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Comprehensive Modeling of Tanzania’s Electric Power System

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Dedicatio

Extended Abstract

Introduction

The conditions of electrical network systems of low-income countries result in poor technological performances when compared to the networks present in developed nations. Infrastructural renewal and expansion, in order to guarantee quality of supply and access to electricity for the population are challenging goals. In this framework, the research conducted through this Master Thesis is focused on Tanzania, a country in eastern Africa. Considering the geographical conformation and the atmospheric conditions, the environmental characteristics of the country make Tanzania a perfect candidate for the exploitation of renewable sources at different scales.

The objective of the thesis consisted in recreating a mathematical model of the Tanzanian grid used to run technical simulations and assess the performances of the network and the operating conditions. The introductory phases of research have been conducted to look for information from local agencies and institutions (e.g. Dar el Salam Institute of Technology, DIT). The research has been then divided into two main parts. The first one has been focused on the analysis of the available data to develop a mathematical model as close as possible to the present electric grid conditions in Tanzania. The reliability and accuracy of the model are the focal points that has been investigated. The second part of the research, aimed at evaluating the possible introduction of microgrids, usually powered by renewable energy sources, with the distribution grid.

Tanzania General Overview

In 2017 Tanzania's population has been estimated by the United Nations at 57.31 million and the socio-demographic composition of the state is richly diversified [1]. Tanzania has various strategic plans for future economic growth, among them, TDV 2025 that aims at transforming it in a middle-income country by 2025 with a target GDP growth rate of 8% per year. As of 2017 large part of Tanzanian population currently lives in rural areas, around 38.36 M [2], [3] therefore, the possibility to provide electrical access is a cardinal issue to trigger and ensure a sustainable economic and social development. However, the combination of geographical diversity of the various regions, the absence of consistent infrastructures make this process inevitably slow and particularly difficult, therefore in August 2016 the World Bank agreed to provide USD 209M funds to the Government of Tanzania, to help the country reach the electrification of all villages by 2021.

Electricity Supply System

In Tanzania the main actor currently providing power supply is TANESCO (Tanzania Electric Supply Company Limited) that is the state-owned electricity supplier. It has the monopoly on the electricity market of the mainland and is responsible for the generation, transmission and distribution systems. In June 2014 the ESI (Electricity Supply Industry) Reform Strategy and Roadmap 2014-2025 [11] the Ministry of Energy and Minerals state that in order to achieve a fast and sustainable economic growth, it is mandatory to create an "*adequate accessible, reliable, affordable and environmentally friendly electricity supply*". On top of subsequent incremental improvements of the infrastructural service, another key element of the strategy exposed in the ESI document is the gradual unbundling of TANESCO into independent generation, transmission and distribution companies. The opening of the market to new actors and the consequent growth of competition could lead to a relevant increase of service quality. The current technical challenges to be solved in search of a quality increase, consist mainly in low energy security, unreliable energy supplies, poor quality of supply and high electricity losses.

Generation

The total power generated and imported reached 1461.69 MW in 2016. The off-grid stations cover an important section of the total production, with an overall installed capacity of 201,44 MW. The government has decided to focus on three main projects to support national energy progress investing directly on renewable resources: geothermal power development, alternative biomass supply options and renewable energy for rural electrification (RERE).

Transmission

The existing transmission system is formed by primary grid stations interconnected by transmission lines at voltages of. 220 kV, 132 kV and 66 kV. The system capacity has limited operating condition particularly during peak hours due to aged infrastructure, high power losses and system overload. Challenges in enhancing transmission networks include land conditions and long distances between the primary stations.

Distribution Grid

The distribution grid is mainly owned by TANESCO and it is composed by medium voltage and low voltage network, including

33kV,11kV and 0,4kV electric lines. The achievement of a reliable Medium-Voltage network is the major problem to solve in order to have an overall connection of the national grid and an increase of renewable penetration (i.e. microgrids).

Power Demand

Regarding the power demand, data show a constant increase of the overall country's load through the years. In November 2009 the peak demand was 755 MW while in December 2014 it reached 935 MW with an average growth rate of 4.7% per year [1].

Review of Power Systems Modelling

The study conducts on the power system of emerging country has to face problem regards inaccuracy of the data collected and lack of precise information. For this purpose, various mathematical models helps us to overcome this problem. A load flow analysis was performed in order to have an overall overview of both transmission and distribution grid. The parameter estimation is a model implemented in order to overcome the inaccurate calculation of the grid parameters of the high-voltage grid and in addition a sensitivity analysis on the main parameters have been performed in order to understand which portion of the grid have more impact on the operating conditions. Then the proposed bricks approach has been applied to the distribution grid in order to make possible the calculation of the hosting capacity even with imprecise information of the network.

Load Flow

The load flow analysis is a widely known methodology commonly used to investigate power systems' operation [4]. Based on the network structure, load flow calculations solve the steady state operation of the grid, computing node voltages and branch power flows of the power system. The mathematic model of the load flow problem is a system of nonlinear algebraic equation.

To describe the electric grid, the π-equivalent branch model has been adopted, considering that the main network parameters are series and shunt impedances.

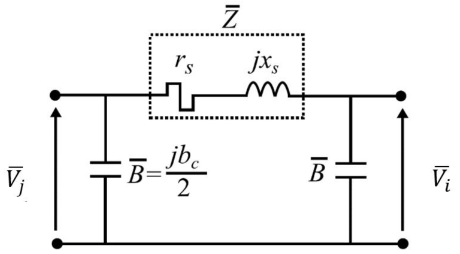

Figure 1- π-equivalent branch model.

In the figure $\overline{V_j}$ stands for the voltage phasor of the “from” bus of the branch while $\overline{V_i}$ is the voltage phasor of the “to” bus of the branch

$$\overline{V_j} = V_j \cdot e^{j\delta_j}$$

$$\overline{V_i} = V_i \cdot e^{j\delta_i}$$

The branch series impedance (magnitude Z and angle θ) an the line charging B are equal to:

$$\bar{Z} = Z \cdot e^{j\theta} = r_s + j \cdot x_s$$

$$\bar{B} = jB = j\frac{b_c}{2}$$

The nodes in the system are classified into three types according to the known variables:

In the ***PQ nodes*** the active and the reactive power are specified as known parameters, and the complex voltage (V, θ) is to be resolved.

In the ***PV nodes*** the active power and the voltage magnitude V are the know variables, the reactive power Q and the voltage angle are unknows.

It is important in the power system to specify a ***Slack Node*** which is characterized by a given voltage, constant in magnitude and phase angle. The active power P and the reactive power Q are the variables that must be solved.

Given the non-linearity of the problem, a nonlinear solving method has to be employed, such as the Newton-Raphson method.

Power System Parameter Estimation

When considering the developing countries scenario, there is often lack of reliable and complete data regarding transmission and distribution networks. Often, data are provided in the form of network maps with general information regarding voltage profiles and power flows in the lines. The parameters of the network lines (e.g. lengths and impedances) are hardly available and their estimations could lead to relevant errors in the power flow results. To overcome this problem, one possible solution could be the use of a reverse engineering procedure that, starting from available data, allows to determine all the unknown network parameters. The problem can be formulated as an Optimization Problem (OP), with the goal of minimizing the error among estimated and available input data. The input data is collected into a vector $\boldsymbol{x^m}$. $\boldsymbol{x^{est}}$ is the vector containing the values for the same parameters estimated by the network model. The distance between $\boldsymbol{x^m}$ and $\boldsymbol{x^{est}}$ is estimated by solving the following optimization problem:

$$min[\boldsymbol{x^m} - \boldsymbol{x^{est}}] \cdot \boldsymbol{W} \cdot [\boldsymbol{x^m} - \boldsymbol{x^{est}}]$$

where $\boldsymbol{x^m}$ is the column vector of input values, e.g. voltage magnitudes, power flows through branches etc., and $\boldsymbol{x^{est}}$ is the column vector of estimated values, linked by non-linear PF equations. $\boldsymbol{W}$ is the diagonal matrix of weight coefficients, which consider the accuracy of each input. The error between the measured and estimated values is considered with a uniform distribution as shown in the Figure 2 and is:

$$x^{est} = x^m \pm \Delta x$$

with an interval from -A to +A which represent the rounding error according to the probability density function (PDF).

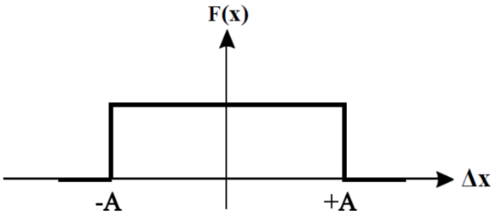

Figure 2- Uniform distribution error.

The W coefficients are calculated as

$$W = \frac{1}{\sigma^2}$$

where

$$\sigma = \frac{A}{\sqrt{3}}$$

In this way different variables have different weights, input data that are more accurate have higher weight in comparison with the more inaccurate ones.

Hosting Capacity

As already introduced, microgrid installations in the rural areas in Tanzania are increasing. This phenomenon is caused by the continuous investments aimed to bring access to electricity in the remote areas of the country. With the improvement and enlargement of the electric grid a further step could be the connection of the microgrids to the distribution one. As a consequence, the active users in both low and medium voltage grid will increase.

Several studies have been made to estimate the maximum amount of dispersed generation that can be integrated into a power systems respecting the performance limits. Those studies are named in literature Hosting Capacity evaluations [5]. For each grid several constraints can be taken into account. They can be categorized based on the impact they can have. The ones that affect the power quality the most are the Supply voltage variation (SVV) and the Rapid voltage changes (RCV) in each bus. Reverse power flow has an effect on network automation and on the Line Thermal Limits (LTL).

- *Steady-State Voltage Variation (SVV)*

In the calculation of the HC the increasing of DG in the distribution grid causes an increase of the voltage value of the hosting feeder. Therefore, in order to avoid problems and malfunctions of the grid, the steady state voltage variations according to EU network codes (EN 50160), must remain within $\pm$ 10% of the rated voltage for at least 95 % of the time.

$$V_{min,k} \leq V_{DG,k} \leq V_{max,k}$$

- *Rapid Voltage Change (RCV)*

The rapid voltage change is the difference between the voltage of node when the DG is connected and when it is suddenly detached. According to the EU regulation there is not a severe constraint but an approximate admissible variation range:

$$\left|V_{DG,k} - V_k\right| \leq 4\ \% \div 6\ \%$$

- *Line Thermal Limit (LTL)*

Adding DG to the grid causes an increase also of current flowing in MV grid, for this reason thermal limits on the branches have to be considered. The maximum current flowing on a branch depends on the parameters of the line (R and X) and it must respect:

$$I_{DG,k} \leq I_{max,kj}$$

Distribution grid modelling

The hosting capacity is defined as the maximum nodal power injection respecting HC limits.

HC = Max(Nodal Loading Parameters)

It is required a complete model of the distribution grid with the exact topology, grid parameters and also power profiles of loads and generators. These kind of data in developing countries scenarios are quite difficult to gather and to solve this issue a novel procedure, proposed in [6] and called *Bricks Approach*, can be used.

The standard structure of a distribution grid is made by a main line named feeder and by several collaterals that are branches connected to the main one. In this new approach the feeders of the distribution grid are represented with just three nodes (N1, N2, N3). The three branches, that are connecting the three nodes and the primary station, embody the total impedance (Z) of the feeder. The first one embodies the first 10% of the total impedance, each of the other two branches accounts for 40% of the total impedance. The same procedure is followed for the collaterals but in this case, there are two nodes in the long collateral and one in the short one (in the Figure 1 is reported the redesign of the feeder graphically).

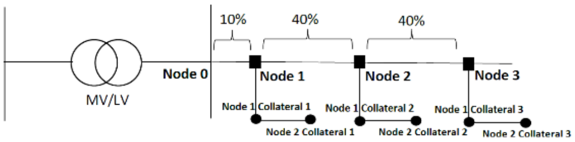

Figure 1- Feeder Brick's approach

The main part of the approach consists in the calculation of the maximum power that can be injected by the DG. For this purpose, a generator is connected to each node of each combination of the feeder and collaterals, the iterative process consists in the gradually increase the generators in the nodes to calculate the HC.

Data Collection

The data collection process has been conducted in collaboration with Dar es Salaam Institute of Technology. In this phase the author spent as a visiting student for three months in Tanzania, collecting data by interacting directly with local university researchers and governmental agencies.

Actually, thanks to the collaboration with DIT electrical engineering professor Godfrey J. Moshi, it has been possible to obtain updated data regarding ongoing projects of energy development in Tanzania, main source of this information have been the Power System Master Plan 2016 [12] and the Power System Plan of Da es Salaam [1]. The first one is a document made by inter-governmental institutions to assess a generation and transmission plan regarding three main aspects: the increasing of reliable power supply, the connection with off-grid regions and expansion projects with neighbouring countries. The second one is a study conducted by JICA (Japan International Cooperation Agency) on Dar es Salaam. It shows the city, accounting for about the 10% of total population, and for nearly the 50% of country's electric demand, is expected to increase it, following Tanzania's economic development.

These two plans were the starting point for the study of the transmission and distribution grid, and the research period on field in the collaboration with TANESCO and DIT helped to gather the initial data for the analysis.

The Approached Proposed and Results

The proposed work consists in the modelling of electrical systems in a statistic approach necessary to represent it.

The work has been divided into three main phases. The first one consisted in the mathematical modelling of the transmission grid, in order to perform a load flow representing the current situation in Tanzania in the most realistic way possible. This step has bene integrated with the Parameter Estimation and the sensitivity analysis for the investigation of errors committed in the calculation of the grid parameters. The second phase consisted in the mathematical modelling of the distribution grid with the calculation of the hosting capacity, in order to understand the maximum amount of Distributed Generation allowed by the existing distribution grid. Last phase defined possible scenarios of integration between microgrids and the national grid, in order to demonstrate the feasibility to integrate microgrids and renewable technologies.

Transmission Grid Model

The transmission grid taken into consideration for this study is been taken from PSMP 2016 [12]. The scheme represents the conditions of the electrical grid that should be in place at the end of 2020. The assessment has been done on the nodal phasor of the grid, in particular on their module and on the nodal injections at the equilibrium point of the system.

The Figure 2 shows a comparison between the voltage modules at each node resulting from the load flow analysis (blue lines) and the ones reported on the PSMP 2016 [7] (red lines) . Th overall outline is showing a good result, all the values are within the nominal range of the (0.94, 1.06).

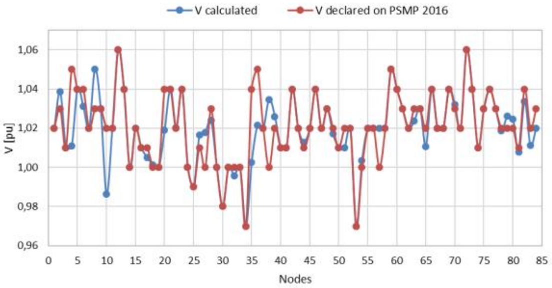

Figure 2- Results of the voltage profiles (p.u.)

The second comparison is about the power profile of both active and reactive power. The power flowing in each branch resulting from load analysis has been compared to the one reported in the grid map. Figure 3 and Figure 4 show the active and reactive power exiting from each node. The active power has a behaviour very close to the starting one, this fact could evidence that the estimation of the resistance is or close the real one or not influencing the overall trend. Instead, regarding the reactive power there is a discrepancy meaning that suscettance and inductance have bigger effects on the operating conditions.

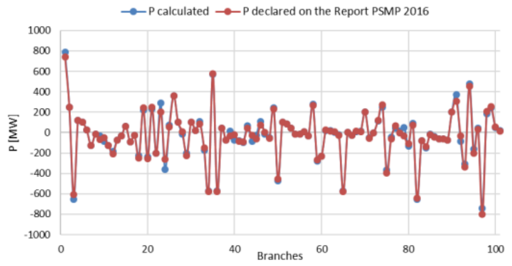

Figure 3- Comparison between the active power at the beginning of each branch

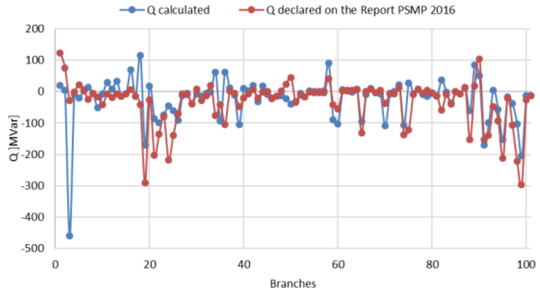

Figure 4- Comparison between the reactive power at the beginning of each branch

The result of the current flowing in branches has been compared with maximum current allowed I_{max}. In the Figure 5 it is reported the percentage ratio between the branch current and its threshold. The graphic shows that almost all the branches have a current lower than the half of the maximum value, the worst case is the branch number 49 that consists in the line connecting Shynyanga e Mwanga: this is a single cable which is connecting two primary substations of 220 kV put in place in the 1988, the type conductor is *Bison* which has a cross section lower than the cables recently installed.

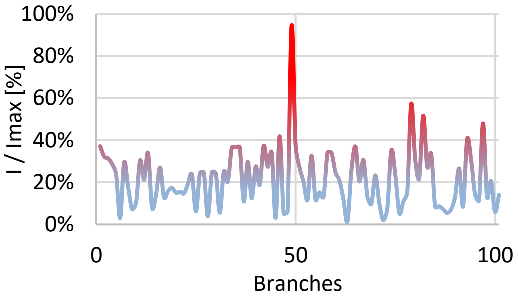

Figure 5- Currrent flowing in each branch compared to the maximum one

Parameter Estimation

Since the grid parameters have been calculated through assumptions based on input data, which was partially missing or imprecise, the Parameter Estimation method has been put in place in order to validate the analysed grid model. Starting from the voltage at each node and the power flowing in each branch of the grid, it is possible to estimate the various measures of the grid: R, X and B. In this computation problems arose because the mathematical model was unable to find *global minimum values*, the only possible solution was the *local minimum value* and the final comparison has been based on this results.

Sensitivity Analysis

A further investigation about the grid parameters has been made through the sensitivity analysis. The assumptions made for the power flow analysis were mostly related to the length and to the type of the cables, as a matter of fact errors on them can have a great impact on the results of the study. This procedure has the aim of understanding in which measure the estimation of such parameters has affected our initial calculation phase and how the errors committed in the initial phase can impact on the overall operating conditions. The analysis has been conducted on the parameters of the lines (R, X and B) , they have been modified in the range of +/- 30% of the starting value (see Table 2). They have been changed as reported in the Table 3: the study has been conducted just on the *Bluejay* cables (code name of cables used in Tanzania characteristic reported in the Table 1) because they are the main type used for the overall grid (70%).

Table 1- Characteristic of the Bluejay conductor

Voltage	**Conductors**	**Code**	**Cross Section (mm²)**
400/220kV	**ACSR**	Bluejay	565

Table 2- Parameters used for the power flow analysis

Type of Conductor	**R (ohm/km)**	**X (ohm/km)**	**B (ohm/km)**
Bluejay	0.056	0.4016	2.860 e-06

Table 3- Range considered for all the parameters

Bluejay	**(ohm/km)**
R-	0.0392
R+	0.0728
X-	0.28112
X+	0.52208
B-	2.00E-06
B+	3.72E-06

Results show that bus voltage modules do not change significantly with the increase of line resistance, see Figure 6.

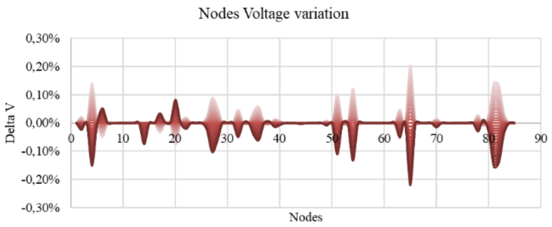

Figure 6- Percentage of voltage variation changing R

Regarding the study conducted on the inductance, the node voltages tend to decrease when reactances, i.e. with the increase of X. The maximum total variation is equal to 0.30% when increasing or decreasing X around the equilibrium point. (see Figure 7).

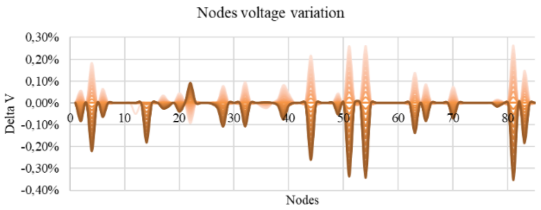

Figure 7- Percentage of the nodes voltage variation changing X

With respect to the *B* parameter, the reactive power injected due to shunt capacitances leads to an increase in node voltage modules. The maximum sariation is limited to +-0.80% as shown in the Figure 8.

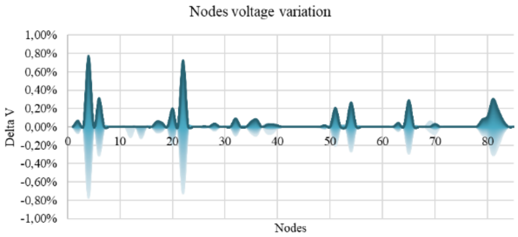

Figure 8- Percentage of the nodes voltage variation changing B

The sensitivity analysis shows that the parameters investigated aren't significantly affecting the operating conditions of the grid. For this reason it's possible to state that the grid studied can be considered validated.

Distribution Grid model and Hosting Capacity calculation

After the implementation of the transmission grid model, the distribution grid has been analysed, so to have a comprehensive vision of Tanzania's power system. The goal of the study is to have both an overall picture of the system as of today and to understand how the future plans aimed to increase the electricity access rate in the country can have an impact on it.

The primary station considered is the facility of Ubungo in Dar es Salaam, which is the one connected to the thermal plant in Kynierezi. To this node are connected 9 main feeders: the first one is the principal and has many collateral feeders exiting from it, while the remaining 8 are shorter with less nodes and collateral. The Figure 9 is showing a schematic view of the portion of the grid considered.

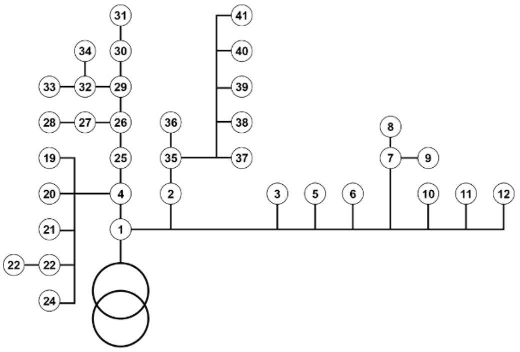

Figure 9-Schematic view of the distribution grid

To analyse the hosting capacity of this distribution grid the two following steps have been conducted: the first one is to model the distribution grid using the Bricks Approach defining a short, medium, long feeder and a short and long collateral, the second one is the calculation of the hosting capacity of all the bricks rearranged creating different configurations.

The Bricks Approach allows to create a model of the distribution grid and to calculate the hosting capacity even when data of the overall grid are missing. Since the data gathered through the field research are not accurate, even the calculation of the exact parameter could be biased and could provide results with an excessive deviation.

Knowing the impedance of each feeder and collateral, with the Bricks Approach they have been redefined as here reported.

- *Short Feeder*

The subdivision of each feeder depends on the length of the cables, the number of nodes and their impedance. The Table 4 represents the parameters for the short feeder branch.

Table 4- R and X values of a short feeder.

Short Feeder		**R (pu)**	**X (pu)**
1	2	0.003141	0.002911
2	3	0.012709	0.011775
3	4	0.012709	0.011775

- *Long Feeder*

The only long feeder in the model is the Nr 3. The Table 5 represents the parameters taken in consideration for the long feeder.

Table 5- R and X values of a long feeder

Long Feeder		**R (pu)**	**X (pu)**
1	2	0.054288	0.048723
2	3	0.219618	0.197107
3	4	0.219618	0.197107

- *Short and Long Collateral*

Following the Bricks approach, branches considered as collateral in relation to the main feeder must be added to the grid depending on their impedance. Collaterals are subdivided in short and long collaterals and they are added to the grid by considering their position in the distribution grid. In Table 6 is reported the parameters calculated for the short collateral and in the Table 7 is reported the parameters calculate for the long collateral.

Table 6- R and X values of a short collateral

Short Collateral		**R (pu)**	**X (pu)**
2	5	0.0414	0.0475

Table 7-R and X values of a long collateral

Long Collateral		**R (pu)**	**X (pu)**
2	5	0.2439	0.2667
5	8	0.2439	0.2667

The hosting capacity of the grid is calculated considering all the possible configurations. It is important to mention that for the computation of the hosting capacity the three performance indexes previously mentioned– steady state voltage variations, rapid voltage change and the line thermal limit – have been considered. In this case the most limiting factor of the three taken in consideration was the thermal limit of the cables.

The hosting capacity of all the configurations with a short feeder is reported in Table 8.

Table 8-Hosting Capacity for all the combinations of a short feeder plus collateral

(MW)	AVG	MIN	MAX
SHORT FEEDER	7.2966	6.8055	8.1795
SH + SH1	7.2268	6.779	8.511
SH + LO1	0	0	0
SH + SH2	7.3148	6.7785	8.5105
SH + LO2	0	0	0
SH + SH3	7.3797	6.816	8.511

Instead, the hosting capacity with all the configurations with a long feeder is then reported in the the Table 9 .The maximum value is 8.78 MW considered as the maximum DG power that the distribution grid can bear.

Table 9-Hosting Capacity for all the combinations of a long feeder plus collateral

(MW)	AVG	MIN	MAX
LO + 0	7.3612	7.1715	7.6445
LO + SH1	7.36117	6.8305	8.2955
LO + LO1	7.4601	7.1045	8.7665
LO+ SH2	7.4856	6.9815	8.3005
LO + LO2	7.6432	7.0815	8.7765
LO + SH3	7.617	7.147	8.304
LO+ LO3	7.5107	7.1715	7.6445

Tanzania Evolution Scenarios

After the modelling of the transmission and distribution grid, in order to have an overall picture of the Tanzanian power system different evolution scenarios, where DG can have a primary role in meeting the energy needs of the country, have been analysed. In particular the overall distribution grid have been integrated with possible future scenario in order to have first comprehensive of the evolution of the power system. Knowing the hosting capacity of the Dar es Salaam 33kV distribution grid, a proportional estimation, based on distribution grid length, has been made in order to have a rough approximation of the total hosting capacity. The overall length of the distribution grid has been taken from the website of the Mini-Grids Information Portal [21]. In the Figure 10 it is reported the topology of the distribution grid now in place (blue lines) and Figure 11 shows the new lines that will be installed by the end of 2021 (green lines and blue lines). In the first case the total length is equal to 31800 km and in the second case the total distribution line length is equal to 64300 km. The Dar es Salaam distribution grid modeled previously has instead an overall line length equal to 1047 km.

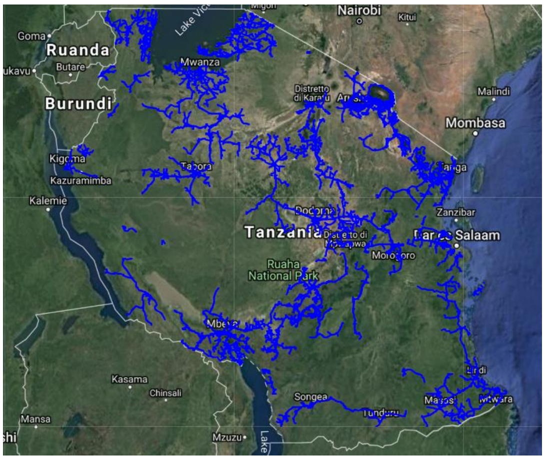

Figure 10-Tanzania distribution grid in 2019

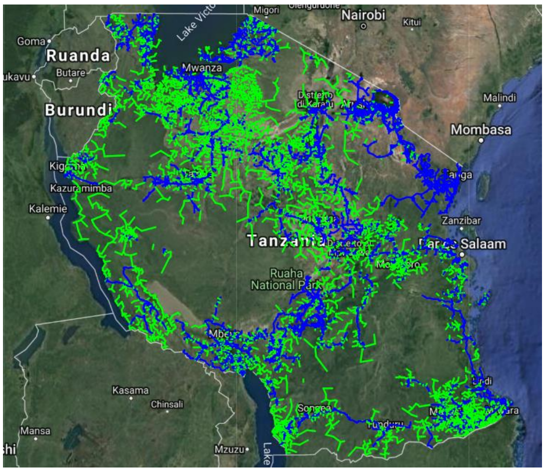

Figure 11- Planned Tanzania distribution grid at the end of 2021 [21].

The Table 10 reported below is showing the results for the three different grids. The first is the one considered for the calculation of the hosting capacity, the second one is the distribution grid of the overall country as reported on the mini-grid portal [21] and the third is the one planned by REA (Tanzanian's Rural Areas Agency) by the end of 2021[21].

Table 10- Hosting capapcity for the different distribution grid.

	Length (km)	Hosting Capacity (MW)
DAR Distribution Grid	1047	8.78
Total Distribution Grid (2019)	31800	264.2
Future Distribution Grid	64300	539

The power generation now connected to the grid, as gather from the Data Collection phase, is equal to 1234 MW, so summed to the overall hosting capacity gives a total power generation equivalent to 1498 MW demonstrating that, looking at the peak power demand expected for the 2019 in the Table 11, is lower then the power demand expected for the next years.

