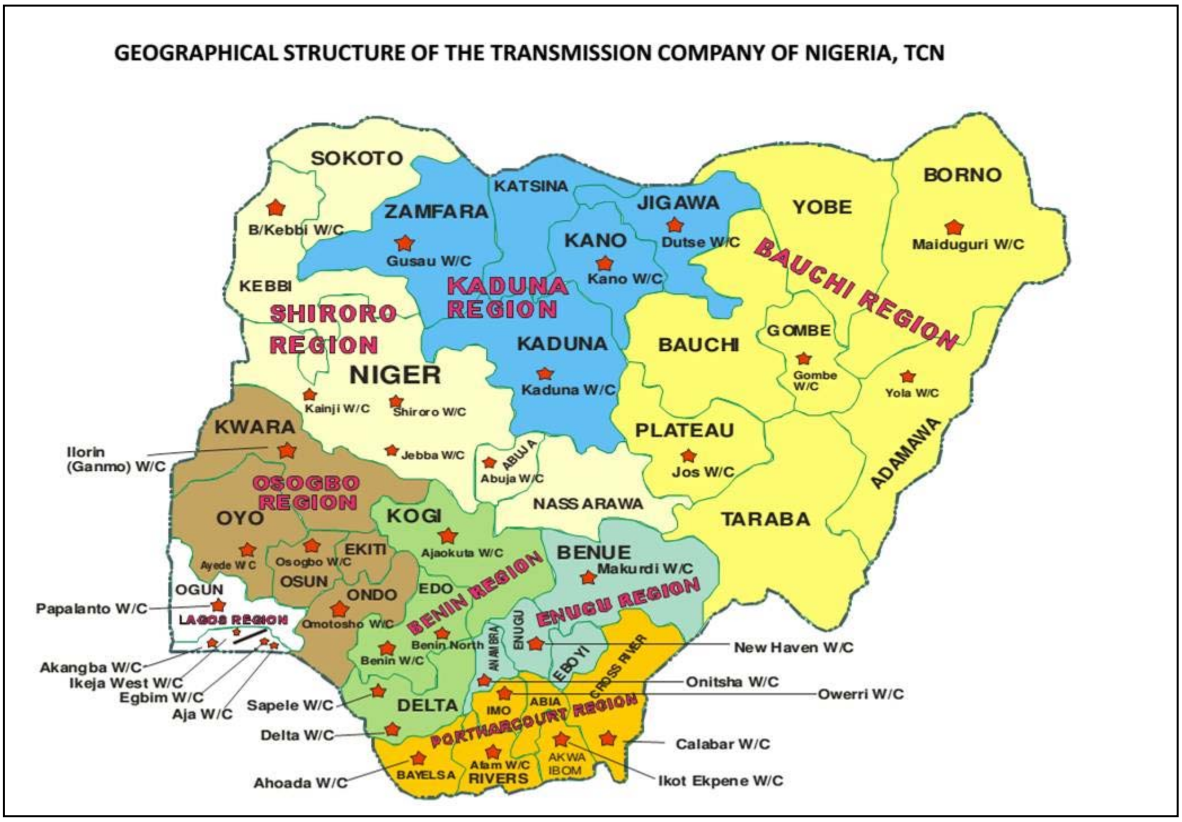
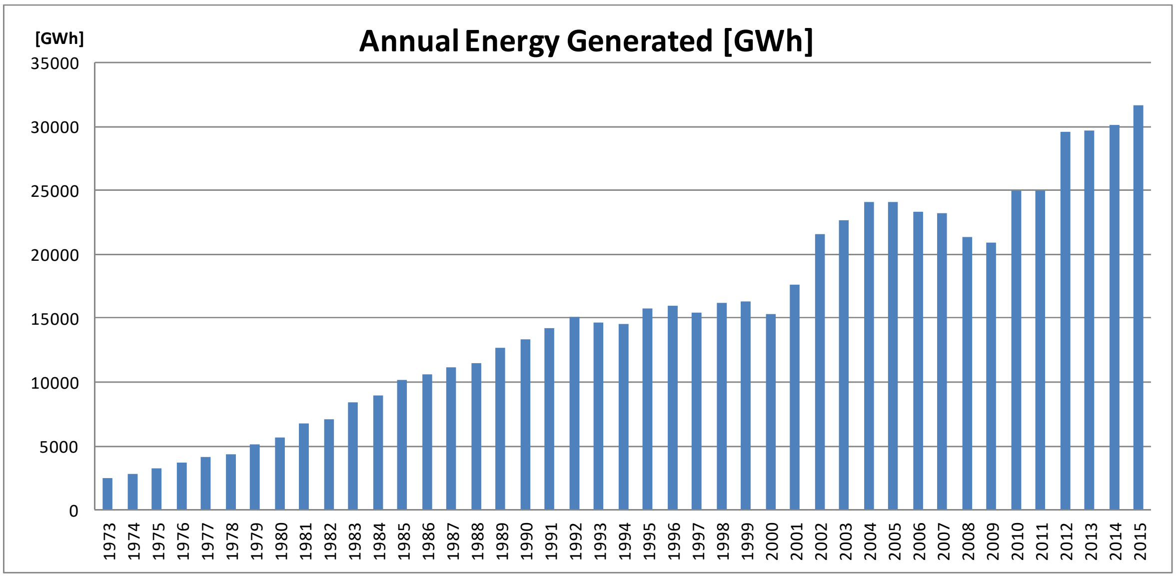


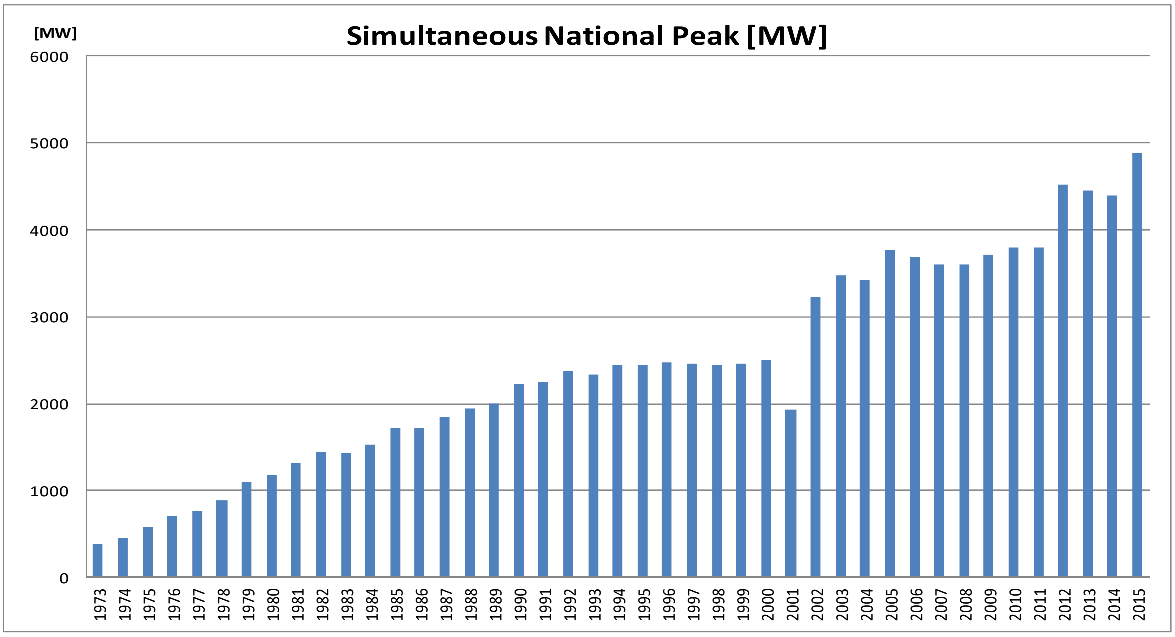
Figure 2-1: Geographical Structure of TCN

Figure 2-2 and **Figure 2-3** indicate the historical development of the peak generation and of the peak demand. Between 1973 and 2015 peak generation was increased from 385 MW to 4,884 MW, i.e. with an average growth rate of about 6.3%. During the same period the annual energy generated increased from 2493 GWh to 31,616 GWh, i.e. with an average growth rate of about 6.4%.



Source: TCN Annual Report 2015

Figure 2-2: Annual Energy Generated



Source: TCN Annual Report 2015

Figure 2-3: Simultaneous National Peak

In 2015 peak generation reached 4883.9 MW and on 2nd February 2016 peak output reached 5074.7 MW

Presently the produced energy cannot cover the demand. Main reasons for shortage of generation are outages of generation units and the unavailability of gas for power generation. The gas supply is very often interrupted because of sabotage of pipeline network.

The main concern for the future expansion of generation, however, is the availability of gas for additional generation capacity and the expansion of the gas pipeline network. Currently, most of the power plants are installed in the Southern part of Nigeria close to the oil and gas fields.

3. High Voltage Transmission System

The starting point of the transmission expansion masterplan has been laid down for year 2020. The high voltage transmission is using the 330 kV and 132 kV voltage levels. The configuration for year 2020 includes, beside the existing network, the projects expected to be completed under development by TCN or considered for financing by different donors (NIPP and JICA projects). The model of the transmission network has been implemented in PSS/E power system simulation software.

The 330 kV transmission system configuration for year 2020 is presented in **Figure** 3-1**.**

In terms of generation and load balance in the eight TCN planning regions, in four or five regions there is a significant generation deficit to be observed. With the exception of Benin and Port Harcourt regions, in all other regions in Nigeria the demand exceeds the available generation. In Shiroro region, the situation will be reversed once new HPP plants (e.g. Zugeru) will be commissioned.

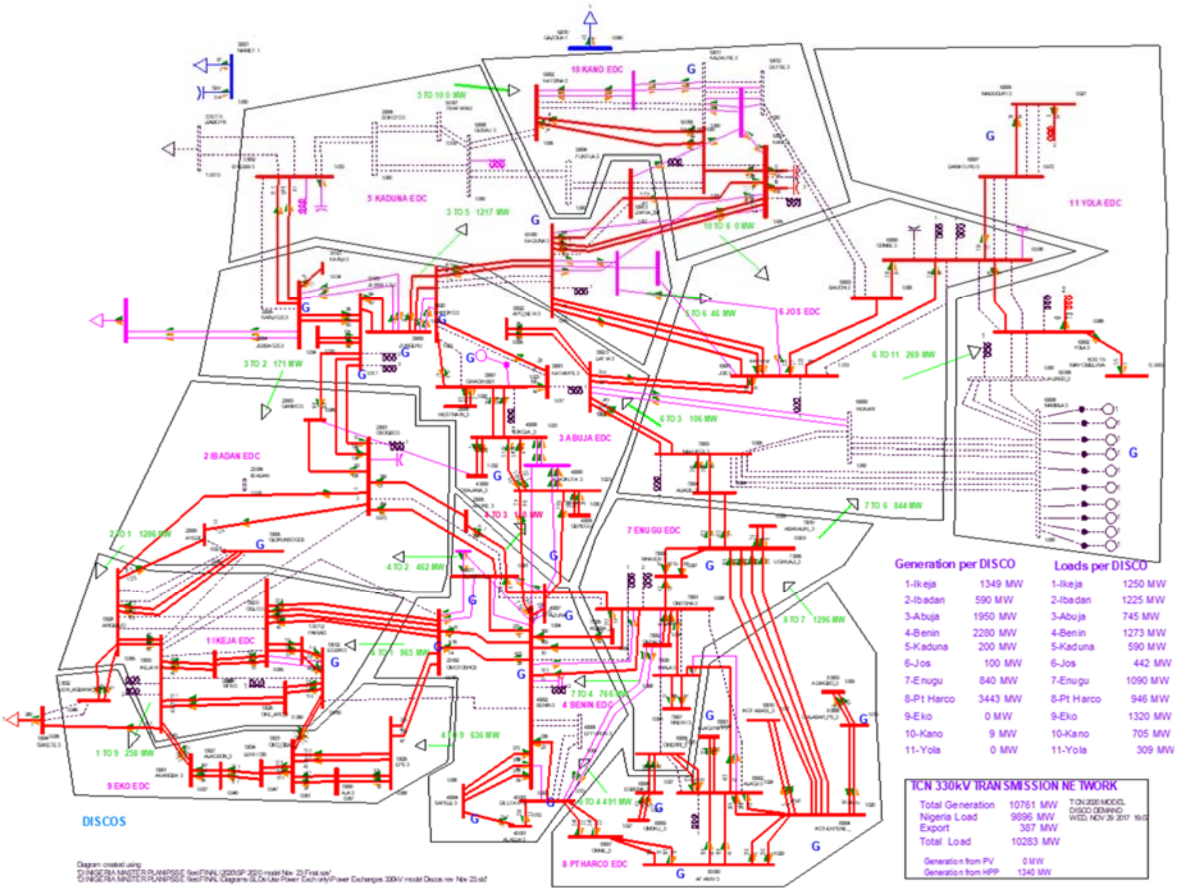


Figure 3-1: 330 kV transmission system configuration for year 2020

The reason for this imbalance is due to the generation being mainly concentrated in South (thermal stations in Port Harcourt, Enugu, Benin and Lagos) and Central West (hydro stations of Jebba, Kainji and Shiroro in Shiroro region). Central, North and North East in particular are characterized by the total absence of generating stations, while the load demand is mainly in South and South West.

To supply the load in the areas with little or no generation such as North East, long 330 kV transmission lines are built (radial system). As a result, voltage regulation problems can be encountered and the excessive reactive power flowing through these lines necessitates large reactive power compensation equipment (reactors) at the corresponding substations (Kano, Gombe, Maiduguri).

4. Demand Forecast

The bottom-up approach was applied for the starting point of the demand forecast, namely year 2016. TCN has carried out an extensive data collection to identify the load at the main 33 kV and 11 kV feeders and to identify and include also suppressed demand in the forecast.

Supplementary, a review of the load forecasts performed in previous studies, by other donors or directly by TCN has been performed and the underlying assumptions made on the interaction between energy and the economy has been done. A new forecast developed under the framework of this study for the next 20 years includes three credible scenarios

(high, medium and low demand growth scenarios), taking into account a optimistic, most likely and conservative view on potential capital investment reflected by the GDP growth rate.
The estimation of the future electricity demand takes into account:

- consumers which are already connected to the grid and supplied with electricity
- consumers supplied off-grid
- consumers which are not yet supplied with electricity
- the demand of the present consumers which cannot be served.

In line with the foregoing demand forecasts and following roughly the retail tariff structure, five consumer groups have been determined that are most adequate to perform the demand forecast:

- residential
- commercial
- industrial
- LNG
- exports.

In addition, network losses, suppressed demand (outages and disconnected demand), off-grid demand and load shedding have been estimated and added to the future demand.

Economic growth rates, historical demand data, population and demographic forecasts and other variables (such as growth in various energy-intensive sectors) have been considered. Based on the data collected for the electricity sector, key indicators relevant for future power demand development were calculated, such as electricity demand elasticity, energy intensity, price elasticity etc. An overview of key drivers used for each sector is presented in the **Table 4-1** below:

Table 4-1: Key drivers used for demand forecast per customer group

Sector	Population	Number of customers	GDP	Electricity Tariff
Residential	x	x	x	x
Commercial			x	x
Industrial			x	
LNG			x	
Exports	Constant as rather based on agreements than economic development			

Figure 4-1 shows the results of the demand forecast for the whole of Nigeria for the three scenario cases.

From its level in 2015 total demand is expected to increase by a factor of 5.8 to 246,147 GWh in 2035 in the base case. This means an average annual growth rate of 9.2% in the base case during the observation period. Residential demand is being the main driving force during the whole study period.

