Regional Power Trade Opportunities based on New Transmission Interconnections in East Africa

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***Abstract*—The Nile Equatorial Lakes countries currently face a generation capacity shortage which not only causes frequent black-outs and load shedding, but also represents a big risk for the region's future growth and development. A least cost optimization generation and transmission expansion plan for the interconnected system was done using the Generation and Transmission Maximization (GTMax) tool. By gaining access to inexpensive power, this interconnecting line will be critical for the development of power exchange and economic prosperity for countries in the East African Power Pool.**

Index Terms—East African Power Pool, interconnection link GTMax.

I. Introduction

THE Nile Equatorial Lakes (NEL) countries: Burundi, D.R. Congo, Egypt, Kenya, Rwanda, Sudan, Tanzania and Uganda currently face a generation capacity shortage which not only causes immediate concerns, but also represents a risk for the region's future growth and development.

This region is characterized by constrained isolated power systems where suppressed demand exceeds present generation capacity. It is estimated that the energy deficit in the five Nile upstream countries (excluding Tanzania) will be 2461 GWh in 2010, 4173 GWh in 2015 and 24452 GWh in 2030. Access to electricity is very low averaging less than 10% in all the countries. Annual consumption per capita is presently less than 150 kWh compared to a world average of 2500 kWh per capita. A power systems in a NEL country is either isolated or weakly interconnected with its neighbors. The top priority mission of the NELSAP (NEL Action Program) is to eradicate poverty, promote economic growth, and reverse environmental degradation in the Nile Equatorial Lakes region. The long term objectives of the NELSAP power development and trade program are to promote regional economic development and improve the quality of life through provision of ample power supply at reasonable prices; to increase the regional power supply in the NELSAP Region by improving export and import capabilities between NEL member countries; and to improve the reliability of power supply and the quality of power delivered by interconnecting the currently isolated networks in each country.

A. Scope of the project

A transmission link between Ethiopia and Kenya is vital for the development of power exchange in Africa, because it:

- establishes an interconnection between the ENSAP and the NELSAP countries,
- links the Northern and Southern African Power Systems, and
- provides an opportunity to transmit power from Ethiopia to Tanzania and, potentially, to countries further South.

It is anticipated that the demand will increase in concert with supply opportunities, as inexpensive power becomes available.

This paper presents the results of a **feasibility study** that addresses technical, economic and financial issues **related to** interconnecting the Ethiopian and Kenyan power systems via a high voltage transmission line. It connects the Wolayta / Sodo area in Ethiopian to Nairobi in Kenyan. The length of the propsed transmission line is up to 1200 km long and will be required to carry high levels of energy. This poses both technical and economic challenges. Therefore HVAC, HVDC, or combinations thereof (hybrid solutions) to obtain a technically and economically acceptable performance.

The Feasibility Study included: review of the load forecast and associated generation and transmission development plans of both countries, identification of technical alternatives for the interconnection using most suitable technologies, with due consideration of other regional power system developments, optimally phased sizing of the interconnection, making efficient and reliable use of the complementary hydropower resources in Ethiopia and the thermal and geothermal resources in Kenya, prediction of the electrical performance of the interconnected system by steady state and dynamic power system analysis, estimation of capital expenditure and risks and economic and financial analysis for the most promising technical alternative.

The target capacity for cross-border exchanges considered generation expansion planning and load forecast over the 2007-2030 planning horizon, covered by the Ethiopia's Master Plan Update and Kenya's Power Development Plan. Under various assumptions on energy exchanges with Sudan, Egypt and Djibouti as well as on the hydrological risks in Ethiopia, two-stage development of the interconnection capacity to Kenya was defined:

Phase 1 : 1000 MW transfer capacity by 2012, the year scheduled for availability of hydropower from Gilgel Gibe III in Ethiopia

Phase 2 : 2000 MW transfer capacity by 2020, up to the planning horizon 2030.

Power received in Nairobi over the planned Ethiopia interconnection can be used for other markets:

Interconnection Phase 1 (1,000 MW): 100 MW to Uganda and 300 MW to Tanzania

Interconnection Phase 2 (2000 MW): 200 MW to Uganda and 500 MW to Tanzania.

II. Approach and Methodology

The methodology used for the study is shown in **Fig. 1**.