Table 11- Peak Power Demand expected for the different scenario (MW) [7]

Year	High (MW)	Base (MW)	Low (MW)
2019	1,960	1,920	1,800
2020	2,260	2,190	2,030
2025	4,020	3,660	3,170
2030	7,380	5,870	4,770
2035	13,510	9,350	7,120
2040	23,720	14,330	10,290

Conclusions

The analysis presented in this thesis allowed to recreate comprehensive of the Tanzanian electric grid conditions. The first part of the focused on the transmission grid that will be in place at the end of 2020. A validation of parameters of the transmission grid has been made throught different prospective: a geopraghical overview, a paramter estimation and a sensitivity analysis to further investigate which parameter has more impact. Results show that missing data and unreliable/innacurate one could make difficult the evaluation of the exact parameters thourght mathematical models, althought could be a first step for further studies. The analysis has continued on the medium-voltage grid, the calculation of the hosting capacity of the distribution grid has allowed to investigate how much DG (Distributed Generation) could be connected. Results showed that the grid considered, a portion of the distribution grid of the most industrialized city, has an hosting capacity equal to 8.78 MW. It demonstrates that the grids at the medium-voltage level has to be implemented thinking at possible integrations with micro-grids, on the other side the exploitation of the DG compensates, at least partially, the growth of the load proving to be a relevant option with solid potential.

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Abstract

Power systems in developing countries are usually characterized by poor infrastructural conditions and lack of information about the operating conditions of the grid. The approached here proposed has the purpose to implement some mathematical model to overcome these issues.

The purpose of the thesis work is to collect and elaborate useful data for a better understating of the electric power system in Tanzania. The author spent a period in the country collaborating with the local TSO and with the university of Dar es Salaam in order to collect useful data.

The proposed approach has the aim of studying the overall power system, both transmission and distribution networks, considering a scenario where data are often inaccurate or missing. For the transmission grid a power flow analysis is performed to determine the operating condition of the grid. Results are critically discussed and parameter estimation procedure and sensitivity analysis approach are applied to further investigate the parameters of the grid that could hide errors or inaccuracies. The study has continued on the share of the distribution grid in order to better investigate the condition regarding the integration with micro-grids. The calculation of the hosting capacity explores the possibility of this scenario in order to have an overall comprehension of the medium-voltage grid.

Finally, a global consideration about future scenario of the Tanzanian power system makes it possible to understand if the visions of the country from an energetic point of view can meet with present condition of the system.

Keywords: *Power system, TSO, Transmission Grid, Distribution Grid, Hosting Capacity, Micro-Grid, Tanzania.*

INTRODUCTION

The conditions of electrical network systems of low-income countries, shaped not only by the lack of public financial resources but also by the diversity and inaccessibility of many geographical areas, result in poor technological performances when compared to higher end networks like the ones existing in developed nations.

Infrastructural renewal and the expansion of access to electricity for the population are pressing goals for emerging countries since decades now. In Southern Africa the energy sector is currently a central focus for national development, and thanks to the opening of the market to private actors, the resulting area is potentially attractive for new businesses and private entrepreneurs. The energy market of this nations provides an additional level of interest, as micro-grid solutions may be exploited as a response to the geographical fragmentation and diversity of the country. This condition implies that the business space, usually requiring large capital investments and the necessity of operating through economies of scale to perform in the sector, is also open to relatively small actors that may increase local performances faster and in a more diversified way.

Local governments try to encourage the entrance of private actors in the energy market, but independent organizations face many difficulties in retrieving state of the art information regarding the networks, with a subsequent increase in costs and evaluation complexity of their projects both from a financial and technical perspective. Data regarding local norms and regulations, information on the actual conditions of the existing grid, socio-economic indicators and the current state of energy access among the population are crucial but not easily obtainable.

In this general framework, the research conducted through this Master Thesis is focusing on Tanzania, a Sub-Saharan country. Considering the geographical conformation and the atmospheric conditions, many natural resources could be exploited to produce renewable energy locally, in fact environmental characteristics of the country make Tanzania a perfect candidate for the exploitation of renewable sources at different scales.

Local entities such as Tanzania Electrical Supply Company (TANESCO) and Rural Energy Agency (REA) are developing new policies regarding grid models and renewable energy sources and even if data are increasingly available, the reliability of presented information remains a big concern, since data are usually inaccurate and uncertified.

The objective of the thesis consisted in recreating a mathematical model of the Tanzanian grid used to run technical simulations and assess the performances of the network under different operating conditions. The introductory phases of research have been conducted to look for information from local agencies and institutions, typically available in printed network diagrams representing geographically the conformation of the electrical grid. These maps contain the branches of the network, together with nodal voltage magnitude and power flows, and are published during specific operating conditions, such as yearly peak load.

The research has been then divided into two main areas. The first one has been focused on the analysis of the available data, which have been reconfigured and enriched with the amount of information retrieved in the collaboration with DIT, to develop a mathematical model as close as possible to the present electric grid conditions in Tanzania. The reliability and accuracy of the model were focal points needed to conduct the second part of the research, aimed at evaluating the possible introduction of microgrids powered by renewable energy sources.

The thesis is divided in this way:

- A general description of the Tanzanian framework from the economic point of view to the power supply system.
- An overview of the mathematical model utilized for the power system analysis.
- Description of all the data collected during the period abroad collaborating with the Dar es Salaam Institute of Technology.
- The overall analysis conduct on the transmission and distribution grid.
- Results obtained and conclusions.

Chapter **1**

1 TANZANIA

1.1 General Overview

Situated in eastern Africa within the African Great Lakes region, Tanzania is the 13th largest country of the continent. Officially known as the United Republic of Tanzania, the state covers a total surface of 947,303 square kilometres.

The north-eastern area of Tanzania is mountainous and densely forested, while almost all the borders are surrounded by water, by the Indian ocean and by lakes on the other sides. The main water basins are present in the northern and western sides of the country; instead central Tanzania is a large plateau, with plains and arable land.

Climate varies greatly within the whole surface of Tanzania and during seasonal periods across the year. Considering the geographical conformation and the atmospheric conditions of the country, many natural resources could be exploited to produce renewable energy locally, in particular the presence of vast flat sunny regions, natural extensive lake basins and heavy winds in the mountainous areas. In the Figure 3 and Figure 4 are reported photos taken directly during the research period.

Figure 3-Example of flat and sunny areas

Figure 4- Example of mountains area (Ngorongoro Crater)

In 2017 Tanzania's population has been estimated by the United Nations at 57.31 million and the socio-demographic composition of the state is richly diversified [1]; in Figure 5 it is possible to see the population growth rate regarding the urban and rural areas. According to the International Monetary Fund, Tanzania's 2018 gross domestic product (GDP) was estimated at $55.65 billion on nominal basis, or $176.5 billion on a purchasing power parity basis (PPP); GDP per capita was $1,090 [1].

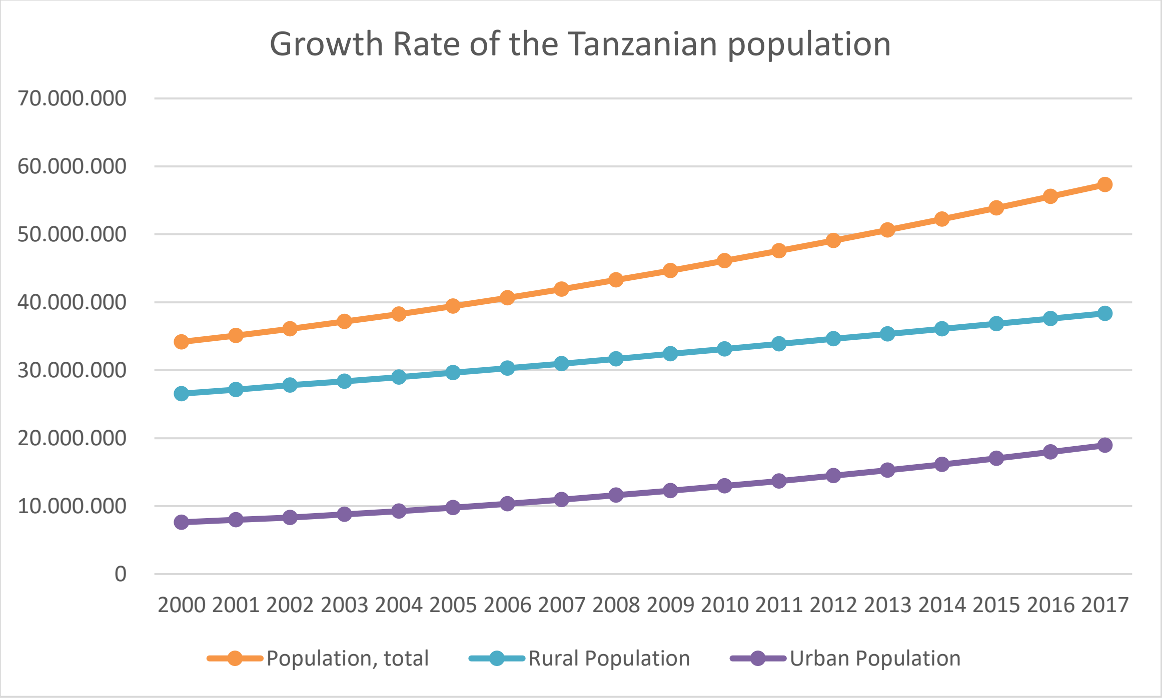


Figure 5- Graphical view of the growing rate of the population.

Tanzania has various strategic plans for future economic growth, summarized in three main long-term plans:

- Tanzania Development Vision 2025 (TDV 2025) [9];
- Five Year Development Plan (FYDP and FYDP II) [10];
- Long Term Perspective Plan (LTPP) .

Among them, TDV 2025 aims at transforming Tanzania in a middle-income country by 2025 with a target GDP growth rate of 8% per year. It has been developed in 1995 to define a roadmap for the economic development of the country. The document states that at the maturity of the program “the economy will have been transformed from a low productivity agricultural economy to a semi-industrialized one” by targeting an annual GDP per capita (PPP) of at least US$ 3,000 by the end of 2025. On top of the overall growth of the country the document also reported a clear vision regarding the value attributes that would have to be achieved throughout the nation in 2025 in which the economic element is just the last one. The five factors are: high quality livelihood, peace with stability and unity, good governance, a well-educated and learning society and a competitive economy capable of producing sustainable growth and shared benefits [11].

FYPD expired in 2016, while FYPD II started the same year with an end target in 2021, setting industrialization policies that are expected to increase the GDP share of manufacturing sector from 8% to 19%. LTPP, instead has three target periods: short, medium and long term. The short term period (2010 –2015) was intended to construct infrastructure and energy supply, medium (2015 –2020) should facilitate the growth of natural gas industry and agroindustry while long (2020 –2025) is expected to increase manufacturing, services and export industries [1].

1.2 Urban and rural areas in Tanzania

As of 2017 the total amount of population in Tanzania was 57.31 M, while rural population was 38.36 M [2], [3]. The share of population residing in rural areas remains high if compared with international standards, with just 67% of population living in urban areas. Yet a rapid urban growth in population is currently observable in Tanzania, with an estimated average increase of 1.4 million urban residents every year between 2012 and 2050. Figure 6 represents the population levels of the six largest cities in Tanzania: Dar es Salaam, Mwanza, Zanzibar, Arusha, Mbeya and Morogoro [12].

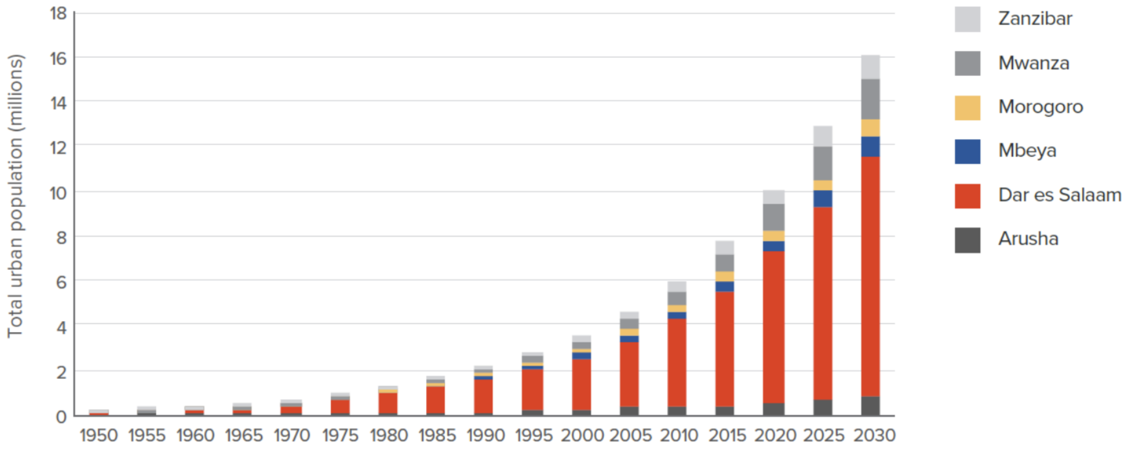


Figure 6- Largest six cities in Tanzania population [12].

The most developed region in Tanzania is Dar es Salaam, followed by Mwanza, Arusha, Mbeya, and Pwani, where approximately 33% of the populations is inhabiting urban areas. Rural–urban linkages are an important aspect of local living conditions, as households often rely on resources, livelihoods and exchanges between urban and rural areas [13].

Large part of Tanzanian population currently lives in rural areas, which are usually characterised by independent villages, local communities where a limited number of families live together in self-made huts. These small isolated centres are also generally difficult to reach from outside regions, due to the tropical land configuration and excessively poor road conditions. In particular the issue of viability conditions and long distances from urban settlements make these places accessibility limited not only to wheeled transportation vehicles, but to all sorts of infrastructural services. Therefore, the possibility to provide electrical access in rural areas is a fundamental prerequisite to trigger and ensure a sustainable economic and social development. However, the combination of geographical diversity of the various regions, the absence of a network of infrastructures and the scarcity of financial resources to employ in the progress of rural electrification make this process inevitably slow and particularly difficult to implement.

1.3 Access to electricity in Tanzania

As mentioned in the previous chapter, electricity access is one of the most important problems to address in Tanzania to favour the economic and social development of the country. In 2016, the average access to electricity throughout the population was 32%, with relevant differences throughout the country. In the same year urban electrification coverage was 65,3%, while rural coverage was 16,9%. The amount of population still living in rural areas was 67,6%, making the electrification of non-urban regions a fundamental milestone to achieve to increase electricity access throughout the country.

The reasons behind the non-uniform distribution of the electrical network are manifold. The geographical conditions of rural areas, together with the extension of the country and the shortage of financial resources, increase significantly both costs and difficulty in the process of electrification. In addition, it has been easier for local entities to target urban areas for investments and effective implementation of electrical services, in order to exploit the beneficial effects of a greater concentration of population. The higher level of local density provided a better absorption of fixed costs and a faster increase in local economic and social growth due to network effects at urban scale. In the Figure 7 there is a scheme of steps leading to facilitate this path:

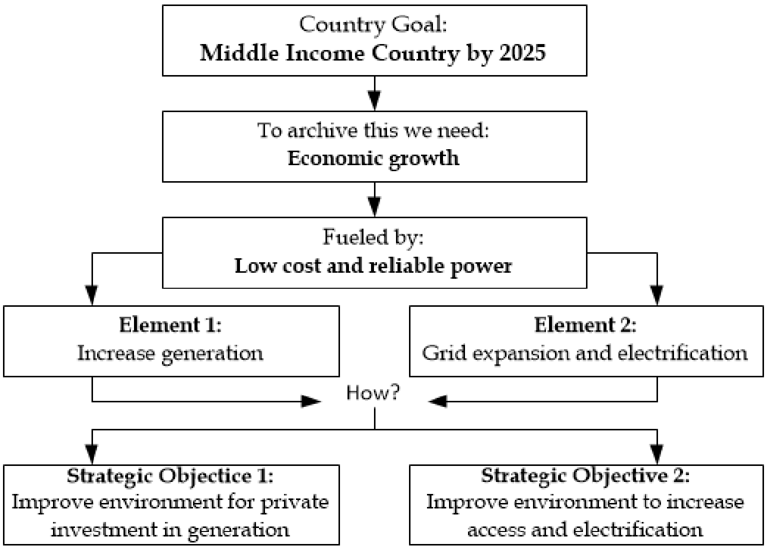


Figure 7- Scheme of the strategic plan to increase electricity access

By looking at data in the Figure 8, from past years is easily possible to denote the different growth rates of rural and urban areas. In 2000 the percentage of electricity access in urban areas was 33,5% with an almost constant growth until 2014, represented by a final value of 51,7%. Instead, in the same period rural areas electrification changed from 2,8% to 4,3%, with a total percentage growth over the 14 years of 1,5%., low when compared to the 18,2% of urban areas On the contrary, in 2015 and 2016 the percentage of access in both areas augmented relevantly, showing a consistently higher growth rate, thus bringing the urban level at 65,3% and the rural one at 16,9% in the end of 2016.

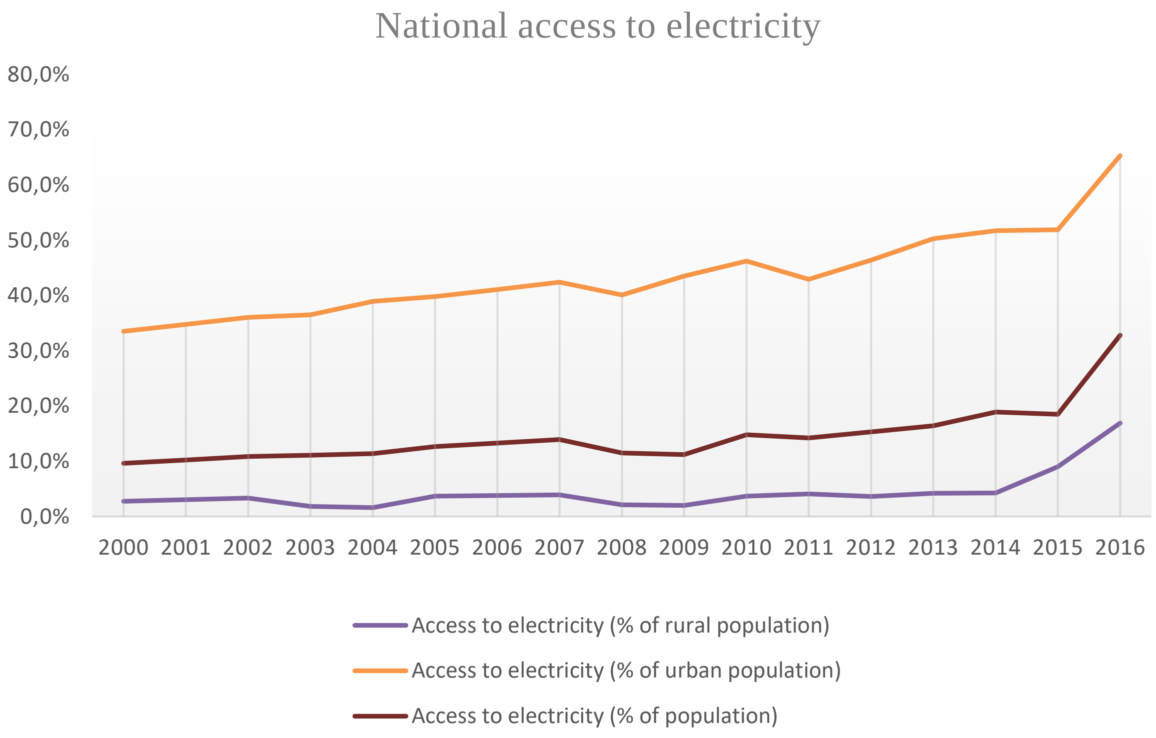


Figure 8- National access to electricity[3]

The peak growth in energy supply diffusion in non-urban areas from 2014 to 2016 is mainly attributable to the efforts of the rural electrification project under the National Rural Electrification Program 2013–2022 (NREP) launched by REA [14].To support the development of the program, in August 2016 the World Bank agreed to provide USD 209M funds to the Government of Tanzania, to help the country reach the electrification of all villages by 2021. The program aims to connect 2.5M Tanzanian households in rural areas with four main priorities [15]:

- The connection of new customers to the grid in already electrified settlements;
- New connections to the grid;
- Electrification through off-grid investments;
- The development of renewable technologies;
- Increase of power generation.

1.4 Power Supply and Demand

Electricity Supply System

In Tanzania the main actor currently providing power supply is TANESCO (Tanzania Electric Supply Company Limited) that is the state-owned electricity supplier. In 1964, three years after national independence, the Government bought two private electricity companies operating in Tanzania and in 1975 it merged them into TANESCO with the government as sole shareholder. Since then, the company has been responsible for electricity supply in the country. It has the monopoly on the electricity market of the mainland and, as shown in Figure 9 is responsible for the generation, transmission and distribution systems.

The electricity supply system is built around TANESCO. On top of that there are three main organizations: the Ministry of Industry and Trade (MOIT), in charge of Business Licenses and of the Industry Development Plan; the Ministry of Energy and Minerals (MEM) that formulates energy and electricity policies and the Energy and Water Utilities Regulatory Authority (EWURA), established in 2005 to oversee and regulate TANESCO operations granting licenses for Generation, Transmission, Distribution and Supply.

Collaborating with TANESCO, there are the Internal Power Producers (IPPs), owned by the supplier itself and the Emergency Power Producers (EPP) which are mainly thermal plants. The latter were introduced in 2010 after a severe drought caused a serious shortage in the power system traditionally dependent on hydropower. Nowadays EPPs represent more than one third of the country’s thermal generation capacity.

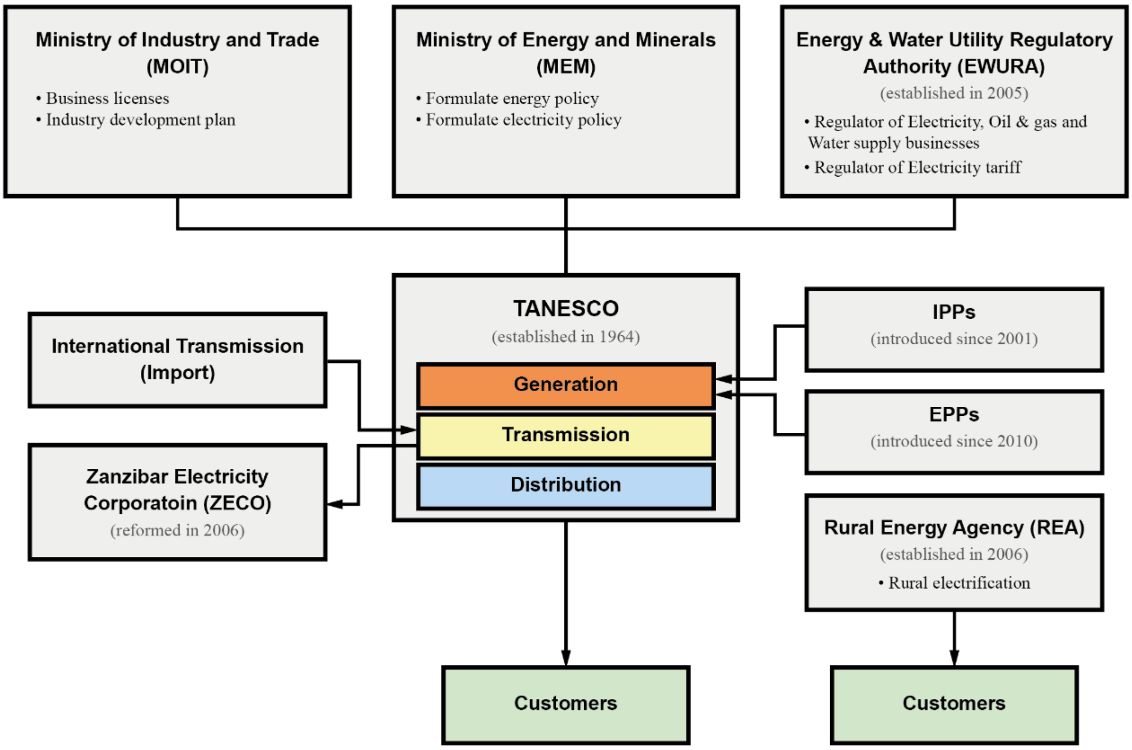


Figure 9- Overall scheme of the electricity supply system

To sustain the targets of TDV 2025, (see par 1.1),the Ministry of Energy and Minerals announced and published in June 2014 the *ESI (Electricity Supply Industry) Reform Strategy and Roadmap 2014-2025* [16]. The document states that in order to achieve a fast and sustainable economic growth, it is mandatory to create an “adequate accessible, reliable, affordable and environmentally friendly electricity supply”. To achieve this goal, the ESI strategy aims at increasing access to electricity levels from 24% as of March 2014 to 30% by 2025 and to 75% by 2033. On top of subsequent incremental improvements of the infrastructural service, another key element of the strategy exposed in the ESI document is the gradual unbundling of TANESCO into independent generation, transmission and distribution companies. The opening of the market to new actors and the consequent growth of competition could lead to a relevant increase of service quality.

The current technical challenges to be solved in search of a quality increase, consist mainly in low energy security, unreliable energy supplies, poor quality of supply and high electricity losses. Centralized generation, together with old and overloaded transmission and distribution systems cause high technical losses throughout the grid. By moving from technical to financial issues, access to electricity and electricity penetration in Tanzania are significantly lowered by the deficit of specific budget from the government. TANESCO official plan [7], aims to increase its customers base to 1,500,000 by 2025 reducing connection fees to 75% in rural areas and to 60% in urban areas. It is relatively straightforward that in this complex scenario, sources of private capital investment have become a relevant option to be exploited in bridging the financing gap.

Generation

The total power generated and imported reached 1461.69 MW in 2016, The off-grid stations cover an important section of the total production, with an overall installed capacity of 201,44 MW. The pie chart in Figure 10 shows the percentage share of primary resources utilized for power production in the same year. Hydro generation dominated the market until 2005 when many plants' operations were severely affected by low rainfalls levels. The drastic change in climatic conditions pushed the Government to respond with the Emergency Power Supply Project [17] , financed by the World Bank, which helped to reduce negative effects of the drought by providing TANESCO funds to procure emergency power sources.

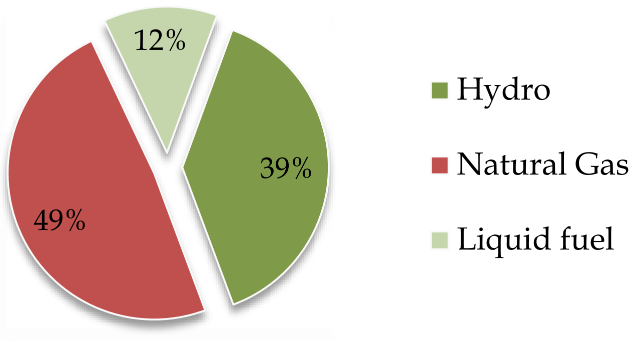


Figure 10 – Percentage fo resources utilized

Throughout the whole country there are 24 Thermal Power Plants (TPP) and six Hydro Power Plants (HPP); 6 TPPs are connected to the national grid, while the remaining 18 , located mainly in the western and southern areas, are operated in their own isolated systems. In the 2016 the government assessed the Power System Master Plan 2016 [7] where are reported projects of generation expansion which aim to build several power plants in the next 5 years, involving technologies like natural gas, wind and solar PV, for a total of 1000 MW new generation capacity.

In 2009, the Government approved a new Small Power Project through EWURA [18], funding a plan that consists in RE investments (mini-hydro, biomass, solar PV and wind) with a capacity range between 0,1 MW to 10 MW. Until now only mini-hydro and biomass power plants are under development, as it is possible that the large capital requirements needed to exploit economies of scale in wind and solar power projects under SPP arrangements have received a weaker response from private actors.

As of today, energy is also imported from bordering countries. 20 MW are insourced from Uganda through a 132kV line in the Kagera region, 10 MW are imported from Zambia through a 66kV line in the Rukwa region and 1MW is imported from Kenya through a 33kV line.

The favourable geographic conditions and the presence of many technological alternatives for natural resources exploitation allow Tanzania to bridge the gap with more advanced countries, by avoid focusing on fossil fuel technologies and investing directly on renewable resources. The government has decided to focus on three main projects to support national energy progress: geothermal power development, alternative biomass supply options and renewable energy for rural electrification (RERE). This last project is part of Scaling-Up Renewable Energy Program (SREP) developed by under the Strategic Climate Fund of Climate Investment Funds (CIF) [19] . The SREP-Tanzania Investment Program will consist of two distinct and complementary development projects with a combined generation potential of about 147 MW.

Project 1

The Geothermal Power Development Project has as main purpose the adoption of geothermal energy as a low-cost, reliable and important source of production in Tanzania's electricity supply, counting on the support of the public sector. The total project budget is $ 450 million, of which $ 400 million will be targeted to a 100 MW geothermal power plant covered by the PPP (Public-Private Partnership) contract. The expected project outcome is a PPP project aims to develop the operation and maintenance of about 100 MW of geothermal power supplying about 700 GWh per year to the national grid.

Project 2

The second project is known as Renewable Energy for Rural Electrification (RERE). The purpose of this project is to define a rural electrification plan as composed by a variety of independent and expandable plants, that could attract investments by private companies to further expand the system. This project will support the Tanzanian government's plan (2016 PSMP) to increase electrification access from 18.4% to at least 75% by 2035 by rural electrification with renewable energy. The project expects to generate a renewable energy potential of 47 MW directly co-funded with SREP resources and directly benefitting about half a million people and to create a pipeline of RERE projects that will eventually help 2.2 million people.

Transmission

The existing transmission system is formed by primary grid stations interconnected by transmission lines at voltages of. 220 kV, 132 kV and 66 kV. The system capacity has limited operating condition particularly during peak hours due to aged infrastructure, high power losses, lack of proper rehabilitation and maintenance and system overload. Challenges in enhancing transmission networks include vandalism of transmission network, land conditions and long distances.

The expansion plan reported in the 2016 PSMP of the transmission grid consists in the implementation of power evacuation lines from generation centres to load centres. Moreover, the plan includes the building of new 400kV interconnection lines between Tanzania, Zambia and Kenya and of 220 kV transmission lines between Tanzania, Uganda, Mozambique and Kenya. Development Partners are currently financing some of these projects and others have shown interest to finance new projects. The planned transmission grid is shown in the Figure 11.