The peak load forecast is shown in **Figure 4-2.** The load forecast shows a similar pattern to the demand development. Peak load in Nigeria increases by a factor of 6 from its currently estimated level of 6,648 MW in 2015 to 40,141 MW in 2035 in the base case. This would translate into an average annual growth rate of 9.4%

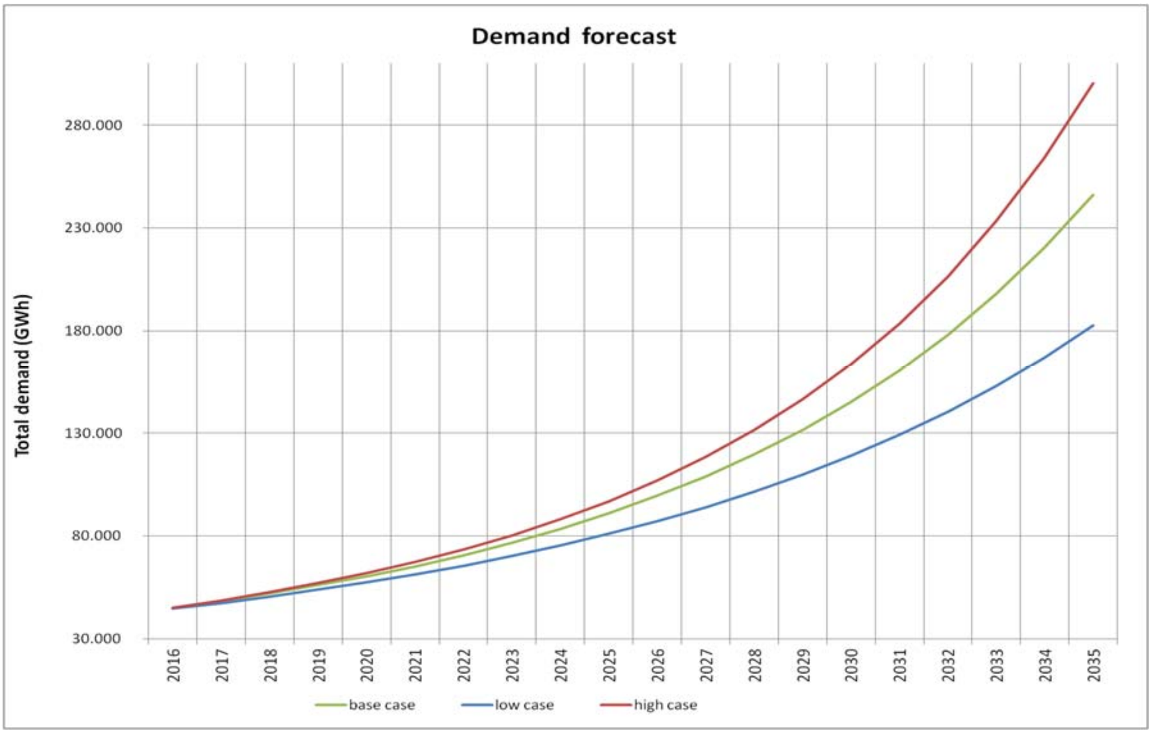


Figure 4-1: National demand forecast of Nigeria

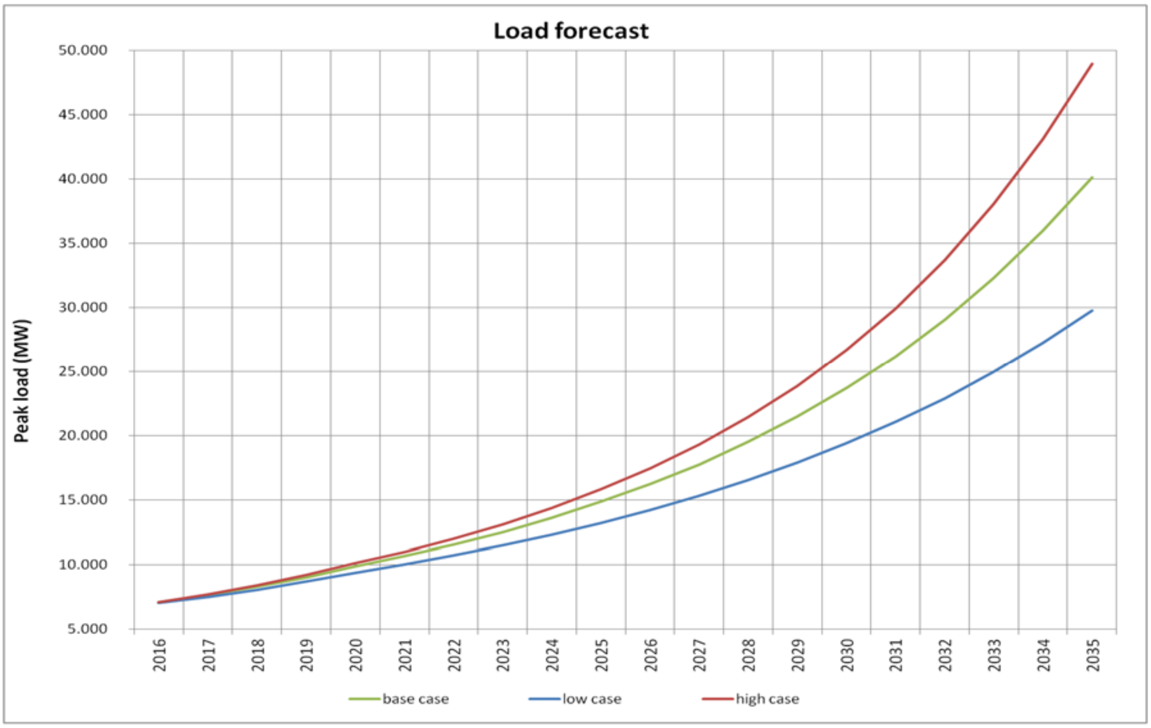


Figure 4-2: National peak load forecast

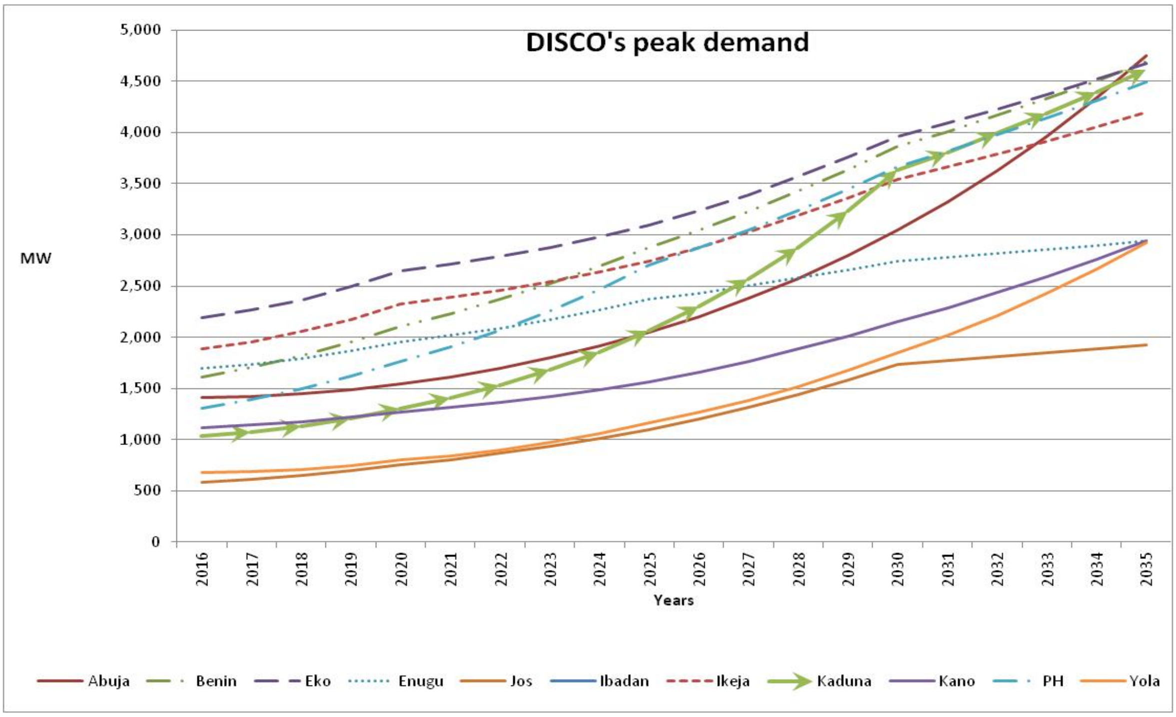


Figure 4-3: Peak demand projection per DisCo

The major advantage of the demand forecast herein consists in the circumstance that compared with other forecasts a validated set of figures of suppressed demand has been included in the forecast per DisCo. It is shown in **Table 4-2** and Figure **4-3**.

Table 4-2: Validated 2016 suppressed demand per DisCo

VALIDATED SUMMARY OF SUPPRESS LOAD DEMAND DATA BY DISCO'S IN 2016					
NAME OF DISCO	DISCO LOAD DEMAND FROM 2016 FIELD MEASURENT CAMPAIGN (SUM OF 11kV FEEDER AND 33kV FEEDER POINT LOADS) (MW)	HISTORIC 33kVPEAK LOAD COLLECTED IN 2016 FROM DISCO (MW)	DISCO ESTIMATE ON-GRID SUPPRESSED LOAD (MW)	DISCO ESTIMATED OFF GRID SUPPRESSED (POTENTIAL) LOAD (MW)	TCN COMMENT
AEDC	762.2	577.0	270.3	381.3	Validated without modification by AEDC
BEDC	1,223.3	776.7	163.1	220.6	Reviewed bY BEDC
EKEDC	1,350.4	856.6	493.8	350.9	Reviewed by EKEDC
EEDC	1,026.5	802.5	379.6	287.4	Validated by EEDC
IBEDC	1,285.9	1,119.2	183.7	279.7	Validated by IBEDC
IKEDC	1,215.6	977.2	302.8	364.5	Validated by IKEDC
JEDC	399.2	416.3	43.7	143.0	Validated by JEDC
KAEDCO	602.1	632.1	93.3	341.5	Validated by KAEDCO
KEDCO	708.1	513.8	186.8	224.4	Validated by KEDCO
PHEDC	948.5	884.9	130.1	229.5	Validated by PHEDC
YOLA	279.7	304.6	34.9	364.5	Validated without correction by YOLA
TOTAL ESTIMATED TCN DEMAND	**9,801.5**	**7,860.9**	**2,282.1**	**3,187.3**	

5. Existing Generation and Generation Expansion Plans

The data regarding the existing power generation assets and the availability of installed units has been obtained from the different stakeholders and consolidated in one common data bank. In addition to the existing facilities, the data bank includes listed candidates for expansion of generation capacity by installation of new units or plants. Some candidates have a more advanced implementation status, other candidates are still requesting for permits by NERC and other authorities. However, it is not certain that all these candidates will finally be permitted to be implemented in projects.

Based on provided information, the already installed gross power generation capacity is about 13,300 MW, of which some 11,800 MW are noted as net available capacity.

Considering latest information by generation companies, about 9,500 MW (80%) of this capacity should have been available at the end of the year 2015. However, only 5,900 MW net capacity has been available as statistics of the National Control Center (NCC) show.

Reasons for unavailability are: planned outages for maintenance or forced outages due to technical deficiencies of assets, as well as unplanned unavailability due to shortage of fuel supply or sabotage of gas pipelines. A further analysis of meanwhile provided information shows that about 20% of installed generation capacity is based on plants which are 25 years old or even older. Some of these plants have an efficiency of less than 30%. It is obvious that most of the old thermal power plants are - or will be - causing more frequent forced outages or long term planned maintenance outages in near future. For this reason, they should be replaced by new facilities with higher efficiency. Some of the generation companies already started this modernization process during the past 15 years and this process is ongoing as announced projects and plants under construction show.

Table 5-1 shows the new power plants which will be commissioned until 2020. The gas fired power plants are under construction. Regarding the PV power plants, it is expected that their construction will start soon.

Besides the above-mentioned projects with generation plants / generation units under construction, further projects are in a status of being committed for implementation.

Most feasible projects are listed in **Table 5-2** for the time period 2021 to 2025, in **Table 5-3** for the time period 2026 to 2030 and in **Table 5-4** for the time period 2031 to 2037. These projects will be considered also as generation expansion candidates for the generation and transmission expansion optimization.

Based on the discussion with TCN, the Master Plan is based on consideration of all currently existing power plant units being available latest in the year 2020 even in case that they are unavailable at the moment for serious technical reasons.

The Transmission Expansion Plan shows a program for step by step modernization of these plants in parallel to implementation of new units at existing sites, as well as complete new power plants. It further shows technical data of all existing and of new generation facilities and the respective implementation time table. Newly proposed power plants are considering a diversification of primary energy sources in form from solar / wind / hydro technology, as well as modern gas and coal fired thermal plants. Installation of new assets will follow the assumed increasing power demand, as well as the need for replacement of existing power generation assets.

Table 5-1: Power Plants to be commissioned until 2020

NAME OF STATION	PRIMARY ENERGY RESSOURCE	COMMERCIAL OPERATION DATE	NO. OF UNITS	GROSS UNIT CAPACITY (MW)	GROSS PLANT CAPACITY (MW)
GBARAIN / UBIE I	GAS	2017	1	113	113
GURARA	HYDRO	2017	2	15	30
EGBEMA I - NIPP	GAS	2018	1	113	113
OMOKU - NIPP	GAS	2018	1	113	113
MABON - DADIN KOWA	HYDRO	2018	1	39	39
AZURA	GAS	2018	3	150	450
AFAM III	GAS	2018	8	30	240
NOVA SOLAR	PV	2018			100
NOVA SCOTIA POWER	PV	2018			80
EGBEMA I - NIPP	GAS	2019	1	113	113
EGBEMA I - NIPP	GAS	2019	1	113	113
KADUNA IPP	GAS	2019	1	215	215
OMOKU - NIPP	GAS	2019	1	113	113
KASHIMBILLA	HYDRO	2019		40	40
ZUNGERU	HYDRO	2019	4	700	700
PAN AFRICA SOLAR	PV	2019			75
LR AARON SOLAR POWER PLANT	PV	2019			100
QUAINT ENERGY SOLUTIONS	PV	2019			50
NIGERIA SOLAR CAPITAL PARTNERS	PV	2020			100
MOTIR DUSABLE	PV	2020			100
MIDDLE BAND SOLAR	PV	2020			100
AFRINERGIA SOLAR	PV	2020			50
KVK POWER NIGERIA LTD	PV	2020			55
ANJEED KAFACHAN SOLAR IPP	PV	2020			100
CT COSMOS	PV	2020			70
ORIENTAL	PV	2020			50
EN Consulting & Projects - Kaduna	PV	2020			100
OKPAI IPP II - AGIP(*NNPC POWER BUSINESS PLAN*)	GAS	2020	2	150	300
OKPAI IPP II - AGIP(*NNPC POWER BUSINESS PLAN*)	STEAM	2020	1	150	150
IBOM II	GAS	2020	4	138	552
Generation Capacity Additions until 2020					**4,524**

Regarding the firm generation capacity, it has to be mentioned that this is usually about 20 to 30% lower than the installed capacity because of maintenance and repair requirements. Furthermore, generation capacity based on renewable energy resources has a lower utilization factor that thermal generation using gas, or coal:

- PV plants will not be available at peak load hours which are usually in the evening. The utilization factor is about 0.22 (corresponding to 2000h/year full load operation).

- The planned Mambilla HPP (3050 MW installed capacity) has a low utilization factor of about 0.19 (corresponding to 2640h/year full load operation, 5000 GWh/year energy output). The maximum output is only available in the rainy season for about 2 to 3 months. Its reservoir will be relatively small and behaves like a run-off-river power plant.
- Also output of the three exiting HPPs - Kainji, Jebba and Shiroro is much lower during dry season (sometimes less than 50% of installed capacity). Also other planned HPPs will have a similar performance.

Table 5-2: Power Plants to be commissioned between 2020 and 2025

NAME OF STATION	PRIMARY ENERGY RESSOURCE	COMMERCIAL OPERATION DATE	NO. OF UNITS	GROSS UNIT CAPACITY (MW)	GROSS PLANT CAPACITY (MW)
ASCO	GAS	2021	2	55	110
ELEME	GAS	2021	1	75	75
QUA IBOE POWER PLANT	GAS	2021	4	130	520
Cummins Power Gen. LTD.	GAS	2021	1	150	150
ONDO IPP - King Line	GAS	2021	1	200	200
TURBINE DRIVE	GAS	2021	3	167	501
EGBIN 2+	GAS	2021	4	300	1200
EGBIN 2+	STEAM	2021	2	350	700
SAPELE POWER PLC	GAS	2021	30	20	600
ZUMA (Egbema)	GAS	2021		374	374
PARAS	GAS	2022	2	150	300
OMA POWER GENERATION COMPANY LTD	GAS	2022			500
CENTURY IPP	GAS	2022	4	124	496
BRESSON Nigeria Ltd	GAS	2022	2	45	90
SAPELE POWER PLC	GAS	2022	1	100	100
ETHIOPE	GAS	2022	2	172	344
ONDO IPP - King Line	GAS	2022	1	150	150
ONDO IPP - King Line	GAS	2022	2	100	200
ETHIOPE	STEAM	2023	1	156	156
PROTON	GAS	2023	1	150	150
ZUMA *(Itobe)*	COAL	2023	4	300	1200
DELTA III 2+	GAS	2023	1	143	143
DELTA IV 2+	GAS	2023	4	148.5	594
LAFARAGE PHASE I	GAS	2023	1	50	50
CALEB INLAND	GAS+STEAM	2023	2	250	500
JBS Wind Power Plant	WT	2024	1	100	100
MAMBILLA	HYDRO	2024	10	305	3050
ALSCON *(Phase 1)*	GAS	2024	1	100	100
YELLOW STONE	GAS	2024	2	180	360
ETHIOPE	GAS	2024	2	172	344
ETHIOPE	STEAM	2024	1	156	156
ALAOJI 2+ NIPP	STEAM	2025	1	285	285
IKOT ABASI	GAS	2025	2	125	250
LAFARAGE PHASE II	GAS	2025	2	110	220
CALEB INLAND	GAS+STEAM	2025	2	250	500
KAZURE (KANO DISCO) *)	PV	2025			1000
Generation Capacity Additions between 2021 - 2025					**15,768**

There are some uncertainties whether the implementation of the generation expansion program is possible because of the huge investment requirements.

