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Africa: The African Union and New Partnership for Africa's Development (NEPAD)-The Power Footprint

19.1 Introduction

The last century has demonstrated that every facet of human development is woven around a sound and stable energy supply system with the electricity grid in its various forms being the most optimized motive source for maintaining a sustainable standard of living and quality of life. The last century has also created a vast knowledge base of man's delicate relationship to the environment and its relationship to his own survival. The historical continuance of resource wars represents the clearest indication of this imbalance and which has spurred environmental protection in all its facets. Global economic growth will drive electrification, both in developed and developing countries. Almost without exception, the major technology trends depend upon an advanced electricity infrastructure. In Africa, widespread access to electricity will be a prerequisite for sustaining economic growth. Developing countries need clean, affordable electricity to grow their economies and meet the aspirations of their people. Thus, electrification will be a key factor in global stability.

Particularly important are the four linked goals of protecting earth's life support systems, improving human welfare, eliminating poverty, and stabilizing population. Only when the world's citizens have achieved a minimal quality of life will they have the will and resources to participate in the global economy. Without this headroom, economic development will be sub marginal.

In last 20 years there has been a concerted effort by African countries in formulating strategies to address the continent's social economic crisis and integration into 21st century development challenges. Africa the world's richest continent in terms of readily accessible natural resources and 13% of the world population accounts for about 2% of world economic output. Real gross domestic product (GDP) in Africa as a share of the world total remained constant at about 2% and earlier projections suggested it would remain at 2% through 2020. In the past five years however, there has been a dramatic increase in economic activity largely driven by a shifting geopolitical landscape brought on by an intense demand for energy and other natural resources to feed the Asian '*Tiger*' economies of China and India. This comes as African statesmen have sought to consolidate various development initiatives such as the OMEGA, New African Initiative (NAI), and Lagos Action Plan (LAP) into an efficient body. The African Union (AU) and New Partnership for African Development (NEPAD) have emerged as the umbrella organizations positioned to steer the continent for effective change from its recent historical past of post-colonial development into an African Renaissance. As part of this vision for development there are a number of firsts being introduced in the planning and implementation of some of these projects over a large resource mix of natural gas, hydro, coal, petroleum based fossil fuels and various alternative energy resources to support the vast rural development needs.

New high voltage (HV) transmission lines are at the top of the agenda for many energy planners in the various regions of Africa. These lines are identified within the power pools of Southern Africa (SAPP) and West Africa (WAPP) and the Mediterranean ring of North Africa with links to the Middle East Gulf States. The Central Africa Power Pool (CAPP) is also in the process of identifying its new HV lines and the East Africa region (EAPP) has been formulated with projects identified. The proceeding chapter looks at the centrality of the huge hydropower potential of the Grand Inga project and the sensitivity of pricing electricity exports as they relate to transmitting power across Africa's proposed new HV lines. Capacity-planning in Africa's power pools will be significantly affected by the proposed new HV lines and as such the costs of interconnection across Africa draws upon comparisons with HV line networks in other locations.

The Southern African Power Pool (SAPP), West African Power Pool (WAPP), Egypt, and the East African Power Pool (EAPP) have each expressed their interest in continental interconnection, a major step forward in development. The hydropower potential from the River Congo is a big attraction to regional planners and the key development project of Grand Inga (39GW potential, located 150km from Kinshasa) necessitates the planning of very long HV lines. The Central African Power Pool (CAPP) and the Democratic Republic of Congo (DRC) have much to gain from exporting the potential hydropower at the right price. Despite the challenges, it is also clear that there has never been throughout human history a period of more potential to harness 21st technology for rapid and sustained infrastructure development across all sectors for a modern sustainable economy. The new benchmarks set by petroleum prices reaching above USD$120 per barrel significantly influence the economics of comparative energy solutions such as natural gas combined cycle plants and other fossil fuels in favor of the capital intensive hydroelectric energy models. These changing dynamics are the challenges faced by governments and the private sector in arriving at practical solutions.

The chapter contributions as such summarize many of the efforts to date in addressing strategic approaches to Africa's development organized through the IEEE PES International Practices Sub Committee forums. The various viewpoints while sharing a fair amount of redundancy in some areas remains it's most welcome aspect as it satisfies the intent to produce an optimization of the various ideas to produce functional, balanced and sustainable economic models. The emphasis throughout the various viewpoints borrow from '*lessons learned*' in the global power industry such as deregulation, the 2001 California energy crisis, environmental activism to curtail Green House Gas (GHG) emissions and the technical challenges of Power Systems operations in a dynamic market environment. A great emphasis is also placed on the human development factor and methods for its integration into new knowledge based industrial systems brought on by the 21st century ICT revolution currently driving the global economic system.

The opening paragraphs outline the vision of the AU and NEPAD organizations emphasizing the various regional power pools at the core of their development roadmap.

Commentaries on these programs from economic, technical and environmental perspectives follow the program vision and status after which commentary from selected academia through comparative studies outline various roadmaps for developing the all important human capacity factor to develop, manage and sustain these complex systems in a complex environment.

19.2 The Need for Infrastructure - New Partnership for Africa's Development

19.2.1 Why Regional Infrastructure

The need for Infrastructure--New Partnerships for Africa's Development is summarized in Figure 19.1 [1].

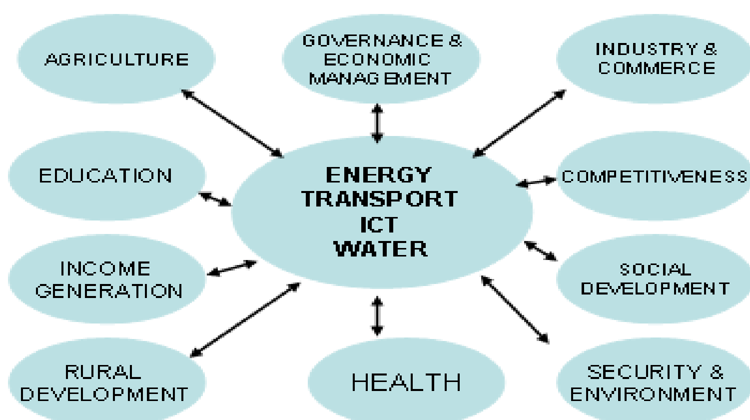


Figure 19.1. Need for Infrastructure in New Partnership for Africa's Development

The continuing demise of the human social condition is what has spurred the leadership through the formation of the African Union and NEPAD. At its core infrastructure deficiency found throughout the continent is the clear focus for development. There is also the realization from experiences in their individual national economic programs and other global economies that greater efficiencies can be derived through regional and ultimately continental cooperation articulated as follows:

- Regional and International trade are central to economic growth and development
- Efficient infrastructure network has the effect of generating new investments in other sectors
- African countries, individually, are too small to generate economies of scale found in larger markets
- Weak infrastructure linkages condemn the region to low competitiveness in the global market
- Regional infrastructure leads to larger project sizes capable of attracting more private sector investments.