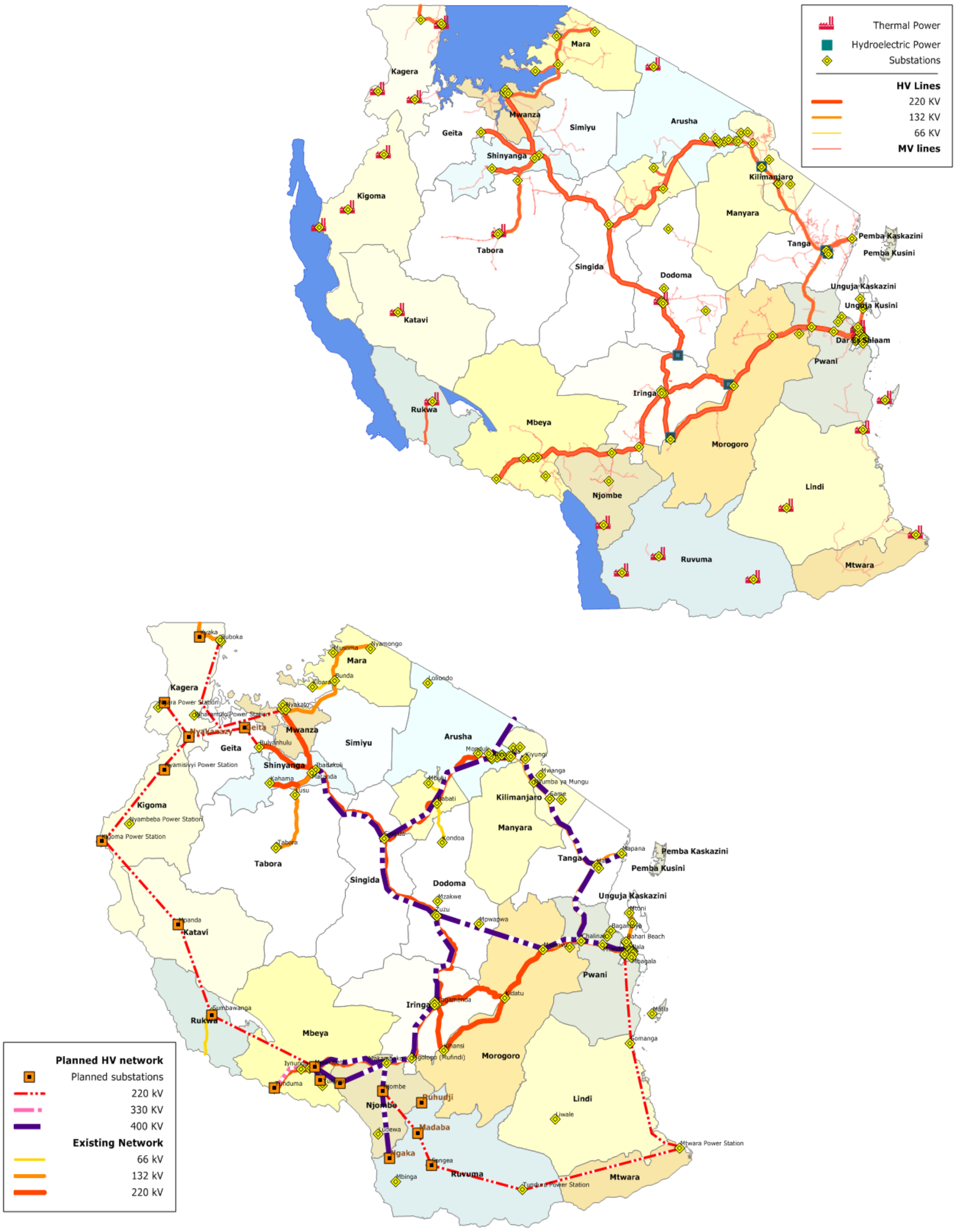


Figure 11- Comparison between the existing transmission grid (2013) and the planned one (2025)

Distribution

The distribution grid is mainly owned by TANESCO and it is composed by medium voltage and low voltage network, including 33kV,11kV and 0,4kV electric lines.

The challenges facing distribution networks include dilapidated networks, vandalism, outages as well as technical and non-technical losses, considering that 11kV lines are being progressively abandoned. The achievement of a reliable Medium-Voltage network is the major problem to solve in order to have an overall connection of the national grid and an increase of renewable penetration (i.e. microgrids).

Power Demand

Data show a constant increase of the overall country's power demand through the years. In November 2009 the peak demand was 755 MW while in December 2014 it reached 935 MW with an average growth rate of 4.7% per year [1]. Tanzania's annual per capita power consumption is very low, about 105 kWh in 2014 (MEM, 2014), less than half the average in Least Developed Countries. In 2012, the largest electricity consumer was the residential sector, responsible for 44% of total electricity consumption. It was followed by industry, accounting for 25% of total share, and commercial and public services 23% while Agriculture accounted for only 4% of electricity consumption (International Energy Agency, 2012) as shown in the Figure 12.

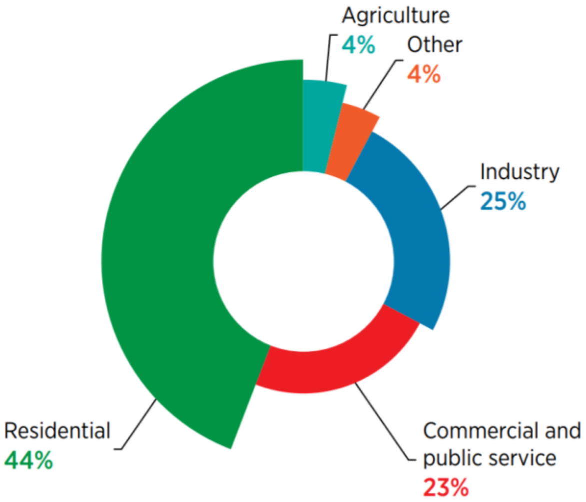


Figure 12- Electricity consumption by sector 2012 [11]

2 REVIEW OF POWER SYSTEMS MODELING

The study conducts on the power system of emerging country has to face problem regards lack of information. For this purpose, various mathematical models that helps us to overcome this problem have been used. A load flow analysis was performed in order to have an overall overview of both transmission and distribution grid. The parameter estimation is a model implemented in order to overcome the inaccurate calculation of the grid parameters of the high-voltage grid and in addition a sensitivity analysis on the main parameters have been performed in order to understand which portion of the grid is the lower accurate and why. Finally, the bricks approach has been applied to one distribution grid in order to simplify it and for the calculation of the hosting capacity. In the Figure 13 is reported a flowchart showing the correlation between the different approach utilized and in the following paragraph it is reported a briefly description of the models used.

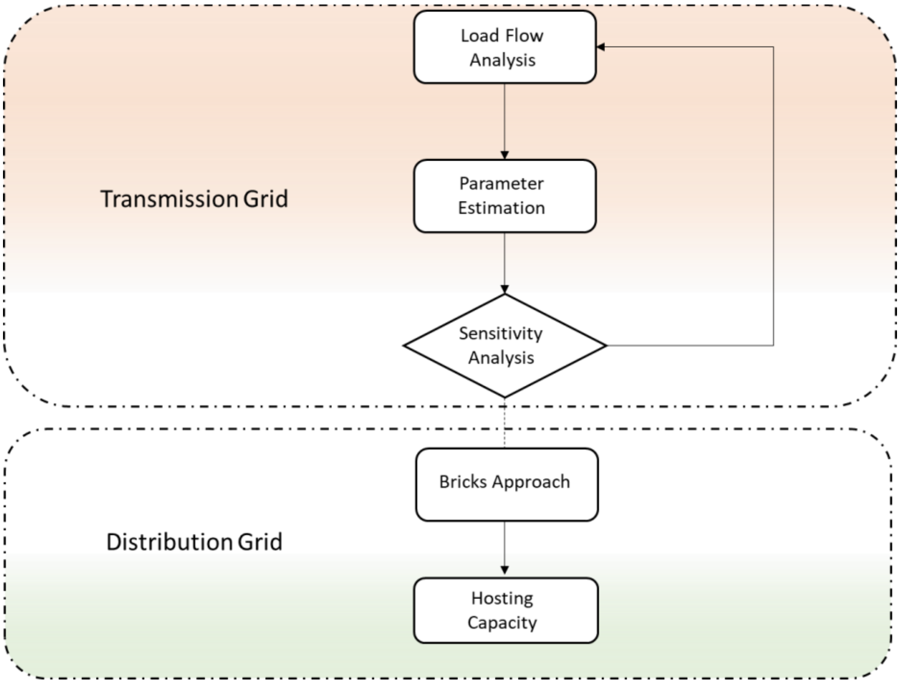


Figure 13- Flowchart of mathematical model

2.1 Load flow analysis

The load flow analysis is a widely known methodology commonly used to investigate power systems’ operation [4]. Based on the network structure, load flow calculations solve the steady state operation of the grid, computing node voltages and branch power flows of the power system. The mathematic model of the load flow problem is a system of nonlinear algebraic equation.

Electric branch model

Transmission grids are composed of generators, transformers, transmission lines and loads as shown schematically in Figure 14.

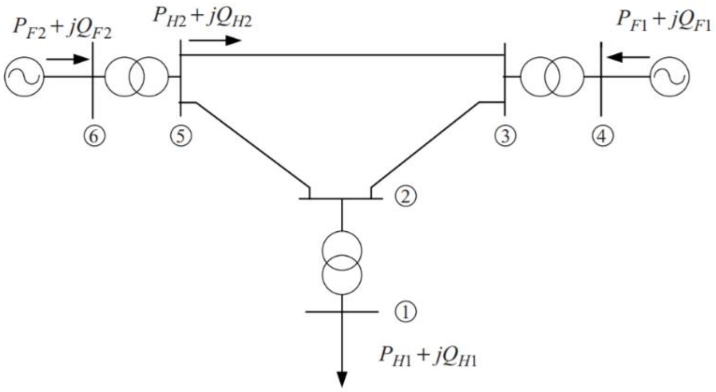


Figure 14-Simplified transmission grid model

To describe the electric grid, the π-equivalent branch model has been adopted, considering that the main network parameters are series and shunt impedences (see Figure 15).

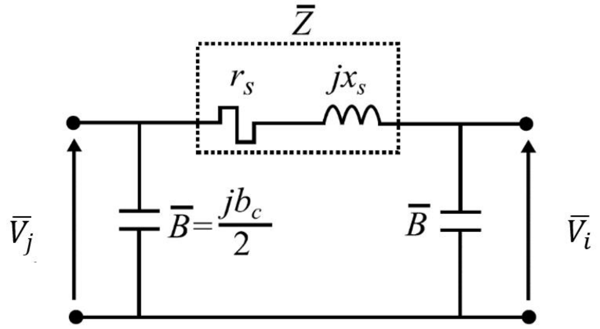


Figure 15- π-equivalent branch model.

In the figure $\bar{V}_j$ stands for the voltage phasor of the "from" bus of the branch while $\bar{V}_i$ is the voltage phasor of the "to" bus of the branch

$$\bar{V}_j = V_j \cdot e^{j\delta_j}$$

$$\bar{V}_i = V_i \cdot e^{j\delta_i}$$

The branch series impedance (magnitude Z and angle θ) an the line charging B:

$$\bar{Z} = Z \cdot e^{j\theta} = r_s + j \cdot x_s$$

$$\bar{B} = jB = j\frac{b_c}{2}$$

Node model

The nodes in the system are classified into three types according to the known variables:

PQ Nodes

In the PQ nodes the active and the reactive power are specified as known parameters, and the complex voltage (V, θ) is to be resolved. Usually the substations are treated as PQ nodes, with known load power profile. Most nodes in power systems belong to the PQ type in load flow calculation.

Considering the rectangular form, the voltage can be expressed as:

$$\overline{V}_i = e_i + jf_i$$

$$e_i = V_i cos\theta_i \ \ and \quad f_i = V_i sin\theta_i$$

and the bus formula are:

$$\left.\begin{aligned}\Delta P_i &= P_{is} - e_i \sum_{j\in i}\left(G_{ij}\, e_j - B_{ij} f_j\right) - f_i \sum_{j\in i}\left(G_{ij}\, f_j + B_{ij} e_j\right)\\ \Delta Q_i &= Q_{is} - f_i \sum_{j\in i}\left(G_{ij}\, e_j - B_{ij} f_j\right) + e_i \sum_{j\in i}\left(G_{ij}\, f_j + B_{ij} e_j\right)\end{aligned}\right\} \quad (i = 1,2, \ldots., n)$$

where P_{is} and Q_{is} are given and are the active and reactive power of the node i , G_{ij} and B_{ij} are the elements of the admittance matrix:

$$Y_{ij} = G_{ij} + jB_{ij}$$

PV Nodes

In the PV nodes the active power and the voltage magnitude V are the know variables, the reactive power Q and the voltage angle are unknows. Generators are usually modelled as PV nodes with some controllable reactive power resources maintaining node voltage magnitude at a desirable value. Some substations can be considered as PV nodes when they have enough reactive power compensation devices to control the voltage.

For the PV nodes P_{is} ,V_{is} are given and the equations are:

$$\left.\begin{aligned}\Delta P_i &= P_{is} - e_i \sum_{j\in i}\left(G_{ij}\, e_j - B_{ij} f_j\right) - f_i \sum_{j\in i}\left(G_{ij}\, f_j + B_{ij} e_j\right)\\ \Delta {V_i}^2 &= {V_{is}}^2 - \ ({e_j}^2 + {f_j}^{\ 2})\end{aligned}\right\} \quad (i = 1,2, \ldots., n)$$

Slack Node

It is important in the power system to specify a Slack Node which is characterized by a given voltage, constant in magnitude and phase angle. The active power P and the reactive power Q are the variables that must be solved.

Load flow problem

Accordingly with what described before, the problem of the power flow system is to calculate the node voltage phasor knowing the injected power in that node. Given the non-linearity of the problem, a nonlinear solving method has to be employed, such as the Newton-Raphson method, with the Jacobian matrix here reported, in order to obtain a solution:

$$\boldsymbol{J}^{(t)} = \begin{bmatrix} \left.\frac{\partial P_{PQ}}{\partial V_{PQ}}\right|_t & \left.\frac{\partial P_{PQ}}{\partial \delta_{PQ}}\right|_t & \cdots & \left.\frac{\partial P_{PQ}}{\partial \delta_{PV}}\right|_t \\ \left.\frac{\partial Q_{PQ}}{\partial V_{PQ}}\right|_t & \left.\frac{\partial Q_{PQ}}{\partial \delta_{PQ}}\right|_t & \cdots & \left.\frac{\partial Q_{PQ}}{\partial \delta_{PV}}\right|_t \\ \vdots & \vdots & \ddots & \vdots \\ \left.\frac{\partial P_{PV}}{\partial V_{PQ}}\right|_t & \left.\frac{\partial P_{PV}}{\partial \delta_{PQ}}\right|_t & \cdots & \left.\frac{\partial P_{PV}}{\partial \delta_{PV}}\right|_t \end{bmatrix}$$

The convergence characteristic of the Newton-Raphson is quite rapid, if the initial guess is particularly close to the initial guess it can converge in six/seven iterations. The definition of the initial guess is therefore an important step, in the power systems at normal conditions the voltage of the nodes is quite close to the nominal one and the differences between the phase angles of the nodes relatively small, that's why a "flat start" is considered as an initial value ($e_i{}^{(0)} = 1.0 \;\; f_i{}^{(0)} = 0.0 \;\; (i = 1,2, \dots., n)$).

In the Figure 16 is reported the flowchart of the Newton method where the convergence condition is

$$\left\| \Delta \boldsymbol{P}^{(t)}, \Delta \boldsymbol{Q}^{(t)} \right\| < \varepsilon$$

that is the norm of the power errors both active and reactive at each node. Usually when the calculation is based on the per unity system ε is set equal to 10^{-4} or 10^{-3}, with a base of 100 MVA the maximum error is in the range of 0.1-0.01 MVA.

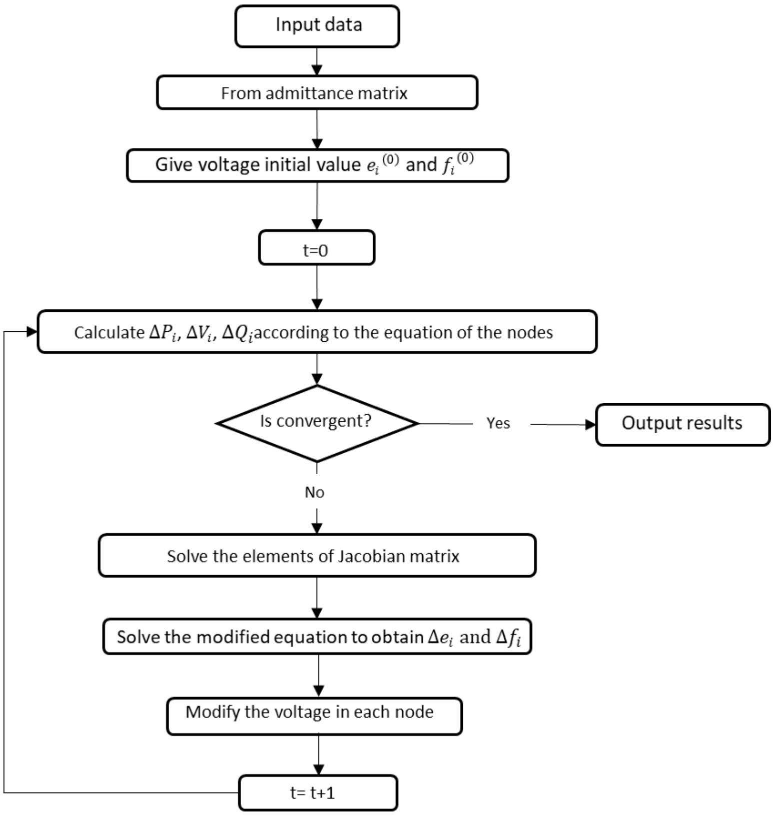


Figure 16- Flowchart for the load flow analysis

2.2 Power System Parameter Estimation

Problem definition

One of the most relevant issues in the analysis of electrical networks and power flow computations is the accuracy of input data. When considering the developing countries scenario, there is often lack of reliable and complete data regarding transmission and distribution networks. Often, data are provided in the form of network maps with general information regarding voltage profiles and power flows in the lines. The parameters of the network lines (e.g. lengths and impedances) are hardly available and their estimations could lead to relevant errors in the power flow results.

To overcome this problem, one possible solution could be the use of a reverse engineering procedure, that, starting from available data, allows to determine all the unknown network parameters. The procedure, described in detail in the paper [8], is a reformulation of the traditional state estimation problem [20]. In the latter, the state of the grid (voltage and angle at each bus) is estimated based on real measurements and grid parameters. On the contrary, in [8], the so-called parameter estimation allows to accurately estimate network parameters starting from information on system state (e.g. voltage, power flows).

The problem can be formulated as an Optimization Problem (OP), with the goal of minimizing the error among estimated and available input data. The input data is collected into a vector $\boldsymbol{x^m}$. $\boldsymbol{x^{est}}$ is the vector containing the values for the same parameters estimated by the network model. The distance between $\boldsymbol{x^m}$ and $\boldsymbol{x^{est}}$ is calculated by solving the following optimization problem:

$$min[\boldsymbol{x^m} - \boldsymbol{x^{est}}] \cdot \boldsymbol{W} \cdot [\boldsymbol{x^m} - \boldsymbol{x^{est}}]$$

where $\boldsymbol{x^m}$ is the column vector of input values, e.g. voltage magnitudes, power flows through branches etc., and $\boldsymbol{x^{est}}$ is the column vector of estimated values, linked by non-linear PF equations. $\boldsymbol{W}$ is the diagonal matrix of weight coefficients, which consider the accuracy of each input.

Optimization model

Considering the electric branch model described in paragraph 2.1, the generic vector of the optimization problem can be rewritten as:

$$\boldsymbol{x^m} = \begin{bmatrix} {P_{ft,1}}^m & \cdots & {P_{ft,n}}^m & {P_{tf,1}}^m & \cdots & {P_{tf,n}}^m & {Q_{ft,1}}^m & \cdots \\ & {Q_{ft,n}}^m & {Q_{tf,1}}^m & \cdots & {Q_{tf,n}}^m \dots & V_1^m & \cdots & V_l^m \end{bmatrix}^T$$

$$\boldsymbol{x^{est}} = \begin{bmatrix} {P_{ft,1}}^{est} & \cdots & {P_{ft,n}}^{est} & {P_{tf,1}}^{est} & \cdots & {P_{tf,n}}^{est} & {Q_{ft,1}}^{est} & \cdots \\ & {Q_{ft,n}}^{est} & {Q_{tf,1}}^{est} & \cdots & {Q_{tf,n}}^{est} \dots & V_1^{est} & \cdots & V_l^{est} \end{bmatrix}^T$$

$$\boldsymbol{W} = diag \begin{bmatrix} W_{P_{ft,1}} & \cdots & W_{P_{ft,n}} & W_{P_{tf,1}} & \cdots & W_{P_{tf,n}} & W_{Q_{ft,1}} & \cdots \\ & Q_{ft,n} & W_{Q_{tf,1}} & \cdots & W_{Q_{tf,n}} \dots & W_{V_1} & \cdots & W_{V_l} \end{bmatrix}^T$$

where ${P_{ft}}^m$, ${Q_{ft}}^m$, ${P_{tf}}^m$, ${Q_{tf}}^m$ are the known active and reactive power flowing in the network branches, V^m is the known nodal voltage, *n* is the number of branches and *l* number of buses. Instead ${P_{ft}}^{est}$, ${Q_{ft}}^{est}$, ${P_{tf}}^{est}$, ${Q_{tf}}^{est}$ are the variables calculated through the equation reported above.

The error between the measured and estimated values is considered with a uniform distribution as shown in the Figure 17 and is

$$x^{est} = x^m \pm \Delta x$$

with an interval from -A to +A which represent the rounding error according to the probability density function (PDF).

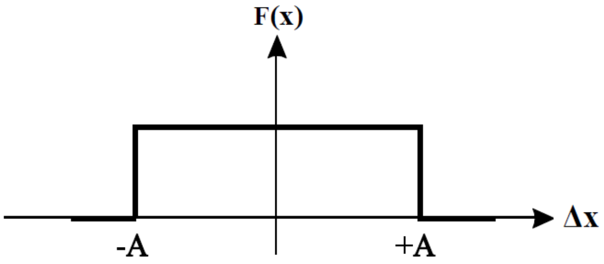


Figure 17- Uniform distribution error.

The W coefficients are calculated as

$$W = \frac{1}{\sigma^2}$$

where

$$\sigma = \frac{A}{\sqrt{3}}$$

In this way different variables have different weights, input data that are more accurate have higher weight in comparison with the more inaccurate ones.

2.3 Hosting capacity

Problem Definition

As described in the previous chapters microgrid installations in the rural areas in Tanzania are increasing. This phenomenon is caused by the continuous investments aimed to bring access to electricity in the remote areas of the country. With the improvement and enlargement of the electric grid a further step could be the connection of the microgrids to the distribution grid. As a consequence, the active users in both low and medium voltage grid will increase. Nowadays, the distribution networks (MV – LV) have been developed radially with the energy flowing mainly from the PS (primary station) to the lower voltage transformers. Even in the industrialized countries such architecture was chosen and implemented until recent times, as long as the DG (Distributed Generation) were rare.

Several studies have been made to estimate the maximum amount of dispersed generation that can be integrated into a power systems respecting the performance limits. Those studies are named in literature Hosting Capacity evaluations [5].

The Figure 18 is showing the standard operating condition of a distribution grid where the current is flowing from the generator to the load and in the Figure 19 is highlighted the behaviour of the grid when a DG is connected to it. In this second case the currents is flowing in the opposite direction creating problem from the point of view of the stability of the grid. That is the reason why a hosting capacity has to be performed, when the procedure evaluates the maximum DG capacity connected to each node of a network, the methodology is called Nodal Hosting Capacity. This will be explained in detail the following paragraph.

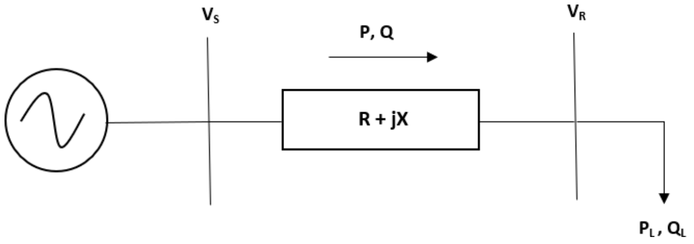


Figure 18- Normal operating condition of a grid

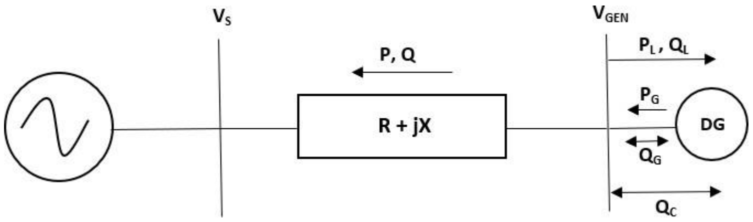


Figure 19- Operating condition of a grid with DG connection

Nodal Hosting Capacity

The first step in the evaluation of the hosting capacity is to establish the parameters related to the performance of the system and consequently set an acceptable limit range of each of them. As an example, short circuit current and voltage profiles could be used as reference parameters. The hosting capacity is calculated by gradually increasing the amount of DG injection until the performance index into consideration passes the limit. This procedure has to be performed for several performance indices to evaluate the maximum Distributed Generation (i.e. the hosting capacity) allowed for a given network. Figure 20 shows graphically the definition of the hosting capacity with respect to the deterioration of the performance index.

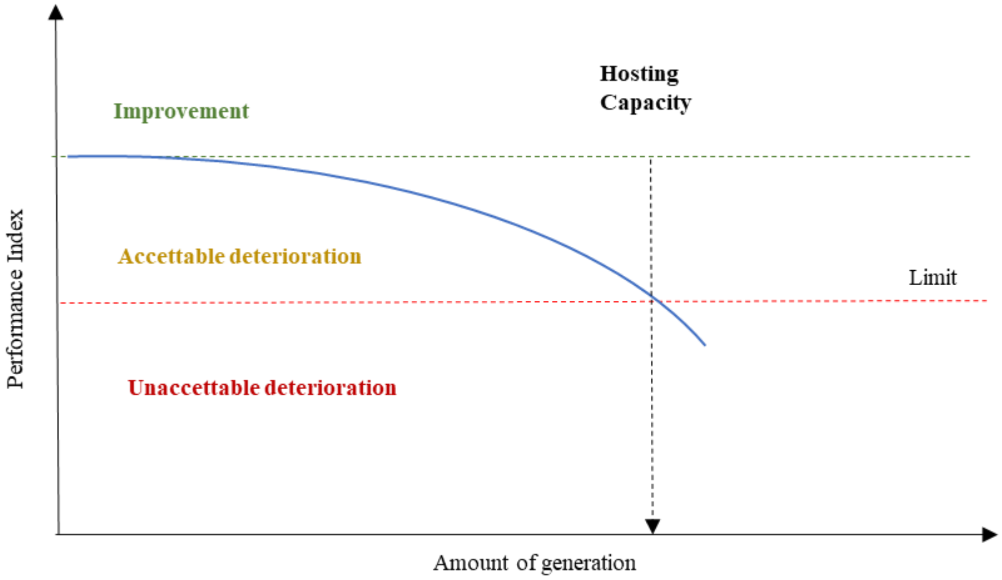


Figure 20- Graphic view of the hosting capacity

At each iteration, a power flow analysis is performed in order to calculate the voltages, the current and the active and reactive power at each node. The equations utilized are the following:

$$\left.\begin{aligned} P_k &= P_{DG,k} - P_{D,k} = \sum_{j=1}^{N} \left|V_{DG,k}\right| \left|V_{DG,j}\right| \left(G_{kj} cos\theta_{DG,kj} + B_{kj} sin\theta_{DG,kj}\right) \\ Q_k &= Q_{DG,k} - Q_{D,k} = \sum_{j=1}^{N} \left|V_{DG,k}\right| \left|V_{DG,j}\right| \left(G_{kj} sin\theta_{DG,kj} - B_{kj} sin\theta_{DG,kj}\right) \end{aligned}\right\}$$

where $P_{DG,k}$, $Q_{DG,k}$ represent the DG power and $P_{D,k}$, $Q_{D,k}$ the power of the load at the same node k. N is the total number of nodes in the feeder , the scheme of the flowchart in the

Figure 21.