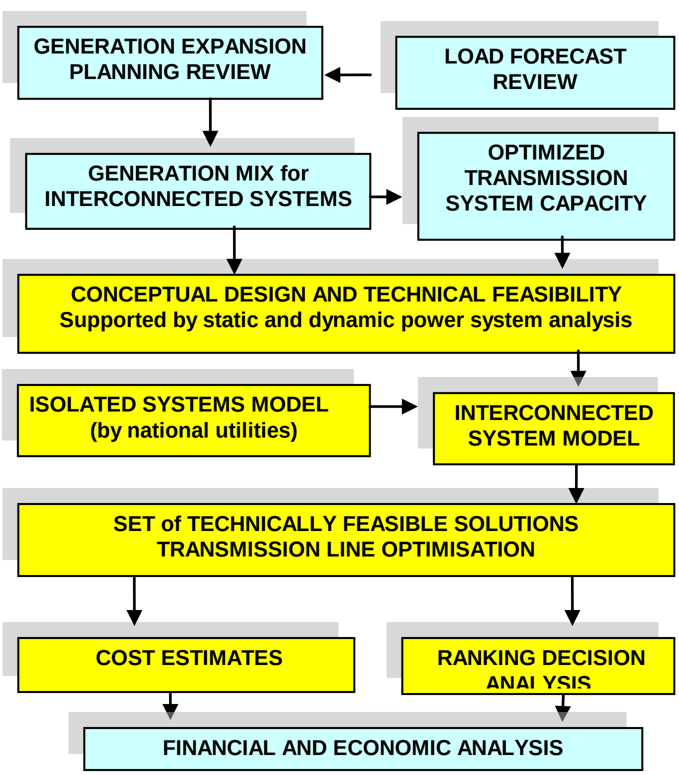

Fig. 1: Approach and Methodology

The Main Steps of the Generation and Transmission Optimization were: review of generation expansion plans and load forecasts of both utilities, investigation of generation mix for the interconnected systems of Ethiopia and Kenya, identification of the optimized transmission system capacity for the both phases, conceptual design and technical feasibility for three technical variants, the feasibility of each of them was investigated in power system analysis (for the isolated systems and for the interconnected system), identification of viable exchange scenarios among the countries of the East African Power Pool and cost estimation and financial and economic analysis for each technical variant.

The generation and transmission optimization for the interconnected system Ethiopia – Kenya was done using the generation and transmission optimization tool GTMax.

III. Generation and Transmission Optimization

A. GTMax Introduction

The Generation and Transmission Maximization Program GTMax allows the simulation of the operation of a complex electricity market, competitive or regulated. The transmission planner can maximize the value of the power system, taking into account not only the each utility's own limited resources but also firm contracts, independent power producers IPP and bulk power transaction opportunities for a group of interconnected systems in the region.