19.2.2 Approach Adopted

The approach adopted by NEPAD in Infrastructure is two-pronged:

i) A short-term action plan (STAP) based on a survey of countries and RECs
ii) A Medium-Long Term Action Plan/Strategic Framework, which is linked to and complements the short-term action plan. It will take up projects and initiatives that require more time for preparation and development as well as institute an enabling framework for future development of infrastructure.

19.2.3 The Role of NEPAD and the Typology of STAP

NEPAD tasks to ensure the successful implementation of Short Term Action Plan:

- Mobilizing political will:
  a) Facilitate the mobilization of resources.
  b) Facilitate knowledge sharing, networking and dissemination of best practices among countries, Regional Economic Cooperatives (RECs) and technical agencies
- Underpinning all NEPAD infrastructure programs is the objective of strengthening *sector governance.*

STAP Projects and Programs are mainly of four types:

- *Facilitation* – establishment of policy, regulatory and institutional framework to create a suitable environment
- *Capacity Building* initiatives to empower particularly the implementing institutions
- *Physical/Capital Investment* projects and programs
- *Studies* to prepare new priority projects and Programs.

STAP Projects/Program Selection Criteria

The STAP project selection process was guided by the following criteria:

- Projects that are at an advanced stage of preparation and that can be fast-tracked
- Projects that support both a regional approach to infrastructure provision and regional integration
- Projects that have stalled for various reasons and where NEPAD's intervention could be expected to make a difference
- Initiatives that offer solutions to regional policy, regulatory or institutional constraints.

19.2.4 NEPAD Energy Flagship Projects

- Regional Pools and Inter-connections
- Greater Inga Integrator Study
- Establishing Regional Linkages for African Energy Commission
- West African Gas Pipeline.

Projects under Implementation

- Electricity Master Plans for sub-regional interconnections in West, East (EAPP) and Central Africa (CAPP)
- West African Power Pool (WAPP)
- Southern Africa Power Pool (SAPP)

- WESTCOR Power inter-connect (DRC – Angola – Namibia – South Africa)
- Nigerian Benin Electricity Interconnection
- Mozambique-South Africa Gas Pipeline
- Electricity Networks Interconnection in Central Africa Study
- Kenya-Burundi-Rwanda-DRC Electricity Interconnection Study
- Morocco-Spain Electricity Interconnection
- Eastern Nile Power Trade Program Study
- Zambia-Tanzania-Kenya Electricity Interconnection
- Ethiopia-Djibouti Electricity Interconnection
- Benin-Togo-Ghana Electricity Interconnection
- Mozambique-Malawi Electricity Interconnection (Kenya-Uganda Oil Pipeline and West African Gas Pipeline).

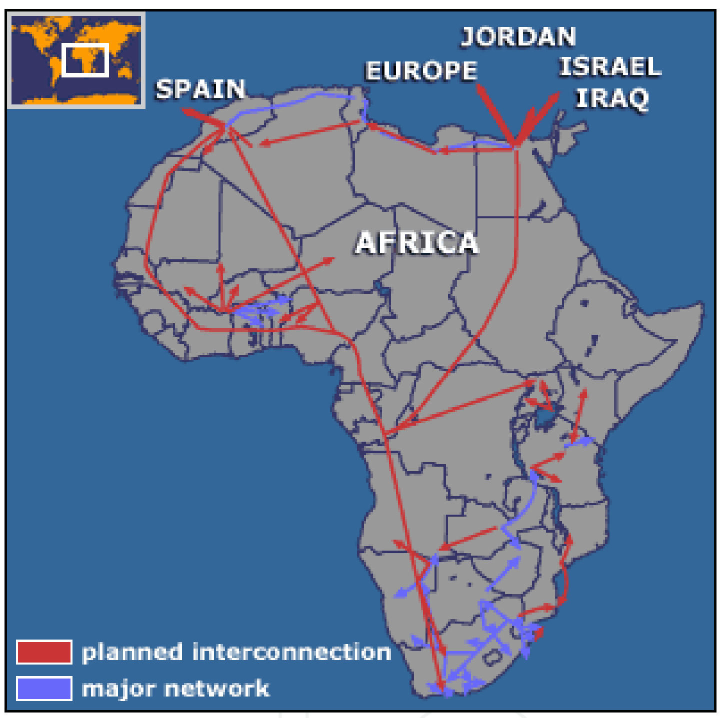


Figure 19.2. Planned Interconnections and Major Networks in Africa

19.3 The Future of SAPP, WAPP, CAPP, and EAPP with INGA

19.3.1 African Power Pools and the Centrality of INGA

Over the past decade there have been major initiatives taken by African governments to improve reliability and reduce costs by promoting the development of regional power pools.

The Southern African Development Community (SADC) created the SAPP in 1995 and the Economic Community of West African States (ECOWAS) created the WAPP in 2001 (see Chapter 10). Each of these power pools covers a very extensive area including 12 countries in the first instance and 14 in the latter (transmission lines being built (Figure 19.3).

Most recently the CAPP was created in early 2005 and there is currently discussion for developing an EAPP. These regional initiatives for improving trade among states all depend on new international HV lines being built.