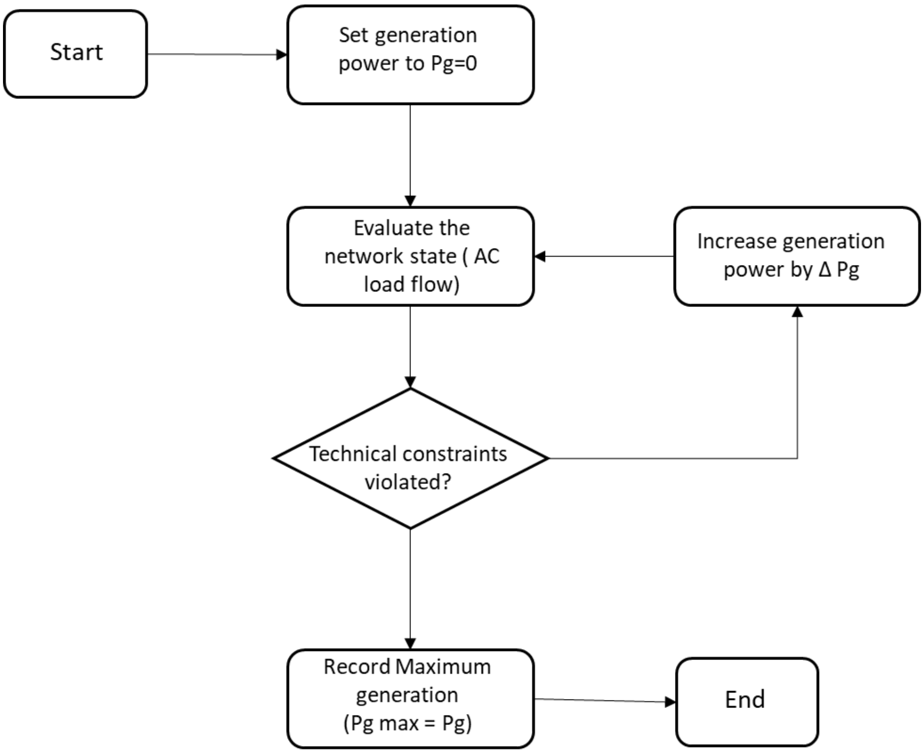


Figure 21- Flowchart for the calculation of the HC

Operating limits

For each grid several constraints can be taken into account. They can be categorized based on the impact they can have. The ones that affect the power quality are the Supply voltage variation (SVV) and the Rapid voltage changes (RCV) in each bus. Short circuit currents and unwanted line protection tripping have an impact on the protection relays. Reverse power flow has an effect on network automation and the Line Thermal Limits on the network expansion.

Steady-State Voltage Variation (SVV)

In the calculation of the HC the increasing of DG in the distribution grid causes an increase of the voltage value of the hosting feeder. Therefore, in order to avoid problems and malfunctions of the grid, the steady state voltage variations according to EU network codes, must remain within $\pm$ 10% of the rated voltage for at least 95 % of the time.

$$V_{min,k} \leq V_{DG,k} \leq V_{max,k}$$

Rapid Voltage Change (RCV)

The rapid voltage change is the difference between the voltage of node when the DG is connected and when it is suddenly detached. According to the EU regulation there is not a severe constraint but an approximate admissible variation range:

$$\left|V_{DG,k} - V_k\right| \leq 4\ \% \ \div 6\ \%$$

Line Thermal Limit (LTL)

Adding DG to the grid causes an increase also of current flowing in MV grid, for this reason thermal limits on the branches have to be considered. The maximum current flowing on a branch depends on the parameters of the line (R and X) and it must respect:

$$I_{DG,k} \leq I_{max,kj}$$

2.4 Distribution grid modelling

In line with what explained in the previous paragraph, the hosting capacity can be calculated with an objective function that maximizes the nodal active power of dispersed generators in each bus.

$$HC = Max(Nodal\ Loading\ Parameters)$$

Practically speaking, in order to perform the HC analysis, it is required a complete model of the distribution grid with the exact topology, grid parameters and also power profiles of loads and generators. These kind of data in developing countries scenarios are quite difficult to gather because sometimes even the DSO itself is unable to collect them. To get to solve this issue a novel procedure, proposed in [6] and called Bricks Approach, can be used.

The standard structure of a distribution grid is made by a main line named feeder and by several collaterals that are branches connected to the main one. The assumption of the new method is that the HC in one feeder is lightly affected by the other feeders. In this way the grid can be modelled as an aggregation of bricks, each one representing a portion of the distribution grid. The components of the system are described in the following paragraphs.

Feeders: The main part of the distribution grid is composed by the feeders that are the main lines connected to the primary station. In the simplification of the grid they are sorted by their length and categorized in Short Feeders (F1), Medium Feeders (F2) and Long Feeders (F3).

Collaterals: Considering that the distribution grid is radially configured, there are smaller branches connected to the main one. They are called collaterals and categorized in two sets: Short Collaterals (C1) and Long Collaterals (C2). In this configuration short feeder are allowed to have just short collaterals.

Nodes: In the simplification of the distribution grid the feeders are represented with just three nodes (N1, N2, N3). The three branches, that are connecting the three nodes and the primary station, embody the total impedance (Z) of the feeder. The first one embodies the first 10% of the total impedance and represents the branch near the primary station; each of the other two branches accounts for 40% of the total impedance. The same procedure is followed for the collaterals but in this case, there are two nodes in the long collateral and one in the short one.

Figure 22 shows a schematic view of a long feeder with the three nodes and long collaterals. [6].

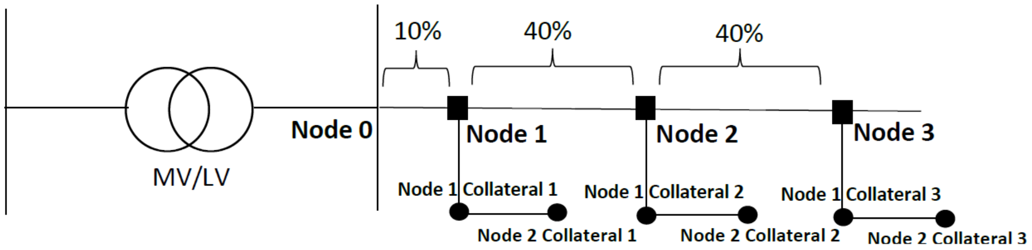


Figure 22- Schematic simplification of a branch though the Bricks Approach

Loads: in a distribution grid the PS can be loaded up to 65% of its rated power as established by the Italian DSO practise. In the Bricks approach such a value as been assumed to be the peak load (L3) the grid is asked to feed. Load values are divided into three groups: the yearly minimum value (L1), the mean value (L2), and the peak value L3.

Generators: The main part of the approach consists in the calculation of the maximum power that can be injected by the DG. For this purpose, a generator is connected to each node of each combination of the feeder and collaterals, As shown in the Figure 23**Errore. L'origine riferimento non è stata trovata.** the iterative process consists in the gradually increase the generators in the nodes to calculate the HC.

The Table 1 shows all the possible combinations of loads and generators in the flowchart. The configurations change with regards of number of nodes of the grid (3 to 9) number of loads consider (L1, L2 and L3) and number of DG that can be connected: maximum amount of DG that can be connected to all the node (G1,G2,G3..,G9).

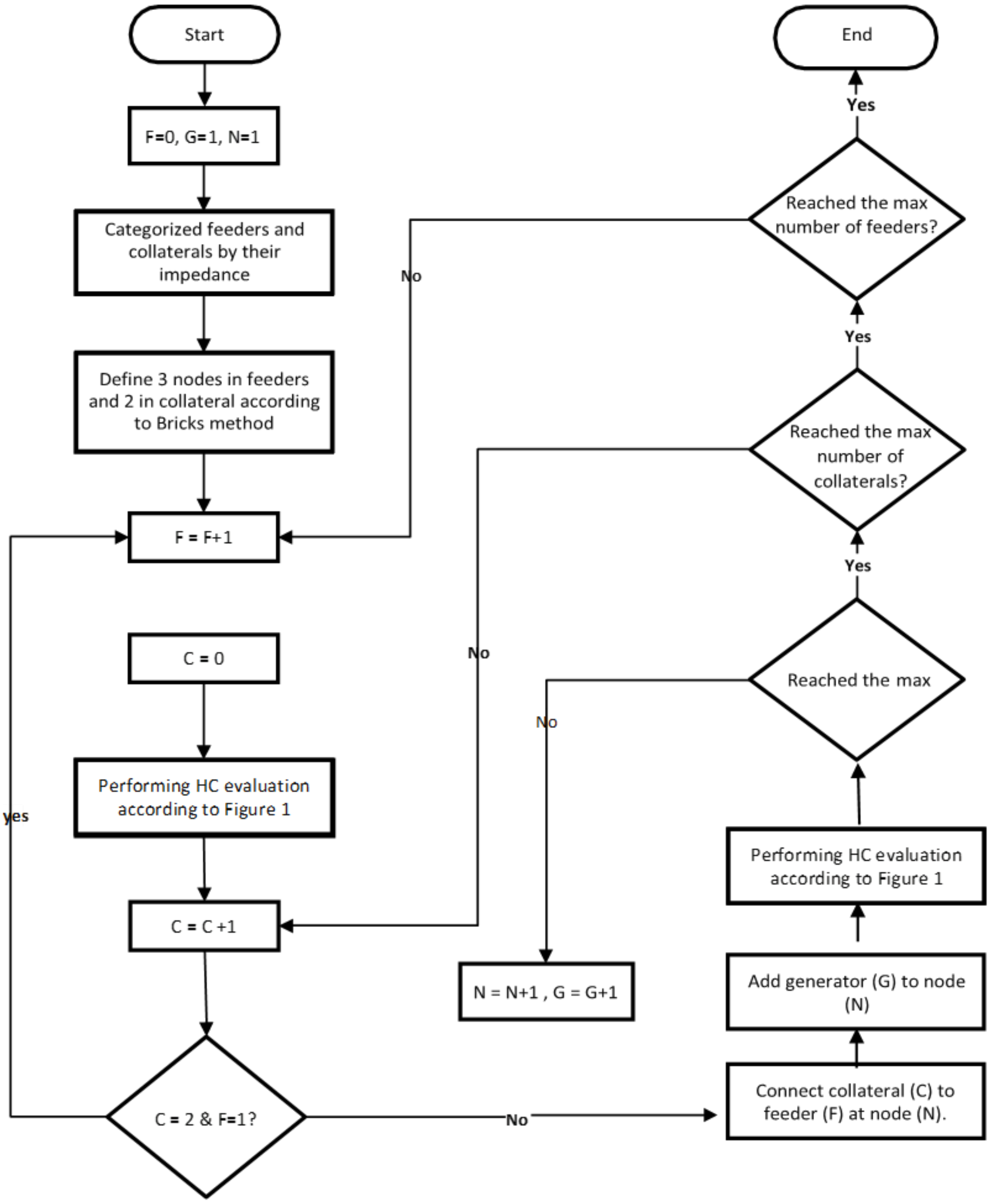


Figure 23- Flowchart for the calculation of the Hosting Capacity [6]

Table 1- Possible combination for the power flow calculation. [6]

Feeder	Collaterals			Load (L1,L2,L3)									DG (G1,. . . ,G9)	No. of Combination
	N1	N2	N3	N1	N2	N3	N4	N5	N6	N7	N8	N9	No. of Positions	
F1	-	-	-	3	3	3	0	0	0	0	0	0	3	81
	C1	-	-	3	3	3	3	0	0	0	0	0	4	324
	-	C1	-	3	3	3	0	0	3	0	0	0	4	324
	C1	C1	-	3	3	3	3	0	3	0	0	0	5	1215
	-	-	C1	3	3	3	0	0	0	0	3	0	4	324
	C1	-	C1	3	3	3	3	0	0	0	3	0	5	1215
	-	C1	C1	3	3	3	0	0	3	0	3	0	5	1215
	C1	C1	C1	3	3	3	3	0	3	0	3	0	6	4374
F2	-	-	-	3	3	3	0	0	0	0	0	0	3	81
	C1	-	-	3	3	3	3	0	0	0	0	0	4	324
	C2	-	-	3	3	3	3	3	0	0	0	0	5	1215
	-	C1	-	3	3	3	0	0	3	0	0	0	4	324
	C1	C1	-	3	3	3	3	0	3	0	0	0	5	1215
	C2	C1	-	3	3	3	3	3	3	0	0	0	6	4374
	-	C2	-	3	3	3	0	0	3	3	0	0	5	1215
	C1	C2	-	3	3	3	3	0	3	3	0	0	6	4374
	C2	C2	-	3	3	3	3	3	3	3	0	0	7	15309
	-	-	C1	3	3	3	0	0	0	0	3	0	4	324
	C1	-	C1	3	3	3	3	0	0	0	3	0	5	1215
	C1	-	C2	3	3	3	3	0	0	0	3	3	6	4374
	C2	-	C2	3	3	3	3	3	0	0	3	3	7	15309
	-	C1	C2	3	3	3	0	0	3	0	3	3	6	4373
	C1	C1	C2	3	3	3	3	0	3	0	3	3	7	15309
	C2	C1	C2	3	3	3	3	3	3	0	3	3	8	52488
	-	C2	C2	3	3	3	0	0	3	3	3	3	7	15309
	C1	C2	C2	3	3	3	3	0	3	3	3	3	8	52488
	C2	C2	C2	3	3	3	3	3	3	3	3	3	9	59049
F3	The same as F2.													

3 DATA COLLECTION

The data collection process has been conducted in collaboration with Dar es Salaam Institute of Technology. In this phase the author spent as a visiting student approximately three months in Tanzania, collecting data by interacting directly with local university researchers and governmental agencies. As previously mentioned, one of the biggest issues in relation with emerging countries is the difficulty in retrieving reliable and usable data: even with a direct presence in the country it has been difficult to establish fruitful relations with local agencies and to obtain qualitatively relevant data. However, thanks to the collaboration with DIT electrical engineering professor Godfrey J. Moshi, it has been possible to obtain updated data regarding ongoing projects of energy development in Tanzania, main source of this information have been the Power System Master Plan 2016 and the Power System Plan fo Da es Salaam that are describe in detail in the following paragraph.

Tanesco Power System Master Plan 2016

The 2016 Power System Master Plan update [7] consists of a document made by inter-governmental institutions to assess a generation and transmission plan regarding three main aspects: the increasing of reliable power supply, the connection with off-grid regions and expansion projects including power exchange with neighbouring countries.

The entire study has been conduct by the Ministry of Energy and Minerals (MEM), National Bureau of Statistics (NBS), Rural Energy Agency (REA), Tanzania Electric Supply Company (TANESCO), Tanzania Petroleum Development Corporation(TPDC), Energy and Water Utilities Regulatory Authority (EWURA) and Japan International Cooperation Agency (JICA) through the Consultant, Yachiyo Engineering Co., Ltd. (YEC).

All the assessment has been divided in short term (2016-2020) mid-term (2021-2025) and long term (2026-2040) plan. The short-term plan has the purpose of taking immediate decisions and actions concerning the power system, the mid and long term plans are intended instead for planning and developing projects to ensure the future electricity supply. The report is the update of older versions: previous PSMP 2008, 2009 and 2012. The first Power System Master Plan (PSMP) was developed in 2008 by the consultant SNC- Lavalin of Canada for the Government of Tanzania through TANESCO to provide a fundamentally new plan to guide the development of the power system in Tanzania for the following 25 years. The plan was updated in 2009 by the MEM and TANESCO with the technical support of the SNC-Lavallin consultant which reviewed the progress and challenges encountered during the first year of implementation. The further updated version also involved various stakeholders and the last one was conducted by the technical assistance from Japan International Cooperation Agency (JICA).

Power System Plan Dar es Salaam

Following the previous study, JICA conducted a Power System Plan focusing on Dar es Salaam municipality [1]. The PSMP shows that Dar es Salaam is expected to increase its electricity demand, following Tanzania’s economic development. Dar es Salaam is in fact the country’s largest commercial city, accounting for about the 10% of total population, and for nearly the 50% of country’s electric demand. In addition, the Government of Tanzania is aiming for the strategic national policy with focuses on shifting its commercial and industrial activities to adjacent coastal area.

These two plans are the starting point for the study of the transmission and distribution grid, and the research period on field in the collaboration with TANESCO and DIT shows :

- The main objectives related to the development of the grid are: the improvement in transmission capacity at national level, power delivery to the rising number of established companies and the increased facilitation of international power exchange.
- Power demand throughout the country is expected to grow intensively in the next years thanks to three main factors identified: economic growth, an increase in the level of industrial activities, and higher levels of energy consumption related.

- The future development of the grid is expected to produce stronger connections between all regions and to contribute to more uniform electricity prices across the country during ordinary climatic and operational situations.

3.1 Generation

The challenge of the new government is to achieve 4,915 MW of power generation by the end of 2020. Currently there are six Hydro Power Plants (HPP) operating in the country: Kidatu (4 x 51MW), Kihansi (3 x 60 MW), and Mtera (2 x 40 MW), are the three plants with higher installed capacity. New Pangani Falls (68 MW), Hale (21 MW), and Nyumba ya Mungu (8MW) are the remaining ones, with a relatively lower nominal capacity as shown in the Table 5.

Table 2- HPP currently in place

Plant Name	Installed Capacity (MW)	Max Generated (MW)
Kidatu	204	198
Kihansi	180	180
Hale	21	18
New Pangani	68	68
Mtera	80	75
Nyumba ya Mungu	8	6
Total	**561.843**	**545**

Thermal plants are mainly concentrated in the Dar es Salaam Region and in the Table 3- Thermal Plants currently in place are reported the installed capacity of each plant. All these data were gathered directly from Tanesco.

Table 3- Thermal Plants currently in place

Plant Name	Installed Capacity (MW)	Max Generated (MW)
Ubungo I	102	
Ubungo II	129	
Kinyerezi I	150	140
Kinyerezi II	168.82	160
Tegeta Gas Plant	45	
Somanga Gas Plant	7.5	7.5
Mtwara Gas Plant	18	
Total	**620.32**	

Further information collected are the off-grid Diesel station installed capacity. Various Tanzanian regions are still detached from the main grid, the generator owned by Tanesco are ones reported in the Table 4.

Table 4- Off-Grid Diesel Station own by Tanesco

Plant Name	Installed Capacity (MW)
Bukoba	2.56
Iyonga	0.476
Kasulu	2.5
Kibondo	2.5
Kigoma	11.81
Liwale	0.848
Loliondo	5
Ludewa	1.27
Madaba	0.476
Mafia	2.18
Mbinga	2
Mpanda	4.296
Namtumbo	0.34
Songea	8.312
Sumbawanga	5
Tunduru	2.948
Total	**52.516**

The overall percentage of hydro plants is around 43% against a 57 % of thermal plants as reported in the Figure 24.

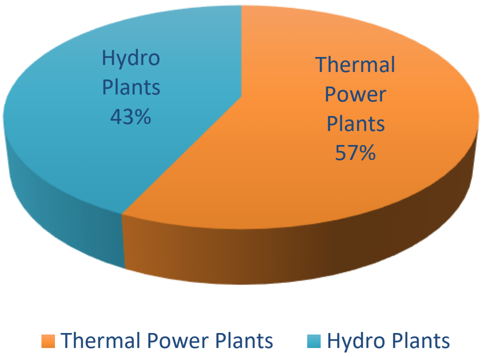


Figure 24- Percentage of plants by fuel

It is expected, in 2020, an increase of power generation in Mbeya and Iringa region Muchuchuma (coal) 600 MW and Kiwira (coal) 400 MW. Instead new Hydro Power Plants are projects on top of the grid expansion and they consist of: one located Rusumo border, among Tanzania, Rwanda and Burundi, where a 90MW HPP will be built and will connect the national grids of the three countries through 220kV transmission line and the other involves Tanzania and Malawi with an overall capacity of 360 MW that will be connected through 220kV transmission line by 2020.

3.2 Transmission Grid

The main grid was constructed in the 60's / 70's and most of the equipment is now getting obsolete. In the Figure 25 it is reported the existing grid of the whole country; data are taken from the world bank database and from the PSMP. The two sources give a picture of the overall grid now in place. Green lines represent the transmission grid and red dots the primary substations . Instead blue squares are the hydro power plants an the orange triangle the thermal plants.

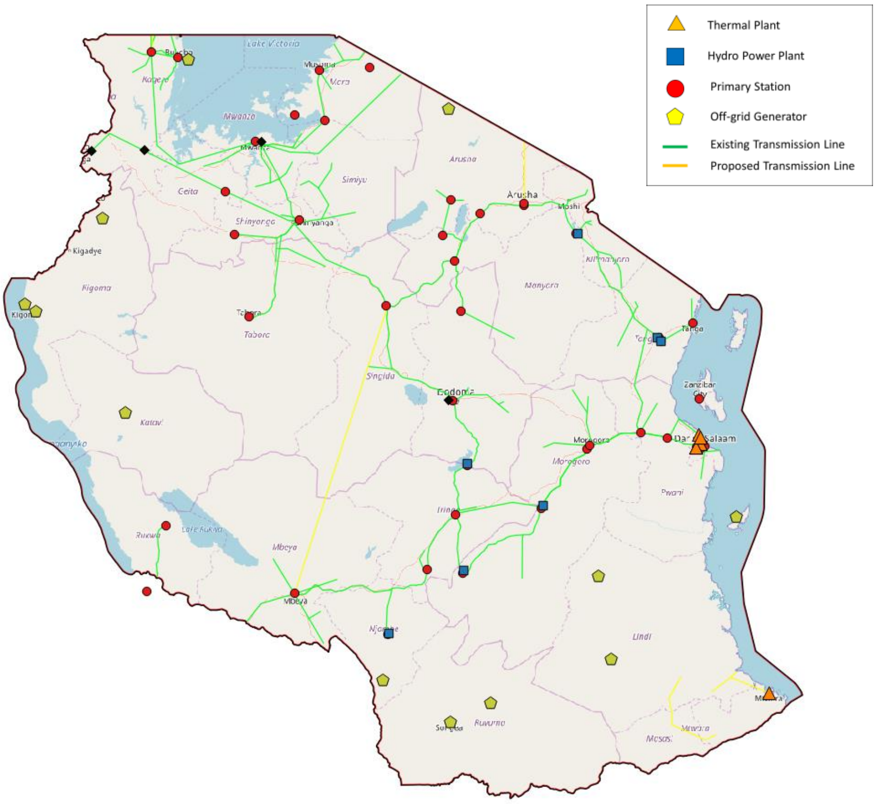


Figure 25- Existing transmission grid and primary station

The transmission grid is comprised of 647 km of 400 kV line, 2745 km of 220 kV 1626 km of 132 kV and 580 km of 66 kV. The rural areas are served by generating units with an aggregate nominal capacity of 81.5 MW (in the picture they are represented by the yellow pentagons). The existing transmission lines are listed in the Appendix A; it is important to highlight that all 400 kV transmission lines are still under final commissioning and not yet used.

TANESCO imports power from Uganda through 132 kV lines (approximately 30 MW during peak time) and from Zambia through 66 kV lines (approximately 10 MW during peak time). The most overloaded portion of lines are the ones between :

- Iringa-Mtera-Dodoma-Singida that are 220 kV line.
- Chalinze-Arusha- Hale 132 kV transmission.

For this reason there in place projects for the connection of:

- Iringa e Shinyanga with a 647 km of 400 kV line
- Dar es Salaam-Chalinze-Segera-Arusha with a 441 km of 400 kV
- Segera and Tanga with 64 km of 220 kV.

The Figure 26 shows the 400/220 kV transmission lines planned by the end of the 2020.

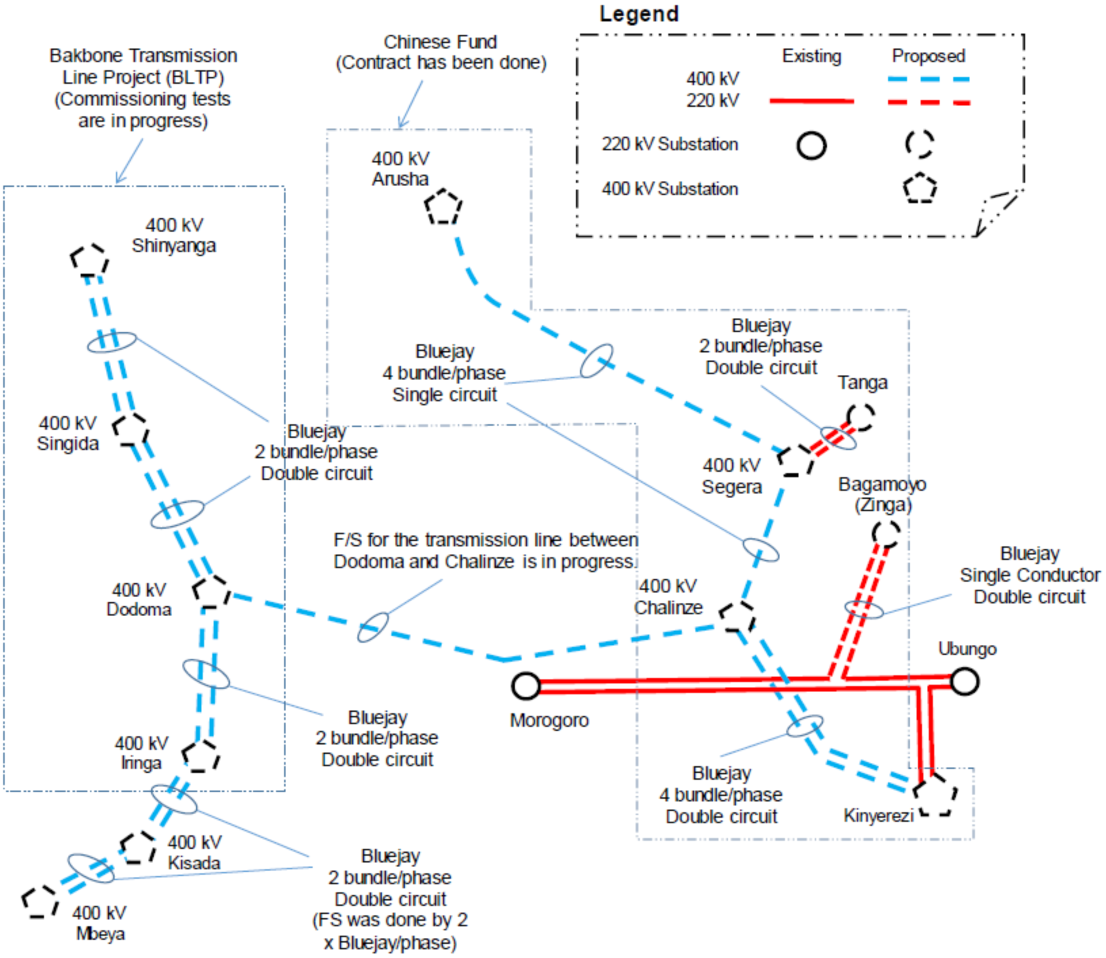


Figure 26-Transmission lines proposed [7]

Expansion Projects

On top of internal integration, the connection with bordering countries would facilitate the adoption of new power generation and increase security of supply domestically. The increase in exchange capacity with other countries would also allow a bilateral power trading which could be exploited to evacuate excess power generated internally from renewable resources. To take advantage of these benefits six new projects listed here are currently expected to be completed in 2020 or before and are:

- 400 kV interconnector with Kenya, where the designed linking point in the grid would be Arusha. The project is currently under implementation and is scheduled to be completed and operating in 2019.
- 400 kV connection with Zambia, which should be connected in the point of Mbeya and is scheduled to start operating in 2020.
- Uganda and Tanzania are currently negotiating the details for a new 220 kV interconnector that would join Masaka (Uganda) and Kyaka (Tanzania), and is expected to be completed by 2020.
- 400 kV connection with Mozambique, a project that was signed between EDM (Electricidade de Mozambique) and TANESCO in 2015.

Further grid expansion projects are shown in Figure 27, Figure 28 and Figure 29.