Table 5-3: Power Plants to be commissioned between 2026 and 2030

NAME OF STATION	PRIMARY ENERGY RESSOURCE	COMMERCIAL OPERATION DATE	NO. OF UNITS	GROSS UNIT CAPACITY (MW)	GROSS PLANT CAPACITY (MW)
ALSCON *(Phase 2)*	GAS	2026	2	130	260
ESSAR	GAS	2026	6	110	660
GEREGU NIPP 2	STEAM	2027	1	285	285
OMOTOSHO II 2+	STEAM	2027	2	127	254
CALEB INLAND	GAS+STEAM	2027	2	250	500
SAPELE 2 - NIPP	GAS	2028	3	151	453
OATS	GAS	2028	7	100	700
GEREGU FGN1-2	GAS	2029	3	138	414
CALABAR / ODUKPANI - NIPP	STEAM	2029	2	127	254
GBARAIN / UBIE 2	STEAM	2029	1	115	115
GEREGU NIPP 2	GAS	2030	3	148	444
CALABAR / ODUKPANI - NIPP	GAS	2030	4	141	564
EGBEMA II	STEAM	2030	1	127	127
IHOVBOR (EYAEN) 2 - NIPP	STEAM	2030	2	127	254
GBARAIN / UBIE 2	GAS	2030	8	113	904
CHEVRON AGURA(*NNPC POWER BUSINESS PLAN*)	GAS	2030			780
SUPERTEK	GAS	2030	5	100	500
MBH	GAS	2030	2	150	300
WESTCOM	GAS	2030	2	250	500
HUDSON POWER	GAS	2030	1	150	150
BRESSON AS NIGERIA	GAS	2030	3	150	450
AZIKEL IPP	GAS	2030	1	76	76
AZIKEL IPP	GAS	2030	1	250	250
AZIKEL IPP	GAS	2030	1	163	163
Generation Capacity Additions between 2026 - 2030					**9,357**

The availability of gas is the most uncertain factor in the generation development. A large quantity of the present gas production is exported. To make more gas available for electricity generation huge investments in gas exploration, gas treatment facilities and gas supply systems (pipelines etc.) will be required. Also the planned measure for rehabilitation and replacement of existing generation capacity after the end of the economic life cycle will require huge investments. The development of the transmission expansion plans presented in section 7 has indicated a scenario which allows to cover for these uncertainties.

Table 5-4: Power Plants to be commissioned between 2030 and 2037

NAME OF STATION	PRIMARY ENERGY RESSOURCE	COMMERCIAL OPERATION DATE	NO. OF UNITS	GROSS UNIT CAPACITY (MW)	GROSS PLANT CAPACITY (MW)
TOTALFINAELF (OBITE)(*NNPC POWER BUSINESS PLAN*)	GAS	2031			420
ANAMBRA STATE IPP	GAS	2031	2	264	528
KNOX	GAS	2031	3	167	501
DELTA STATE IPP	GAS	2032	5	100	500
BENCO	GAS	2033	7	100	700
ASHAKA	COAL	2034	1	64	64
RAMOS	COAL	2034	2	500	1000
ASHAKA / TPGL	COAL	2034	2	250	500
KADUNA (***NNPC POWER BUSINESS PLAN***)	GAS	2034			900
NASARAWA COAL POWER	COAL	2034			500
FORTUNE ELECTRIC	GAS	2035	5	100	500
FORTUNE ELECTRIC	GAS	2035	5	100	500
BENUE COAL POWER	COAL	2037			1200
ENUGU COAL POWER	COAL	2037			2000
GWAGWALADA (CCGT)	GAS	2037			1350
Generation Capacity Additions between 2031 - 2037					**11,163**

6. Least-Cost Generation and Transmission Analysis

With the aid of the GTMax (Generation and Transmission Maximization Model) software, the most economic generation and transmission expansion program for Nigeria for the period 2020 - 2037 has been investigated. The model developed considered the topology of Nigerian transmission network and the generation and load centers grouped on a regional basis (per DisCo's). The topology for year 2020 is exemplarily indicated in **Figure 6-1**. The subsequent models for years 2025, 2030 and 2035 consider the generation and transmission network expansion candidates.

The optimization studies have been performed for each development year considering both dry and wet seasons. Starting from year 2025, two options for generation development have been investigated:

- new thermal generation only in South of Nigeria - Option 1
- new thermal generation in South and in North of Nigeria - Option 2

The generation optimization studies have confirmed that in order to supply the potential demand of 10 GW, all projects which have been included in the expansion plan until year 2020 (as indicated in **Table 5-1**) have to be implemented. Due to the low availability of hydro power projects in Nigeria compared to thermal power generation, the peaking is done also by thermal power plants. The planed solar power projects will not be able to contribute for the evening peaking, only for daily peaking. In general, the power flows between the DisCos in Nigeria are from the south to the north and from the east to the west, in both peak and off-peak hours. The simulations have indicated that the transmission projects planned to be in operation by year 2020 are all needed, so that the installed transmission infrastructure should be able to carry the required power flows.

The expansion plan for year 2025 has considered a potential demand of 13 GW. In order to supply this demand, additional generation is needed. The generation expansion candidates are presented in **Table 5-2**. For the expansion stage 2025 highest priority is given to replacement of old generation capacity with low efficiency which has reached the end of the techno-economic life-cycle. New thermal power plants should be combined cycle power plants (CCPP) with high efficiency and so it will be possible to double the generation at existing locations, like: Delta, Egbin, Gbarain, Sapele, etc. This has the advantage that the gas supply system is already available as well as the transmission line connections of the power plants to the national grid.

As renewable resources in addition to the solar projects and the wind generation project JBS implemented in 2020, the Consultant considered new solar projects in Abuja, Kano, Kaduna, Jos and Yola. The Mambila HPP was considered with 300 MW and the Kazaure PV plant with 200 MW output.

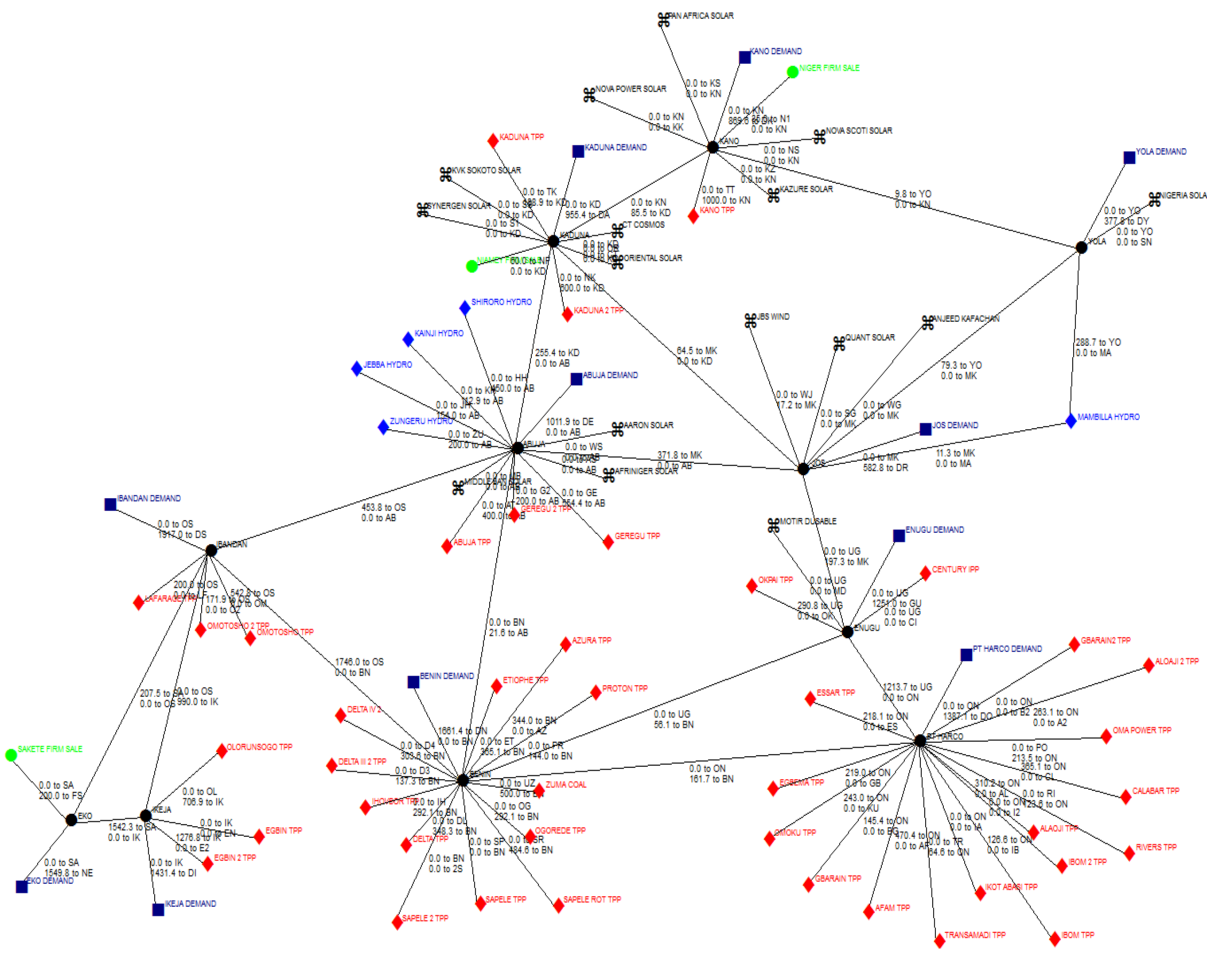


Figure 6-1: GTMax model configuration for year 2020

As thermal generation candidates in the north, following locations have been considered: Abuja, Kaduna and Kano, each with an installed power of 1300 MW.

The results of the GTMax simulations indicate that the power flows on the major transmission backbones, among the DisCos are lower than 2 GW. The highest power flows are from Port Harcourt to Enugu, followed by Benin to Ibadan, Ikeja to Eko and Abuja to Kaduna.
The power flows between the DisCos in Nigeria for the peaking and off-peak hours in 2025 would be from the south to the north and from the east to the west. If additional generation would be installed also in the north, then partially the power flow direction will change (flows from north to southwest will be encountered (Kano to Kaduna, Kaduna to Abuja, Abuja to Ibadan, Abuja to Benin).

Installing generation facilities for base load power on the north lowers the necessity of installation of thermal power plants in the south east (Pt Harcourt) and lowers the overall losses and transmission power flows within the DisCos.
Installing of generation facilities in Ibadan DisCo has advantages for the overall system (generation closer to the big demand centre Lagos)

The transmission infrastructure planed for 2025 (as indicated under Chapter 7) would be able to carry the required power flows and no additional transmission links between the DisCos are necessary up even if the generation expansion would be concentrated in South of Nigeria or also in North of Nigeria.

The generation and transmission expansion optimization for year 2030, when a total demand of 19.2 GW is planed, has indicated that the power flows among the DisCos are lower than 2.5 GW. The highest power flows are from Port Harcourt to Enugu, followed by Abuja to Kaduna, Ikeja to Eko, Ibadan to Abuja and Kaduna to Kano.

The installed transmission infrastructure would not be able carry the required power flows and additional transmission links between the DisCos are necessary up to 2030.

The following connections are recommended:

- Pt Harcourt - Enugu
- Abuja - Kaduna
- Ikeja - Eko
- Jos - Kaduna

The analysis for year 2035 considered a potential demand of 24.3 MW. The power flows among the DisCos on the major transmission corridors are lower than 3.5 GW. The highest power transfer would be from are from Port Harcourt to Enugu, followed by Abuja to Kaduna, Ikeja to Eko, Ibadan to Abuja and Kaduna to Kano.

The analysis has shown that the installed transmission infrastructure would not be sufficient for the required transmission capacity and additional transmission links between the DisCos are necessary up to 2035.

The following connections are recommended, additional to the ones considered for year 2030:

- Enugu - Jos
- Kaduna - Kano.

7. Power System Analysis for the Transmission Expansion Plan

The methodology of the power system analysis performed in PSS/E is summarized as follows:

a) *Definition of the Security Reference Level*
The goal of the study was to propose the necessary updates and reinforcements to the TCN power system in order to achieve the secure operation of the system for the years 2020 to 2037. The analysis was first carried out on the present system model, taking into account the recently completed and ongoing TCN and NIPP projects that are scheduled to be completed by 2020. It has also been assumed that certain projects in the Lagos area undertaken by JICA will be completed by 2020.

b) *Execution of the analyses on the 2020 model*
The initial analysis is related to the static security assessment. Using the outcome of this analysis, a first reinforcement list and recommendations for new lines and transformers is provided. Subsequently a dynamic security analysis was carried out based on the results of the static analysis and considering the reinforcements required, as detailed below.

c) *Execution of the analysis on the 2025, 2030 and 2037 model*
Considering the recommendations and reinforcements to be implemented in the 2020 network model, the same analyses are carried out on the 2025, 2030 and 2035/2037 scenarios. New reinforcements and recommendations for these years are provided accordingly. From 2030 onwards, the options of introducing a “supergrid” (at 330, 500 or 750 kV level) were analyzed and appropriate recommendations were made.

Four milestone study years have been selected to cover the planning horizon of the Master Plan: 2020, 2025, 2030 and 2035/2037.

7.1 Load demand

The load demand in each of the DisCo areas in Nigeria is shown is summarized in **Table 7-1.**

In the 2020 network configuration the assumed total demand is 9895 MW, to closely match the validated DisCos load demand, as presented by the 11 DisCos in the workshop of January 2017 in Abuja. Thereafter, the load demand to be served depends on two factors: (a) the rate of increase of forecasted demand as presented in section 4 and, more importantly, (b) the limits of generation expansion plan due to uncertainties, as presented in section 5.

The maximum load demand that can be realistically supplied will have, therefore, to follow the development of the generation planning schedule and it will be limited by the associated financial and time constraints. The total demand that can be served includes the export requirements to neighboring countries and is indicated in **Table 7-1**.

Table 7-1: Load demand per DisCo

DISCO	DisCo	2020	Increase 2020-2025	2025	Increase 2025-2030	2030	Increase 2030-2035	2035
IKEDC	1-Ikeja	1250	16.08%	1451	39.57%	2025	13.66%	2302
IBEDC	2-Ibadan	1225	45.31%	1780	50.28%	2675	23.94%	3315
AEDC	3-Abuja	745	35.70%	1011	66.92%	1688	49.86%	2529
BEDC	4-Benin	1273	37.47%	1750	39.98%	2450	16.54%	2855
KAEDCO	5-Kaduna	590	78.31%	1052	93.96%	2040	21.82%	2486
JEDC	6-Jos	442	48.64%	657	86.06%	1222	10.40%	1350
EEDC	7-Enugu	1090	22.29%	1333	25.22%	1669	11.36%	1859
PHEDC	8-Port Harcourt	946	55.39%	1470	43.42%	2108	17.70%	2481
EKEDC	9-Eko	1320	25.08%	1651	35.51%	2237	13.38%	2537
KEDCO	10-Kano	705	34.04%	945	59.22%	1505	31.23%	1975
YOLA	11-Yola	309	99.03%	615	83.14%	1126	51.78%	1710
Total MW		**9895**	38.61%	**13715**	51.26%	**20746**	22.42%	**25397**
Export MW		387		1540		1831		2000
Total load MW		**10282**		**15255**		**22577**		**27397**

The increase of load that can be supplied by the planned generation in the period 2020-2035 is shown in **Figure 7-1**.