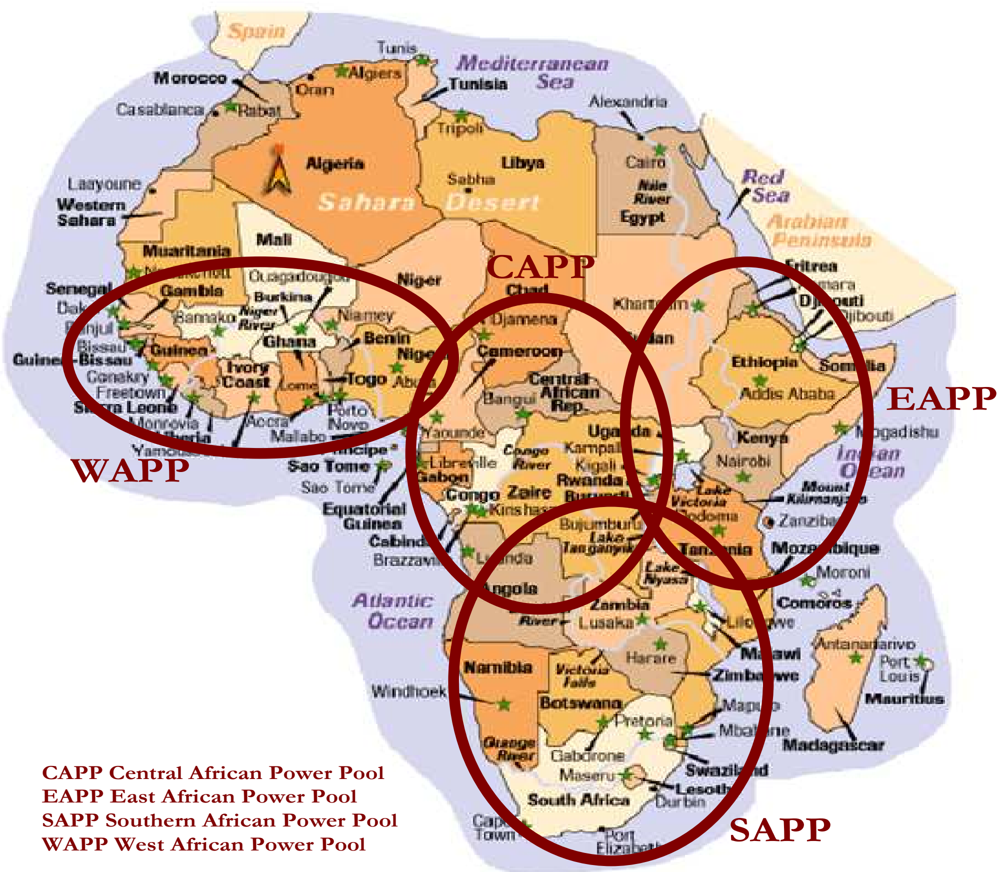


Figure 19.3. Africa Regional Power Pools, CAPP, EAPP, SAPP, and WAPP

Power Pool	Total Existing Generation (MW)	Sub-Sahara Generation (Percentage)
CAPP	4,561	8%
EAPP	3,092	5%
SAPP	42,324	72%
WAPP	8,579	15%
Total	58,556	100%

Table 19.1. Sub-Sahara Regional MW Totals [2]

Africa's largest regional power pool is the SAPP with over 42GW of generation capacity (Table 19.1). Total electricity generating capacity of Sub-Sahara Africa is about 59GW (7% of U.S. total of 983GW). With Africa's much larger area and smaller generating capacity there is the question of whether such a large spread-out continental grid, involving expensive long transmission lines with large line losses, can be economically justified? There is an ever-growing interest, in spite of the economic challenges, to transmit the enormous hydropower potential of the River Congo to the north, south, east and west of the continent. The Purdue modeling team has built models for SAPP and WAPP. A preliminary CAPP model has now been built and a proposal prepared for modeling the East Africa region. These modeling initiatives will provide top level planners with quantitative economic assessments of the new regional interconnections, demonstrating the magnitude of the gains from joint construction and trade.

What are the most critical new lines required in each of these four regions of Africa and how can the experiences of the United States and other large interconnected networks assist in the planning of a network across Africa?

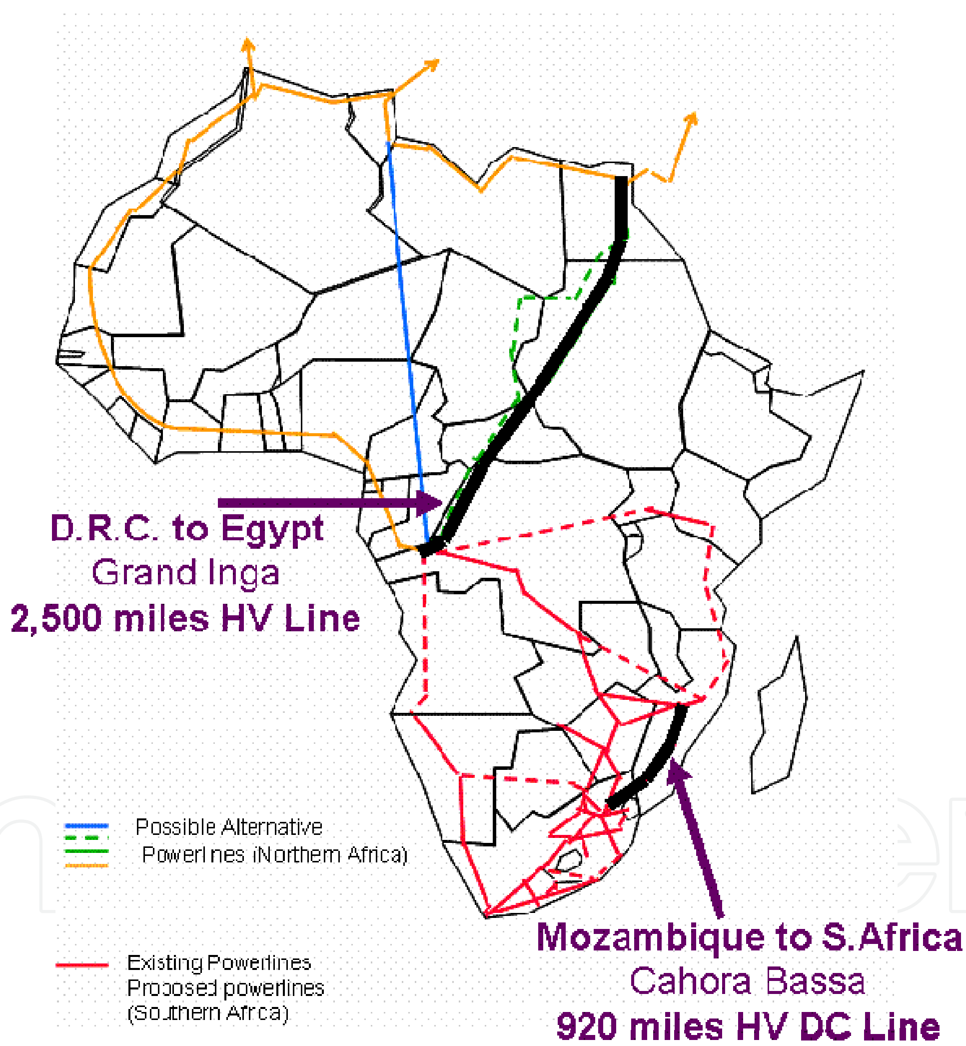


Figure 19.4. Long-Term Transmission Planning in Africa

The great hydropower potential of the River Congo, especially at Inga, can certainly play an important role in providing power regionally. Located at the heart of Africa (150km from Kinshasa) it is at the center of a future continent-wide power network (Figure 19.4). DRC-Inga currently exports and wheels power to SAPP countries including Zambia, Zimbabwe, Botswana and South Africa. Power from Inga is transmitted to the Zambian grid along a 500-kV direct current (DC) line from Inga to Kolwezi in southern DRC, and a 220-kV line from Kolwezi to Kitwe in northern Zambia [3]. Viability of a second southern interconnection, from DRC to SAPP via Angola and Namibia, rests solely on expanding the generating capability of the Inga facility. Expansion of Inga 3 (3,500MW) coupled with the rehabilitation of Inga 1 and 2 can provide enough excess generating capacity that will justify the creation of an expanded regional electricity export scheme. The Western Energy Highway will connect DRC-Inga to Nigeria and WAPP, providing 1,000 MW of electricity. The fully implemented Grand Inga scheme will be the largest generating facility in Africa with 39,000 MW and feasibility studies indicate that it's interconnector to Egypt would be viable with the construction of the Northern Energy Highway, passing through Congo, the Central African Republic, and Sudan to Egypt, a distance of about 2,500 miles.