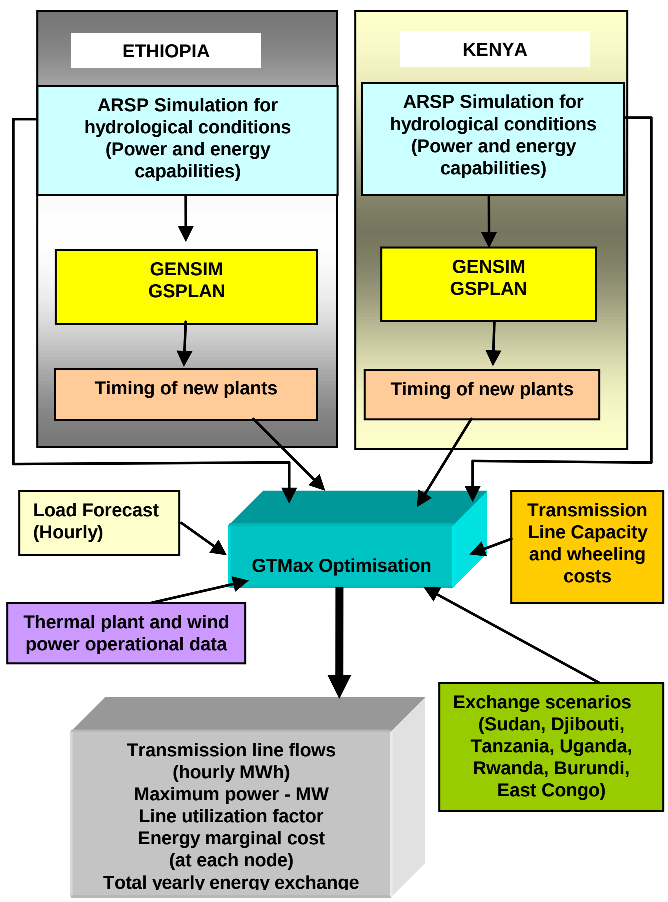

Fig. 2. Generation and Transmission Optimization using GTMax Tool

GTMax maximizes the net revenues of a power system by finding a solution that increases income while keeping expenses at a minimum. The model does this while taking into account that market transactions and system operations respect the physical and contractual limitations of the power systems.

The GTMax analysis takes into account the topology of the network, the interconnection transfer capacity, the hourly loads and the different generation costs in each of the two power systems. The program simulates the dispatch of the generating units and the economic trade of energy between the two power systems over a given network topology.

GTMax calculates the energy sales or purchases in different regions of the power network, taking into account the capacity constraints on the interconnection lines. The model optimizes the transactions in order to minimize the overall operating cost in the region. The output includes the generated power of the dispatched units and the amount of power sold on an hourly basis.

Thermal and hydro power plants are represented with all their characteristics and a generic wind power model is included. The hourly system loads are assigned to user-specified load centers. Firm contracts to surrounding countries can also be included in the model.

B. GTMax model for the interconnected systems

The GTMax Topology for the Ethiopia-Kenya Transmission Study included:

- Loads (Unique profiles for Ethiopia & Kenya allocated by load center) – black rectangle in **Fig. 3**
- Resources
- Thermal units with thermal power plant attributes – red diamond in Fig. 3
- Hydropower plants with expansion schedule and hydrology conditions, based on GENSIM – blue diamond in Fig. 3
- Wind farms (typical power curve for the region was used)
- Potential interconnection transfer capability between Ethiopia & Kenya
- Firm contracts to surrounding countries

One typical week is simulated per season as follows: January – week 1, May – week 19, July – week 27, October – week 40. The simulations have been performed for the 2011-2027 period in the two configurations- base case and alternative, for determination of the required interconnection transfer capability between Ethiopia and Kenya.

Scenarios depict various transmission line configurations and attributes including the without interconnection case

Firm contracts to surrounding countries have been included in the model as follows:

- Export to Djibouti – 100 MW after 2011
- Export to Sudan – 200 MW until 2019, 1200 MW after 2020
- Export to Egypt – 700 MW after 2020

The model includes also interconnections to Tanzania and Uganda, as potential remote targets for the export from Ethiopia (green nodes in **Fig. 3**).