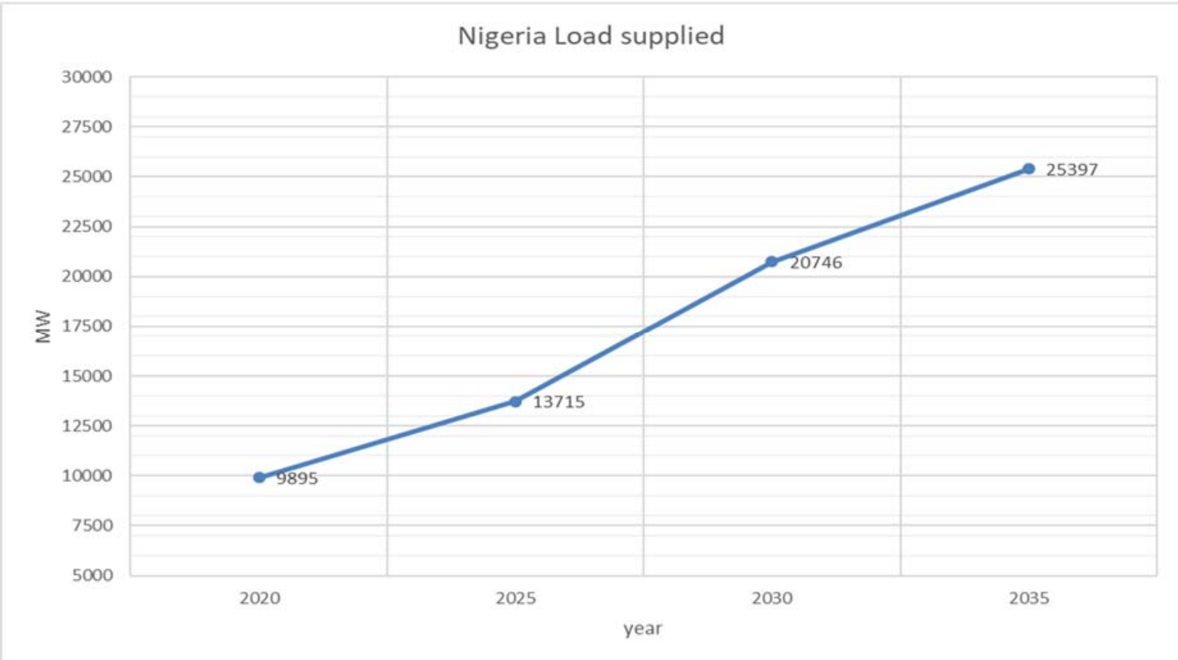


Figure 7-1: Increase of served Nigerian load 2020-2035

The development of the generation system and associated demand can thus be referred to as the **10GW** in 2020, **15GW** in 2025, **23GW** in 2030 and **28GW** in 2035.

7.2 WAPP interconnections

The total demand includes the export requirements to neighboring countries as follows:

Table 7-2: WAPP interconnections

Exports to	2020	2025	2030	2035
Benin (Sakete) 330kV	260	360	550	550
Benin (Faraku) 330kV	0	400	500	550
Niger (Zabori) 330kV	0	630	630	750
Niger (Niamey) 132kV	87	90	90	90
Niger (Gazoua) 132kV	40	60	60	60
Total MW	**387**	**1540**	**1830**	**2000**

7.3 Available generation

On the basis of the generation planning, the maximum generation that can be made available to supply the peak demand is calculated as shown in the following
Figure 7-2 by making a number of rather optimistic assumptions in terms of planned and unplanned outages and implementation of the proposed candidate power plant projects.

The maximum load demand that can be realistically supplied will have, therefore, to follow the development of the generation planning schedule and it will be limited by the associated financial and time constraints, as mentioned before. The generation expansion assumed for the study, for an average of over 2GW per year in the period 2020-2035, is considered rather optimistic and it is the Consultant's opinion that any assumption for a higher development rate would be unrealistic.

Table 7-3: Installed and available generation for 2020, 2025, 2030 and 2035

	2020	2025	2030	2035
Installed generation (GW)	14.4	28.2	39.0	45.6
Proposed candidates (GW)	0.7	7.9	16.1	20.9
Less PV (not available during peak load), in GW	-1.08	-1.31	-2.11	-2.11
Less a % of proposed candidates (in % and GW)	0%	25%	20%	20%
	0.0	-2.0	-3.2	-4.2
Les a min % on planned and unplanned outages (in % and GW)	20%	30%	26%	25%
	-2.7	-7.5	-8.8	-9.8
Available generation (max/rated) in GW	10.7	17.4	24.9	29.5
Available generation (running) during peak demand (GW)	**10.2**	**16.6**	**23.7**	**28.3**
Available generation (max), as % of the total (installed+planned+proposed).	74%	62%	64%	65%

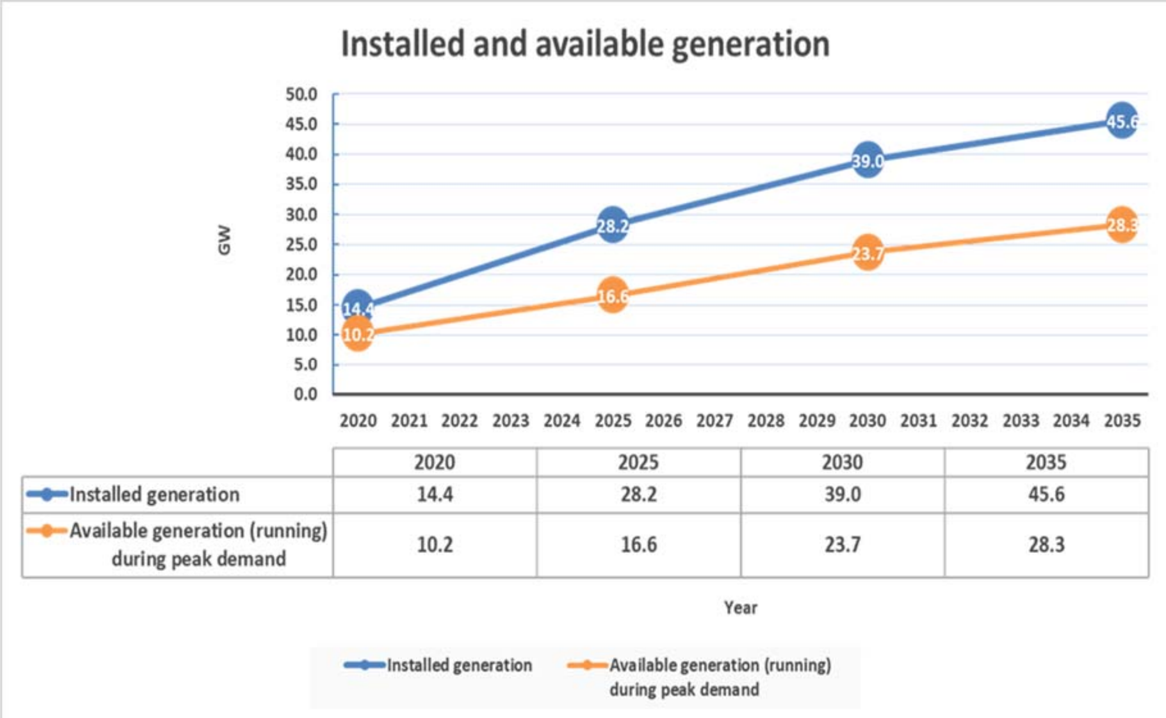


Figure 7-2 Installed and available generation for 2020, 2025, 2030 and 2035

In 2020, the total generation required to meet the load in Nigeria is 10700 MW and since the generation from new power plants that are envisaged to be in operation by 2020 is limited, the existing generating units, which are currently out of service for various reasons, must be made available if 10GW of load is to be served.

7.4 Inclusion of projects in the PSS/E models

7.4.1 Basis for 2020 model

The TCN and NIPP projects that are expected to be implemented by 2020 have been included in the 2020 PSS/E case. This includes:

- All $170m AFD Abuja projects
- $200m pilot procurement for contractor financed transmission projects (mainly rehabilitations)

7.4.2 Basis for 2025 model

Projects included and assessed:

- $200m JICA revised projects
- Proposed $272m AFD projects
- Proposed $200m AFDB projects
- Proposed $500m Exim Bank loan projects
- $486m World Bank (NETAP) projects

- $210m Islamic Development Bank (IDB) projects

If found necessary and in order to improve the voltage stability of the entire system, certain critical projects of the above list may have to be proposed to be included in the 2020 model and their implementation, including financing, will have to be expedited.

7.4.3 Main TCN 330kV and 132kV transmission line projects

The main 330 kV and 132 kV transmission line projects advised by TCN in October 5, 2017, are summarized in **Table 7-4** together with the expected year of operation. The projects entailing 330 kV lines are highlighted in blue fonts.

Table 7-4: Main TCN 330 kV and 132 kV transmission line projects

Area	Region	Location	Description	kV	in operation by
PROPOSED ABUJA TRANSMISSION RING PROJECT (AFD1)					
North Central	Abuja	New Apo	Construction of about 172km of new 330 kV double circuit line from Lafia 330 kV Substation (new) to the proposed New Apo 330/132/33 kV Substation.	330	2020
North Central	Abuja	Old Apo	Construction of about 7km of new 132 kV double circuit line from new Apo 330/132/33 kV substation to Old Apo 132/33 kV substation:	132	2020
North Central	Abuja	Old Kuje	Construction of 35km of new 132 kV double circuit line from New Apo 330/132/33 kV substation to the proposed Kuje 132/33 kV substation.	132	2020
North Central	Abuja	West Main Lugbe	Construction of 29km of new 132 kV double circuit line from the proposed Kuje 132/33 kV Substation to West Main (Lugbe) 330/132/33V substation.	132	2020
LAGOS/OGUN TRANSMISSION PROJECTS (JICA)					
South West	Lagos	New Abeokuta	Arigbajo – New Abeokuta 132 kV D/C Transmission Line (37.8km)	132	2022
South West	Lagos	Arigbajo	Olorunsogo – Arigbajo 330 kV D/C Transmission Line (12.9km)	330	2022
South West	Lagos	Ikeja West	Arigbajo – Ikeja West / Osogbo 330 kV D/C Turn in-out (5.9km)	330	2022
South West	Lagos	Arigbajo	Ogijom- Aribajo D/C Transmission Line (43.7km)	330	2022
South West	Lagos	Shagamu	132 kV Quad Line (2.3km) from Ogijo – Existing Ikorodu/Shagamu 132 kV 2x D/C Transmission Line	132	2022
South West	Lagos	Redeem	132 kV D/C Transmission Line (10.3km) from Ogijo – Redeem.	132	2022
South West	Lagos	Ikeja West	MFM – Existing Benin (Omotosho)/Ikeja West 330 kV 2 x D/C Transmission Line (4.2km)	330	2022
South West	Lagos	New Agbara	Arigbajo – New Agbara 330 kV D/C Transmission Line (30.6km)	330	2022
South West	Lagos	Agbara	New Agbara – Agbara 132 kV D/C Transmission Line (20.8km)	132	2022
South West	Lagos	Badagry	New Agbara – Badagry 132 kV D/C Transmission Line (34.2km)	132	2022
PROPOSAL FOR NORTH EAST TRANSMISSION INFRASTRUCTURE PROJECT TO BE FINANCED BY AFDB					
North East	Bauchi	Maiduguri - Manguno - Marte - Dikwa - Bama	Construction of a New 321km, 132 kV Double Circuit Line Between Maiduguri - Manguno - Marte - Dikwa -Bama	132	after 2020
North East	Bauchi	Maiduguri - Bama - Goza - Gulak	Construction of a New 165km, 132 kV Double Circuit Line from Maiduguri - Bama - Goza - Gulak	132	after 2020

Area	Region	Location	Description	kV	in operation by
North East	Bauchi	Mayo Belwa - Jada - Ganye	Construction of a New 78km, 132 kV Double Circuit Line from Mayo Belwa - Jada - Ganye.	132	after 2020
North East	Bauchi	Biu - BuniYadi - Damaturu	Construction of a New 134km, 132 kV Double Circuit Line from Biu - BuniYadi - Damaturu	132	after 2020
North East	Bauchi	Dambua - Chibok - Uba - Mubi	Construction of a New 130km, 132 kV Double Circuit Line from Dambua - Chibok - Uba - Mubi	132	after 2020
North East	Bauchi	Mayo Belwa - Jada - Ganye	Construction of a New 78km, 132 kV Double Circuit Line from Mayo Belwa - Jada - Ganye.	132	after 2020
North East	Bauchi	Biu - BuniYadi - Damaturu	Construction of a New 134km, 132 kV Double Circuit Line from Biu - BuniYadi - Damaturu	132	after 2020
North East	Bauchi	Dambua - Chibok - Uba - Mubi	Construction of a New 130km, 132 kV Double Circuit Line from Dambua - Chibok - Uba - Mubi	132	after 2020
PROPOSED NETAP PACKAGE AS AT 03RD APRIL, 2017 - $486 MILLION					
South West	Osogbo	Osogbo- Offa - Ganmo - Ilorin	Reconductoring of 150km, 132 kV Line Between Osogbo-Offa/Omuaran to Ganmo and Ilorin TS	132	2020
South West	Osogbo	Ayede - Shagamu	Reconstruction and Conversion of SC to Double Circuit of Ayede -Ajebo-Ishara-Shagamu 132 kV Line (54km) and Creation of Additional Bays 132 kV Line Bays at Ayede , Ajebo, Ishara and Shagamu.	132	2020
South West	Osogbo	Osogbo- Ife / Ilesha	Reconstruction and Conversion to Double Circuit of Osogbo-Ife/Ilesha 132 kV Line (39.21 km) and Osogbo-Ilesha 132 kV Line **Tie-Off** (22.1km) and Creation of Additional 132 kV Line Bays at Osogbo and Ilesha.	132	2020
South East	Port Harcourt	Afam - PH Main	Reconstruction of Existing Double 132 kV Line Circuit to 4 x 132 kV Line Circuit Using the Same Right of Way from Afam to Port Harcourt Main (37.8km), and Creating Additional 3 x 132 kV Line Bays	132	2020
South East	Port Harcourt	PH Main - PH Town	Reconductoring of 132 kV Double Circuit of Port Harcourt Main to Port Harcourt Town 132 kV Line (6km)	132	2020
North West	Kaduna	kumbotso - Hadelja	Reconductoring of Kumbotsho- Hadeji 132 kV Line (165km)	132	2020
North West	Kaduna	kumbotso - Kankia	Reconductoring of Kumbotsho- Kankia 132 kV Line (100km)	132	2020
south East	Enugu	Onitsha - Oji River	Reconductoring of Onitsha- Orji 132 kV Line (87km) with Turn In- Turn Out Tower at Nibo (Agu Awka) in Awka 132 kV Substation.	132	2020
south East	Enugu	Alaoji to Aba Town	Reconductoring of Alaoji - Aba Town Double Circuit 132 kV line (8km) Including Rehabilitation of Two Nos. Towers along the Line.	132	2020
South South	Benin	Irrua - Benin	Reconductoring of Irrua - Benin 132 kV line (81km)	132	2020
South South	Benin	Irrua - Okpila	Reconductoring of Irrua- Okpilai 132 kV line (43km).	132	2020
South South	Benin	Okpila - Okene	Reconductoring of Okpilai - Okene 132 kV line (65km)	132	2020
South South	Benin	Ajakuta-Okene	Reconductoring of Ajakuta- Okene 132 kV line (60km)	132	2020
North East	Bauchi	Gombe-Biu-Damboa-Maiduguri	Reconductering of the Entire Route Length from Gombe - Dadin Kowa- Biu -Damboa - Maiduguri 132 kV line of 356km Route Length	132	2020
NIGERIA TRANSMISSION EXPANSION (IDB)					
North West	Kaduna	Construction of Quad 330 kV on Kaduna-Kano 330 kV Single DC Transmission Line	Construction of Double Circuit 330 kV Quad Conductor Kaduna-Kano Transmission line.	330	after 2020