There are striking differences in the amounts of HV transmission lines in Africa and North America. Sub Sahara Africa is about 2.5 times the size of USA. The SADC has an almost equal area to that of USA. Its 5,710km of international HV lines together with South Africa's 25,180km of HV lines amounts to 12% of the HV lines in USA (Table 19.2). The high demand centers in Africa are mostly concentrated in the capital urban areas and are very widely dispersed making a marked difference with the much higher number of high demand centers in USA.

Region/Country	Surface Area (1000 km^2)	HV Transmission Line Length Above 110kV (km)
Sub-Sahara Africa	24,267	N/a
SADC	9,275	5,710
Rep. South Africa	1,221	25,181
Nigeria	924	11,000
USA.	9,629	248,648
Canada	9,971	N/a
Mexico	1,958	23,500

Table 19.2. HV Transmission Lines in Africa and America [3,4]

19.3.2 Electricity Trading Between the North American Interconnects

Long distance electricity shipments in USA were originally reserved for unexpected outages in generation. An interesting exception to this comes from Canada's net flows of hydropower exports to New England and the west coast states. Net power flows between the three U.S. interconnections tends to be very limited. Canada's exports account for 5% to 10% of its total generation. In the case of CAPP these numbers will become reversed, with domestic consumption taking 5% to 10% of Inga's total production, assuming new continent wide interconnections will be constructed.

In the 1990s, the wholesale trade of electricity in USA was promoted and the Federal Energy Regulatory Commission (FERC) established procedures to ensure the availability of non-discriminatory transmission access. It had been the formation of the North American Electric Reliability Council (NERC) in 1965 that ensured compliance with guidelines for providing overall reliability and system security. In Africa there is going to be need for a similar organization, as several countries will be involved with the proposed long HV lines.

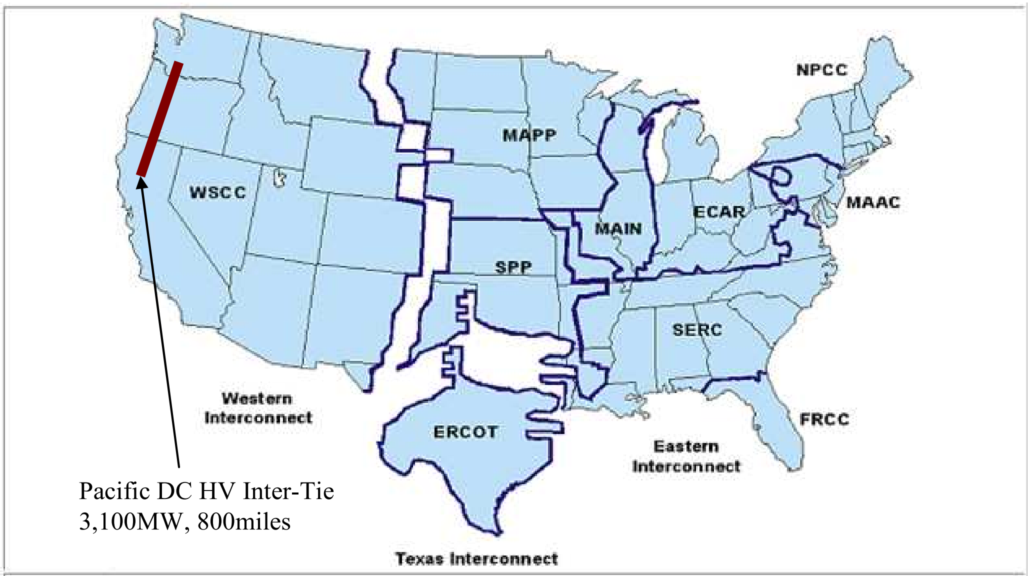


Figure 19.5. The Main Interconnections of the U.S. Electric Power Grid and the 10 North American Electric Reliability Council Regions

North America's three interconnected networks (Figure 19.5) are the Eastern Interconnect (the largest), Western Interconnect (second largest, west of the Rocky Mountain ranges) and the Texas Interconnect. There is very little load carrying capability between these three regions. Is it a technical problem, economics, or simply no demand exists at present? Each regional grid operates as a single large utility with a common set of operating rules. The Texas System is not interconnected with the other two networks (except by certain direct current lines). The other two networks have limited interconnections to each other. Both the Western and the Texas Interconnect are linked with different parts of Mexico. The Eastern and Western Interconnects are completely integrated with most of Canada or have links to the Quebec Province power grid. Virtually all U.S. utilities are interconnected with at least one other utility by these three major grids. Mexico has a national interconnected grid with four regional divisions and about 23,500 miles of HV lines. It connects with the U.S. at several points over the border and in 2003 imported about 72GWh and exported 953GWh.

Voltage	1990	1999	Change
230kV	70,511	76,762	6,251
345kV	47,948	49,250	1,302
500kV	23,958	26,038	2,080
765kV	2,428	2,453	25
Total	**144,845**	**154,5033**	**9,658**

Source: EIA, Electricity Transmission Fact Sheet [5]

Table 19.3. US High Voltage AC Transmission Mileage - Selected Years

In planning Africa's new HV lines, control of the lines is to be an important issue. The FERC expects new regional transmission organizations (RTO) to improve power grid reliability while reducing discriminatory transmission practices, and increasing investments in the transmission infrastructure. The issue of exactly who will control transmission of electricity under a nationwide system of RTOs needs resolving [6]. During this debate, in the 1990s, over 9,500 miles of new HV transmission lines were built in the U.S. giving approximately a 7% increase (Table 19.3).

The early 21st century has seen less new HV lines being constructed and this is becoming of great national concern especially for the summer peaking seasons. At what level of administration is Africa to debate the construction and transmission controls of the inter-power pool interconnections? To date the HV lines have been limited to within the regional power pools.

Most electricity trade in the U.S. takes place not between the three interconnected systems but among the power pools in each interconnect. The main exception to this, as already noted, is in the case of Canada exporting its hydropower. Major transfers of more than 3,900MW of peak demand takes place between the two NERC regions ECAR and MAAC, for example. Typical tie line transactions between U.S. power pools can vary between about 30 MW and over 3,000 MW (Table 19.4) but the lines are shorter than those being proposed for Africa.