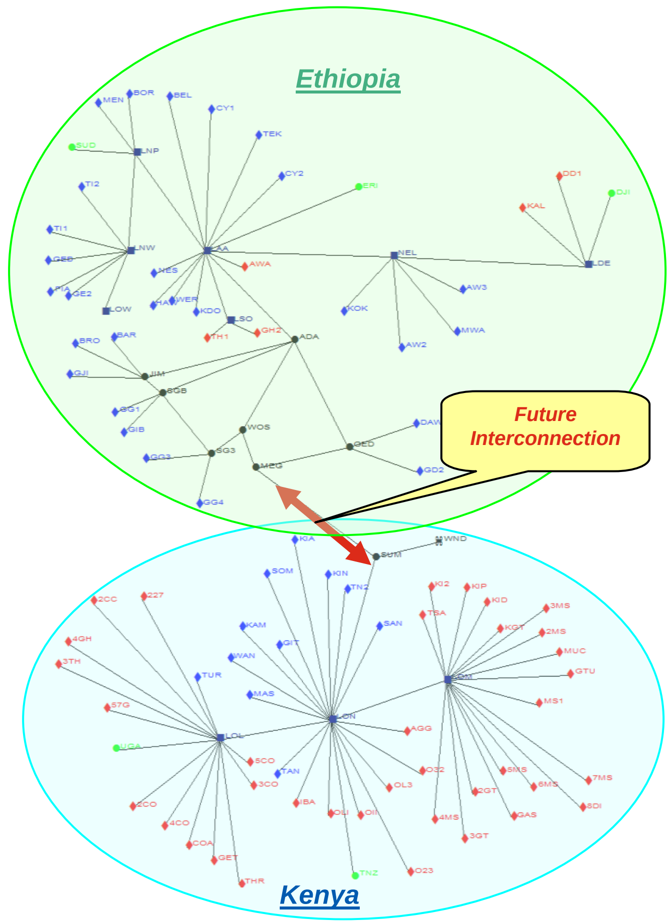

Fig. 3. Topology of the interconnected System Ethiopia – Kenya in GTMax Tool

C. Results of GTMAx Simulations

The results of the GTMax investigations for the interconnected operation of the power systems of Ethiopia and Kenya are presented in the following Figures 4 - 11.

An hourly optimization of the interconnected system operation was performed for each year from 2012 to 2027.

Fig. 4-6 presents the isolated and combined power system load and resource projections. On Fig. 4 it is evident that there is no reserve margin in Kenya in case of isolated operation.

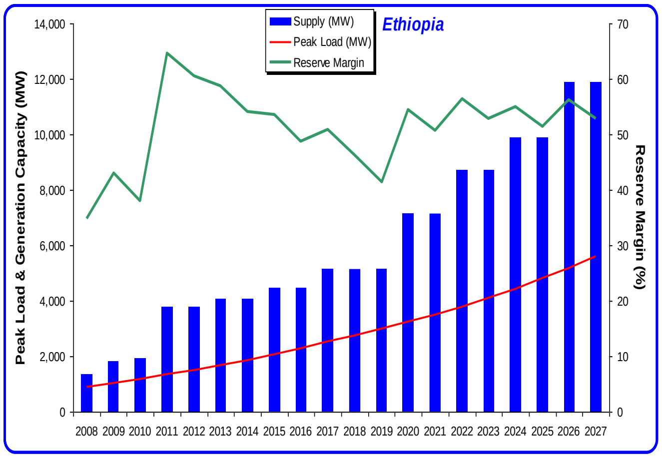

Fig. 4. Ethiopia Loads & Resource Projection (blue supply, red peak load, green reserve margin)

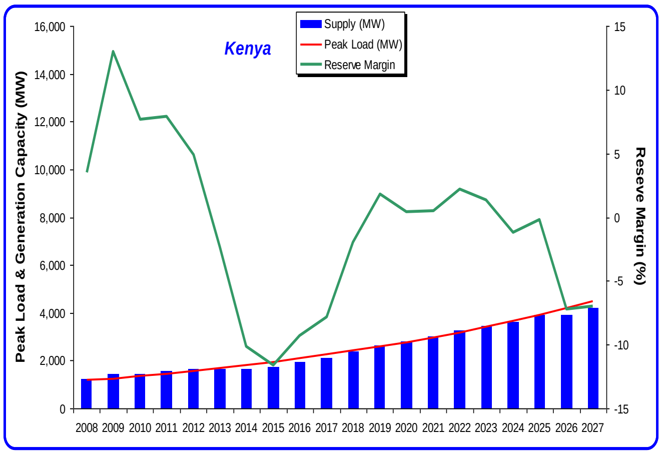

Fig. 5. Kenya Loads & Resource Projection (blue supply, red peak load, green reserve margin)

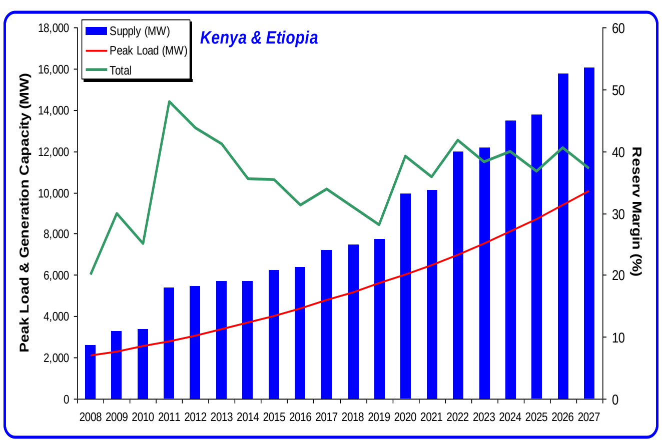

Fig. 6. Combined System Loads & Resource Projection (blue supply, red peak load, green reserve margin)

Fig. 7 presents the Ethiopian and Kenyan thermal (violet colors) and hydro generation (blue colors) and corresponding load curves, as well as the power flow curve of the interconnecting link in the example week in July 2023.