Area	Region	Location	Description	kV	in operation by
North West	Kaduna	Zaria	Turn-in Turn-out and Installation of 2x150MVA 330/132/33 kV Transformer, 6x330 kV bay extension, 2x60MVA 132/33 kV Transformer, associated 132 kV line bays and 6 number 33 kV feeder bays at Zaria	330	after 2020
North West	Kaduna	Millenium City Kaduna	Turn-in Turn-Out and Installation of 2x150MVA 330/132/33 kV Transformer, 2 x330 kV bay extension, and 2x60MVA 132/33 kV Transformer and 2x3number associated outgoing 33 kV feeders.	330	after 2020
North West	Kaduna	Rigasa town, Kaduna	Turn-in Turn-out and Intallation of 2x60MVA 132/33 kV Transformer and 5 number outgoing 33 kV feeders	132	after 2020
North West	Kaduna	Jaji, Kaduna	Turn-in Turn-out and Installation of 2x60MVA 132/33 kV Transformer and 6 number outgoing 33 kV feeders	132	after 2020
South South	Benin	Reconstruction of Delta to Benin 330 kV Transmission Line	Reconstruction of one of Delta-Benin 330 kV Transmission Line Double Circuit to Quad Conductor 330 Double Circuit Line	330	after 2020
South South	Port Harcourt	Reconstruction of Alaoji to Onitsha 330 kV Transmission Line	Double Circuit Alaoji-Ihiala-Onitsha to Quad conductor 330 kV transmission line	330	after 2020
South South	Ahoda, Gilili and Sapele	Environmental Impact Assessment and Resettlement Action Plan and Payment of Compensation	Double Circuit(DC) 132 kV Ahoda-Gilli-Gilli DC Transmission Line and 2x60MVA 132/33 kV Transformer at Gilli Gilli plus associated 6 number outgoing 33 kV feeders and DC 132 kV Sapele - Odilli DC Transmission Line and 2x60MVA 132/33 kV Transformer at Gilli Gilli plus associated 6 number outgoing 33 kV feeders	132	after 2020
North East	`Bauchi	Environmental Impact Assessment and Resettlement Action Plan and Payment of Compensation	132 line and associated substations: Maiduguri-Manguno-Marte-Dikwa-Bama,Maiduguri-Bama-Gwoza; Hadeja-Nguru-Gashua-Damaturu; Biu-Miringa-Buni Yadi-Damaturu; Dambua-Chibok-Askira-Uba-Mubi; Mayo Belwa-Jada-Ganye	132	after 2020
NORTHERN CORRIDOR TRANSMISSION PROJECT 2 (AFD2)					
North West	Shiroro	Kainji - Birnin Kebbi 330 kV Double Circuit (DC) Line (310km)	330 kV DC Transmission Line Kainji-Birnin Kebbi (following the existing ROW of the SC 330 kV line) and 4x 330 kV bay extension at B/ Kebbi and 2 x 330 kV bay extension at Kainji	330	after 2020
North West	Shiroro	Birnin Kebbi-Sokoto 330 kV Double Circuit (DC) Line (130km)	(1) Birnin Kebbi-Sokoto 330 kV DC Transmission Line on the existing 132 kV Birnin-Kebbi Sokoto ROW and reconducting the existing 132 kV Single circuit Birnin-Kebbi Line to double its capacity	330	after 2020
North West	Kaduna	Katsina-Daura-Gwiwa-Minjibir-Kura (234KM)	Construction of length of 330 kV DC Twin line between Katsina-Daura-Gwiwa-Jogana- Kura	330	after 2020
North Central	Shiroro	Lambata (Mina-Suleja Rd)	Turn in Turn out Mina - Suleja 132 kV DC and Construction of 1 x 60MVA 132/33 kV Complete substation	132	after 2020
North West	Shiroro	Fakon Sarki-Argungu	Turn in Turn Out on Brinin Kebbi-Sokoto 132 kV Line and Construction of 2 x 60MVA 132/33 kV Complete substation	132	after 2020
North West	Shiroro	Yelwa- Yawuri	Construction of 1 x 60MVA 132/33 kV Complete substation and High Voltage Switchgears and Associated Equipment.	132	after 2020
North Central	Shiroro	Birnin Gwari	Construction of 1 x 60MVA 132/33 kV Complete substation and High Voltage Switchgears and Associated Equipment.	132	after 2020
North West	Kaduna	Daura-Katsina State	Installation of 2x150MVA 330/132/33 kV Double Circuit Substation and with associated 132 kV bay extension and Installation of 2x60MVA 132/33 kV transformers, 6number outgoing 33 kV feeder bays	330	after 2020

Area	Region	Location	Description	kV	in operation by
North West	Kaduna	Jogana-Kano	Installation of 2x150MVA 330/132/33 kV Double Circuit Substation and with associated 132 kV bay extension and Installation of 2x60MVA 132/33 kV transformers, 6number outgoing 33 kV feeder bays	330	after 2020
North West	Shiroro	330 kV Sokoto Transmission Substation	Installation of 2x150MVA 330/132/33 kV Transformers at Sokoto New 330 Double Circuit Substation and with associated 132 kV bay extension and Installation of 2x60MVA 132/33 kV transformers, 6number outgoing 33 kV feeder bays	330	after 2020
North Central	Shiroro	Shiroro –Kaduna (Mando) 330 kV Lines 1 & 2 SC Transmission Lines (96km)	Reconstruction and upgrading of 2 Single Circuit 330 kV Transmission Lines 1 & 2 from Shiroro PS to Mando (Kaduna) to a 2 Double Circuit,Quad conductor Shiroro-Mando (Kaduna) Transmission lines 1 and 2. The line bay extension at Mando and Shiroro	330	after 2020
North East	Bauchi	Bauchi 330 kV Transmission Substation (2km)	Turn in-out of the existing 330 kV SC Jos-Gombe line at Bauchi, and installation of 2x150MVA 330/132/33 kV Transformers with associated 132 kV bay extension and 2x60MVA 132/33 kV transformers, 6number outgoing 33 kV feeder bays	330	after 2020

7.5 Study cases

In 2020 four scenarios were studied in detail, as shown in **Table 7-5**, to capture the extreme combinations of generation and load:

Table 7-5: 2020 study cases

Case		Description	Generation	Load (MW)	
Dry Season Peak	DP	Dry Night Peak Load	Dry-Reduced HPP generation No PV generation Increased requirement from GTs	Peak load (night)	9870 + export
Wet Season Peak	WP	Wet Night Peak Load	Wet-Normal HPP generation No PV generation Increased requirement from GTs	Peak load (night)	9870 + export
Dry Season Off-Peak	DOP	Dry Day Off-Peak Load	Dry-Reduced HPP generation PV generation Increased requirement from GTs	Off-Peak load (day)	8300 + export
Wet season Off-Peak	WOP	Wet Day Off-Peak Load	Wet-Normal HPP generation PV generation Increased requirement from GTs	Off-Peak load (day)	8300 + export

In 2025 the two most critical scenarios were studied: Dry Season Peak and Dry Season Off-Peak:

Table 7-6: 2025 study cases

Case		Description	Generation	Load [MW]	
Dry Season Peak	DP	Dry Night Peak Load	Reduced HPP generation No PV generation Increased requirement from GTs	Peak load (night)	13715 + ex-port
Dry Season Off-Peak	DOP	Dry Day Off-Peak Load	Reduced HPP generation PV generation Increased requirement from GTs	Off-Peak load (day)	11650 + ex-port

The results of the load flow analysis for the worst case (Dry Season Peak) in 2020 are shown diagrammatically in the SLD of **Annex 7.4a**.

The results of the load flow analysis for the worst case (Dry Season Peak) in 2025 are shown diagrammatically in the SLD of **Annex 7.7a**.

Following the power system analysis, a transmission expansion plan was developed with its associated cost estimations.

7.6 Expansion plan for 2020

Transmission Lines

The first priority is to resolve the overloads occurring under *normal (N-0)* operation of the 132 kV lines:

- Alagbon-Ijora: Convert to DC
- Omoku-Rumusoi: Reconductoring of the DC
- Ibom IPP-Ikot Abasi: Convert to DC

As a next priority 23 overloaded 132 kV lines (circuits) under N-1 contingencies must be reinforced (ref. Table 12.2 in main report). This entails either re-conductoring to higher rating conductors or, in case of SC, conversion to DC by installing a 2nd parallel circuit.

Finally, in addition to the projects proposed and undertaken by JICA, the following new transmission lines are required to be implemented by 2020, as shown in **Table 7-7** :

- Part of 330 kV North East Ring:
  Damaturu-Maiduguri, Gombe-Damaturu, Gombe-Yola, Yola-Jalingo and Jos-Gombe.

- Part of 330 kV North West Ring:
  Kainji-Birnin Kebbi

In addition:

- 330 kV: Kaduna-Kano (needs to be expedited)
- 330 kV: Akangba-Alagbon, Ugwaji-Abakaliki, Osogbo-Arigbajo (if not by JICA)
- 132 kV: Ayede-Ibadan North, New Agbara-Agbara, Ogojo-Redeem, Birmin Kebbi-Dosso

Table 7-7: New transmission lines required by 2020

No		From	To		kV	km	Remarks	Priority /Ranking
1	Part of North East Ring	Damaturu	Maiduguri	DC	330	260	a SC already exists	1
2		Gombe	Damaturu	DC	330	180	a SC already exists	1
3		Gombe	Yola	DC	330	240	a SC already exists	1
4		Yola	Jalingo	DC	330	160	Can be delayed beyond 2020 but asap thereafter. One circuit via Mayo Belwa.	3
5		Jos	Gombe	DC	330	270	Should be completed by 2020 or asap thereafter. A SC already exists	1
6	Part of North West ring							
7		Kainji	Birnin Kebbi	DC	330	310	a SC already exists. Needs to be expedited by 2020 if possible or asap thereafter.	3
8		Kaduna	Kano	DC	330	230	Undertaken by TCN as part of the NTEP to be financed by IDB. Needs to be expedited by 2020 if possible or asap thereafter.	2
9		Akangba	Alagbon	DC	330	14		2
10		Ugwaji	Abakaliki	DC	330	85		1
11		Osogbo	Arigbajo	DC	330	183	If not undertaken by JICA	
12		Ayede	Ibadan North	DC	132	15		1
13		New Agbara	Agbara	DC	132	18		2
14		Ogijo	Redeem	DC	132	14	If not undertaken by JICA	
15		Birmin Kebbi	Dosso	DC	132	128	a SC already exists	2
15		Ibom IPP	Ikot Abasi	DC	132	30		1

It should be noted that the lines recommended for the North East ring are required in order to comply with the N-1 static security criterion, as well as to improve the voltage stability of the area. It is recognized however that in terms of implementation it will be challenging to complete all by 2020.

However, if not possible to implement by 2020 they should be implemented as soon as possible thereafter within the period 2020-2025 and therefore the investment plan, detailed in section 8, has been based on this assumption.

The JICA project of new 330 kV lines (DC) from Ogilo to Arigbajo is not considered necessary, as it is lightly loaded under all scenarios.

The JICA project of new 330 kV lines (DC) from Arigbajo to New Agbara is not considered necessary for 2020, as it is lightly loaded. Only for N-1 for exports.

Transformers

The upgrading of 14 x 330/132 kV three-winding transformers and autotransformers which are overloaded above their 100% rating MVA under normal (base case) operation, is required (ref. to Table 7-21 of the main report).

The upgrading of 25 x 132/33 kV and 132/11 kV transformers which are overloaded above their 100% rating MVA under normal (base case) operation, is required (ref. to Table 7-22 of the main report).

The upgrading of the following types of transformers overloaded above their 85% rating MVA under normal (base case) operation shall be upgraded (ref. to Table 7-23 of the main repor)t:

a) 10 x 330/132 kV three-winding transformers and autotransformers,
b) 25 x 132/33 kV and 132/11 kV transformers

Reactive Power Compensation

SVC requirements
No SVC at Gombe is necessary by 2020.

Reactors
In *Dry Season Peak* case only four of the existing reactors are required to be in operation at Gombe and Yola and it is assumed they are in good working order.

In *Dry Season Off-Peak* case new reactor required at Maiduguri of 75MVar, in addition to existing reactors at Gombe, Kano and Yola.

Capacitors
New capacitors required at 132 kV at Omuaran (50MVar), Ondo (24MVar) and Irrua (24MVar), in addition to existing ones.

Power factor correction at DisCos level
With reference to the Grid Code requirements (ref. article 15.6 on *Demand power factor corrections and 16.7 on provision of voltage control* stating that *The Off-takers shall maintain a Power Factor not less than 0.95 at the Connection Point*), since the resulting power factor of loads connected at 33 kV level and below is less than the 0.95 required, all DisCos shall be required to undertake a program of having capacitors installed at distribution level to ensure the power factor at all 33 kV S/S is not less than 0.9 by 2020 and 0.95 by 2025, in line with the Grid Code requirements.

Fault level remedial measures

The fault analysis has shown that the most critical 330 kV substations are BENIN, OMOTOSHO, SAPELE, ALAOJI and AFAM IV, with fault levels ranging from 34.9 kA to 25.7 kA for a 3ph busbar fault.

The most relatively critical 132 kV substation is IKEJA WEST, with fault level of 29.6 kA.

The TCN standard switchgear ratings of 31.5 kA are therefore inadequate particularly when new power plants are to be commissioned in the following years.

In order to solve the violations detected in the substations of TCN network, the following solutions could be adopted:

(a) Install breakers with a higher breaking capacity,
(b) Study different topological configurations of the elements connected to the different bus sections and
(c) Install Current Limiting Reactors (CLR) aimed at reducing the short circuit currents contributions from adjacent bus sections.

7.7 Expansion plan for 2025

Transmission lines

In addition to the projects undertaken by TCN and NIPP, the following 330 kV and 132 kV lines are included in the 2025 model, as shown in **Table 7-8**. These lines are also in addition to those that have been included in the 2020 expansion plan.

- *Part of the 330 kV North West ring*
  Birnin Kebbi- Sokoto, Sokoto-Talata Mafara, Talata Mafara-Gusau, Gusau-Funtua, Funtua-Zaria

- *Part of the 330 kV North East ring*
  If cannot be implemented by 2020, implement as soon as possible thereafter: Damaturu-Maiduguri, Gombe-Daimaturu, Gombe-Yola, Yola-Jalingo (via Mayo Belwa)

- *330 kV lines for Mambila evacuation*
  Mambila-Jalingo, Mambila-Wukari, Wukari-Makurdi, Wukari-Lafia

In addition, the following 330kV lines:

- Olorusongo-Arigbajo (additional DC), Katsina-Daura, Daura-Kazaure, Shiroro-Kaduna (new DC and/or upgrade existing to Quad)

Table 7-8: Additional lines required by 2025 (1)

No		From	To		kV	km	Remarks	Priority/ Ranking
1		Arigbajo	Ayede	SC	330	50		1
2	Part of North West Ring	Birnin Kebbi	Sokoto	DC	330	130	in parallel of existing 132 kV	3
3		Sokoto	Talata Mafara	DC	330	100		3
4		Talata Mafara	Gusau	DC	330	125		3
5		Gusau	Funtua	DC	330	70		2
6		Funtua	Zaria	DC	330	70		2
7		Olorusongo	Arigbajo	DC	330	20	Already a DC. 4 circuits are required.	3

No		From	To		kV	km	Remarks	Priority/ Ranking
8		Katsina	Daura	DC	330	40	Undertaken by TCN as part of the Northern Corridor Transmission projects 2, to be financed by AFD	2
9		Daura	Kazaure	DC	330	25	Undertaken by TCN as part of the Northern Corridor Transmission projects 2, to be financed by AFD	2
10	Part of North East Ring	Damaturu	Maiduguri	DC	330	260	If not by 2020, implement as soon as possible thereafter (a SC already exists)	3
11		Gombe	Daimaturu	DC	330	160	If not by 2020, implement as soon as possible thereafter (a SC already exists)	3
12		Gombe	Yola	DC	330	240	If not by 2020, implement as soon as possible thereafter (a SC already exists)	3
13		Yola	Jalingo	DC	330	160	If not by 2020, implement as soon as possible thereafter (1 SC via Mayo Belwa)	3
14	Mambila evacuation	Mambila	Jalingo	2xDC	330	95	2xDC only if N-2 is adopted, otherwise 1xDC	1
15		Mambila	Wukari	2xDC	330	159	2xDC only if N-2 is adopted, otherwise 1xDC	1
16		Wukari	Makurdi	DC	330	159		1
16		Wukari	Lafia	DC	330	95	after 2025	3
18		Shiroro	Kaduna	DC	330	96	or upgrade to 4-b (Quad). Two DC project with quad conductors is undertaken by TCN as part of the Northern Corridor Transmission projects 2, to be financed by AFD	3
19		Arigbajo	New Agbara	DC	330	40	JICA.	
20		Arigbajo	Ogijo	DC	330	48	JICA.	
21		New Agbara	Badagry	DC	132	32	JICA.	
22		Arigbajo	New Ajeokuta	DC	132	37	JICA.	