In the U.S. a 765kV line might carry 3.8 GW but it will only be 100 miles long (Table 19.5). Extra long lines as being considered in Africa will need further technical study and will be much more expensive. In the U.S. the transfer of 3,000MW over several hundred mile and more will normally involve several lines. Transmission lines that are 1,000 miles long or more, similar to the Mozambique to South Africa DC line, are special designs for which the capital costing and operating costs require extra evaluation.

Exporting electricity from Mozambique's Hydro Cahora Bassa (HCB) to South Africa, and Canada's hydropower generation to the U.S. provides significant revenues to the exporting countries. In the case of DRC the export revenues could become substantial from building Grand Inga (Stages 1 and 2) with initial exports of 8,000MW (56,000 GWH/year). This could raise annual export revenues of $1.5 Billion or more once the full demand is being supplied.

Interface	Peak Demand (MW)
NEPOOL to NYPP	27
NYPP to NEPOOL	888
Net, NYPP to NEPOOL	861
NYPP to MAAC	1,261
MAAC to NYPP	1,684
Net, MAAC to NYPP	422
MAAC to ECAR	969
ECAR to MAAC	3,908
Net, ECAR to MAAC	2,939
Total Gross Transactions (Four NERC Regions)	**8,737**

Source: Office of Integrated Analysis and Forecasting, PowerWorld® model runs [7]

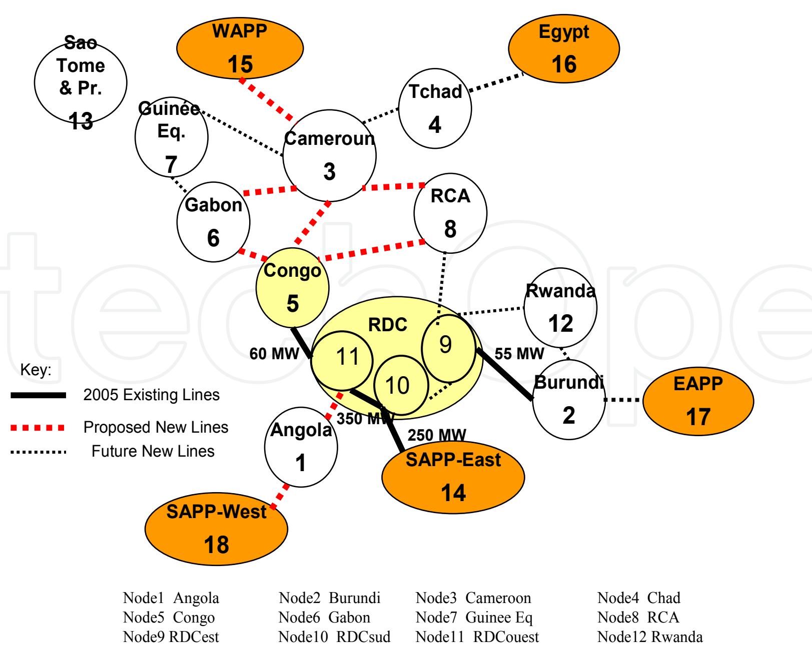
Table 19.4. US. Electric Transmission Network - A Multi-Region Analysis Interregional Gross and Net Tie Line Transactions

Voltage (kV)	Length (miles)	Maximum Capacity (GW)
765	100	3.8
	400	2.0
500	100	1.3
	400	0.6
230	100	0.2
	400	0.1

Table 19.5. Capacity Limits for Electrical Transmission Lines [8]

In the case of Canada it is one of the world's largest producers of hydroelectricity, generating over 315,500 GWh (2002). Very similar to DRC it is estimated that Canada has 180 GW of hydroelectricity potential remaining, although only 34 GW is currently deemed economically feasible. The economic analogy of building more hydropower in Canada with the DRC's Inga might help planners in Africa. Export potential for sending power to the U.S. from Canada has the attraction of further massive energy revenues but the capital-intensive nature of new hydro capacity could overwhelm benefits from trading. This is an issue that confronts the Inga project. Correctly pricing Inga's electricity exports is going to be essential for the successful launching of the project as it looks towards providing mutual benefits to consumers in Africa's power pools as well as to DRC.

19.3.3 The Preliminary CAPP Model



Note: RDC is French for DRC, similarly Tchad for Chad

Figure 19.6. The Preliminary CAPP Model - With 18 Nodes Including 5 Export Nodes [9]

Recently, Purdue's Power Pool Development Group's (PPDG) long-term planning software has been utilized to explore the economic gains that could be expected from the future development of the CAPP with its' 10 connected countries as indicated in Figure 19.6.

As Figures 19.3 and 19.6 indicate, the central location of CAPP allows it to consider exports to each of the two major Power Pools already in existence, SAPP and WAPP, as well as possible sales to Egypt and EAPP. These export opportunities, along with the well documented advantages of common operation and expansion of the grid within the 10 country regions, should make the establishment of CAPP a top priority for any Pan-African electricity generation planning project.

The model simultaneously cost minimizes expansions in both the generation and transmission sectors [10,11]. The water cost was set at $0.5/MWh which was the value stipulated by the SAPP some years earlier [12]. For demonstration purposes initial export demands were set at 1,000 MW each for SAPP west, WAPP, and EAPP, 250 MW for SAPP east, and 4,000 MW for Egypt. A general growth rate was assumed of 5% for CAPP as well as at the export nodes of SAPP, WAPP, Egypt and EAPP.

The 18-node model provides an optimal planning strategy for new lines emanating from Inga (node 11, DRC west, Figure 19.6). It is a 20-year long-term capacity expansion and electricity trade model as developed over the past several years for the SAPP and WAPP [13]. Unserved energy costs are set at $140/MWh and unmet MW at $3M/MW. The unserved energy and unmet MW costs could be argued for being raised but these values have been used in SAPP and WAPP and were therefore employed in the preliminary CAPP model.

While the CAPP modeling report [9] is still a work in progress, the model predicts the need for major transmission construction projects to serve the need for power flows within CAPP, and even larger investments in HV lines to allow power flows from the Inga sites to the five export markets shown in Figure 19.6. As the demand from Egypt, SAPP, WAPP, and EAPP increase, as well as demand within CAPP, then a portion of the larger expansion capacity envisioned at Grand Inga appears to be justified.

However, the CAPP data still needs careful compilation and validation, a task planned for the next phase of the project.

19.3.4 Investment and Electricity Pricing Issues

The determination of the electricity demand growth rates, demand forecast figures, and electricity prices are critically important in the planning process for new capacity. Improved forecast training in many countries of Africa, with more detailed data collection, will improve the determination of such critical numbers. The less industrialized nations frequently have problems with inadequate power supplies. These are reflected in the growth rates data as "*hoped for rates*" and do not provide satisfactory input data for planners.