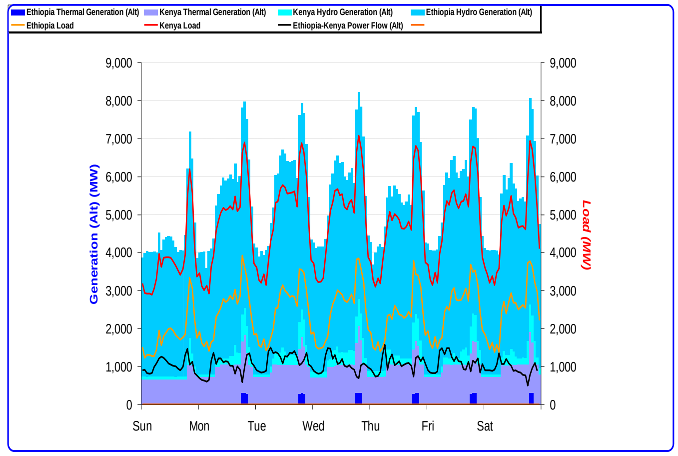

Fig. 7. GTMax simulation results for year 2023 (blue hydro generation, violet thermal generation, red load in Kenya, orange load in Ethiopia, black power flow on the interconnecting line)

The hourly optimization of the interconnected system operation was performed for each year from 2012 to 2027 in two configurations: from 2012 until 2019 and from 2019 until 2027. The bidirectional, cost-minimized energy flow was investigated for the years 2012 up to 2019. The line loading, the power flow for 5000 hours in MW, the power export over 650 MW and its duration were investigated.

The energy flow for the years 2020 up to 2027 was investigated for the following two variants:

- Variant 1: 1200 MW export to Sudan and 100 MW export to Djibouti
- Variant 2: 1200 MW export to Sudan, 700 MW to Egypt and 100 MW export to Djibouti.

The line load factor, the power flow for 5000 hours, the power export higher than 1300 MW (variant 1), or 1950 MW (variant 2) and its duration were investigated.

Fig. 8 presents the results of the simulation for the years 2011 to 2027 in case that the Ethiopian system is exporting 200 MW to Sudan up to year 2019 and 1200 MW after year 2020. The curves in the graph are showing the variables- hydro generation (blue), thermal generation (red), wind power (green) and the import from Ethiopia (yellow).

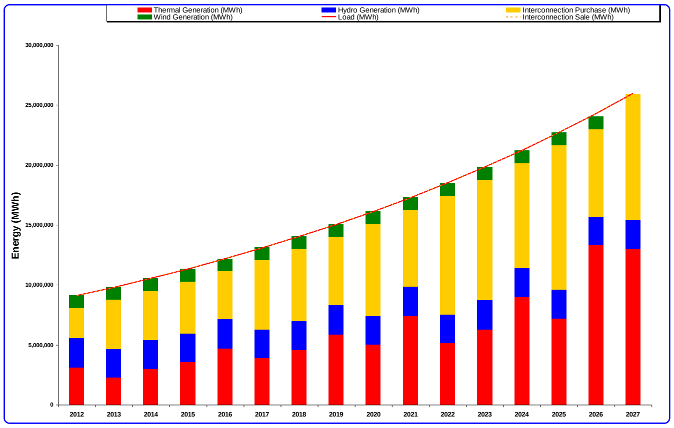

Fig. 8. Energy balance for Kenya between 2012 and 2027 Thermal (red), hydro (blue), wind (green) power generation and import from Ethiopia (yellow)