The 132 kV lines which are overloaded under normal operation (base case) requiring reinforcements, in addition to those reported for the 2020 case, are the following:

- Ogijo-Shagamu,
- Dadinkowa-Kwaya Kusar,
- PHCT Main-PHCT Town.

It should be noted that the overloads of these lines have been reported in the 2020 case, but under N-1 conditions.

Furthermore, since a number of undervoltages were encountered in the Dry Season Peak case, and also in order to meet the N-1 security criterion, the following line additions or conversions to a double circuit are required at 132 kV level:

- Shiroro-Tegina,
- Tegina-Kontagora,
- Kontagora-Yelwa,
- Yelwa-Yauri,
- Ganmo-Ilorin,
- Obajana-Egbe,
- Omotosho-Ondo,
- Benin-Irrua,
- Irrua-Ukpilla,
- Ukpilla-Okene,
- Shagamu-Ijebu Ode,
- Dakata-Gagarawa,
- Gagarawa-Hadejia,
- Dakata-Kumbotso,
- Birmin Kebbi-Dosso.

Finally, the contingency N-1 analysis carried out for the 330 kV lines in 2025 has shown that the following 330 kV double circuit lines are overloaded and require reinforcement by converting to Quad conductors.

- Aliade-Ugwuaji
- Makurdi-Aliade
- Aja-Lekki
- Gwagwalada-Lokoja
- Lokoja-Ajaokuta

Transformers

The following upgrades are required, in addition to those reported for the 2020 case:

The upgrading of 20 x 330/132 kV three-winding transformers and autotransformers which are overloaded above their 100% rating MVA under normal (base case) operation, is required (ref. to Table 7-36 of the main report).

The upgrading of 51 x 132/33 kV and 132/11 kV transformers which are overloaded above their 100% rating MVA under normal (base case) operation, is required (ref. to Table 7-37 of the main report). 25 of these transformers have already been reported as loaded above their 85% rating in 2020.

Reactive power compensation

SVC requirements
There is no requirement for an SVC in 2025. More detailed and dedicated studies will be necessary at a later stage to determine any need for such equipment in the period beyond 2025.

In 2025 a number of reactors and capacitors are required for reactive power compensation (ref. to Table 7-38, Table 7-39, Table 7-40 and Table 7-41 of the main report) . Suplementarry, reactive power compensation (150 MVAr capacitors) will be required at Bernin Kebbi due to export requirements to WAPP.

With regards to Gombe, should additional reactive power compensation be required at lightly loaded conditions, instead of SVC a more cost-effective option would be to relocate from other S/S to Gombe approximately 100-150 MVAR of reactors that, as it has been shown in this analysis, are not needed there anymore.

As it is shown in the static security analysis for 2025, a more appropriate candidate for an SVC or capacitor banks could be the Lagos / Ikeja/Eko region, where there is a reactive power deficit of approximately 400-500 MVar.

It should be noted however that this deficit is expected to be greatly reduced when the DisCos implement the reactive power control program at distribution level, as proposed and in line with the Grid Code requirements, as well as when transmission lines and transformers are upgraded, as it has been shown in previous chapters of this report.

Reactors
In *Dry Season Peak* case no new reactors are required.
In *Dry Season Off-Peak* case new reactors are required at Maiduguri (75Mvar).

Capacitors
In *Dry Season Peak* case one additional capacitor at Uyo (50 MVar) is required in addition to the those new required for 2020.

In *Dry Season Off-Peak* case also, no new capacitors are required in addition to those required for 2020.

Fault level remedial measures

As in the 2020 case, the most critical 330 kV substations are BENIN, OMOTOSHO, AZURA, EGBIN and BENIN NORTH, with fault levels ranging from 54.3 kA to 42 kA for a 3ph busbar fault.

The most relatively critical 132 kV substation is IKEJA WEST, with fault level of 39.3 kA. The recommended remedial measures are the same as those described for the 2020 case.

7.8 Expansion plan and “supergrid” options for 2030 and 2035

The load flow simulations have shown that without major upgrade of the transmission system, there will be widespread undervoltages and overloads throughout the system and at all voltage levels. Consequently, the system losses will be high.

It is therefore considered necessary and appropriate at this stage to introduce a new “supergrid”, i.e a backbone for bulk transmission at either 330, 500 or 750 kV.

A number of configurations have been examined and compared in terms of their efficacy in voltage support, system losses and relieve of line loadings of existing and planned 330 kV system.

The optimum configuration of a 330, 500 or 750 kV EHV grid is shown in **Figure 7-3**, encompassing the following substations:

Ikot Ekpene, Benin, New Agbara, Osogbo, Gwangwalada, Makurdi, Ajeokuta, Funtua and Kainji.

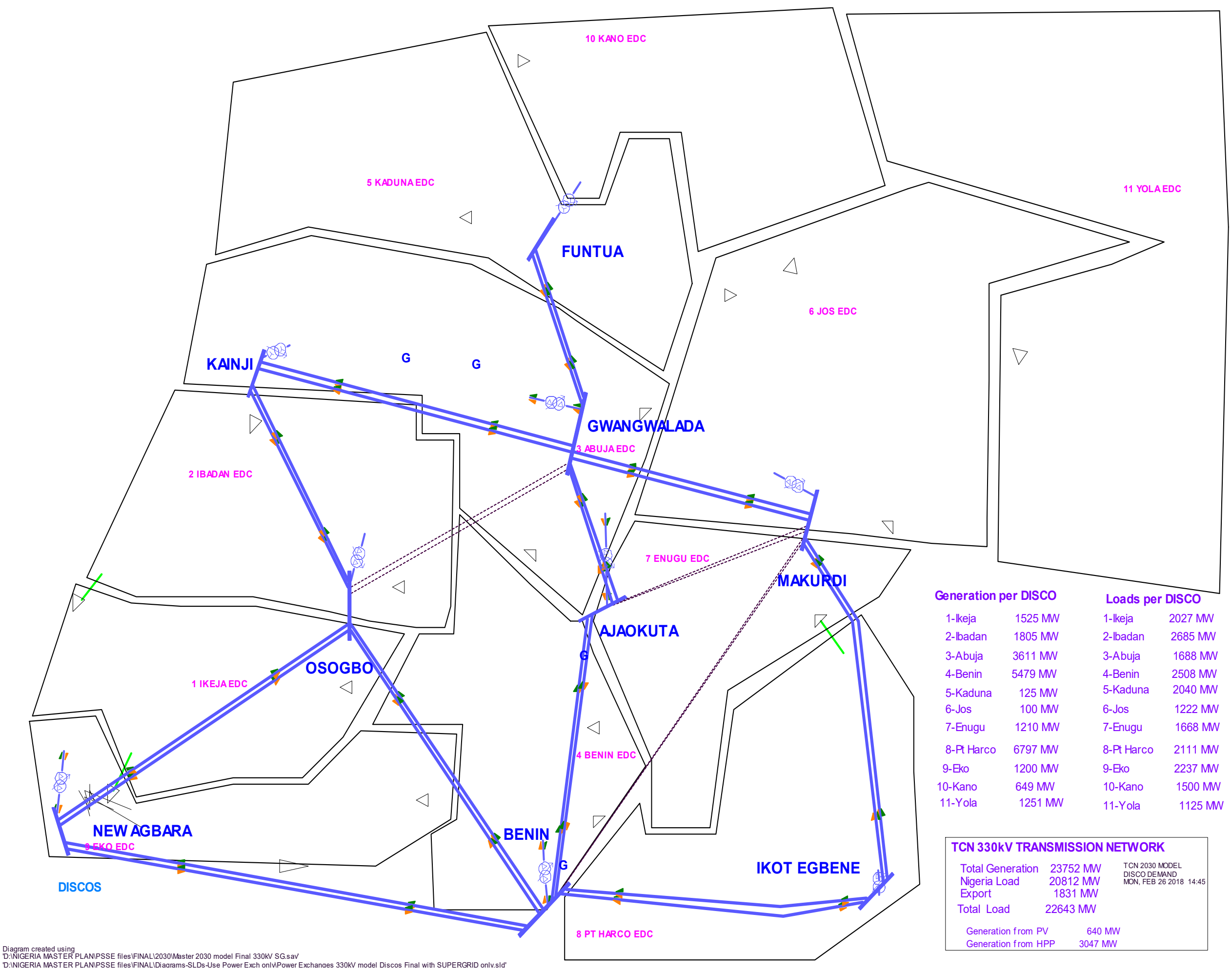


Figure 7-3: Configuration of 330, 500 or 750 kV grid in 2030

With regards to the conductor type necessary for each supergrid option, the following arrangements are recommended:

- At 330 kV a Double Circuit is proposed with 4-bundle (Quad) Bison conductors for each circuit. Capacity 2x1550 MVA
- At 500 kV a Single Circuit is proposed with 4-bundle (Quad) Bison conductors. Capacity 2350 MVA
- At 750 kV a Single Circuit is proposed with 5-bundle Bison conductors, which is typical at this voltage level due to corona phenomenon. Capacity 4400 MVA.

The cost comparison indicates that the investment cost in million US$ is: (a) For 330 kV is 1381, for 500 kV is 1256 and for 750 kV is 1589.

The comparison indicates that the 500 kV supergrid will require the lower investment cost. However, the cost difference to 330 kV is relatively small.

Based on the technical considerations both the 330 and 500 kV options are adequate. Furthermore, taking into considerations that:

a) Capacity of 330 kV supergrid lines:	3100 MVA
b) Capacity of 500 kV supergrid lines:	2350 MVA
c) Difference in losses between 330 and 500 kV supergrids:	Marginal
d) Impact on O/U voltages and overloads:	330 kV advantageous
e) Higher static N-1 security of the 330 kV supergrid due to double circuit lines involved	

it appears that the 330 kV supergrid system is technically the preferred option and its 10% higher investment cost could be justified. In summary:

- More detailed studies are required to confirm the conclusions of this study in this respect.
- It is therefore recommended to have these detailed studies carried out in due course, before a final decision can be made on the selection of voltage level (330 kV or 500 kV) for a future super grid.
- There is no justification to adopt and/or consider further any higher (750 kV) option for the EHV grid, particularly when the implications of the high cost differences are taken into account, as detailed in section 8. The higher transmission capacity (4400 MVA) is not required at this stage and the marginal differences in losses cannot offset the high investment cost required in the planning horizon of this Master Plan.
- Furthermore, the network calculations have indicated that a transmission capacity of the 330 kV and 500 kV supergrid system is sufficient.

7.9 Dynamic simulations

The dynamic model of the TCN system was developed based on data received for the representation in PSS/E of generators, governors and exciters of conventional power plants.

Furthermore, Wind and PV dynamic models were introduced by one set of the following PSS/E models:

- Renewable Energy Generator/Converter Model,
- Generic Electrical Control Model for large scale PV and Wind generation,
- Generic Renewable Plant Control Model.

Table 7-9 shows the cases simulated for 2020 and 2025, as a typical representation of extreme scenarios.

Table 7-9: Dynamic study cases

Case	Scenario	Fault at bus	Trip line / disturbance
F1	2020 Dry Season Peak	Ikeja West 330 kV	Trip 330 kV line from Ikeja to Arigbajo
F2		Benin 330 kV	Trip 330 kV line from Benin to Omotosho
F3		Kainji 330 kV	Trip 330 kV line from Kainji to Birnin Kebbi
F4		Ikot Ekpene 330 kV	Trip 330 kV line from Ikot Ekpene to Ugwaji
F5		Gwagwalada 330 kV	Trip 330 kV line from Gwangalada to Shiroro
F6		Afam 330 kV	Trip largest generating unit Afam VI
F7	2020 Dry Season Off-Peak	Gwagwalada 330 kV	Trip 330 kV line from Gwangalada to Shiroro
F8	2025 Dry Season Peak	Ikeja West 330 kV	Trip 330 kV line from Ikeja to Arigbajo
F9		Benin 330 kV	Trip 330 kV line from Benin to Omotosho
F10		Kainji 330 kV	Trip 330 kV line from Kainji to Birnin Kebbi
F11		Ikot Ekpene 330 kV	Trip 330 kV line from Ikot Ekpene to Ugwaji
F12		Gwagwalada 330 kV	Trip 330 kV line from Gwangalada to Shiroro

The results of the dynamic simulations have shown that the power system and all generating machines, including the PV and wind generation, remain synchronized for all cases studied.

8. Investment plan

A transmission investment plan has been prepared based on the results of the power system analysis, to provide sufficient transmission capacity as well as sufficient 330/132 kV and 132/33 kV transformer capacities. Furthermore, also necessary reactive power compensation equipment (capacitor banks and shunt reactors) have been identified to maintain voltage levels within permissible range.

In addition to the network expansion measures identified by the Consultant, TCN has indicated that an ongoing investment program until 2025 includes rehabilitation measures of existing substations and transmission lines, construction of new substations and transmission lines to connect additional areas within Nigeria to the national grid and to strengthen existing substations (additional 330/132 kV and 132/33 kV transformers). These investments have been also included in the investment plan.

8.1 Transmission network investments until 2020

A summary of the investment required until 2020 is presented in **Table 8-1**.

Table 8-1: Summary of all additional investments in transmission lines and substations until 2020 to establish a 10 GW transmission network

Transmission System Expansions	Transmission Lines	Substations	Total
	Million US$	Million US$	Million US$
Additional Transmission Lines to Relieve Existing Lines	12,0	19,2	**31,2**
Additional Transmission Lines to Relieve Existing Lines	162,8	140,8	**303,6**
Additional 330/132 kV Transformers	0,0	35,0	**35,0**
Additional 132/33 and 132/11 kV Transformers to relieve existing transformers loaded above 100%	0,0	78,2	**78,2**
Additional 132/33 and 132/11 kV Transformers to relieve existing transformers loaded above 85%	0	131,7	**131,7**
New Reactors and Capacitors	0	18,9	**18,9**
New Transmission Lines by 2020	147,5	53,6	**201,1**
Total Additional Investment Cost by 2020			**799,6**

8.2 Transmission network investments between 2021 and 2025

A summary of the investment required between 2021 and 2025 is presented in **Table 8-2**.

8.3 Transmission network investments after 2025

Regarding transmission network investments after 2025, only the investments in the highest transmission voltage level has been investigated, i.e. 330 kV and higher. The estimation of network investments in the 132 kV system and 132/33 kV substations is not possible at this stage because it requires detailed investigations and is considered to be part of medium term planning and not long term planning.

According to the Consultancy Contract, options for the introduction of a higher transmission voltage have to be studied. The Consultant has checked three options: continuation of network expansion with 330 kV and introduction of 500 kV or 750 kV as a new voltage level.

Table 8-2: Summary of all additional investments in transmission lines and substations until 2025 to establish a 13 GW transmission network

Transmission System Expansions	Transmission Lines	Substations	Total
	Million US$	Million US$	Million US$
Project 1: 330 kV North West Ring	355,5	165,8	**521,3**
Project 2: 330 kV North East Ring	499,5	152	**651,5**
Project 3: 330 kV Mambilla Network Connections	254,25	37,3	**291,6**
Additional Transmission Lines to Provide N-1 Reliability by 2025	216,45	67,2	**283,7**
Additional Transmission Lines to Relieve Existing Lines by 2025	16,4	25,6	**42,0**
Additional 330/132 kV Transformers by 2025	0,0	78,1	**78,1**
Additional 132/33 and 132/11 kV Transformers	0,0	68,2	**68,2**
New Reactive Power Compensation in Lagos Region			**50,0**
Costs for converting 330 kV DC lines to quad conductors			**90,0**
Total Additional Investment Cost by 2025			**2076,3**

With regards to the 3 voltage level options for introducing a "Supergrid" beyond 2030, the cost comparison is summarized in **Table 8-3.**

Table 8-3: Summary of cost comparison between 330, 500 and 750 kV

Voltage level	Transmission Lines (million US$)	Substations (million US$)	Total (million US$)
330 kV	1161	220	1381
500 kV	722	533	1256
750 kV	903	686	1589

The investigations indicated lower investment costs for network expansions with a new 500 kV voltage level compared with the exiting 330 kV voltage level. However, the difference is relatively small. Prior to a decision on the introduction of a new voltage level the actual load and generation development has to be taken into account.