The problem with all the plans to utilize the enormous hydro power potential of the Congo lies in, unlike distributed generation projects having short construction times and small construction costs, centralized hydro projects require very large initial investments in dams and the transmission lines long before any project revenues are generated. The demand growth numbers for projects like Inga have significant affects.

A realistic model of constrained growth will improve the forecasting technique (Figure 19.7). The demand numbers significantly affect the attraction of suitable investments for the two Inga projects (Inga 3 and Grand Inga Stage 1) being modeled. The growth rates of 5% and more are often considered as reasonable but looking at the historic numbers for the instances of Egypt, Nigeria and South Africa this is higher than what has been happening.

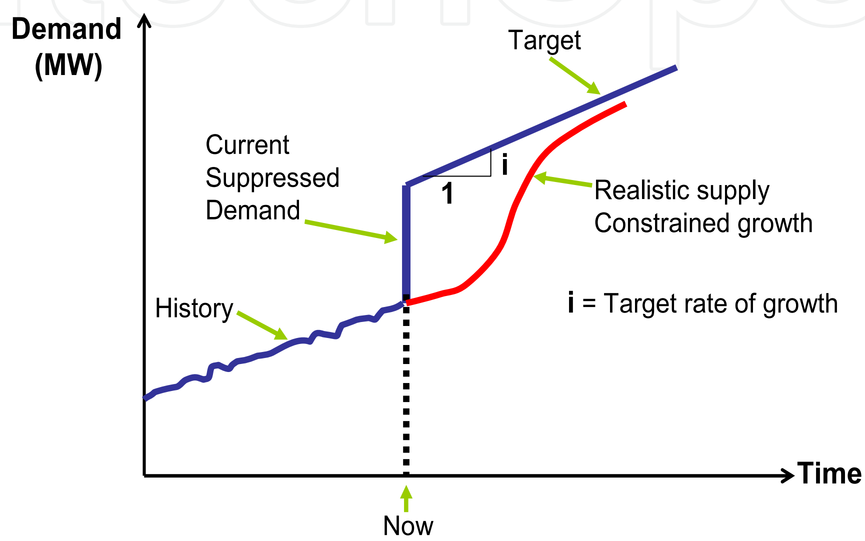


Figure 19.7. Electricity Growth Rate and Suppressed Demand

The average historic electricity demand growth rates for the largest national utilities in Africa over the past 10 years or more has been in the order of about 2%. This rate has been considered as a "*low case*" expansion scenario in the SAPP and WAPP. The numbers in Table 19.6 show the historic and average growth rates for these three countries.

Consider an illustration of the magnitude of the problem with having low demand growths. The two Inga hydro projects, the 3500MW Inga 3, and the 4000MW Grand Inga Phase 1 project – which are the driving forces behind much of the power pool activity in Africa - have estimated capital costs of roughly $4 Billion each. To this must be added the estimated transmission costs of $8.7 Billion to hook up the Inga sites to the export markets within SAPP ($1 Billion estimation at $1M/MW), WAPP ($1 Billion estimation), EAPP ($1 billion), and Egypt ($5.7 Billion). Thus the total upfront investment costs of the two Inga projects are in excess of $16.7 Billion.

Assuming a capital cost 10% and a project lifetime of 40 years, a range of $2.12 to $1.67 Billion dollars a year in returns to the investors must be assured for the projects to be financially viable. Further, all these export markets, each a functioning or planned power pool in itself, have local base load combined cycle generation construction options whose capital and operating costs are in the range of $30 to $40 per MWh (gas price range of $2.00 to $3.00 per MBtu), depending on the price of natural gas in these regions. These gas prices are reasonable estimates of current gas prices in Africa. If opportunities for LNG exports develop then these prices could increase. These domestic regional options will determine the maximum price these markets would be willing to pay for hydro electricity imported from the Inga projects. A further complication is that many of these regions already have capacity expansion projects on-going to satisfy near term needs for new capacity.

If we make the optimistic (for Inga) assumption that all projected growth in demand beyond 2005 in the four regions would be met by Inga power, as long as the price does not exceed the $/MWh range indicated above, we have the basic structure of a procedure to determine if the Inga projects make economic sense.

Billion kWh	1992	1993	1994	1995	1996	1997	1998
Egypt	40.45	44.41	46.56	48.44	48.13	51.65	55.6
Nigeria	13.15	12.84	13.74	12.92	13.36	13.47	13.5
S.Africa	144.6	149.37	156.2	160.89	168.3	175.5	175

Growth Rates	1993	1994	1995	1996	1997	1998
Egypt	9.80%	4.80%	4.00%	-0.60%	7.30%	7.70%
Nigeria	-2.40%	7.00%	-6.00%	3.40%	2.30%	-1.10%
S.Africa	3.30%	4.60%	3.00%	4.60%	4.30%	0.10%

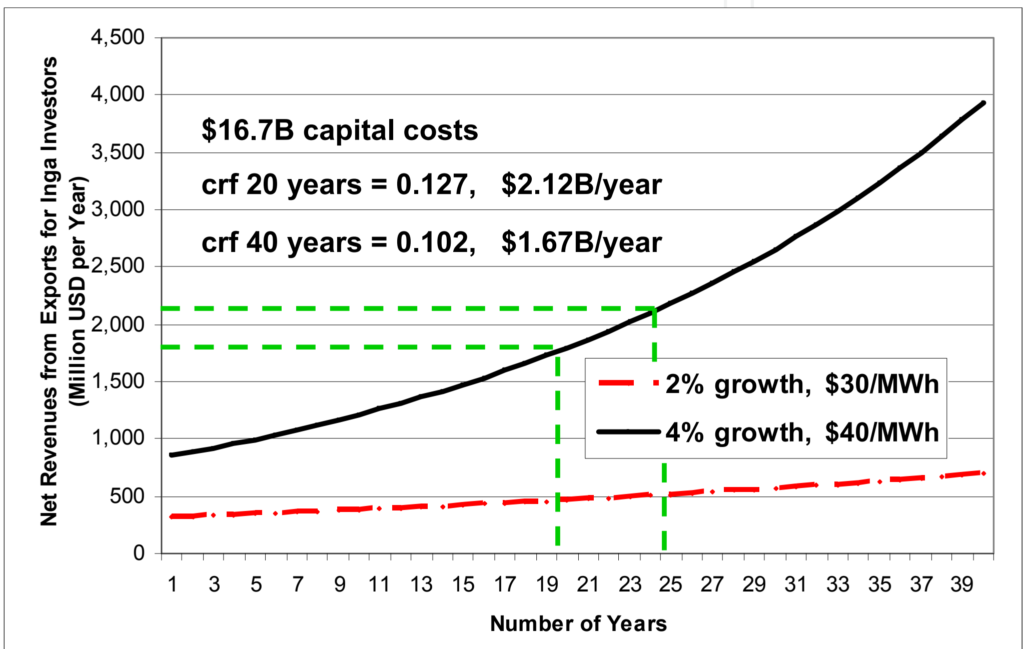
Billion kWh	1999	2000	2001	2002
Egypt	60.59	66.86	72.93	75.58
Nigeria	13.63	13.9	16.13	18.43
S.Africa	178.14	183.76	185.9	189.36