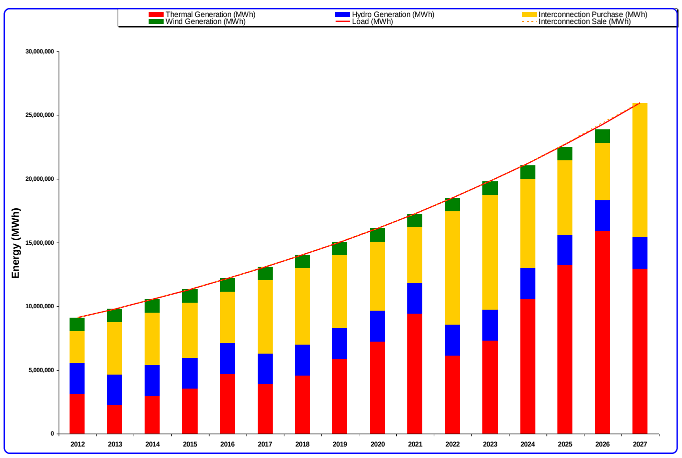

Fig. 9. Energy balance for Kenya between 2012 and 2027 Thermal (red), hydro (blue), wind (green) power generation and import from Ethiopia (yellow)

Fig. 9 presents the results of the simulation of years 2011 to 2027 for the Kenyan system, in case that the Ethiopian system is exporting 200 MW to Sudan up to year 2019, 1200 MW after year 2020 and 700 MW to Egypt after 2020. The graph is showing the same variables like in **Fig. 8**, the higher amount of thermal generation in Kenya is evident.

Fig. 10 exemplifies the Ethiopia - Kenya power flow distribution function for the year 2027, on top of 100 MW export to Djibouti, 1200 MW export to Sudan and 700 MW export to Egypt.

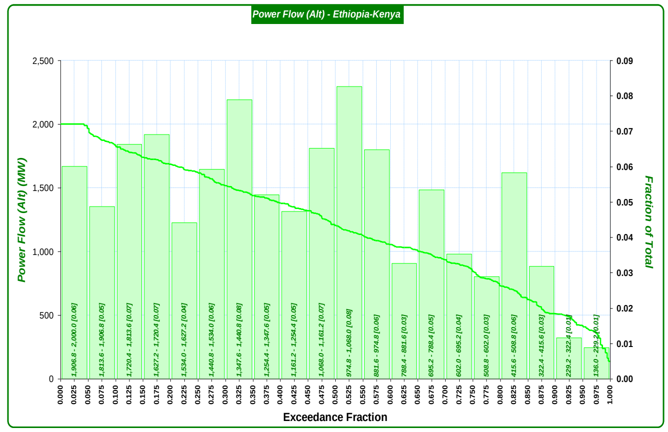

Fig. 10. Power flow distribution on the interconnection Ethiopia - Kenya Year 2027, export to Djibouti 100 MW, to Sudan 1200 MW and to Egypt 700 MW

Of special importance for sizing the interconnection capacity is the time duration of a particular exchange magnitude, extracted from GTMax. It allows quantifying of the economic impact of a capacity restriction due to a single outage, in particular at the converter station, and interacts therefore directly with the economic and financial analysis. The following graphics show that, for an annual average of 5000 h, the N-1 capacity of 650 MW in Phase 1 (DC pole outage) restricts the export flow beyond 2019, this year being therefore recommended for the transition to Phase 2 (one additional DC pole and line circuit).

The bottlenecks are specific to the HVDC alternatives, where the strict application of the N-1 criterion leads to very high investment costs. As partial substitute, the conceptual design in case of one pole unavailability recommends specifying a continuous overload of 30%. This will constrain the transfer capacity for the duration of the DC pole outage to 650 MW in the first phase and 1300 MW in the Phase 2 of the Project. In order to quantify the export opportunity loss under outage condition of one DC pole, the number of hours/year with power flow in excess of the specified overload capability was included.

Fig. 11 shows that an interconnection design capacity of 1000 MW in Phase 1 (2102-2020) and 2000 MW in Phase 2 (2020-2027) is adequate for the identified economically optimized power flows, in any of the considered generation commitment and export scenarios.