The introduction of a 750 kV voltage level is considerably costly and technically is not required.

8.4 TCN's Transmission Investment Plan up to 2025

TCN has allocated their network rehabilitation and expansion program for the time period up to 2025 in accordance with the expected financing by development banks. Details regarding the individual packages are presented in **Annexes 4.2.-1 to 6** of the main report.

Development Bank	Total million US$
AFD (French Development Agency - Agence Française de Développement)	170
JICA (Japan International Cooperation Agency)	200
AFDB (African Development Bank)	200
World Bank	486
Islamic Development Bank (IDB)	210
AFD (French Development Agency - Agence Française de Développement)	272
Total Additional Investment Cost by 2025	**1,538**

9. Financial Analysis

The financial analysis in the framework of the Master Plan has included three "Projects" which are in fact clustering different transmission expansion elements. These are:

Project 1: 330 kV North West Ring
Project 2: 330 kV North East Ring
Project 3: 330 kV Lines for connection of Mambilla HPP

The "Projects" have been defined under consideration that the benefits depend on the completion of a project rather than on completion of individual lines. However, the actual implementation sequence may be different.

All costs and benefits in the financial assessment are expressed in market prices and in US Dollar. The costs include project investment costs and O&M costs of 1% of the project investment costs. The total project costs include cost of new transmission lines and substations as well as physical and price contingencies and estimates of engineering, consulting and environment costs. **Table 9-1** presents the total financing cost of the project investment (excluding price contingencies) of the three projects.

In a first step, the Consultant has calculated the financial levelized electricity costs (LECs) that provide an indicator for the level of the cost-recovering transmission charges required to render the project financially viable.

The LECs are calculated as the net present value of project costs divided by the net present value of energy transmitted. **Table 9-2** shows the LECs of the three projects.

The financial LECs of the projects 1 and 3 are below the current average transmission tariff in Nigeria, which is estimated at US$ 0.0085 per kWh. At the current tariff, the projects have a FIRR of 6.79% and 7.31% respectively showing that these projects are financially feasible.

Table 9-1: Cost estimates

Cost Estimates			Project 1	Project 2	Project 3
1. Transmission line		US$ million	355.60	499.50	254.30
2. Substations		US$ million	165.80	152.00	37.30
Total estimated equipment		**US$ million**	**521.40**	**651.50**	**291.60**
3. Engineering - foreign	5%	US$ million	26.07	32.58	14.58
4. Owners Engineer	3%	US$ million	15.64	19.55	8.75
5. Other Consulting Services, ESIA	1%	US$ million	5.21	6.52	2.92
6. Environmental Safeguard	1%	US$ million	5.21	6.52	2.92
7. Land acquisition, Resettlement	1%	US$ million	5.21	6.52	2.92
Total CAPEX		**US$ million**	**578.75**	**723.17**	**323.68**
Physical Contingencies	5%	US$ million	28.94	36.16	16.18
Project investment cost		**US$ million**	**607.69**	**759.32**	**339.86**

Table 9-2: Levelized electricity cost

Results LEC		Project 1	Project 2	Project 3
LECs at				
WACC 1.15%	US$/kWh	0.0033	0.0094	0.0035
WACC 2%	US$/kWh	0.0039	0.0111	0.0040
WACC 4%	US$/kWh	0.0055	0.0163	0.0054

The next step was to set up the financial costs of the projects as cash flows over the entire lifetime of the projects and compare to the project revenues. The basic technique for comparing costs and benefits occurring in different periods is to discount costs and benefits and to express them in a common value at one point in time. The discount rate applied in the financial analysis for calculating net present values is equal to the weighted average cost of capital (WACC). A discount rate equal to the WACC of 1.15% is applied. The results of the base case assessment are summarized in **Table 9-3**

Table 9-3: Financial indicators

Results Base Case			Project 1	Project 2	Project 3
Project investment cost		US$ million	607.69	759.32	339.86
NPV at					
WACC	1.15%	US$ million	1,174	-91	610
WACC	2.00%	US$ million	848	-208	459
WACC	4.00%	US$ million	348	-374	65
FIRR			6.79%	0.63%	7.31%
Benefit/Cost Ratio			2.55	0.90	2.43
Payback Period		years	19.8	38.1	15.7

A sensitivity analysis was carried out to show the robustness of the projects versus changes in major parameters which may have an adverse impact on the viability of the projects. Parameter changes include project investment costs, O&M cost, transmission charges, volume of energy transmitted and WACC.

TCN's latest investment plan up to 2025 to connect additional areas to the national grid will have positive effects on the economic viability of the projects.

10. Environmental and social impact considerations related to transmission network expansion

The possible environmental and social impacts have been identified based on four transmission lines which are indicated in **Figure 10-1**. These are located in different regions and fit to all lines eventually planned in Nigeria.

Figure 10-1: Overview selected transmission lines for environmental and social impact assessment

Degradation is a major problem in Nigeria and the processes of desertification and deforestation are of special concern. Especially the fact that almost all primary forest is lost and only very little and degraded forest is left makes the cutting of trees inconceivable. Existing forest patches have therefore to be contoured. Depending on the type of forests, they can eventually be spanned.

All protected areas have to be strictly avoided. This includes the one existing National Park (Gashatka Gumti, crossed by line 2) and also the forest reserves concerned (including the two of them being proposed for the formation of new National Parks, close to line 1 and 4). Second issue for Nigeria is the regionally very high population density.

Physical relocation has to be avoided whenever possible. In the more populated areas, this might not always be feasible and resettlements might become necessary. However, the number of affected people has to be kept to a minimum. Wherever fruit trees must be cut or agriculturally used fields have to be used for the masts, compensation has to be paid.

There are two major requirements in respect to environmental and social impact: spare the national resources and avoid physical relocation of people. Therefore, deviations and numerous angle towers might become necessary.

11. Appraisal and benefits of transmission projects

11.1 Benefits of major projects

The benefits of major projects (North West Ring, North East Ring and Mambilla evacuation transmission lines) are summarized in the **Table 11-1**.

Table 11-1: Benefits of major transmission projects

No	From	To	Type	kV	km	Benefits
North East Ring						
1	Damaturu	Maiduguri	DC	330	260	Load in Maiduguri is supplied by a 330 kV SC line. If tripped, load of 55-83MW will be lost between 2020-2025 and 200MW by 2035. Widespread undervoltages may result in tripping additional load. A new DC 330 kV will prevent this and will increase system security, by meeting the N-1 criterion.
2	Gombe	Damaturu	DC	330	180	Load in Damaturu and Maiduguri is mainly supplied by a 330 kV SC from Gombe. If the line from Gombe is tripped, load of 135-482MW (2020-2035) will be lost. Widespread undervotlages may result in tripping additional load. A new DC 330 kV Gombe-Damaturu will prevent this and will increase system security by meeting the N-1 criterion
3	Gombe	Yola	DC	330	240	Load in Yola is supplied by a 330 kV SC from Gombe and a 132 kV SC line fro Jalingo. If the line from Gombe is tripped, load of 140-500 MW (2020-2035) will be lost. Widespread undervotlages may result in tripping additional load. A new DC 330 kV Gombe-Yola will prevent this and will increase system security by meeting the N-1 criterion
4	Yola	Jalingo	DC	330	160	Load in Jalingo is supplied by a 132 kV SC from Yola. If the line from Yola is tripped, load of at least 45-160MW will be lost (2020-2035). Widespread undervotlages may result in tripping additional load. A new DC 330 kV Yola-Jalingo will prevent this and will increase system security
5	Jos	Gombe	DC	330	270	If only one 330 kV circuit is in operation, voltage stability issues would necessitate additional reactive power compensation at Gombe. If this line trips voltage collapse will result in heavy load loss (400-1428MW in 2020 and 2035 respectively). Since the second line is needed anyway to meet N-1 too, it is recommended to have it implemented as soon as possible and save the cost of reactive power compensation at Gombe.
1	Kainji	Bernin Kebbi	DC	330	310	Required for N-1. If not installed, tripping the existing SC 330 kV line will result in voltage collapse and heavy loss of load, 240-900MW (2020-2035)
2	Birnin Kebbi	Sokoto	DC	330	130	Mainly voltage stability and prevention of load shedding. Required by 2025. If the lines are not installed by 2025, the loads will be fed via the 132 kV system only, resulting in widespread undervoltages, which would necessitate load shedding of approx 350MW in 2025 and 800MW in 2035 in order to stabilize the voltage.
3	Sokoto	Talata Mafara	DC	330	125	Mainly voltage stability and prevention of load shedding. Required by 2025. If the lines are not installed by 2025, the loads will be fed via the 132 kV system only, resulting in widespread undervoltages, which would necessitate load shedding of approx 240MW in 2025 and 550MW in 2035 in order to stabilize the voltage

No	From	To	Type	kV	km	Benefits
North East Ring						
4	Talata Mafara	Gusau	DC	330	85	Mainly voltage stability and prevention of load shedding. Required by 2025. If the lines are not installed by 2025, the loads will be fed via the 132 kV system only, resulting in widespread un-dervoltages, which would necessitate load shedding of approx 160MW in 2025 and 400MW in 2035 in order to stabilize the voltage
5	Gusau	Funtua	DC	330	70	Mainly voltage stability and prevention of load shedding. Required by 2025. If the lines are not installed by 2025, the loads will be fed via the 132 kV system only, resulting in widespread un-dervoltages, which would necessitate load shedding of approx 100MW in 2025 and 150MW in 2035 in order to stabilize the voltage
6	Funtua	Zaria	DC	330	70	Required by 2020. The area is supplied via 132 kV lines only. If the 132 kV line from Zaria to Funtua trips, approx 90 MW of load will be lost in 2020 and 120 MW by 2025. A new DC 330 kV will prevent this and will increase system security.
9	Mambila	Jalingo	DC	330	95	To evacuate the power from Mambilla HPP, rated 3000MW, it is necessary to maintain two evacuation routes, one towards Makurdi and another towards north to Jalingo. If the generation from Mambilla exceeds 1400MW, a DC only of Quad conductors cannot meet the N-1 requirements, hence the need to have the DC Mam-billa-Jalingo. Additional reasons include voltage stability.
10	Mambila	Wukari	DC	330	150	

11.2 Appraisal criteria for TCN network expansions

Each of the main 330 and 132 kV project has been appraised using the methodology used by the Association of European Transmission System Operators ENTSO-E. As such the benefit of each project is assessed against a number of indicators ranging from technical and socio-economic issues to environmental impact.

The analysis has been performed for projects planned for implementation in the transmis-sion network by 2025. Applying the ENTSO-E methodology, expected benefits where weighted and applied individually for each project. For this study, the projects were ap-praised against the following criteria:

Increase of Network Transfer Capacity, providing estimate of the incremental power transfer capacity between two points of transmission system (MW);

Social and Environmental Impacts, reflecting level of certainty with respect to the planned commissioning time of the project and its impacts on the environment;

Security of Power Supply, evaluating project impact on reliability status of the connected part of the network;

Integration of Renewable Energy Sources (RES), Support to RES integration is defined as the ability of the system to allow the connection of new RES plants and unlock existing and future "green" generation;

Effect on Transmission Losses (Energy Efficiency), comparing losses (in MWs) relevant to the scenarios with and without project (or its specific components);

Technical resilience / system safety margin, evaluating project influence on entire system reliability;

The radar format graphs of **Figure 11-1** show, as an example, the points scored by the North East Ring project and hence its priority ranking.

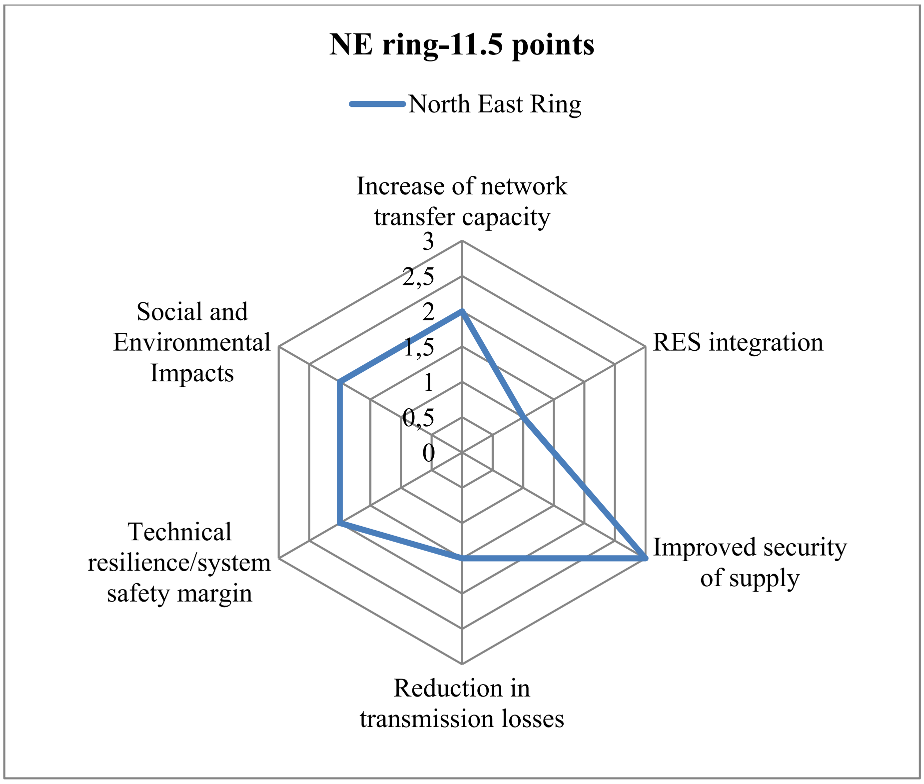


Figure 11-1: Project appraisal criteria and scores for NE ring project

Similar radar format graphs were prepared for the appraisal of other 330kV and 132kV projects.

12. Conclusions and Recommendations

12.1 Proposed transmission expansion plan

The proposed transmission expansion plan is shown in **Figure 12-1** of the map of Nigeria with transmission network, showing the new projects proposed in the Master Plan and the already considered TCN projects. The map is also attached in pdf format as **Annex 7.1.**

The transmission expansion plan is a challenging undertaking which requires coordinated and continuous action from the stakeholders involved for a successful implementation.

It is recommended to implement all network expansions and rehabilitation/reinforcement measures detailed in section 7 as soon as possible. However, a lot of preparatory work (e.g. feasibility studies, tender documents etc.) for most of the proposed measures needs to be done. At this stage, only implementation of system expansions projects to be financed by AFD s is ongoing and commissioning until 2020 can be achievable.

For projects financed by other donors, it can be assumed that implementation between 2020 and 2025 is feasible. In general, 2 to 3 years are required for feasibility studies, environmental impact studies, route survey, preparation of technical specifications and tender documents, bidding, tender evaluation and contracting and arrangement financing agreements. In addition, 2 to 3 years can be assumed for construction and commissioning of the projects.

The analysis under this project has indicated that some of the on-going and proposed projects are critical for the operation of the system in 2020 and if the load of 10GW is to be served adequately, these projects will have to be expedited with the aim to be completed by 2020 or as soon as possible after 2020.

12.2 Power factor correction at DisCo`s level

With reference to the Grid Code requirements (ref. article 15.6 on *Demand power factor corrections and 16.7 on provision of voltage control* stating that *The Off-takers shall maintain a Power Factor not less than 0.95 at the Connection Point*), since the resulting power factor of loads connected at 33 kV level and below is less than the 0.95 required, all DisCos shall be required to undertake in parallel a program of having capacitors installed at distribution level to ensure the power factor at all 33 kV S/S is not less than 0.9 by 2020 and 0.95 by 2025, in line with the Grid Code requirements.