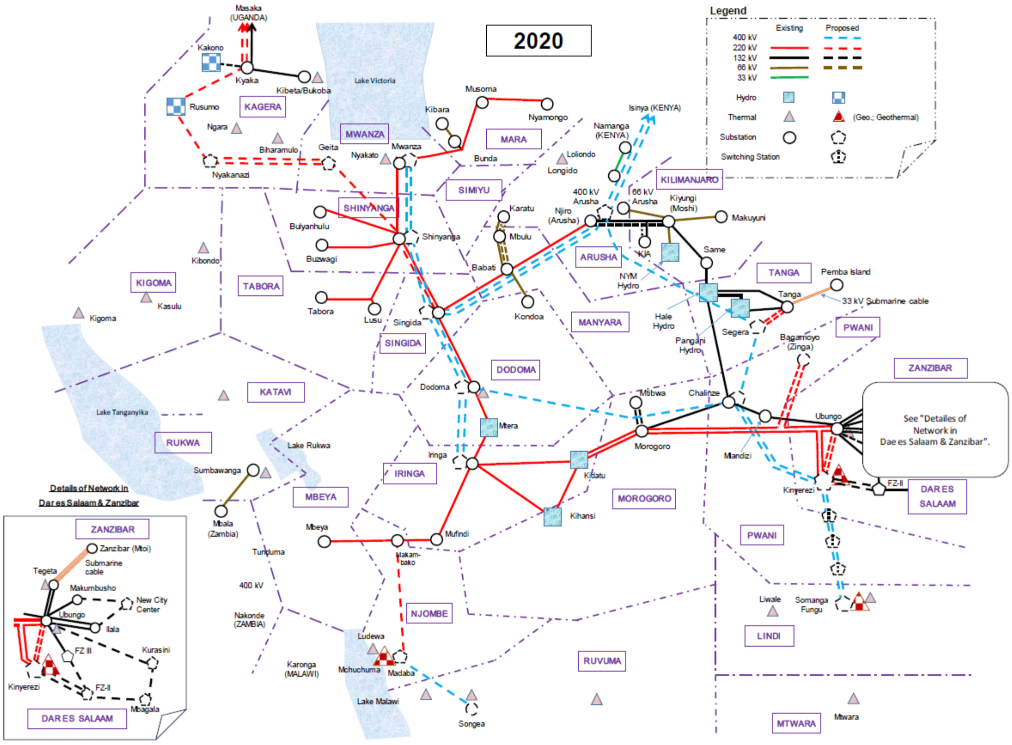


Figure 27 - Generation and Transmission- Year2020 [7]

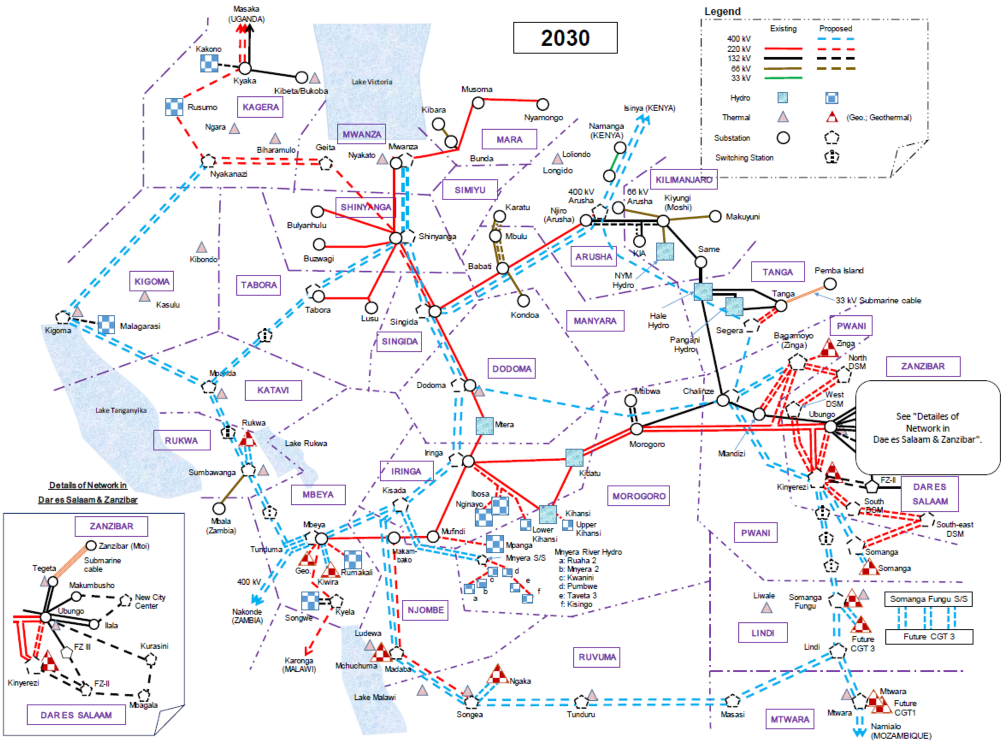


Figure 28- Generation and Transmission- Year 2030 [7]

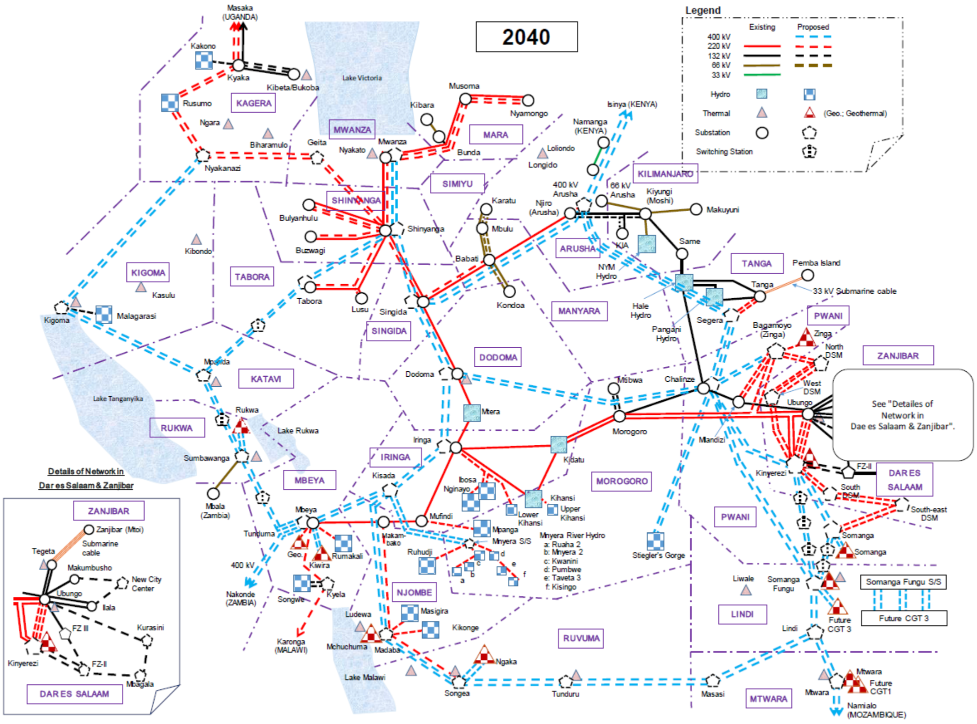
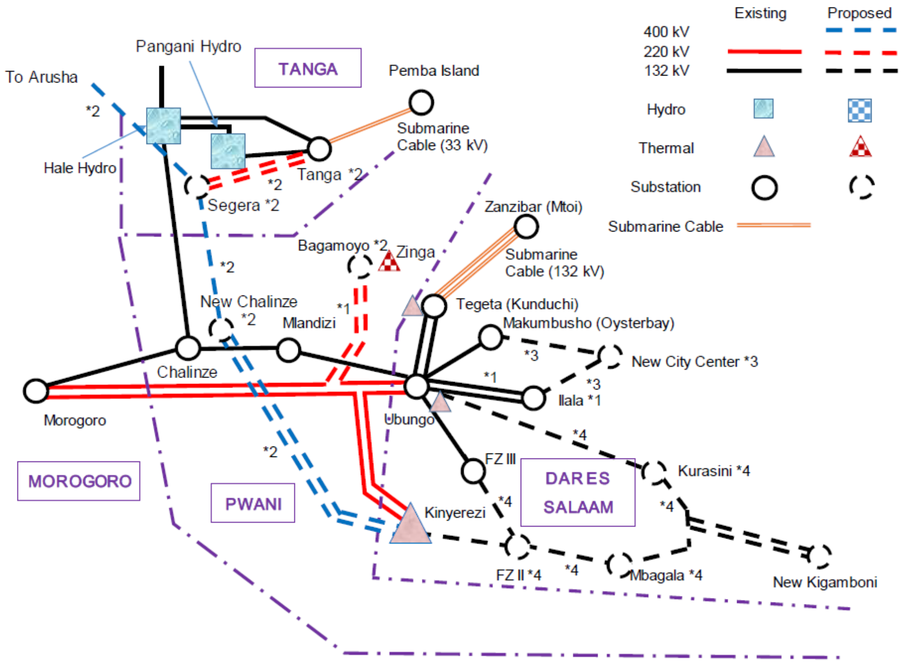


Figure 29- Generation and Transmission - Year 2040 [7]

3.3 Distribution Grid In Dar es Salaam

Dar es Salaam and Coast region distribution network departs radially from the 220/132 kV Ubungo substation, where two thermal power plants are installed. The power supply is conducted through 33kV and 11kV voltage lines. Table 28 (APPENDIX C) are reported the information collected about the distribution grid: data are derived by site surveys coming from a study of the JICA team and by talks with Regional offices.

The power supply in the area of Dare es Salaam has improved since 2015, when the Kinyerezi Gas power plant was put in place. Nevertheless, various projects are now in place in order to cope with the growth of power demand as shown in the Figure 30, the continuous lines are representing the existing connection and the dashed lines the proposed one (the connection between Dar es Salaam and FZ III is still in progress).



Note; Projects by Donors
*1; Japan Grant Aid Project
*2; China (Exim Bank) Project
*3; Finland Project
*4; TEDAP (World Bank)

Figure 30- Transmission grid of Dar es Salaam area [1]

While in the Figure 30 is showing just the transmission network in Dar es Salaam region, in the following Figure 31 is reported distribution one.

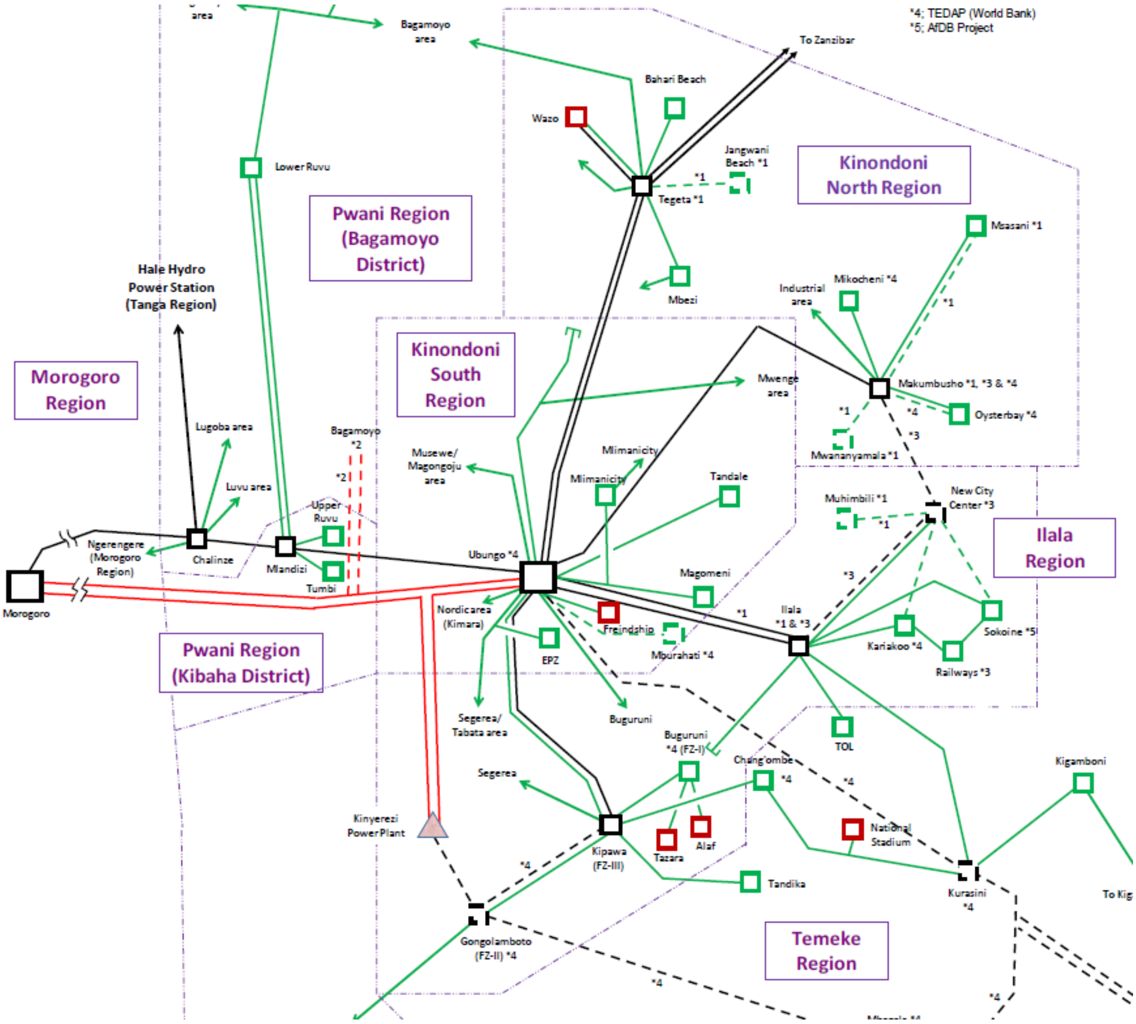


Figure 31- Scheme of the Distribution Grid in Dar es Salaam [1]

3.4 Power Demand

The data for power demand have been collected directly from Tanesco. The Figure 32 is showing the maximum power demand for each substation in October 2018 that is the month in which were performed during the Data Collection period. The total amount is equal to 1071 MW for the all country.

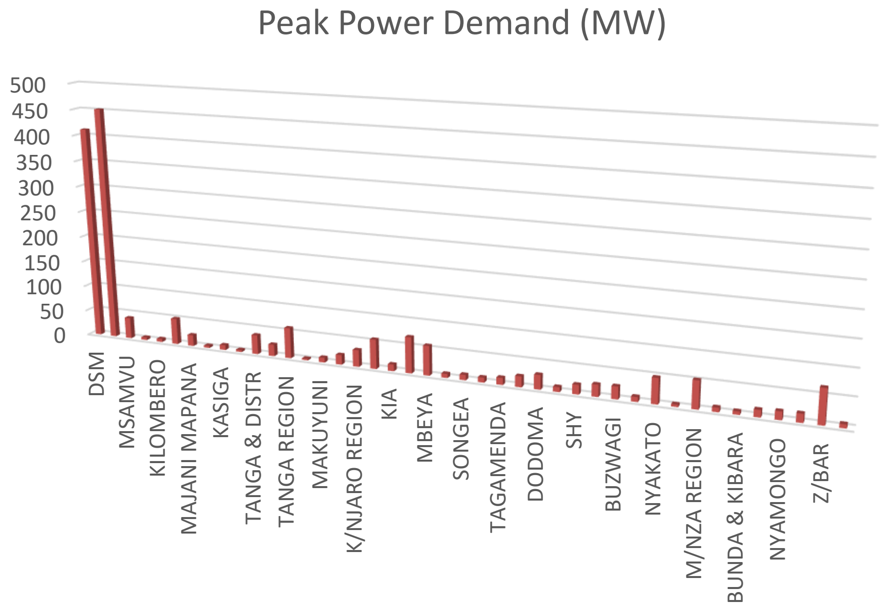


Figure 32- Peak Power Demand of the main primary substations.

4 TANZANIA’S GRID MODELING: APPROACH PROPOSED

The scientific contents of the proposed work are to be identified in the modelling of interacting electrical systems, in particular in the simulation of a relevant network and its interaction with regulated subsystems (i.e. microgrids). The approach used is a classical electrical engineering methodology for the purpose of modelling networks and statistic approach necessary to represent it.

The work has been divided into three main phases:

- The mathematical modelling of the transmission grid, in order to perform a load flow representing the current situation in Tanzania in the most realistic way possible.
- The Parameter estimation integrated with the sensitivity analysis for the investigation of errors committed in the calculation of the grid parameters.
- The mathematical modelling of the distribution grid, including the calculation of the hosting capacity, in order to understand the maximum amount of Distributed Generation allowed by the existing distribution grid.
- The definition of possible scenarios of integration between microgrids and the national grid, in order to demonstrate the feasibility to integrate microgrids and renewable technologies.

4.1 Transmission Grid Model

The transmission grid taken into consideration for this study is the one shown in Figure 33 and it has been taken from PSMP 2016 [12]. The image is representing the conditions of the electrical grid that should be in place at the end of 2020, when all the projects described in chapter 0 are expected to be concluded. In Figure 33 are shown the results of power flow analysis of the grid during peak load conditions and is the most complete representation of Tanzanian grid that could be found during the data collection process. However, as long as the network model is not available and the data shown in the Figure 33 image are not clearly visible, the subsequent work of grid modelling has been subject to some uncertainties.

In the Figure 33 it is possible to see the 400kV (blue line) transmission grid that is connecting the main network with the neighbouring countries and with the main Tanzanian primary stations; 220 kV transmission lines are represented in red, 132 kV line are in black colour and 66 kV lines in green.

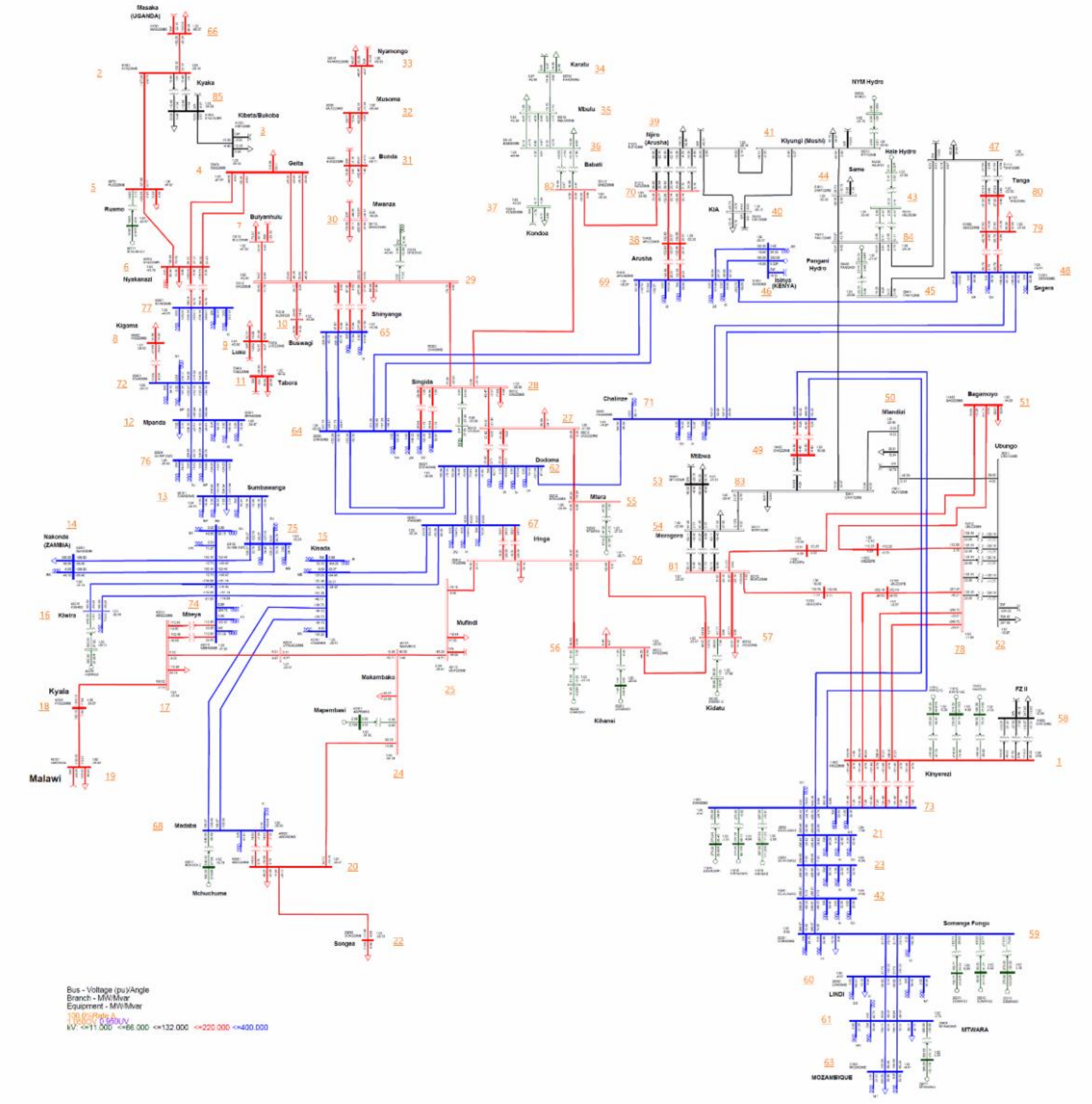


Figure 33- Scheme of the transmission grid at Peak Load (2020) [7].

The power generators are mainly concentrated on the borders of the grid and the maximum power generated comes from node nr.1 which is located within the Dar es Salaam area (the Kynierezi thermal plant showed in Figure 34) .

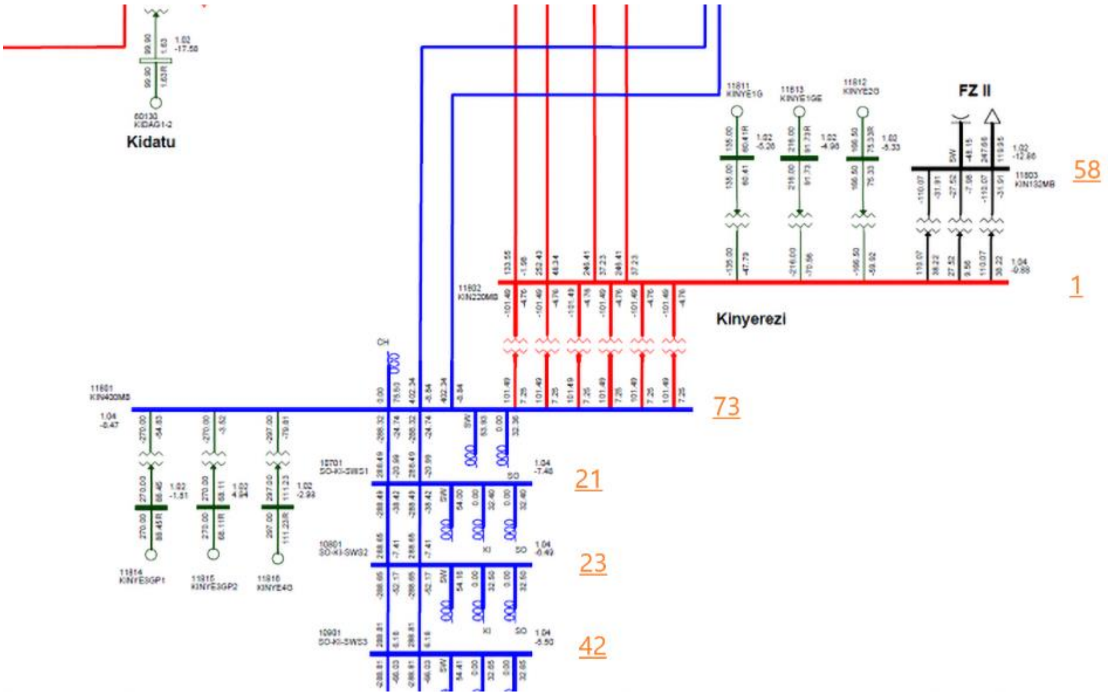


Figure 34- Detail of the Kynierezy themal plant

The total peak load considered is equal to 3536 MW, while the total generated power reaches 3573 MW. It is possible to notice the presence of many reactive power generators, especially on 400kV cables, which, as explained on Tanesco’s Master Plan 2016 [12] , have been added in order to have a basin of reactive power to be used depending on the grid conditions.

As described in the chapter of *Data Collection* data related to the network branches were possible to gather thanks to the collaboration with TANESCO (see APPENDIX A). A match between these information and the map reported in the Figure 33 has been made in order to have an overall picture of the grid at the end of 2020.

Important considerations must be made on the lengths of the cables. As shown in the sixth column in the table (APPENDIX A) some of them are longer than 100 km, in fact many of these projects share the aim of connecting rural areas to the main grid which currently rely on off grid solutions and are placed far away from urban centre. Some hypothesis have been made regarding the length and type of missing cables. The overall length has been determined considering the geographical distance between the primary stations; instead for the cable type, *Bluejay* has been selected, being the most used in more recent local projects.

This preliminary information allowed to calculate *R*, *X* and *B* parameters for each branch of the network. Since precise values regarding cable impedances were missing, a comparison with Italian standard has been made. Knowing the wires section and the material, it has been possible to compare the Table 5 and

Table 6 to determine the value of each parameter.

Table 5- Characteristic of the conductors used in Italy

Type	**MAX I**	**R_d**	**X_d**	**C_d**
Conductor	A	Ohm/ km	Ohm/km	nF/km
A1AA104	310	0.3133	0.4337	8.3494
A1AA148	390	0.2148	0.4168	8.6949
A1AA149	385	0.2211	0.4234	8.5620
A1AA173	420	0.1896	0.4066	8.9064
A1AA186	440	0.1764	0.4126	8.8436
A1AA209	605	0.1066	0.4025	9.0390
A1AA210	465	0.1655	0.4059	8.9030
A1AA214	480	0.1537	0.4172	8.9791
A1AA222	495	0.1477	0.3745	9.7518
A1AA228	485	0.1528	0.4143	8.7563
A1AA260	470	0.1697	0.4260	8.3828
A1AA299	605	0.1068	0.4067	9.0248
A1AA308	600	0.1068	0.3909	9.2881
A1AA428	720	0.0813	0.4230	8.6070
A1AA509	810	0.0685	0.4277	8.6066
A1AA585	920	0.0548	0.4016	9.1050
A1AA683	965	0.0518	0.4014	9.0952
A1AA708	1035	0.0454	0.3980	9.1666

Table 6- Characteristic of the conductors used in Tanzania

Voltage	**Conductors**	**Code**	**Cross Section (mm^2)**	**Number of Conductor**	**Capacity (MVA)**
400/220kV	**ACSR**	Bluejay	565	1	333
				2	666
				4	1,232
		Bison	350	1	207
		Pheasant	644	1	362
		Rail	483	1	303
132kV	**ACSR**	Wolf	150	1	74
		Hawk	241	1	121
		Tiger	130	1	66
	XLPE	-	300/400	-	143
		-	95	-	52
66kV	**ACSR**	Wolf	150	1	37
		Rabbit	50	1	18

In order to simplify the network and given the lack of information, some assumptions related to transformers modelling have been made. Transformers connecting generators with the grid have been considered negligible, so to decrease the number of branches and buses of the network (see fig. Figure 35).

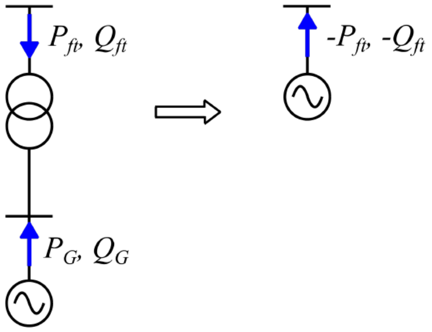


Figure 35-Transformer simplification in the study [8]

As for the transformers connecting branches at different voltage levels, they have been modelled as inductances, neglecting their resistive and capacitive behaviour (see Figure 36).

To determine the transformers' reactance given the reactive power flowing through (Figure 33), the equation has been applied.

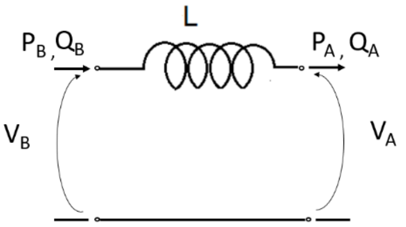


Figure 36- Simplified transformer model

$$X_L = \frac{(Q_A - Q_B) \cdot {V_B}^2}{({Q_B}^2 + {P_B}^2)}$$

The impedances values have been converted in PU (base 100 MVA) to obtain a unique grid connected by different voltages. The numerous reactances of the grid have been considered as PV nodes, to find their necessary input reactive power through load flow computations. The slack bus considered in the examined grid coincides with the bus Nr.55 which is a central node of the overall grid.

By taking in account this set of hypothesis the grid power flow has been calculated to determine the possible operating conditions and the overall network stability.

4.2 Parameter estimation

Since the grid parameters have been calculated through assumptions based on input data, which was partially missing or imprecise, the *Parameter estimation* method has been put in place in order to validate the analysed grid model.

The input data to the procedure are reported in Appendix B and consist of values of the active and reactive power flowing in the branches and of voltage magnitude at each node of the network, which were taken from the Figure 33.

4.3 Sensitivity Analysis

A further investigation about the grid parameters has been made through the sensitivity analysis. As explained in the paragraph 3, data collected to model the Tanzania's transmission grid were inaccurate or missing and various hypothesis had to be made in order to have a complete model. The assumptions made were mostly related to the length and to the type of the cables, as a matter of fact errors on them can have a great impact on the results of the study.

This procedure has the aim of understanding in which measure the estimation of such parameters has affected our initial calculation phase and how the errors committed in the initial phase can impact on the overall operating conditions. The analysis has been conducted on the parameters of the lines (*R*, *X* and *B*) , they have been modified in the range of +/- 30% of the value considered at the beginning (Table 7), taking fixed the overall grid condition. They have been changed as reported in the Table 8:the study has been conducted just on the *Bluejay* cables because they are the main type used for the overall grid (70%).

Table 7- Parameters used for the power flow analysis

Type of Conductor	**R (ohm/km)**	**X (ohm/km)**	**B (ohm/km)**
Bluejay	0.056	0.4016	2.86042 e-06

Table 8- Range considered for all the parameters

(ohm/km)	**R-**	**R+**	**X-**	**X+**	**B-**	**B+**
Bluejay	0.0392	0.0728	0.28112	0.52208	2.002E-06	3.7185E-06

4.4 Distribution Grid model and Hosting Capacity calculation

After the implementation of the transmission grid model, the distribution grid has been analysed, so to have a comprehensive vision of Tanzania's power system. The goal of the study is to have both an overall picture of the system as of today and to understand how the future plans aimed to increase the electricity access rate in the country can have an impact on it.

The collaboration with the DIT gave the opportunity to collect enough data to have a model of the medium-voltage grid. Moreover, in the Mini-Grid Information Portal [21], data related to medium voltage distribution lines and to micrograds installed in the country are reported. Data are related both to the grid currently in place and to microgrid expansion projects, as reported also in the paragraph 1.4.

Starting from data collected, a portion of the medium voltage grid has been modelled, and the hosting capacity has been evaluated. The calculations allowed to make a first rough estimate of the total amount of distributed generation that would be possible to connect to Tanzania’s power system.

During the Data Collection phase, it was possible to understand that even DSO themselves do not have complete and totally reliable information related to the distribution grid, meaning that all the data provided are subject to inaccuracy. For this reason, the distribution grid has been modelled through the new procedure described in 2.4 as long as it allows to have accurate results with few input information.

The most complete data gathered are related the Dar es Salaam distribution grid, mostly taken from the Power System Plan made by JICA; for this reason, and considering that Dar es Salaam is the biggest electrified area in the country, this grid was taken as the reference one for the study. The combination of data taken from the JICA study and the information collected with TANESCO and DIT, made it possible to define a 33 kV distribution grid as reported in the APPENDIX C. The primary station considered is the facility of Ubungo, which is the one connected to the thermal plant in Kynierezi. To this node are connected 9 main feeders: the first one is the principal and has many collateral feeders exiting from it, while the remaining 8 are shorter with less nodes and collateral. The Figure 37 is showing a schematic view of the portion of the grid considered.