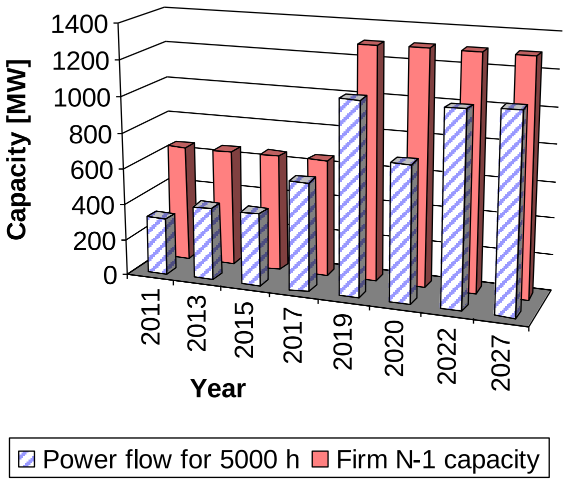

Fig 11. Power Flow for 5000h and Firm N-1 capacity

IV. Expansion Studies

A. Regional Interconnections

A major impediment to the development of a regional market is insufficient transmission infrastructure. Currently, the only two regional HV interconnections in the region, base their power trade on bilateral agreements:

- Uganda – Kenya: 132 kV interconnection between Torora (Uganda) and Lessos (Kenya)
- Rwanda – Burundi – Eastern DR Congo: the hydropower plant Ruzizi supplies each country with a contractual capacity of 15 MW, via an 110 kV interconnection to Rwanda and 70 kV interconnections to Burundi and Eastern DRC.

A HV transmission line between Ethiopia and Kenya is of vital interest for the development of power exchange in Africa, because it establishes not only an interconnection between the ENSAP and the NELSAP countries, but ultimately will serve to link the north of Africa to the South.

Various studies have already explored the potential of power exchange in the region. The East African Power Master Plan Study was completed in 2005. Most recently, in October 2007, the study on the interconnection of the electricity networks of the Nile Equatorial Lakes countries was prepared for NBI/NELSAP. This study confirms the potential for power exchanges and identifies various interconnection projects to facilitate them, as briefly listed in the followings.

- Uganda – Kenya interconnection
- Uganda – Rwanda interconnection
- Burundi – Rwanda interconnection
- Strengthening the interconnection between Burundi, Eastern DR Congo and Rwanda
- Rwanda – Burundi – Tanzania interconnection
- Kenya – Tanzania interconnection

All these projects establish an interconnected power system of Kenya, Tanzania, Uganda, Rwanda, Burundi and Eastern DRC, with a closed loop around Lake Victoria. Power transmitted from Ethiopia to Nairobi, Kenya, could thus be transferred further via the new Lessos - Jinja line on the northern loop to Uganda and from there to Rwanda/Burundi/Eastern DR Congo, or via the Nairobi - Arusha line to Tanzania. South of Tanzania, power markets will become available when the Zambia-Tanzania-Kenya Interconnection Project is realized; this project comprises strengthening of the Tanzanian transmission network and a 400 kV interconnection between Tanzania and Zambia.

For assessing the Kenya –Ethiopia project viability it is therefore realistic to consider in the line capacity optimization that that the power received in Nairobi could be eventually distributed to other regional markets as follows:

- Phase 1 (up to 1,000 MW transfer capacity): 100 MW to Uganda and 300 MW to Tanzania.
- Phase 2 (up to 2000 MW transfer capacity): 200 MW to Uganda and 500 MW to Tanzania.

However, it is pointed out that in assessing the availability of export energy from Ethiopia to Kenya, contracts or prospects for exchanges to surrounding or Northern countries must be included in the capacity optimization:

- Export to Djibouti – 100 MW after 2011
- Export to Sudan – 200 MW until 2019, 1200 MW after 2020
- Export to Egypt – 700 MW after 2020

This emphasizes the fact that the Ethiopia – Kenya interconnection is a true regional power transmission project, contributing to a significant extent to pave the way for an accelerated electrification goal and for mitigating the uncertainties related to the evolution of the fossil fuel prices.

V. Conclusions

The paper presents the results of a feasibility study for the interconnecting line between Ethiopia and Kenya. The least cost optimization generation and transmission expansion plan for the interconnected system was done using the GTMAx tool. Further on three technical variants for the realization of the interconnecting line have been investigated and compared using a multi-criteria decision method. An economic analysis proved the economic benefit of the project.

Acknowledgment

The authors would like to thank the EEPCO (Ethiopian Electric Power Corporation) for the data provision and the cooperation.