Growth Rates	1999	2000	2001	2002	Total	Average
Egypt	8.90%	10.30%	9.10%	3.60%	25.90%	2.6
Nigeria	2.40%	-5.20%	23.00%	14.30%	18.40%	1.8
S.Africa	3.2%	1.2%	1.0%	9.0%	14.4%	1.4

Table 19.6. World Total Net Electricity Consumption and Demand Growth Rates for 1993-2002 [14]

Figure 19.8 shows the yearly net revenue stream available to the investors in the Inga projects assuming a range of demand growth rates from 2% to 4% in the four markets, using the base electricity consumption in 2005. The revenue stream, obtained by extrapolating the kWh figures in Table 19.5, is what remains as a return for investors, after having subtracted from the revenue estimates hydro operating costs of $2/MWh, and assuming no line loss. Also shown in Figure 19.8 are the annual required returns to the investors, assuming two alternative lifetimes for the Inga projects of 20 years, and 40 years, and capital cost of 10%.

Figure 19.8 also shows the most optimistic assumption with a 4% growth rate in demand being well in excess of historical rates as shown in Table 19.5. This results in the project yearly cash flows not covering the yearly-required returns until year 19, while the pessimistic assumption with a 4% growth rate results in the annual revenue stream equaling the required annual return only after 25 years have passed. Note that if the growth rate is 2%, the revenue stream never generates the required annual revenue stream during the lifetime of the Inga projects. Does this mean that the Inga projects should be abandoned? Not at all, but it simply means that much more analysis must be undertaken before any investor group will look seriously at Inga as a viable investment option with these export assumptions.



At $30/MWh & 2% demand growth the annual cost of capital does not break even with revenue from exports within a 20 year or 40 year planning horizon. At $40/MWh and 4% demand growth the annual cost of capital breaks even at 18 years (40 year horizon) and 24 years (20 year horizon)

Figure 19.8. Net Revenues from Exports for Inga Investors With 2% and 4% Demand Growth (USD)

Comparative assessment to similar sized projects can always help if it were possible to obtain the growth and cost data involved. Certainly Mozambique's exports to South Africa are more appropriate for the Inga project than say Canadian hydropower to USA. The level of risk in North America is less and the cost of borrowing capital therefore reduced. High electricity growth rates elsewhere in the world make a major difference and China comes to mind. The huge Three Gorges project can be justified with the 8% to 10% historic growth rate but can the much smaller African growth rates justify the construction of such large projects?

Perhaps it is Egypt and the Mediterranean region with its large and growing demand for electricity that is the additional market for an enlarged Inga. If this is the case then the expansion costs of the DRC to Egypt line together with Inga, and the electricity export prices appear to be the first two most important issues for consideration. Secondly, firm power contracts as well as wheeling rates will need to be agreed upon among all the players and stakeholders to secure adequate investments.

Without the Egyptian export gateway it is hard to justify the capacity expansions as growth rates as high as 4% or higher for many African countries are not taking place. The suppressed demand has to be remembered but still massive rural and urban electrification programs are required to take place to see the needed growth levels. These are some of the opportunities and challenges facing those energy planners promoting the substantial expansions for Inga and the inter-regional power grid of Africa.

In summary, the vision of a continent wide HV power grid across Africa with Inga at the heart of the network has inspired African electricity planners for many years. The concepts and documented benefits of integrated African power pools, as demonstrated by the studies done by Purdue's PPDG for the SAPP and WAPP, support the impetus towards implementing the Pan-African HV network plan. Central to a strong future continental network is the creation of an efficient CAPP because of its location and the potential of Inga.

While the results of current work by PPDG support the general economic feasibility of the vision, this section (Section 19.3) questions the approach taken by some supporters in their promotion of several very large projects, rather than a series of smaller ones. Both economic theory and industrial practice tell electricity planners that in situations, as in Africa, where capital costs are high and demand growth rates are low, it is best to forgo the scale economies present in constructing a few large projects, and choose instead to expand capacity slowly to allow the expansion in capacity to better match demand growth.

There might be enormous revenues and benefits from building Grand Inga and major new HV lines across Africa. The time has arrived for a combined in-depth analysis of the three broad development scenarios referred to: (a) building Grand Inga for power exports to the Mediterranean, (b) building Grand Inga as a power source for all Africa, and (c) planning for massive urban and rural electrification. Each scenario holds great potential but each one needs to be considered within the complementary inclusiveness of all three scenarios combined, if sustainable development is Africa's goal.

19.4 Security Considerations of Modern Power Pool System Interconnections [15]

The lessons brought on by the advent of deregulation and the resulting weaknesses that unfolded during the 2001 California Energy Crisis have introduced caution to planners in how best to adapt market forces to the requirements of power system operations. In evaluating the planned synchronous interconnection of the African regional power pools interconnection, security issues should be taken care of before any economic analysis is undertaken. Power system security studies have traditionally been used in industries only during planning. This Section will address future real-time security systems for operation of '*deregulated*' power pools with an emphasis on technical aspects, namely: voltage stability, transient stability, and dynamic stability that are three approaches to power system security studies.

	Transient Stability	Dynamic Stability
Synchronous Stability	Observe transient response (1~2 swings after disturbance) of generators	Observe dynamic response (1~6 seconds after disturbance) of generators
Voltage Stability	Observe transient response (1 or 2 swings after disturbance) of bus voltages	Observe dynamic response (1~6 seconds after disturbance) of bus voltages

Table 19.7. Categories of Power System Stability

Stability is categorized as synchronous stability, angular stability, and voltage stability depending on the quantities in which one is interested. Synchronous stability is focused on rotor angles or frequencies of generators and voltage stability is focused on bus voltages. Depending on the time-period one is observing, stability can be categorized as transient stability and dynamic stability. The observed time-period for transient stability is about a couple of swings after the disturbance. That of dynamic stability is normally 1 to 6 seconds after the disturbance. However, if necessary, the simulation time can be longer than 10 seconds. Table 19.7 summarizes different categories of stability.

19.4.1 Transient Stability

For transient stability, one is interested in the system ability to survive a large disturbance, such as a fault, or a sudden change in generation, load, or system configuration, without prolonged loss of synchronism. In this part, rotor angle behavior of generators after the disturbance is looked at. The system is said to be stable in transient state if rotor angle separation between any two machines tends to keep in a certain range after the disturbance. On the other hand, the system is transient unstable if the rotor angles keep running away.