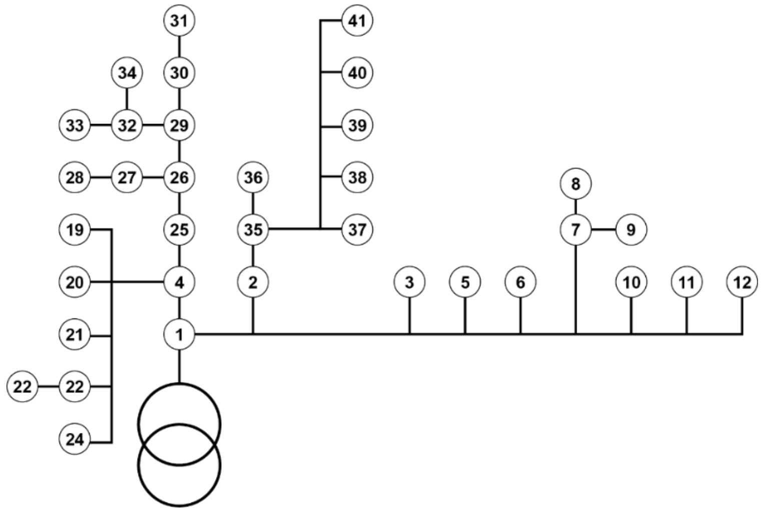


Figure 37-Schematic view of the distribution grid of Dar es Salaam

To analyse the hosting capacity of this distribution grid the two following steps have been conducted:

- Simplification of the distribution grid using the bricks approach and defining a short, medium, long feeder and a short and long collateral.
- Calculation of the hosting capacity of all the bricks rearranged creating different configurations.

Bricks Approach

The *Bricks Approach* allows to create a model of the distribution grid and to calculate the hosting capacity even when data of the overall grid are missing, as highlighted in the literature review (par 2.4). Since the data gathered through the field research and through existing publications are qualitatively poor, even the calculation of the exact parameter could be biased and could provide results with an excessive deviation. The simplification obtained with this method allows to analyse the network even with the relatively low data availability.

The information gathered shows that the distribution lines in Tanzania consist of overhead and underground cables, compliant with the TANESCO standard shown in the Table 9.

Table 9- Cable’s parameters used in the distribution grid

Code Name	Nominal Area	DC Resistance 20°C	Current Rating
	(mm^2)	**(ohm/km)**	**(A)**
Rabbit	50	0.5426	185
Dog	100	0.2733	278
Wolf	150	0.1828	355
Dingo	150	0.1815	349

Knowing the length and the type of the cables, the impedances of all the branches have been calculated and reported in APPENDIX C in the Table 29. These parameters are the starting point for the bricks approach. Once the impedance branches were determined, the short/medium/long feeders of the grid and the short/long collaterals have been defined as reported in the following paragraphs.

Short Feeder

The subdivision of each feeder depends on the length of the cables, the number of nodes and their impedance. The Table 10 represents the parameters for the short feeder branch.

Table 10- Parameters of a short feeder

Short Feeder		R (pu)	X (pu)
1	**2**	0.003141	0.002911
2	**3**	0.012709	0.011775
3	**4**	0.012709	0.011775

Long Feeder

The only long feeder in the model is the Nr 3. The Table 11 represents the parameters taken in consideration for the long feeder.

Table 11- Parameters of a long feeder

Long Feeder		**R (pu)**	**X (pu)**
1	**2**	0.054288	0.048723
2	**3**	0.219618	0.197107
3	**4**	0.219618	0.197107

Short and Long Collateral

Following the *Bricks approach*, branches considered as collateral in relation to the main feeder must be added to the grid depending on their impedance. Collaterals are subdivided in short and long collaterals and they are added to the grid by considering their position in the distribution grid. In Table 12 is reported the parameters calculated for the short collateral and in the Table 13 is reported the parameters calculate for the long collateral.

Table 12- Parameters values of a short collateral

Short Collateral		**R (pu)**	**X (pu)**
2	5	0.0414	0.0475

Table 13-Parameters values of a long collateral

Long Collateral		**R (pu)**	**X (pu)**
2	5	0.2439	0.2667
5	8	0.2439	0.2667

Hosting Capacity

The hosting capacity of the grid is calculated considering all the possible configurations, following the flowchart reported in the Figure 23 in the literature review (2.3). In addition to the topology of the grid the calculation was possible knowing the load of the primary station in Dar es Salaam. As reported in *Data Collection* paragraph, the information about the peak power demand was directly given by TANESCO, the mean and low value were consequently determined through the data reported in the JICA plan [1].

It is important to mention that for the computation of the hosting capacity the three performance indexes previously mentioned in the literature review (2.3) – steady state voltage variations, rapid voltage change and the line thermal limit – have been considered. The most limiting factor of the three has been taken in consideration, in this case it was the thermal limit of the cables, so the flowing current has been imposed as lower than 355A.

4.5 Tanzania Evolution Scenario

After the modelling of the transmission and distribution grid, in order to have an overall picture of the Tanzanian power system different evolution scenarios, where DG can have a primary role in meeting the energy needs of the country, have been analysed. In particular the overall distribution grid have been integrated with possible future scenario in order to have first comprehensive of the evolution of the power system.

As shown in the energy policy paragraph 1.4 Tanzania has different strategic plans that are predicted to increase GDP growth rates. By considering these economic strategies three different scenarios can be assumed.

The first one is the “HIGH” scenario where the Vision 2025 will be achieved and a high economic growth will occur thanks to the development of natural gas and related industries. The second one, the “BASE” scenario, assumes that the two main factors that will drive the economic growth will be the population growth increase and labour productivity increase. This trend will increase the GDP until 2025 where the growth will levelize. The last one is the “LOW” scenario, where the domestic economic conditions will be similar to the BASE scenario but international and economic conflicts will have negative effect on Tanzanian economy.

The predictions made by TANESCO in the Master Plan 2016 [12] are reported in the following tables. Table 14 reports the forecasted GDP growth rate for each scenario. Table 15 shows the dispatched energy forecast and the Table 16 the peak power demand.

Table 14-GDP growth rate by each scenario (%)

	2013/ 15	2015/ 20	2020/ 25	2025/ 30	2030/ 35	2035/ 40
HIGH	7.0	8.0	8.0	8.0~ 10.0	8.0~ 10.0	8.0~ 10.0
BASE	7.0	7.0	7.0	6.0	6.0	5.0
LOW	7.0	6.0	6.0	5.0	5.0	4.0

Table 15-Dispatched Energy Forecast (MW)

Year	High	Base	Low
2015	6,310	6,310	6,310
2016	7,870	7,820	7,640
2017	9,070	8,970	8,650
2018	10,460	10,270	9,780
2019	12,040	11,740	11,060
2020	13,840	13,440	12,470
2025	24,640	22,430	19,450
2030	45,270	36,000	29,250
2035	82,830	57,340	43,660
2040	145,470	87,890	63,090

Table 16-Peak power demand forecast (MW)

Year	High (MW)	Base (MW)	Low (MW)
2015	974	974	974
2016	1,280	1,270	1,250
2017	1,480	1,460	1,410
2018	1,700	1,680	1,600
2019	1,960	1,920	1,800
2020	2,260	2,190	2,030
2025	4,020	3,660	3,170
2030	7,380	5,870	4,770
2035	13,510	9,350	7,120
2040	23,720	14,330	10,290

Table 17- Regional peak demand BASE scenario (MW)

(MW)	2015	2016	2017	2018	2019	2020	2030	2040
Dodoma	20	25	29	33	38	44	105	246
Arusha	55	77	94	116	140	161	398	928
Kilimajaro	24	32	36	43	52	57	115	260
Tanga	44	53	59	67	76	104	259	628
Morogoro	39	48	54	61	69	82	211	490
Pwani	24	41	50	60	69	79	275	670
Dar es Salaam	459	561	632	715	797	873	2,216	5,276
Lindi	3	5	7	9	12	16	46	126
Mtwara	7	9	8	11	13	15	55	163
Ruvuma	5	6	8	10	12	14	69	200
Iringa + Njombe	18	21	23	27	30	35	94	233
Mbeya	33	49	59	70	80	91	243	586
Singida	6	8	9	10	11	14	42	113
Tabora	19	28	39	50	61	72	246	752
Rukwa + Katavi	3	5	6	8	10	12	36	118
Kigoma	4	7	12	16	21	25	82	208
Shinyanga + Simiyu	70	85	93	102	114	116	324	889
Kagera	10	17	24	32	43	42	152	426
Mwanza + Geita	47	66	85	103	121	153	476	1,180
Mara	24	30	36	42	48	63	181	464
Manyara	4	5	6	7	8	9	18	35
Mainland total	**917**	**1,176**	**1,368**	**1,591**	**1,823**	**2,078**	**5,644**	**13,989**
Zanzibar	58	70	81	92	102	112	228	342
Total	**974**	**1,246**	**1,449**	**1,683**	**1,925**	**2,190**	**5,872**	**14,332**

Data regarding the total load of the country with these three possible scenarios gave the possibility of making a comparison between the increase of electricity demand and the total hosting capacity of the distribution grid.

Knowing the hosting capacity of the Dar es Salaam 33kV distribution grid, a proportional estimation, based on distribution grid length, has been made in order to have a rough approximation of the total hosting capacity. The overall length of the distribution grid has been taken from the website of the Mini-Grids Information Portal [21]. In the Figure 38 it is reported the topology of the distribution grid now in place (blue lines) and Figure 39 shows the new lines that will be installed by the end of 2020 (green lines and blue lines). In the first case the total length is equal to 31800 km and in the second case the total distribution line length is equal to 64300 km. The Dar es Salaam distribution grid modeled previously has instead an overall line length equal to 1047 km.

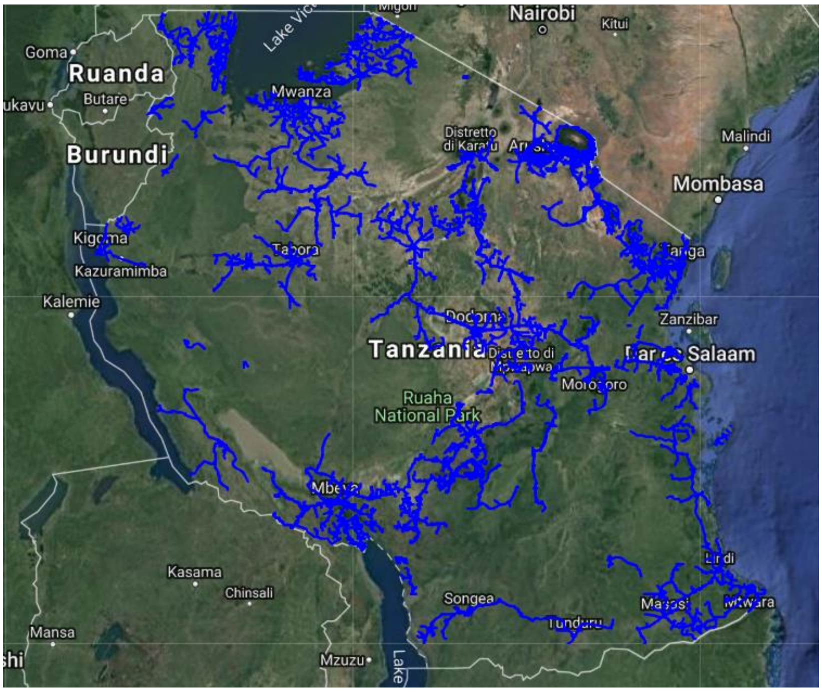


Figure 38- Tanzania Microgrid in the 2019

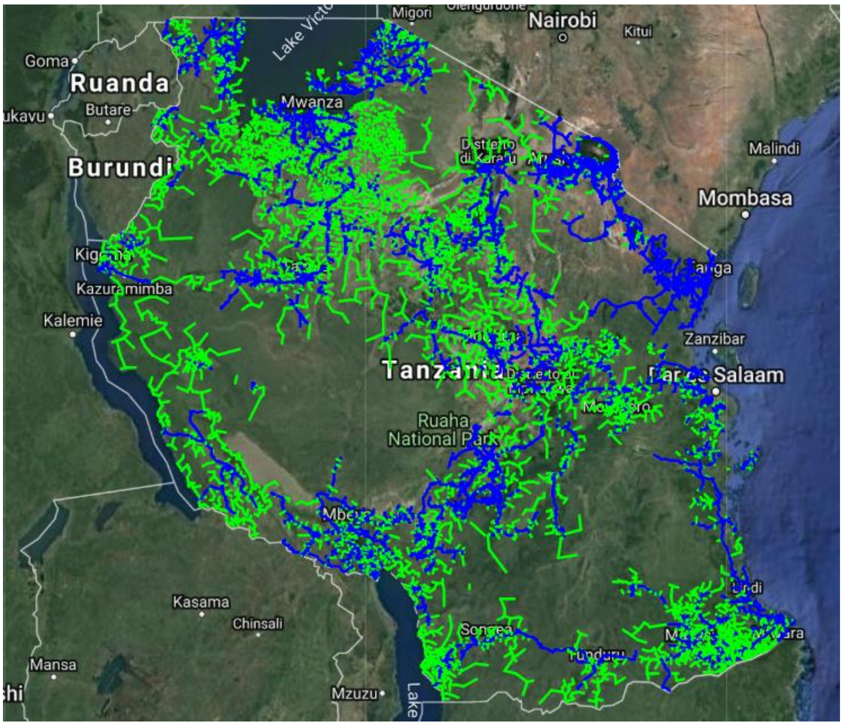


Figure 39-Tanzania Microgrid in the 2021

5 RESULTS

5.1 Transmission Grid Model

As described in the paragraph 4.1, the first analysis consisted in a comparison between the operating conditions of the transmission grid reported in the Figure 33 and the power flow analysis calculated through data collected in Tanzania from the TSO. The assessment has been done on the nodal phasor of the grid, in particular on their module and on the nodal injections at the equilibrium point of the system.

Figure 40 shows a comparison between the voltage modules at each node resulting from the load flow analysis (orange lines) and the ones reported in Figure 33 (blue lines) .

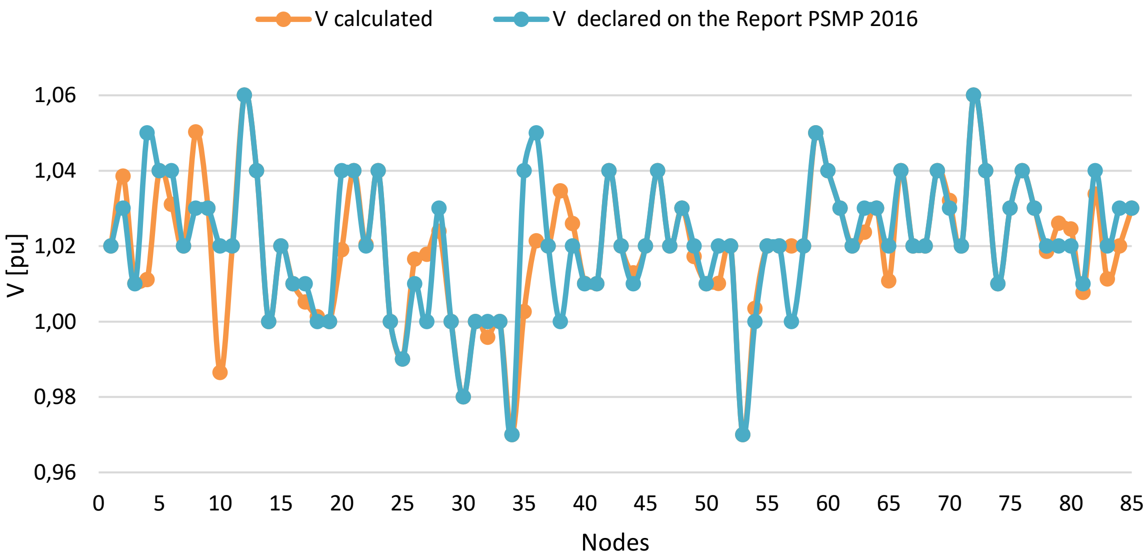


Figure 40- Results of the voltage profiles (p.u.)

Th overall outline is showing a good result, all the values are within the nominal range of the (0.94, 1.06). The percentage error between the two profiles is shown in Figure 41.

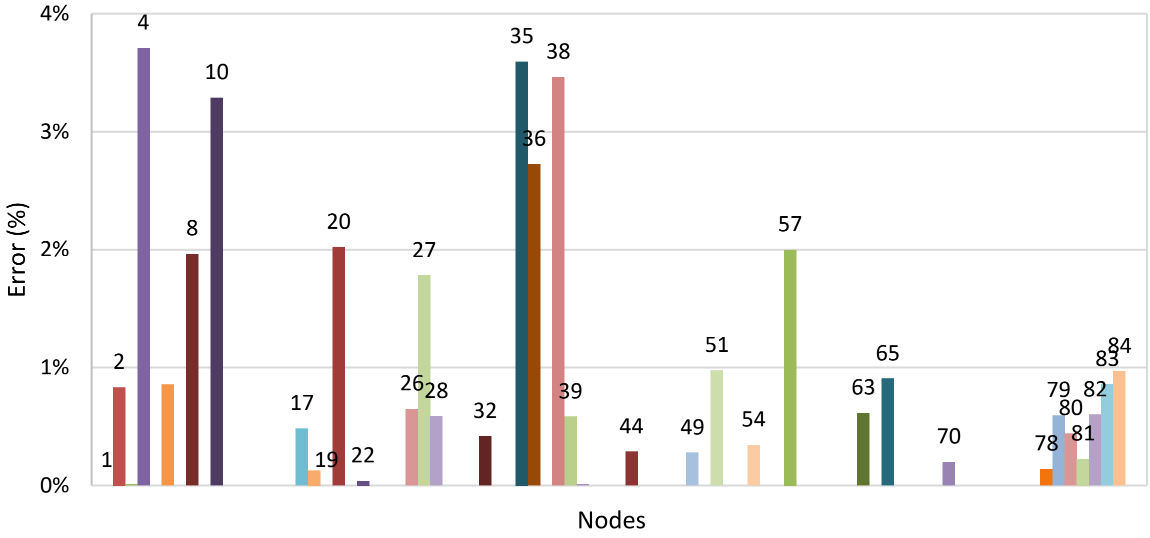


Figure 41-Error between the two voltage profiles (%)

All the nodes with errors are the one modelized in the map as P Q bus and so with a fixed reactive and active power but with a variable voltage in order to balance the grid. Some of them have error lower than the 1%, in node 4, 10, 35, 38 the error is between the 3% and the 4%, no node is exceeding the 4%.

The second comparison is about the power profile of both active and reactive power. The power flowing in each branch resulting from load analysis has been compared to the one reported in the grid map. Figure 42 and Figure 43 show the active and reactive power exiting from each node.

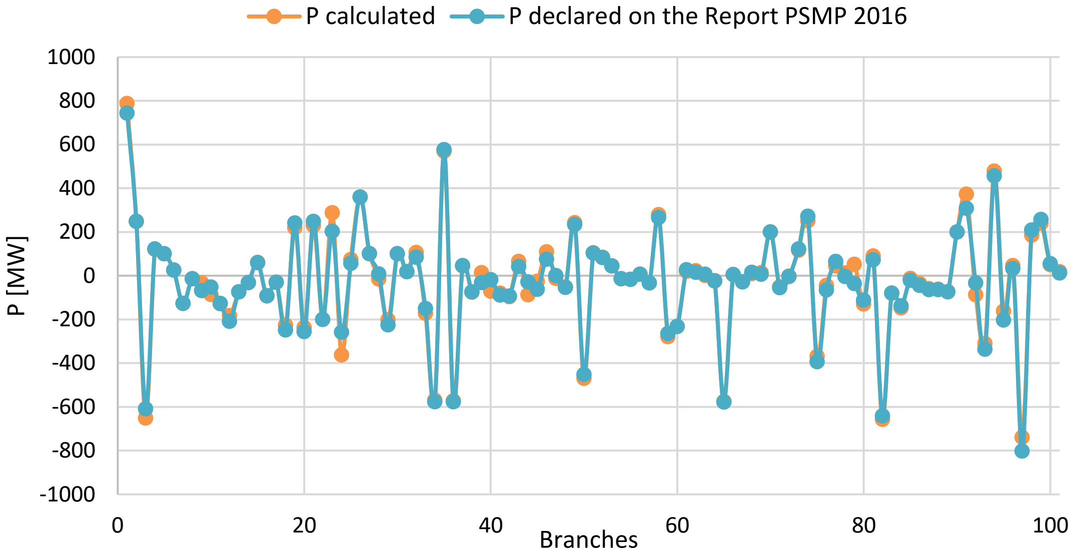


Figure 42- Comparison between the active power at the beginning of each branch

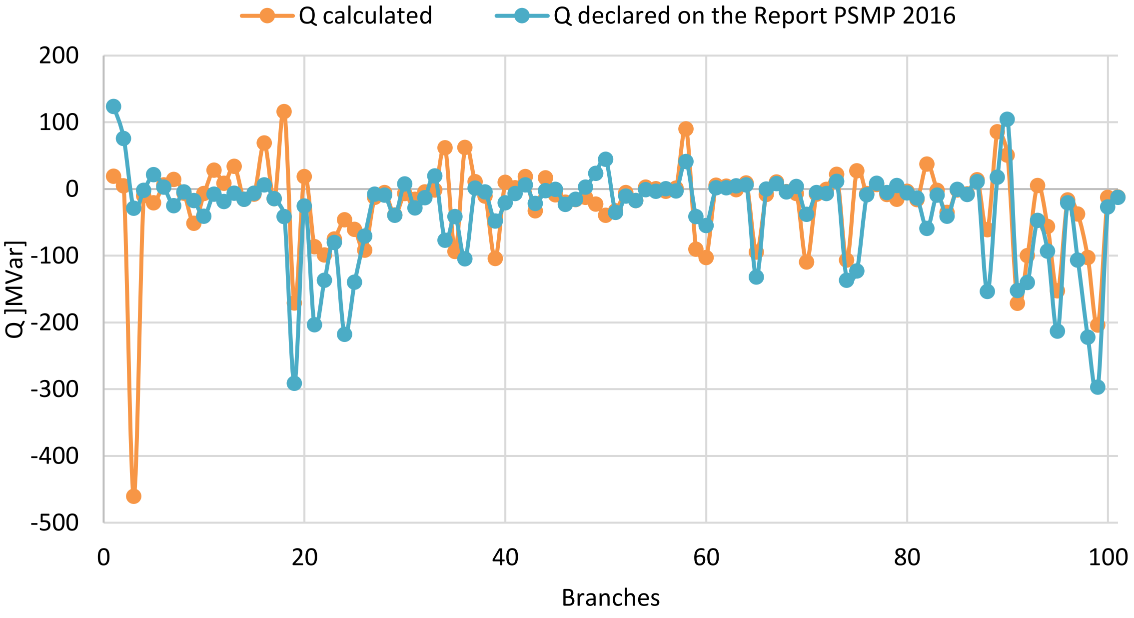


Figure 43- Comparison between the reactive power at the beginning of each branch

Both figures are showing that the overall power flowing in the branches is lower than the one expected. The only exception is regarding the reactive power of the branch number 3 which is the branch connecting the two primary stations of Kynierezi (220 kV – 132 kV).

This means that the reactive power considered flowing in that region is higher than the one expected and so in this area the compensation made with reactances is underestimated.

Another consideration is about the grid parameters that were calculated from the geographical overview. As shown, the active power has a behaviour very close to the starting one, this fact could evidence that the estimation of the resistance is or close the real one or not influencing the overall trend. Instead, regarding the reactive power there is a high discrepancy meaning that in any case the suscettance and inductance have more effect on the operating conditions.

In the following graph, for the sake of completeness, the active and reactive power entering the nodes are reported: , those slightly change from the previous one because of the losses in the branches.

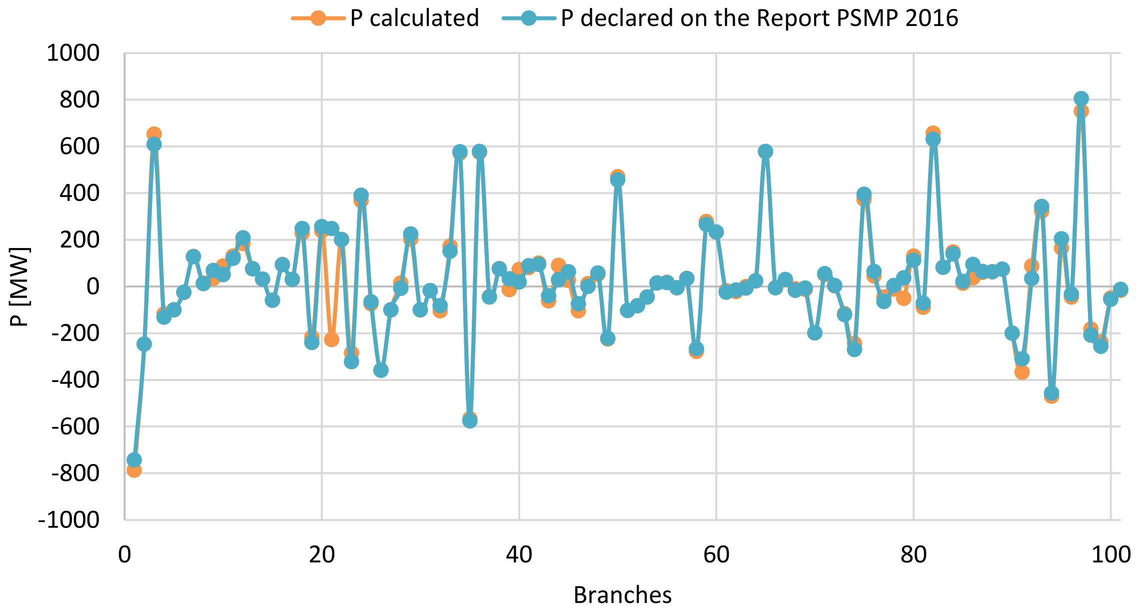


Figure 44-Comparison between the active power at the end of each branch

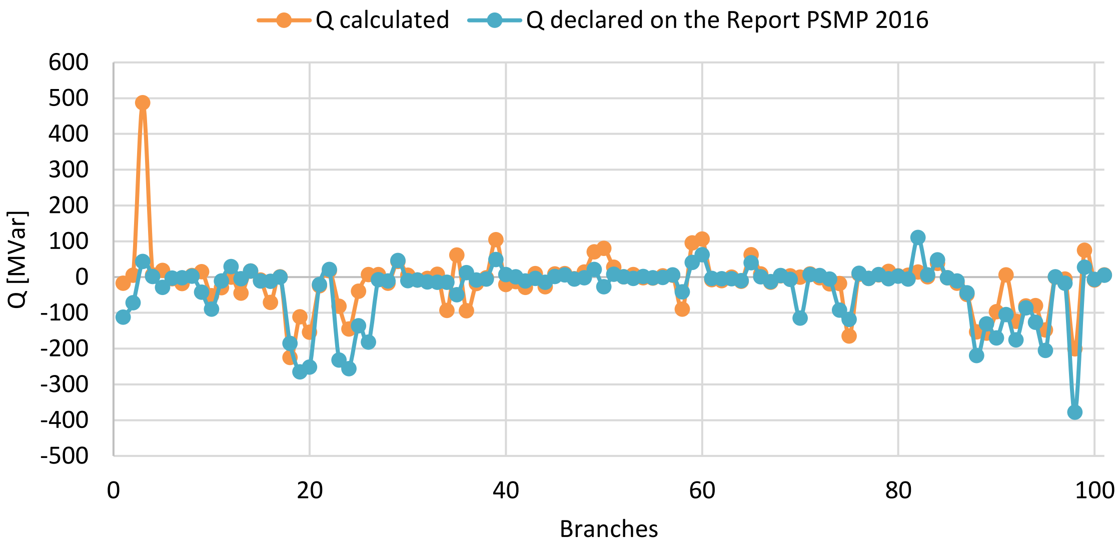


Figure 45- Comparison between the reactive power at the end of each branch

The result of the current flowing in branches has been compared with maximum current allowed I_{max}.

In the Figure 46 it is reported the percentage ratio between the branch current and the maximum limit. It is important to observe that different type of wires have different maximum values, for this reason the comparison has been made in percentage. The graphic shows that almost all the branches have a current lower than half of the maximum value, the worst case is the branch number 49 that consists in the line connecting Shynyanga e Mwanga: this is a single cable which is connecting two primary substations of 220 kV put in place in the 1988, the type conductor is *Bison* which has a cross section lower than the cables now installed.

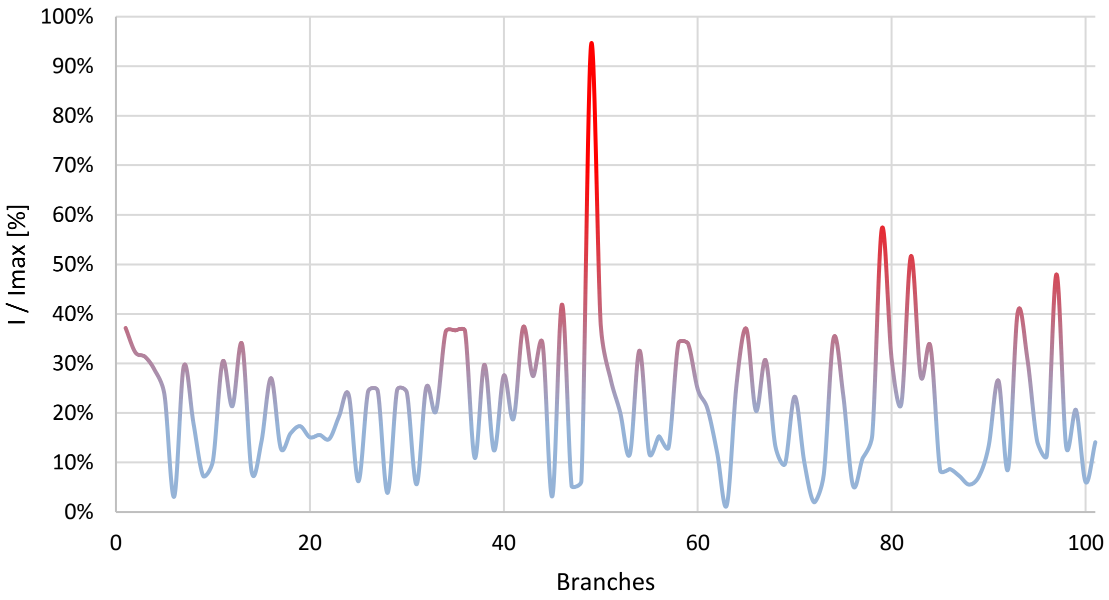


Figure 46- Currrent flowing in each branch compared to the maximum one

Finally, it has been investigated the reactive power of the generators. In the modelling of the grid the main problem was the analysis of all the reactances present in the map. To overcome this issue the solution was to put all that nodes as PV bus in order to understand the real reactive power injected to compensate the grid. The comparison between power flow results and input data is shown in the Figure 47: it is possible to notice that the overall reactive power requested by the generators is lower than the one reported on the map.