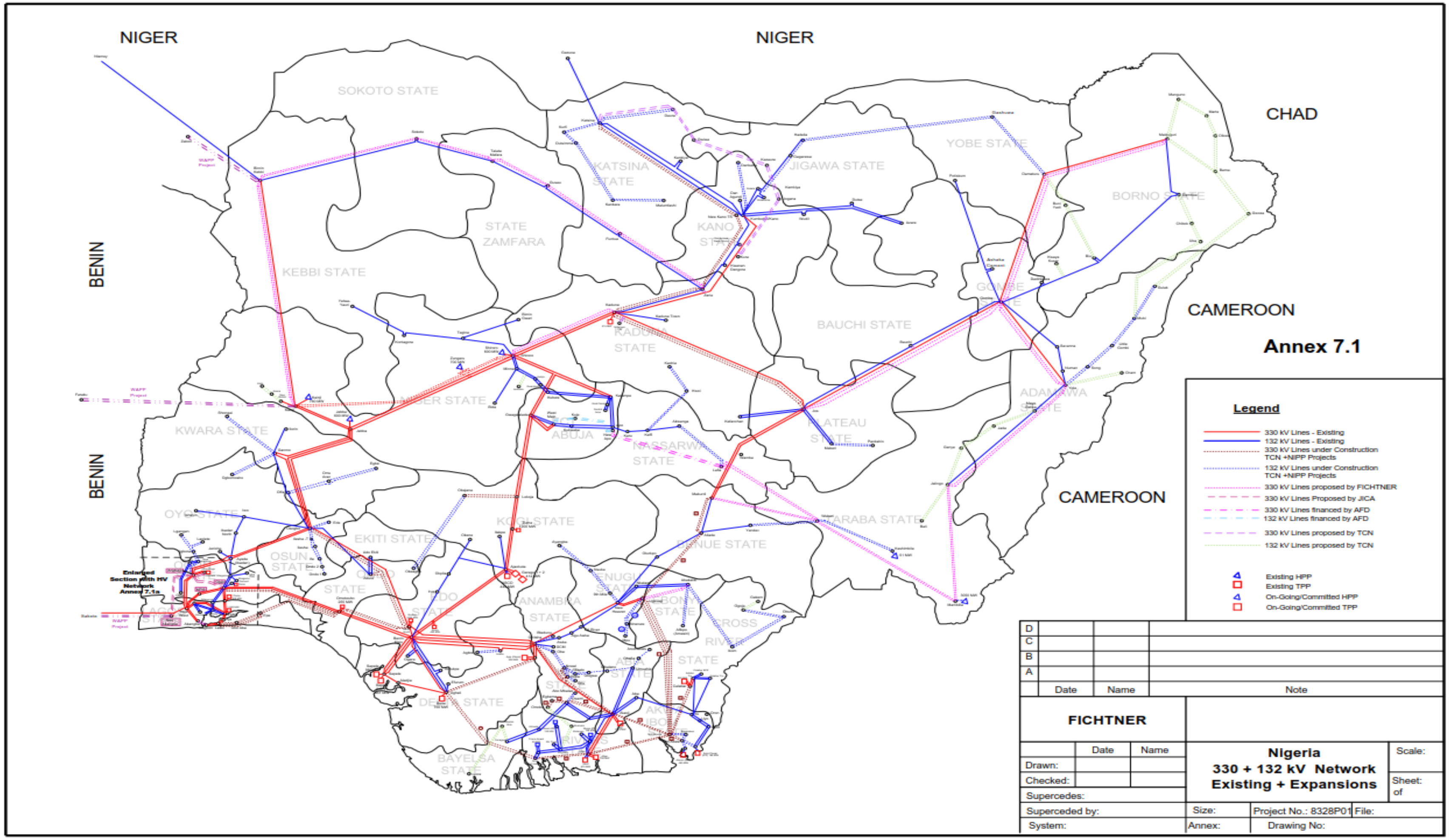
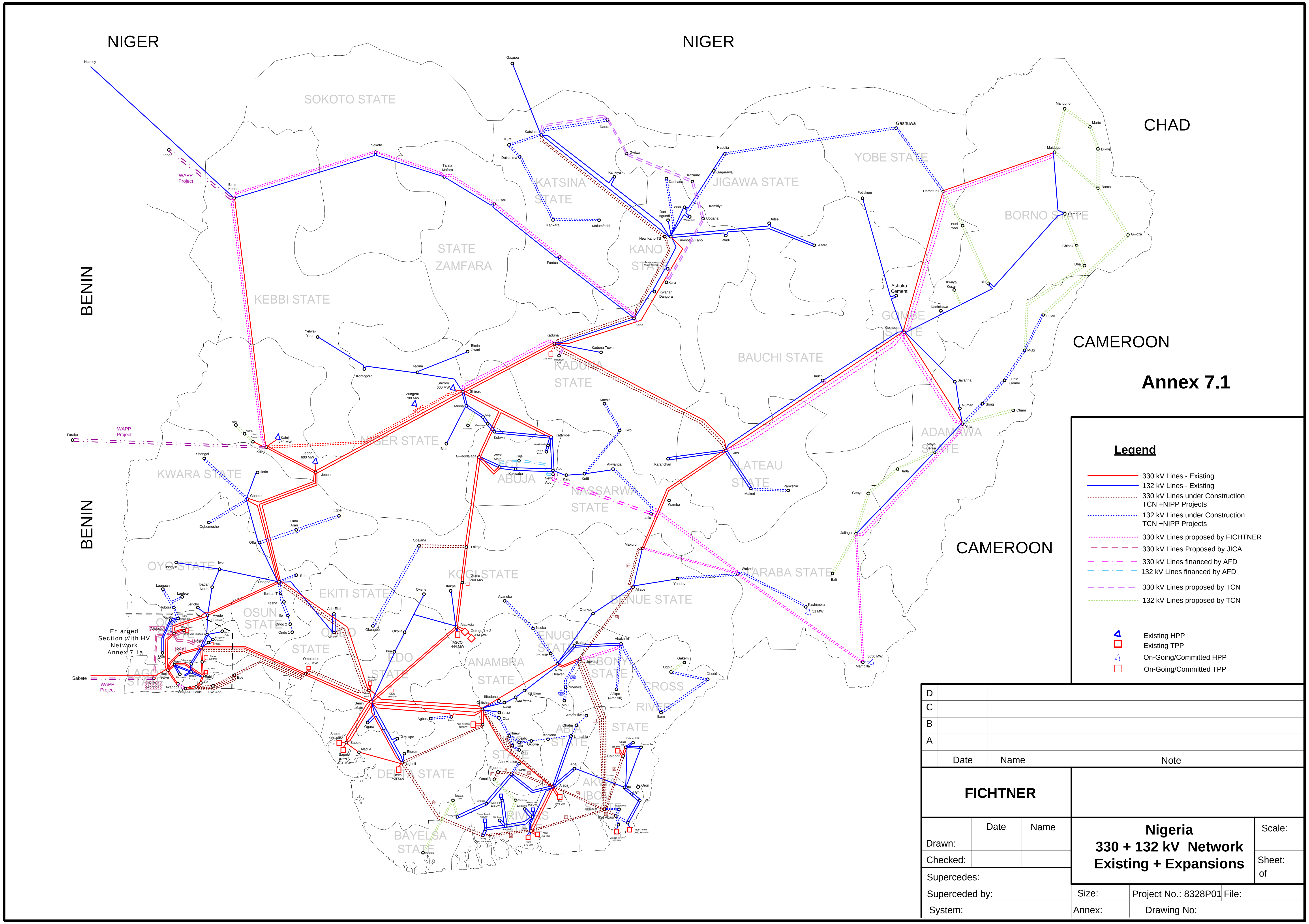
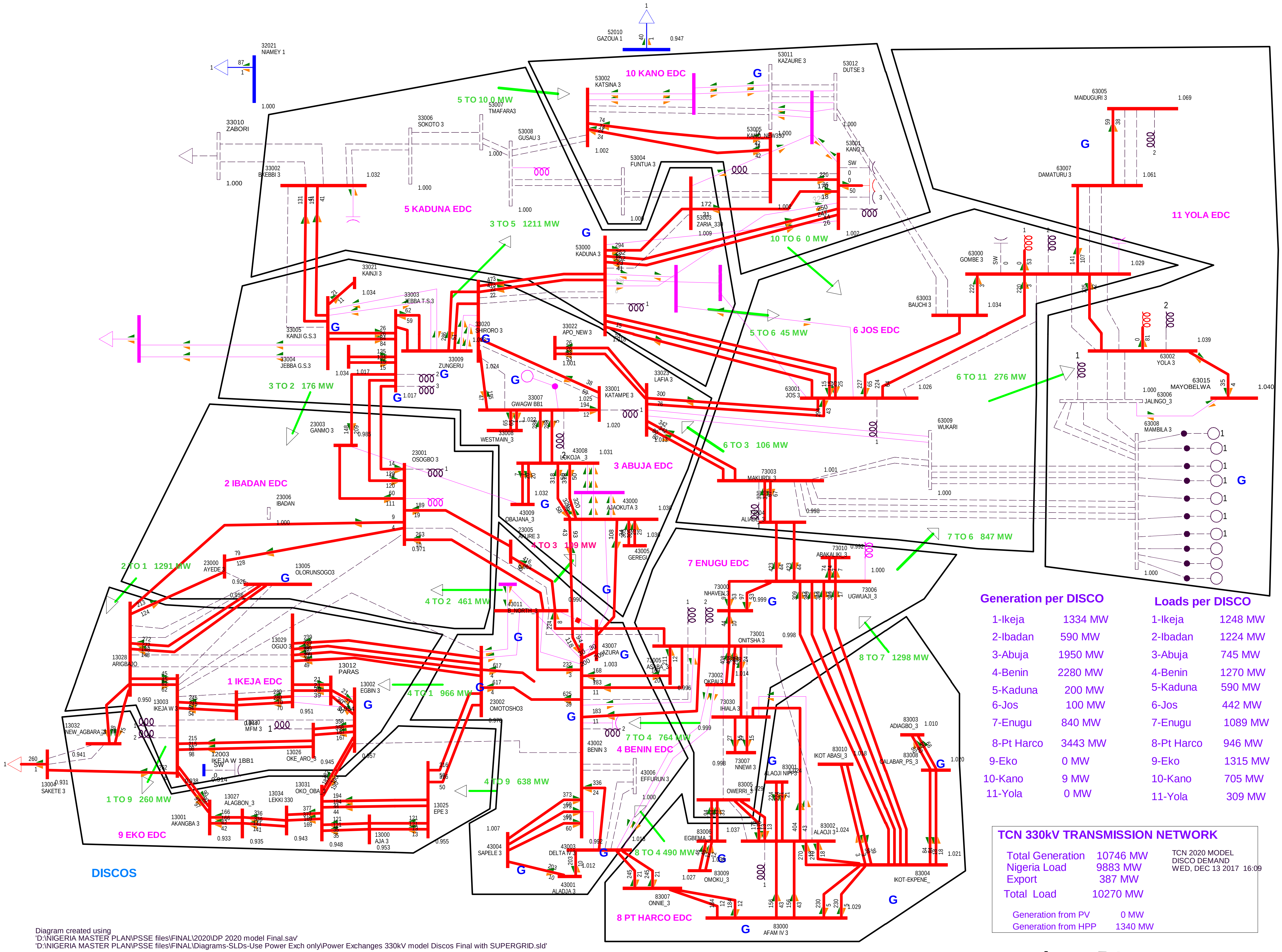


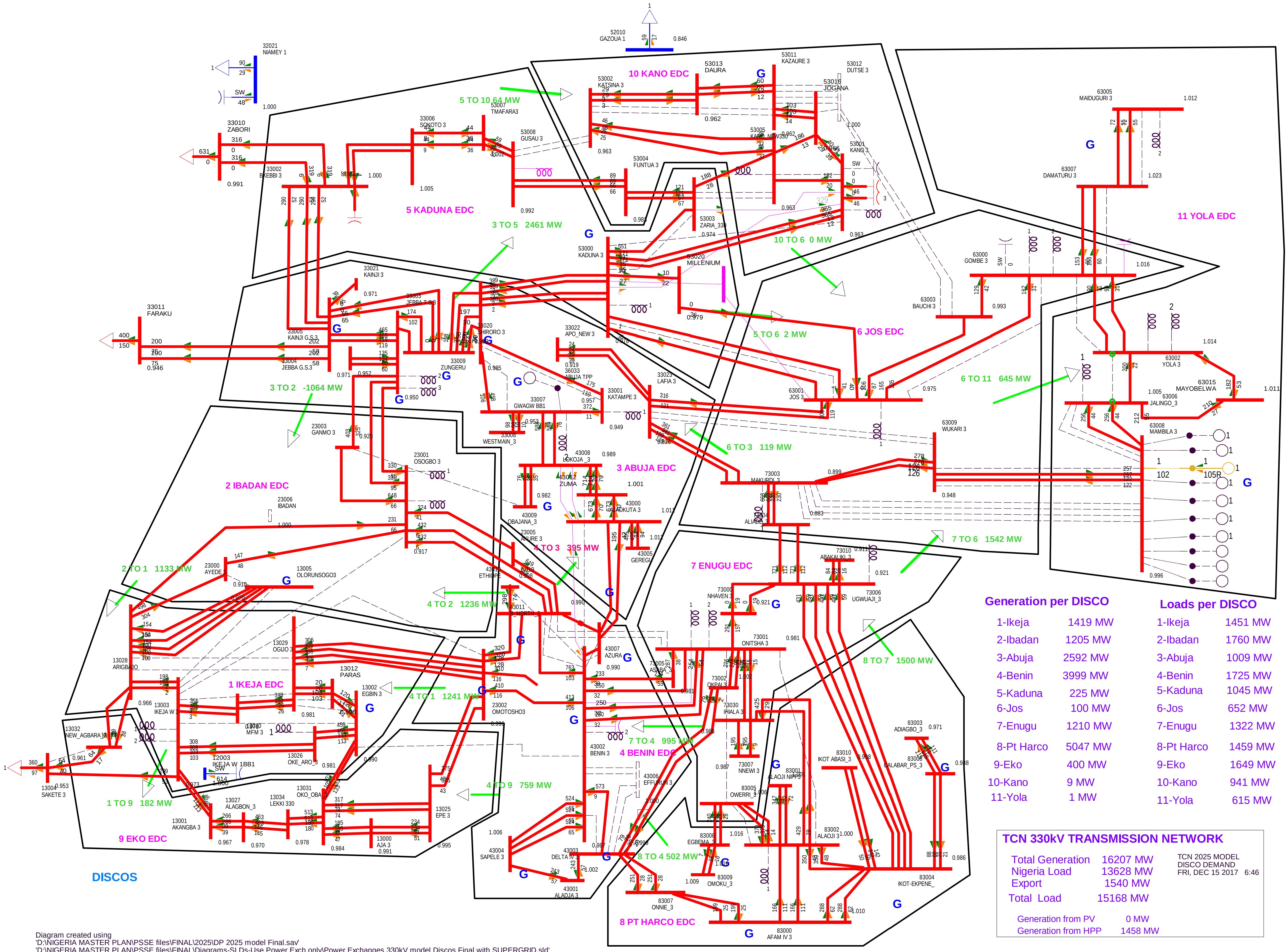
Figure 12-1: Map of Nigeria with transmission network, with new Fichtner and TCN projects

13. Annexes


NIGER
NIGER
BENIN
BENIN
CHAD
CAMEROON
CAMEROON
Annex 7.1
SOKOTO STATE
KATSINA STATE
JIGAWA STATE
YOBE STATE
BORNO STATE
KANO STATE
ZAMFARA STATE
KEBBI STATE
GOMBE STATE
BAUCHI STATE
KADUNA STATE
NIGER STATE
KWARA STATE
ABUJA
NASSARAWA STATE
PLATEAU STATE
ADAMAWA STATE
TARABA STATE
OYO STATE
OSUN STATE
EKITI STATE
KOGI STATE
BENUE STATE
ONDO STATE
EDO STATE
ANAMBRA STATE
ENUGU STATE
EBONYI STATE
CROSS RIVER STATE
DELTA STATE
BAYELSA STATE
WAPP Project
Enlarged Section with HV Network Annex 7.1a
Legend
330 kV Lines - Existing
132 kV Lines - Existing
330 kV Lines under Construction TCN +NIPP Projects
132 kV Lines under Construction TCN +NIPP Projects
330 kV Lines proposed by FICHTNER
330 kV Lines Proposed by JICA
330 kV Lines financed by AFD
132 kV Lines financed by AFD
330 kV Lines proposed by TCN
132 kV Lines proposed by TCN
Existing HPP
Existing TPP
On-Going/Committed HPP
On-Going/Committed TPP
D
C
B
A
Date
Name
Note
FICHTNER
Date
Name
Drawn:
Checked:
Supercedes:
Superceded by:
System:
Nigeria
330 + 132 kV Network
Existing + Expansions
Scale:
Sheet:
of
Size:
Project No.: 8328P01
File:
Annex:
Drawing No:



Annex 7.4a
Dry season Peak 2020



Annex 7.7a

Dry season Peak 2025