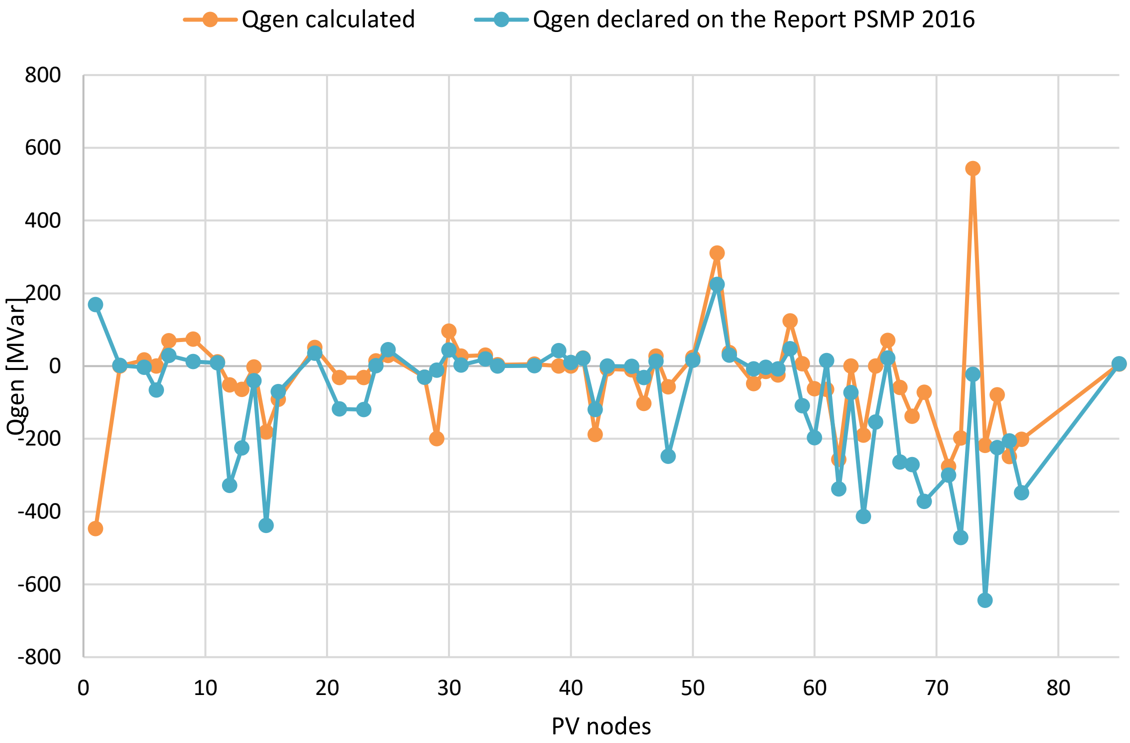


Figure 47- Comparison between the reactive power of the generators

5.2 Parameter Estimation

As described in the literature, the *Parameter estimation* method can be used in the evaluation of the grid parameters. Starting from the voltage at each node and the power flowing in each branch of the grid, it is possible to estimate the various measures of the grid: R, X and B.

This procedure permits the validation of the values calculated in the first part of the power flow. In this computation problems arose because the mathematical model was unable to find *global minimum values*, the only possible solution was the *local minimum value* and the final comparison has been based on this results.

The unsuccessful results can be explained with considerations previously made, as information about the grids is partially unreliable. The comparison has then been made between the local minimum values retrieved and the parameters evaluated through tables and data available. In the Table 18 below is reported the errors between the values for the three parameters (R, X and B).

Table 18- Difference between the parameters estimated and measured

Branch	err_R	err_X	err_B	**Branch**	err_R	err_X	err_B
1	0.87	0.87	0.37	**52**	0.04	0.04	0.06
2	1.00	0.54	1.00	**53**	0.00	0.00	0.12
3	1.00	1.36	1.00	**54**	0.00	0.00	0.04
4	0.01	0.01	0.10	**55**	0.00	0.00	0.19
5	0.15	0.15	0.12	**56**	0.00	0.00	0.12
6	1.00	0.00	1.00	**57**	1.00	0.00	1.00
7	0.01	0.01	0.13	**58**	0.99	0.99	0.15
8	0.00	0.00	0.11	**59**	1.00	0.62	1.00
9	0.04	0.04	0.13	**60**	1.00	0.04	1.00
10	0.03	0.03	0.15	**61**	0.01	0.01	0.10
11	0.03	0.03	0.11	**62**	0.01	0.01	0.09
12	1.00	#####	1.00	**63**	0.00	0.00	0.07
13	0.02	0.02	0.10	**64**	0.00	0.00	0.10
14	1.00	0.03	1.00	**65**	1.41	1.40	0.15
15	0.00	0.00	0.11	**66**	0.98	0.98	0.87
16	0.10	0.11	0.09	**67**	0.00	0.00	0.10
17	0.02	0.02	0.14	**68**	0.03	0.03	0.04
18	5.11	5.07	0.13	**69**	0.00	0.00	0.09
19	0.36	0.37	0.11	**70**	1.26	1.26	0.10
20	0.45	0.46	0.11	**71**	1.00	0.00	1.00
21	3.17	3.16	0.13	**72**	0.00	0.00	0.10
22	0.12	0.11	0.12	**73**	1.00	0.32	1.00
23	1.61	1.64	0.16	**74**	0.09	0.09	0.11
24	4.33	4.37	0.19	**75**	0.22	0.22	0.19
25	0.62	0.62	0.19	**76**	1.00	0.29	1.00
26	3.06	3.05	0.20	**77**	1.00	0.00	1.00
27	0.03	0.03	0.09	**78**	0.00	0.00	0.00
28	0.00	0.00	0.10	**79**	0.02	0.02	0.01
29	1.00	0.52	1.00	**80**	0.28	0.27	0.04
30	0.44	0.44	0.08	**81**	0.03	0.03	0.10
31	0.00	0.00	0.15	**82**	1.00	#####	1.00
32	0.01	0.00	0.12	**83**	0.00	0.00	0.06
33	1.00	0.50	1.00	**84**	1.00	0.10	1.00
34	1.80	1.81	0.33	**85**	0.00	0.00	0.11
35	0.93	0.93	0.01	**86**	0.00	0.00	0.12
36	0.23	0.22	0.30	**87**	0.03	0.03	0.14
37	0.01	0.01	0.10	**88**	0.50	0.50	0.15
38	0.00	0.00	0.09	**89**	0.06	0.06	0.16
39	1.00	0.89	1.00	**90**	0.71	0.71	0.14
40	0.00	0.00	0.12	**91**	9.37	9.27	0.08
41	0.00	0.00	0.09	**92**	0.41	0.41	0.11
42	0.00	0.00	0.08	**93**	0.05	0.05	0.09
43	0.00	0.00	0.09	**94**	0.63	0.66	0.06
44	0.00	0.00	0.09	**95**	0.15	0.15	0.08
45	1.00	0.37	1.00	**96**	0.00	0.00	0.11
46	0.00	0.00	0.06	**97**	2.03	2.05	0.17
47	0.00	0.00	0.09	**98**	0.21	0.20	0.09
48	1.00	0.02	1.00	**99**	38.38	37.73	0.11
49	0.03	0.03	0.03	**100**	0.26	0.26	0.14
50	1.00	1.89	1.00	**101**	0.00	0.00	0.13
51	0.00	0.01	0.12				

5.3 Sensitivity Analysis

The sensitivity analysis is devoted to investigate which parameter determined by a geographical overview can have an impact on the operating conditions of the grid and how it influences the performances. The study has been conducted on *R*, *X* and *B* parameters focusing on the change of behaviour of the voltage profile.

Focusing on *R* It's possible to notice that bus voltage modules do not change significantly with the increase of line resistance. In some nodes, especially the one not compensated by reactive power injections, voltage decreases slightly with the increase of resistance with a maximum delta equal to +-0.2% with respect to voltage at equilibrium condition.

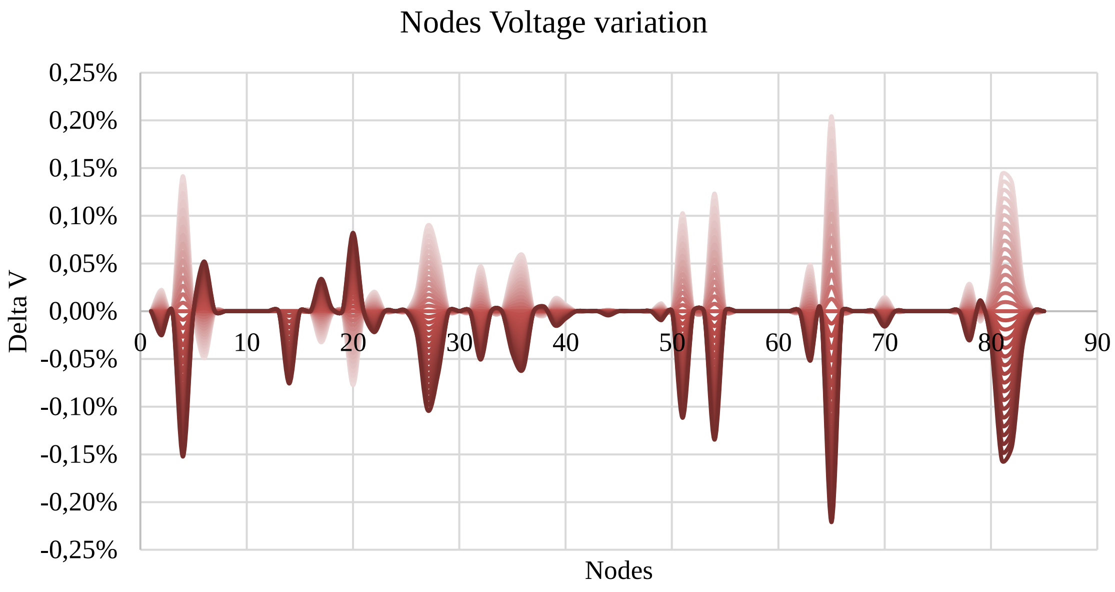


Figure 48- Percentage of voltage variation changing R

P in the slack bus increases linearly with the increase of line resistances. The reason for that is that as line resistances increases, active losses increase and so the slack bus must provide a higher power for compensation, being active power in all the other nodes fixed.

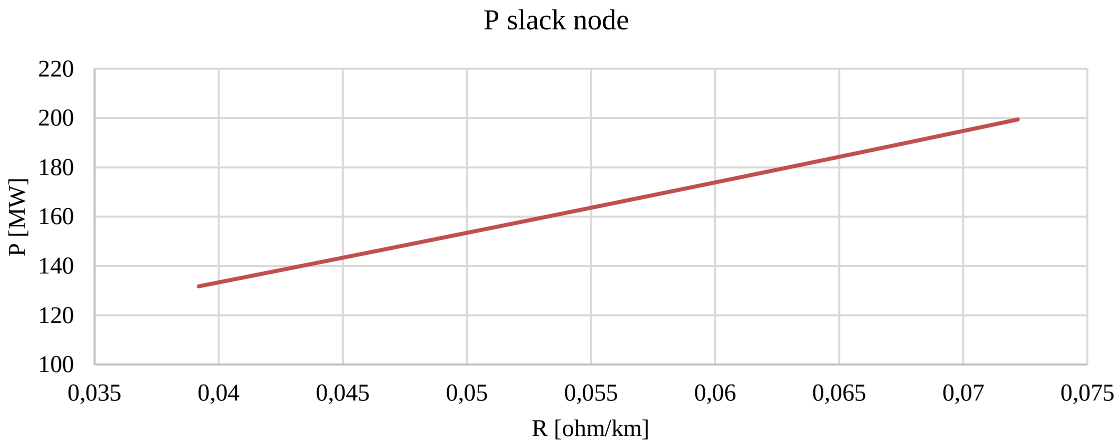


Figure 49- Changing of P slack node varying R

Current flow depends on the type of cable. *Bluejay* wires experience a decreasing current with the increase of resistance: the maximum variation is shown by cable 45 with I=I_eq +-36%. The other wires, whose resistance was kept constant, show the opposite trend and bear a higher current flow when *Bluejay* resistance is increased. The overall profile shows that the current is slightly effected by R (in the Figure 50 the bold line is with the higher value of R considered).

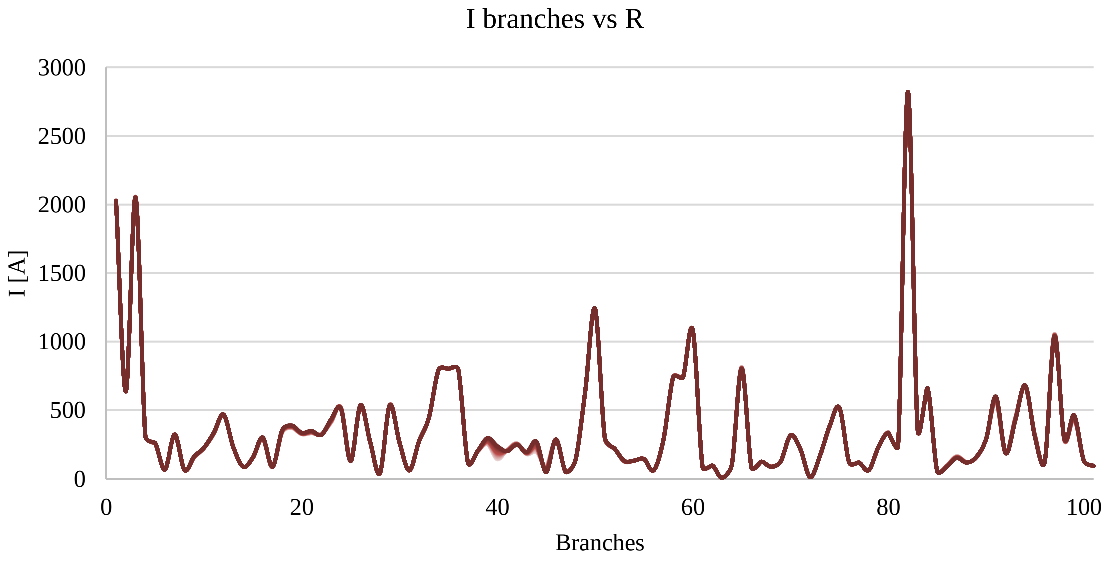


Figure 50- Current flowing in the branches varying R

Regarding the study conducted on the inductance, the node voltages tend to decrease as impedance losses increase, i.e. with the increase of X. The maximum total variation is equal to 0.30% when increasing or decreasing X around the equilibrium point. (see Figure 51).

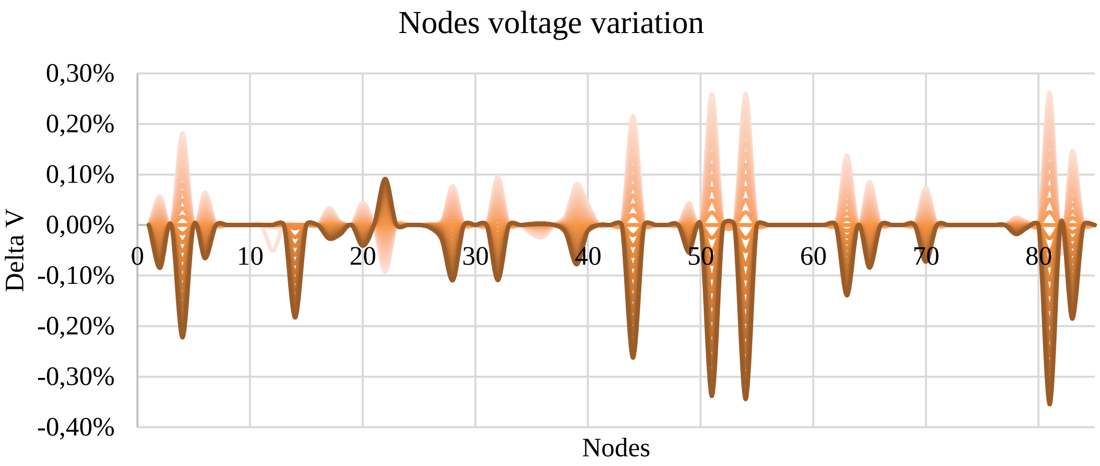


Figure 51-Percentage of the nodes voltage variation varying X

As X increases, the total reactive power provided by the generators must increase as shown in the Figure 52 in fact the bolder is representing the reactive power with the maximum value of the inductance considered. An exception is represented by nodes 9 and 11 that are PQ bus compensate with capacitances.

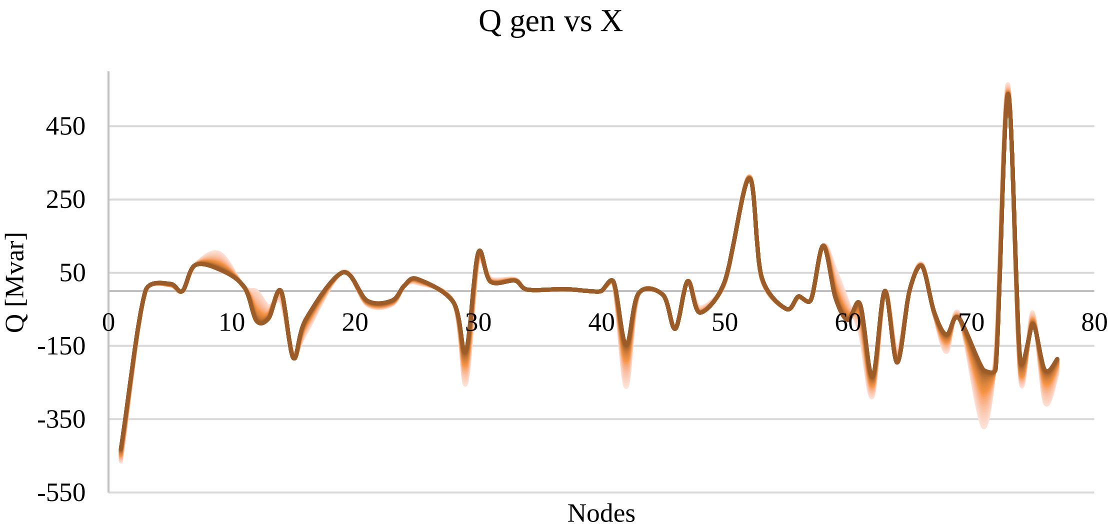


Figure 52- Reactive power of the generators varying X

With respect to the *B* parameter, the reactive power injected increasing shunt capacitances leads to an increase in node voltage modules. The maximum variation detected is +- 80%.

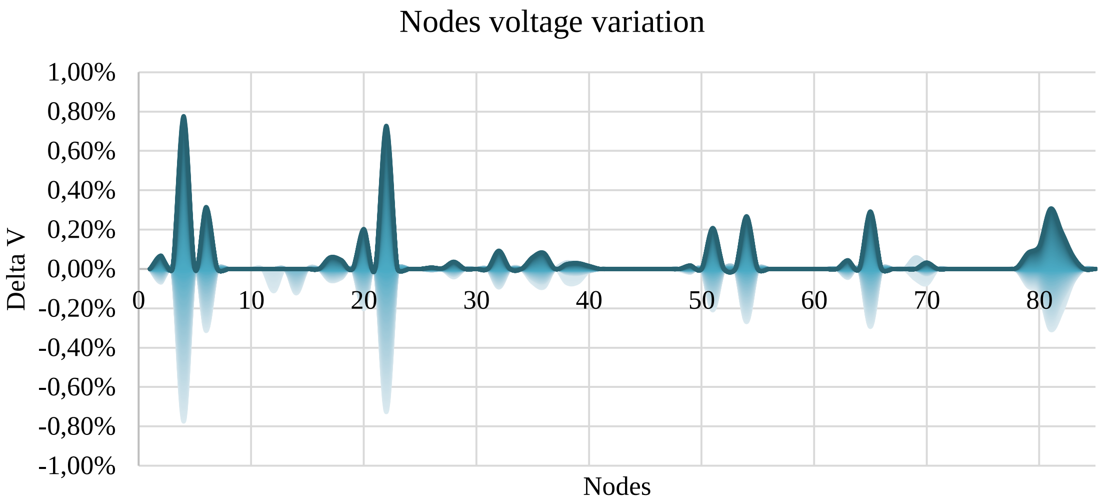


Figure 53- Percentage of the nodes voltage variation varying B

Reactive power provided by generators and compensating reactances decreases as shunt capacitance increase, in the figure is shown this behaviour with the bold line that consists in the reactive power with the higher value of *B* considered. Increase in shunt capacitance leads in fact to an increase of reactive power injected that is not requested anymore to generators. The change is particularly big in nodes where are present the compensating reactances.

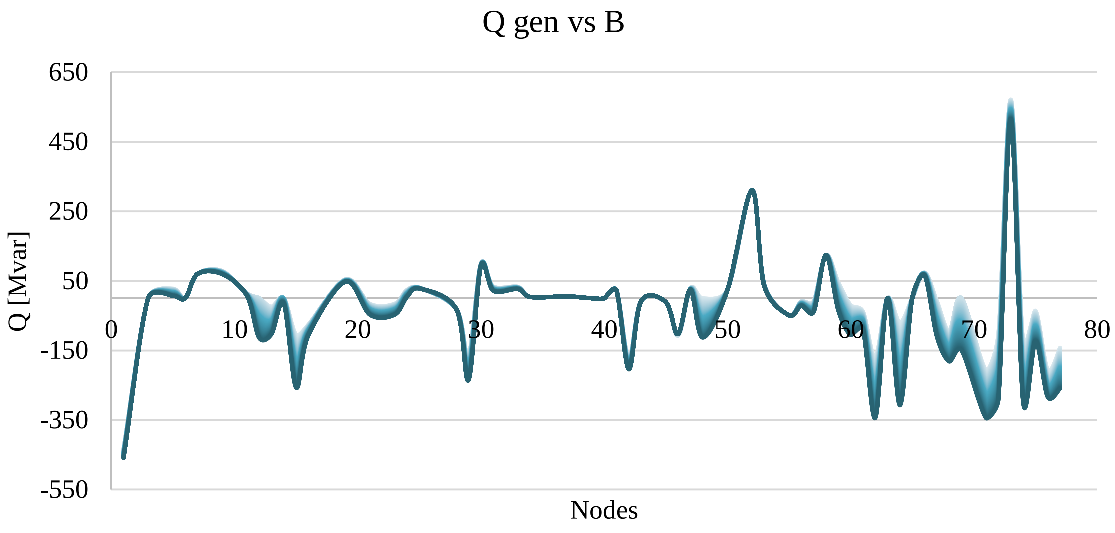


Figure 54- Reactive power of the generators varying B

At the end the sensitivity analysis shows that the parameters investigated aren’t significantly affecting the operating conditions of the grid. For this reason it’s possible to state that the model of the Tanzanian grid is validated.

5.4 Hosting Capacity

As previously explained, data collected on the distribution grid made possible the implementation of the actual network in the Dar es Salaam region with a mathematical model called the “Bricks Approach”. As previously explained, thanks to the *Bricks approach* the initial grid configuration is been simplified and used as starting point for hosting capacity calculations.

After the definition of the simplified grid the hosting capacity is calculated according to the feeder considered. In the case analyzed the grid was composed only by short and long feeders and the possible combinations depend on the feeder in question.

The Figure 55 and the Figure 56 below is showing respectively the overall impedence for each feeder and the overall impedence for each collateral.

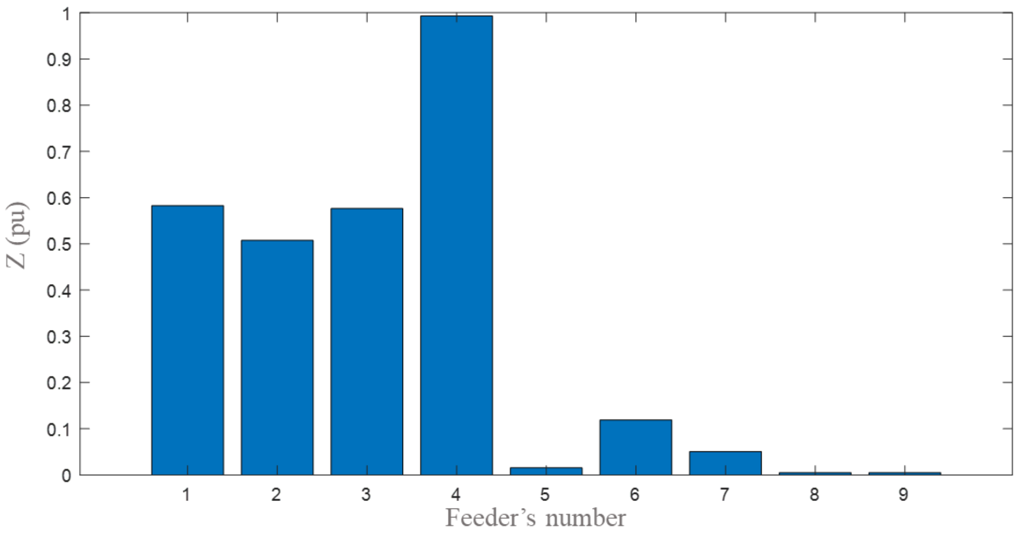


Figure 55- Total impedance in each feeder (pu)

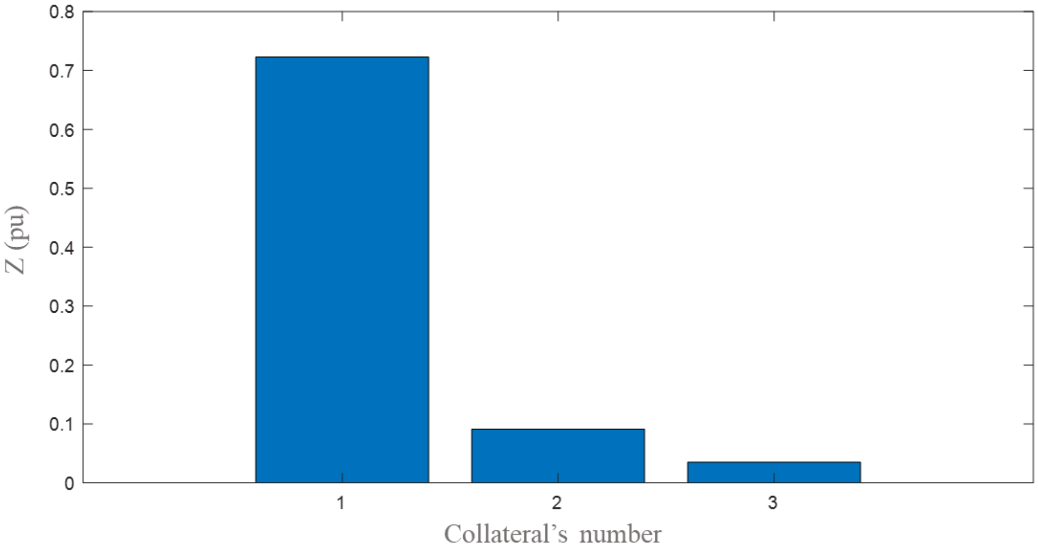


Figure 56-Total impedance in each collateral (p.u.)

In the Table 19 below is reported the maximum and minimum value of the hosting capacity for each node of the short feeder, graphically reported in the Figure 57. Data are consistent with the fact that the hosting capacity is higher in the first node and is decreasing for the other nodes.

Table 19-Hosting Capacity of a Short Feeder

(MW)	**Short Feeder**	
	Min	**Max**
Node 1	7.3085	8.1795
Node 2	7.0575	7.6385
Node 3	6.8055	7.0965

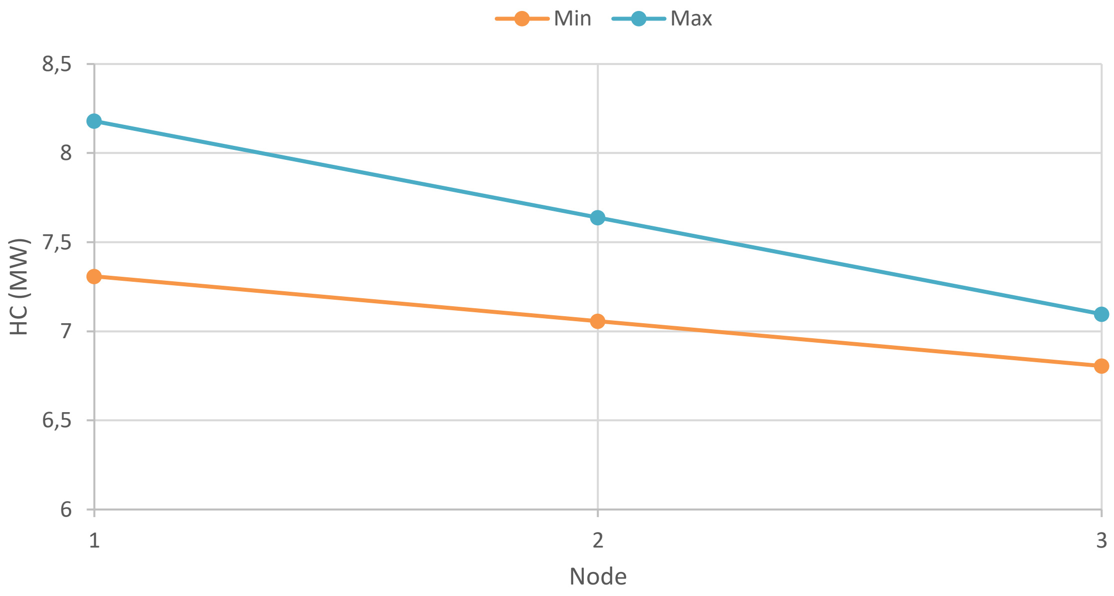


Figure 57- Hosting capacity in each node of a short feeder

After this first step all the “bricks” rearranged gave an overall picture of the hosting capacity for each configuration. The method doesn’t allow the combination of short feeder with long collateral and this is why the third and the fifth column has the value equal to zero. Instead for the other configurations the values are relatively close, the configurations made by short feeder and short collateral in the first node and short feeder and short collateral in the third node are the ones with the higher power consented.

Table 20- Hosting Capacity for the all combinations of a short feeder plus collateral

(MW)	**SHORT FEEDER**	**SH + SH1**	**SH + LO1**	**SH + SH2**	**SH + LO2**	**SH + SH3**
AVG	7.2966	7.2268	0	7.3148	0	7.3797
MIN	6.8055	6.779	0	6.7785	0	6.816
MAX	8.1795	8.511	0	8.5105	0	8.511

For the long feeder the same considerations can be done. In this case the trend of the maximum and minimum values in each node is quite similar, in fact the two lines in the Figure 58 can be considered parallel.

Table 21- Hosting capacity of a long feeder.

(MW)	**Long Feeder**	
	Min	**Max**
Node 1	7.3515	7.6445
Node 2	7.2645	7.5555
Node 3	7.1715	7.4615

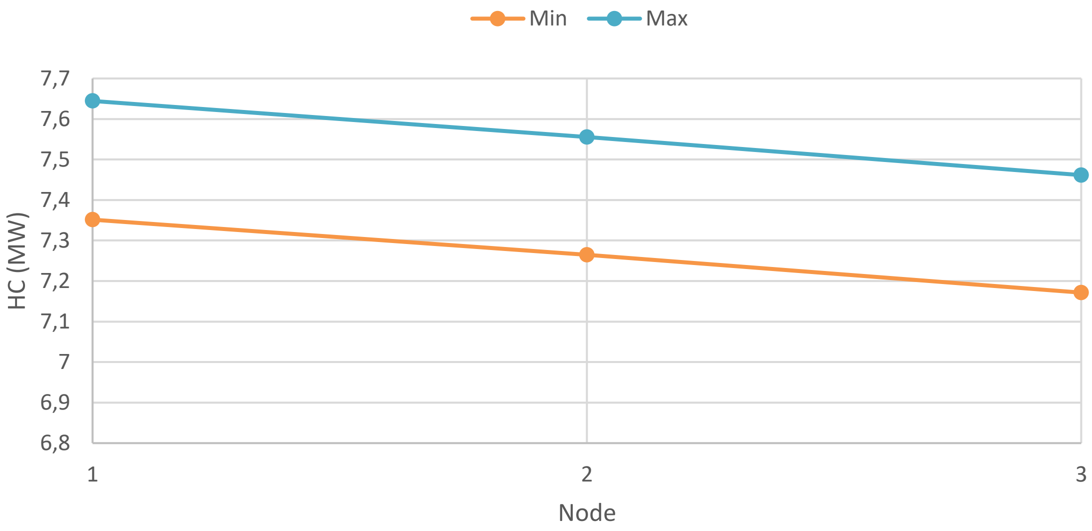


Figure 58- Hosting capacity in each node of a Long Feeder

The hosting capacity taken in considerations all the configuration is then reported in the Table 22 below. In this case all the “bricks” have been combined , the maximum value of the hosting capacity results in the configuration of a long feeder with a long collateral in the second node convenient with the fact that more cables there are more power could host the grid. The maximum value presented is then 8.78 MW consider as the result of our study.

Table 22- Hosting capacity for all the combinations of a long feeder (MW)

(MW)	**LO + 0**	**LO + SH1**	**LO + LO1**	**LO+ SH2**	**LO + LO2**	**LO + SH3**	**LO+ LO3**
AVG	7.3612	7.36117	7.4601	7.4856	7.6432	7.617	7.5107
MIN	7.1715	6.8305	7.1045	6.9815	7.0815	7.147	7.1715
MAX	7.6445	8.2955	8.7665	8.3005	8.7765	8.304	7.6445

5.5 Tanzania Evolution Scenario

Finally has explained in the previous chapter 4.5, a rough consideration about the overall distribution grid has been made. Downloading updated data of the length of medium-voltage Tanzanian grid, a proportion has been done in order to understand how much can be the hosting capacity of the overall distribution grid. The Table 23 reported below is showing the results for the three different grids. The first is the one considered for the calculation of the hosting capacity (see paragraph 4.4), the second one is the distribution grid of the overall country as reported on the mini-grid portal [21] and the third is the one planned by REA by the end of 2021[21].

Table 23- Calculation of the Hosting Capacity of the overall MV grid

	Length (km)	**Hosting Capacity (MW)**
DAR Distribution Grid	1047	8.78
Total Distribution Grid (2019)	31800	264.2
Future Distribution Grid	64300	539

The power generation now connected to the grid, as reported in the paragraph 3.1, is equal to 1234 MW, so the sum of this two contributions is giving a total power generation equivalent to 1498 MW demonstrating that, looking at the peak power demand expected for the 2019 in the Table 24, is not enough to cover all the load.

On the other side, the power generation that will be added from Tanesco at the end of 2020 is around 1450 MW (see paragraph 3.1) and, considering it, the power generation now installed and the hosting capacity calculated, the total amount of power injected into the grid will rise up to 3223 MW. This condition will cover the peak power demand till the 2025 only in the “LOW” scenario (see Table 24) and so just the pessimistic one. It should be noted that for this last consideration the assumptions are that both the plants under construction and the projects on the distribution grid will be ended by then, highlighting that the conclusion of the proposed project is a crucial point to guarantee an improvement of the overall power system.

Table 24- Peak Power Demand expected for the different scenario (MW)

Year	**High (MW)**	**Base (MW)**	**Low (MW)**
2019	1,960	1,920	1,800
2020	2,260	2,190	2,030
2025	4,020	3,660	3,170
2030	7,380	5,870	4,770
2035	13,510	9,350	7,120
2040	23,720	14,330	10,290

6 CONCLUSION

The analysis presented in this thesis allowed to recreate a wide-ranging comprehensive of the Tanzanian electric grid conditions. Both the transimission and distribution study demonstrated that the development level of the network is relatively low from an infrastructural point of view and unreliable data made difficult their analysis.

Focusing on these issues, the proposed approch has the aim to overcome this problematic. The study of the transmission grid that will be in place at the end of 2020 made possible to understand in which operating conditions it will work and the issues related to it. A validation of parameters of the transmission grid has been made throught different prospective: a geopraghical overview, a paramter estimation and a sensitivity analysis to further investigate which parameter has more impact. Results show that missing data and unreliable/innacurate one could make difficult the evaluation of the exact parameters thourght mathematical models, althought could be a first step for further studies. Focusing of the parameters X and B , they have an impact higher then R and so they need to be estimated more precisely. In the thesis a (preliminary) sensitivity procedure has been setted up in order to point out those nodes that could be mostly impacted by innacurate data; a future work should focus in such a direction in oder to validate the model proposed in this Thesis.

The analysis has continued on the medium-voltage grid, the adoption of renewables is remaining constrained to off-grid solutions and lose the advantages of a connection at national scale. Therefore the study of the hosting capacity of the distribution grid has allowed to investigate how much DG (Distributed Generation) could be connected. Results showed that the grid considered, a portion of the distribution grid of the most industrialized city, has an hosting capacity equal to 8.78 MW. It demonstrates that the grids at the medium-voltage level has to be implemented thinking at possible integrations with micro-grids.

Consequently is possible to state that the exploitation of the DG compensates, at least partially, the growth of the load. It proves that the increase of microgrids integrated with the main grid can have a solid potential in the future of the emergiung country considering the sudden growth of the access to electricity.

APPENDIX A

In the following paragraph are reported all the data utilized for the power flow analysis of the transmission grid.

Table 25- Data Collected on the Transmission Grid

bus from	bus to	Rated Voltage (kV)	from	to	Route Length (km)	Conductor (Code Name)	Year to be Com-missioned
1	**78**	220	Kinyerezi	Ubungo	7	Bluejay	2016
1	**58**	132	Kinyerezi	FZ-II	5	Hawk	2020
1	**73**	220	Kinyerezi	Kinyerezi	10	Bluejay	2020
1	**81**	220	Kinyerezi	Morogoro	172	Bluejay	2016
2	**66**	220	Kyaka	Masaka(Uganda)	30	Bluejay	2020
2	**85**	132	Kyaka	Kyaka	0.1	Bluejay	2020
2	**5**	220	Kyaka	Rusumo Falls P/S	150	Bluejay	2018
3	**85**	132	Kibeta/Bukoba	Kyaka	54	Tiger	1992
4	**6**	220	Geita	Nyakanazi	130	Bluejay	2018
4	**29**	220	Geita	Shinyanga	240	Bluejay	2018
5	**6**	220	Rusumo Falls P/S	Nyakanazi	97	Bluejay	2018
6	**77**	220	Nyakanazi	Nyakanazi	10	Bluejay	2018
7	**29**	220	Bulyanhulu	Shinyanga	129	Bison	2000
8	**72**	220	Kigoma	Kigoma	10	Bluejay	2020
9	**11**	220	Lusu	Tabora	139	Bluejay	2020
9	**29**	220	Lusu	Shinyanga	64	Bluejay	2020
10	**29**	220	Buzwagi	Shinyanga	108	Bison	2000
12	**76**	400	Mpanda	Mpa-Sum SwS	119	Bluejay	2020
12	**72**	400	Mpanda	Kigoma	290	Bluejay	2020
13	**75**	400	Sumbawanga	Mbe Sum SwS	150	Bluejay	2020
13	**76**	400	Sumbawanga	Mpa-Sum SwS	119	Bluejay	2020
14	**74**	400	Nakonde(Zambia)	Mbeya	93	Bluejay	2020
15	**74**	400	Kisada	Mbeya	186	Bluejay	2020
15	**68**	400	Kisada	Madaba	243	Bluejay	2018
15	**67**	400	Kisada	Iringa	106	Bluejay	2018
16	**74**	400	Kiwira P/S	Mbeya	110	Bluejay	2020
17	**18**	220	Mbeya	Kyala	106	Bluejay	2020
17	**24**	220	Mbeya	Makambako	162	Bluejay	2020
17	**74**	220	Mbeya	Mbeya	10	Bluejay	2020
18	**19**	220	Kyala	Karonga(Malawi)	20	Bluejay	2020
20	**22**	220	Madaba	Songea	171	Bluejay	2018
20	**24**	220	Madaba	Makambako	162	Bluejay	2018

20	**68**	220	Madaba	Madaba	10	Bluejay	2018
21	**23**	400	Kin-Som SwS1	Kin-Som SwS2	53	Bluejay	2018
21	**73**	400	Kin-Som SwS1	Kinyerezi	53	Bluejay	2018
23	**42**	400	Kin-Som SwS2	Kin-Som SwS3	53	Bluejay	2018
24	**25**	220	Makambako	Mufindi	58	Bluejay	2018
25	**26**	220	Mufindi	Iringa	130	Bison	1985
26	**67**	220	Iringa	Iringa	10	Bluejay	2020
26	**55**	220	Iringa	Mtera	107	Bison	1985
26	**56**	220	Iringa	Low er Kihansi P/S (Hydro)	120	Bluejay	2019
26	**57**	220	Iringa	Kidatu	160	Bison	1985
27	**28**	220	Dodoma	Singida	210	Bison	1988
27	**55**	220	Dodoma	Mtera	130	Bison	1985
27	**62**	220	Dodoma	Dodoma	10	Bluejay	2020
28	**29**	220	Singida	Shinyanga	200	Bison	1988
28	**82**	220	Singida	Babati	150	Rail	1996
28	**64**	220	Singida	Singida	10	Bluejay	2020
29	**30**	220	Shinyanga	Mwanza	140	Bison	1988
29	**65**	200	Shinyanga	Shinyanga	10	Bluejay	2020
30	**31**	220	Mwanza	Bunda	150	Bluejay	2020
31	**32**	220	Bunda	Musona	60	Bluejay	2020
32	**33**	220	Musona	Nyamongo	90	Bluejay	2020
34	**35**	66	Karatu	Mbulu	65	Wolf	1999
35	**36**	66	Mbulu	Babati	85	Wolf	2020
36	**37**	66	Babati	Kondoa	85	Wolf	1999
36	**82**	66	Babati	Babati	0.1	Wolf	2020
38	**70**	220	Arusha	Njiro (Arusha existing)	5	Bluejay	2019
38	**69**	220	Arusha	Arusha	10	Bluejay	2020
39	**70**	132	Njiro (Arusha)	Njiro (Arusha)	0.1	Wolf	2020
39	**40**	132	Njiro (Arusha)	KIA	40	Wolf	1983
39	**41**	132	Njiro (Arusha)	Kiyungi	70	Wolf	1983
40	**41**	132	KIA	Kiyungi	41	Wolf	1983
41	**44**	132	Kiyungi	Same	102	Wolf	1975
42	**59**	400	Kin-Som SwS3	Somanga Fungu P/S	53	Bluejay	2018
43	**84**	66	Hale	Hale	0.1	Wolf	1963
44	**84**	132	Same	Hale	173	Wolf	1975
45	**84**	132	Pangani Falls	Hale	9	Hawk	1995
45	**47**	132	Pangani Falls	Tanga	40	Hawk	2020
46	**69**	400	Isinya (Kenya)	Arusha	114	Bison	1985
47	**80**	132	Tanga	Tanga	0.1	Bluejay	2020
47	**84**	132	Tanga	Hale	60	Hawk	1994
48	**79**	220	Segera	Segera	0.1	Bluejay	2018
48	**69**	400	Segera	Arusha	366	Bluejay	2020
48	**71**	400	Segera	Chalinze	175	Bluejay	2020

49	**71**	220	Chalinze	Chalinze	10	Bluejay	2020
49	**83**	132	Chalinze	Chalinze	0.1	Bluejay	2020
50	**83**	132	Mlandizi	Chalinze	60	Wolf	1963
52	**50**	132	Mlandizi	Ubungo	37	Wolf	1963
51	**78**	220	Bagamoyo	Ubungo	50	Bluejay	2020
51	**81**	220	Bagamoyo	Morogoro	144	Bluejay	2020
52	**78**	132	Ubungo	Ubungo	0.1	Bluejay	2020
53	**54**	132	Mtibwa	Morogoro	88	Hawk	2020
54	**81**	132	Morogoro	Morogoro	0.1	Hawk	2020
54	**83**	132	Morogoro	Chalinze	79	Hawk	2020
56	**57**	220	Kihansi	Kidatu	180	Bluejay	1999
57	**81**	220	Kidatu	Morogoro	130	Bluejay	1993
59	**60**	400	Somanga Fungu	Lindi	216	Bluejay	2019
60	**61**	400	Lindi	Mtwara P/S	74	Bluejay	2019
61	**63**	400	Mtwara	Namialo(Mozambique)	51	Bluejay	2020
62	**64**	400	Dodoma	Singida	210	Bluejay	2016
62	**67**	400	Dodoma	Iringa	237	Bluejay	2016
62	**71**	400	Dodoma	Chalinze	336	Bluejay	2020
64	**65**	400	Singida	Shinyanga	200	Bluejay	2016
64	**69**	400	Singida	Arusha	317	Bluejay	2019
70	**82**	220	Njiro (Arusha)	Babati	131	Bluejay	2020
71	**73**	400	Chalinze	Kinyerezi	138	Bluejay	2020
72	**77**	400	Kigoma	Nyakanazi	317	Bluejay	2020
74	**75**	400	Mbeya	Mbe Sum SwS	150	Bluejay	2020
79	**80**	220	Segera	Tanga	76	Bluejay	2020
83	**84**	132	Chalinze	Hale	150	Hawk	2020

APPENDIX B

In the following paragraph are reported all the data utilized for the parameter estimation.

Table 26- Power flowing in the branches, input data for the parameter estimation (MW)

Branch	Pft	Qft	Ptf	Qtf
1	743.61	123.79	-743.4	-112.5
2	247.59	76	-247.6	-71.78
3	-608.9	-28.56	608.94	43.5
4	122.55	-1.96	-132	1.52
5	100.15	21.73	-100	-29.29
6	24.92	3.02	-24.92	-2.68
7	-127	-24.75	127	-2.17
8	-13.38	-4.45	12.52	2.57
9	-68.12	-17.24	68.24	-42.42
10	-51.8	-40.86	50.76	-90.12
11	-126.3	-7.45	120.65	-10.79
12	-208.3	-18.72	208.28	29.56
13	-73.91	-6.41	74.97	-5.04
14	-31.86	-15.43	31.86	16.2
15	59.07	-6.27	-59.63	-10.87
16	-91.9	6.34	92.5	-11.75
17	-29.5	-14.32	29.71	-0.09
18	-248.4	-41.02	248.4	-185.4
19	240.72	-290.9	-240.7	-265.4
20	-256.3	-25.6	256.54	-251.5
21	248.68	-203.3	248.4	-20.62
22	-200	-136.6	200.3	21.46
23	202.68	-80.22	-322.3	-232.1
24	-258.3	-217.6	390.14	-256
25	55.64	-139.8	-66.72	-136.7
26	360	-70.59	-359.7	-182
27	100.62	-7.73	-100.1	-7.54
28	8.32	-9.23	-8.2	-10.71
29	-224.9	-39.2	224.9	45.92
30	100.1	7.54	-100	-10.37
31	17.87	-28.11	-17.84	-8.64
32	83.72	-12.78	-82.18	-13.6

33	-149.9	19.5	149.86	-14.66
34	-577	-76.98	577.3	-14.82
35	576.98	-41.18	-576.6	-49.48
36	-577.3	-104.3	577.82	12.36
37	45.5	1.48	-45.2	-8.51
38	-74.18	-4.46	75.35	-5.77
39	-31.02	-48	33.02	49.06
40	-18.97	-20.81	19.06	6.86
41	-88.09	-6.59	88.9	0.09
42	-92.49	6.03	94.94	-10.74
43	42.09	-21.49	-40.47	-3.91
44	-28.05	-2.32	28.24	-14.28
45	-62.84	-0.46	62.44	1.42
46	75.54	-22.9	-74.18	5.6
47	0.36	-15.19	-0.36	-6.08
48	-53.27	3.1	57.84	-2.38
49	233.32	23.56	-222.6	20.9
50	-451.9	44.8	456.64	-27.17
51	102.9	-34.92	-102.5	7.95
52	83.02	-10.7	-82.9	0.96
53	45.13	-17.5	-45.07	-4.23
54	-14.36	-0.89	15.15	1.7
55	-16.53	-3.26	16.71	-2.27
56	6.3	0.51	-6.17	-1.24
57	-33.1	-3.12	33.36	5.74
58	265.18	41.14	-265.6	-41.48
59	-265.2	-41.14	265.18	41.02
60	-232.4	-54.62	232.36	62.25
61	26.93	2	-24.76	-3.75
62	14.82	2.14	-14.71	-5.06
63	6.6	5	-6.5	-5.07
64	-23.92	6.39	24.72	-10.15
65	-577.8	-132.1	577.94	39.6
66	5.1	-0.14	-5.1	0.24
67	-28.35	8.3	30.27	-12.76
68	15.93	-4.28	-16.91	3.81
69	6.77	3.64	-6.74	-6.67
70	200	-37.76	-199.7	-114.7
71	-55.2	-5.28	55.2	6.9
72	-4.31	-6.63	4.34	3.79
73	121.56	11.56	-121.6	-5.36
74	271.64	-136.9	-269.8	-92.68
75	-393.2	-122.6	394.14	-118.5

76	-64.84	-8.86	64.84	10.56
77	64.84	8.86	-64.84	-4.26
78	-3.32	-5.22	3.34	6.38
79	-35.5	5.17	36.4	-4.82
80	-111.7	-5.59	112.58	2.15
81	72.8	-13.26	-71.07	-5.59
82	-640.8	-58.85	630.8	110.3
83	-80	-9	82.12	5.5
84	-138.1	-40.72	139.37	48.37
85	-21.5	-0.32	21.97	-2.59
86	-44.52	-8.09	94.94	-10.74
87	-63.52	11.16	63.74	-44.3
88	-63.42	-153.6	63.46	-219.5
89	-73.65	17.58	73.68	-131.3
90	200.22	104.62	-200	-170.4
91	307.88	-152.1	-310.6	-105
92	-33.28	-140	33.7	-176
93	-337	-47.15	342.62	-85.92
94	455.52	-92.82	-456.6	-126.4
95	-202.8	-212.8	203.68	-205.1
96	33.24	-20.77	-33	0.34
97	-801.6	-106.4	804.7	-17.08
98	208.86	-222	-208.3	-378
99	256.8	-296.8	-256.5	27.52
100	55.26	-26.72	-55.2	-6.9
101	13.02	-12.37	-12.6	4.92

Table 27-Voltage values at each node in the Figure 33.

Bus	V (pu)	Bus	V (pu)	Bus	V (pu)	Bus	V (pu)
1	1.02	**23**	1.04	**44**	1.01	**65**	1.02
2	1.03	**24**	1	**45**	1.02	**66**	1.04
3	1.01	**25**	0.99	**46**	1.04	**67**	1.02
4	1.05	**26**	1.01	**47**	1.02	**68**	1.02
5	1.04	**27**	1	**48**	1.03	**69**	1.04
6	1.04	**28**	1.03	**49**	1.02	**70**	1.03
7	1.02	**29**	1	**50**	1.01	**71**	1.02
8	1.03	**30**	0.98	**51**	1.02	**72**	1.06
9	1.03	**31**	1	**52**	1.02	**73**	1.04
10	1.02	**32**	1	**53**	0.97	**74**	1.01
11	1.02	**33**	1	**54**	1	**75**	1.03
12	1.06	**34**	0.97	**55**	1.02	**76**	1.04
13	1.04	**35**	1.04	**56**	1.02	**77**	1.03

14	1	**36**	1.05	**57**	1	**78**	1.02
15	1.02	**37**	1.02	**58**	1.02	**79**	1.02
16	1.01	**38**	1	**59**	1.05	**80**	1.02
17	1.01	**39**	1.02	**60**	1.04	**81**	1.01
18	1	**40**	1.01	**61**	1.03	**82**	1.04
19	1	**41**	1.01	**62**	1.02	**83**	1.02
20	1.04	**42**	1.04	**63**	1.03	**84**	1.03
21	1.04	**43**	1.02	**64**	1.03	**85**	1.03
22	1.02						

APPENDIX C

In the following paragraph are reported all the data utilized for the hosting capacity calculation of the distribution grid.

Table 28- Preliminary data from JICA plan

kV	Bus from	Bus to	From	To	Lenght (km)	R Tot (pu)	X Tot (pu)
33	Ubungo	Wazo2	1	2	21.983	0.077	0.060
33	Ubungo	Nordic1	1	3	151.031	0.487	0.416
33	Ubungo	FZ3-1	1	4	3.781	0.010	0.010
33	Ubungo	Nordic2	1	5	243.298	0.877	0.670
33	Ubungo	EPZ	1	6	4.567	0.011	0.013
33	Ubungo	Magomeni/Mlimami	1	7	9.496	0.024	0.025
33	Ubungo	Mlimani	1	8	22.239	0.077	0.059
33	Ubungo	Wazo1	1	9	15.118	0.038	0.042
33	Ubungo	Tandale	1	10	1.5	0.004	0.004
33	Ubungo	Texile	1	11	1.5	0.004	0.004
33	FZIII	FZ I	4	22	9.866	0.024	0.026
33	FZIII	FZ II	4	20	99.3	0.249	0.274
33	FZIII	Buguruni	4	24	7.421	0.019	0.020
33	FZIII	Tandika	4	19	10.445	0.026	0.029
33	FZIII	Segerea	4	21	57.257	0.112	0.123
33	FZI	ALAF	22	23	8.469	0.021	0.023
33	Chamgombe	Kurasini	25	26	13.595	0.034	0.037
33	Chamgombe	Kipawa (FZ-III)	25	4	3.384	0.008	0.009
33	Kurasini	Kigamboni	26	27	8.667	0.022	0.023
33	Kigamboni	Kigamboni Area	27	28	136.736	0.343	0.376
33	Ilala	Kurasini(KR)	29	26	6.997	0.018	0.019
33	Ilala	Kariakoo	29	30	3.486	0.008	0.007
33	Railway	Kariakoo, Ilala	31	30	3.486	0.008	0.007
33	New City Center	Ilala	32	29	3.964	0.010	0.010
33	New City Center	Sokoine	32	34	5.048	0.011	0.010
33	New City Center	Muhimbili	32	33	2.07	0.003	0.005
33	Tegeta	Wazo II	35	2	24.361	0.061	0.067
33	Tegeta	Mbezi	35	37	8.445	0.021	0.023
33	Tegeta	Bagamoyo	35	36	139.314	0.254	0.278
33	Tegeta	Bahari	35	38	3.192	0.008	0.009
33	Tegeta	Wazo	35	41	3.268	0.000	0.000
33	Tegeta	Spare	35	39	7.684	0.019	0.020
33	Tegeta	Jangwani	35	40	6.49	0.011	0.018

Table 29- Feeder and Collateral of Dar Distribution Grid

Feeder/ Collateral			**Bus From**	**Bus To**	**R (pu)**	**X (pu)**
F1	Ubungo	FZ3-1	1	4	0.0105	0.0104
	FZ3	Chamgombe	4	25	0.0085	0.0093
	Chamgombe	Kurasini	25	26	0.0340	0.0372
	Kurasini	Ilala	26	29	0.0176	0.0193
	Ilala	Kariakoo	29	30	0.0076	0.0070
	Kariakoo	Railway	30	31	0.0076	0.0070
Collateral F1	FZ3	Tandika	4	19	0.0262	0.0288
	FZ3-1	FZ2	4	20	0.2492	0.2736
	FZ3	Segera	4	21	0.1120	0.1229
	FZ3	FZI	4	22	0.0244	0.0263
	FZI	Alaf	22	23	0.0212	0.0233
	FZ3	Bugurini	4	24	0.0185	0.0203
	Kurasini	Kigamboni	26	27	0.0216	0.0235
	Kigamboni	Kigamboni Area	27	28	0.3431	0.3765
	Ilala	New City Center	29	32	0.0097	0.0105
	New City Center	Sokoine	32	34	0.0107	0.0096
	New City Center	Muhimbili	32	33	0.0035	0.0050
F2	Ubungo	Wazo2	1	2	0.0773	0.0604
	Wazo2	Tegeta	2	35	0.0611	0.0670
	Tegeta	Bagamoyo	35	36	0.2536	0.2780
Collateral F2	Tegeta	Mbezi	35	37	0.0208	0.0228
	Tegeta	Bahari Beach	35	38	0.0080	0.0087
	Tegeta	Spare	35	39	0.0185	0.0204
	Tegeta	Jangwani Beach	35	40	0.0109	0.0177
	Tegeta	Wazo Area	35	41	0.0003	0.0002
F3	Ubungo	Nordic1	1	3	0.4867	0.4161
F4	Ubungo	Nordic2	1	5	0.8767	0.6702
F5	Ubungo	EPZ	1	6	0.0115	0.0126
F6	Ubungo	Magomeni/Mlimami	1	7	0.0243	0.0251
	Magomeni/mlimani	Mlimani	7	8	0.0774	0.0594
Collateral F6	Magomeni/mlimani	Magomeni	7	9	0.0243	0.0251
F7	Ubungo	Wazo1	1	10	0.0379	0.0416
F8	Ubungo	Tandale	1	11	0.0038	0.0041
F9	Ubungo	Texile	1	12	0.0038	0.0041

Table 30- Feeders simplified with the Bricks Approach

		F1		**Collateral F1**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0438	0.047689		
2	3	0.1752	0.190754		
3	4	0.1752	0.190754		
2	5			0.243851	0.266725
5	8			0.243851	0.266725
		F2		**Collateral F2**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0392	0.0405		
2	3	0.1568	0.1622		
3	4	0.1568	0.1622		
3	6			0.0586	0.06979
		F3		**Collateral F3**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0487	0.041606		
2	3	0.1947	0.166425		
3	4	0.1947	0.166425		
		F4		**Collateral F4**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0877	0.067024		
2	3	0.3507	0.268097		
3	4	0.3507	0.268097		
		F5		**Collateral F5**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0011	0.001258		
2	3	0.0046	0.005033		
3	4	0.0046	0.005033		
		F6		**Collateral F6**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0102	0.008451		
2	3	0.0407	0.033804		
3	4	0.0407	0.033804		
2	5			0.0243115	0.025135
		F7		**Collateral F7**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0038	0.004165		
2	3	0.0152	0.016659		

3	4	0.0152	0.016659		
		F8		**Collateral F8**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0004	0.000413		
2	3	0.0015	0.001653		
3	4	0.0015	0.001653		
		F9		**Collateral F9**	
Bus From	**Bus To**	**R (pu)**	**X (pu)**	**R (pu)**	**X (pu)**
1	2	0.0004	0.000413		
2	3	0.0015	0.001653		
3	4	0.0015	0.001653		

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