19.4.2 Dynamic Stability

Dynamic stability is the ability of a power system to return to its initial state or reach another steady state after a small disturbance. Dynamic stability of a system can be understood by looking at damping of the system oscillation, which can be triggered by either an unexpected disturbance, or a regular operation of the power system. The oscillation should die out in several seconds after the disturbance for a strong system. If the oscillation is decaying slowly, then the system has bad dynamic characteristics. If the system has a lasting oscillation or even diverging oscillation, the system is dynamically unstable. The poor damping of the oscillation signals a narrow stability margin of the power system. With this small margin, the system operators must be very careful when they are executing system operations because the operation criteria might not apply. The same operation might drive the system to an unstable area though it was good previously.

A power system may be stable during the transient period but unstable during the dynamic period.

One of the phenomena of dynamic stability problems is the oscillation. The frequency of the oscillation is between 0.2 and 1.0 Hz. Thus, this oscillation is called low frequency oscillation since its frequency is low compared to system frequency.

System oscillation is often found in an interconnected system. Power oscillation begins when the power flow on the tie line linking two areas in the system increases to some level. The oscillation disappears if the power flow is reduced. Therefore, the transmission capacities of tie lines are subject to a stability limit and, unfortunately, the stability limit is normally lower than thermal limit.

System dynamic characteristics are changing not only with system expansion, but also with system operation. The power system might have spontaneous low frequency oscillation without any known specific disturbance if the system is operating near the dynamic stability margin. Actually, there must be some but not special disturbance. Because the system is near the margin, this disturbance happens to drive the system to an unstable area and triggers spontaneous oscillation. Once the disturbance disappears, the oscillation will be decaying slowly.

Figure 19.9 is an example of a spontaneous low frequency oscillation observed on April 1991 in a power system. The oscillation frequency is about 0.8 Hz. Figure 19.9(a) is the system frequency oscillation and Figure 19.9(b) is the real power oscillation of a nuclear unit.

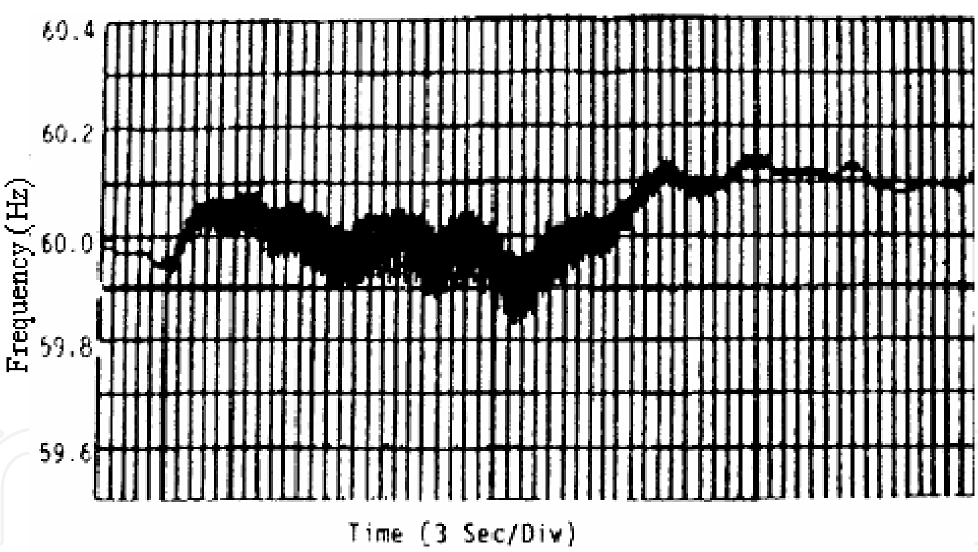


Figure 19.9(a). System Frequency Oscillation

Since the power system is always subject to small disturbances, dynamic stability is essential for system operation, particularly if the system is operated at a tight dynamic stability margin. This is important for the countries of the Sahel region now contemplating Nuclear power as an option to address the looming water crisis through desalination systems. The above example is an important consideration and one to be analyzed as these countries will also be interconnected to the emerging West African Power Pool (WAPP) and the North African Power Pool.

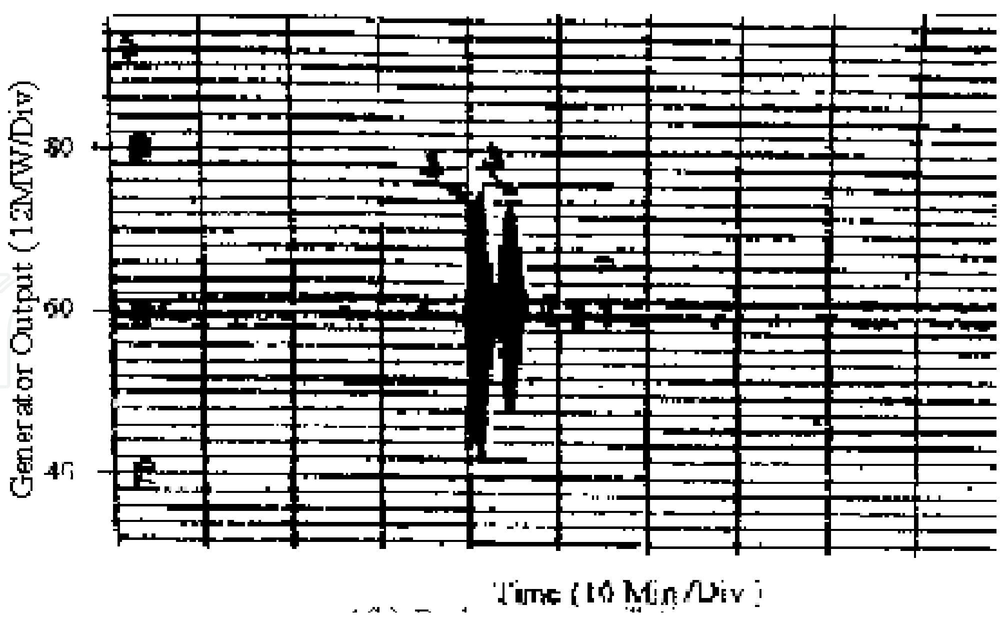


Figure 19.9(b). Real Power Oscillation

19.4.3 Voltage Stability

The power system should be operated securely not only in usual conditions, but also when there exist disturbances. The power system is stable when the system is able to restore to its initial condition or reach another steady state, which is acceptable in terms of operational standards after experiencing a disturbance. For voltage stability, the system should be able to maintain the magnitudes of bus voltages when experiencing the disturbance.

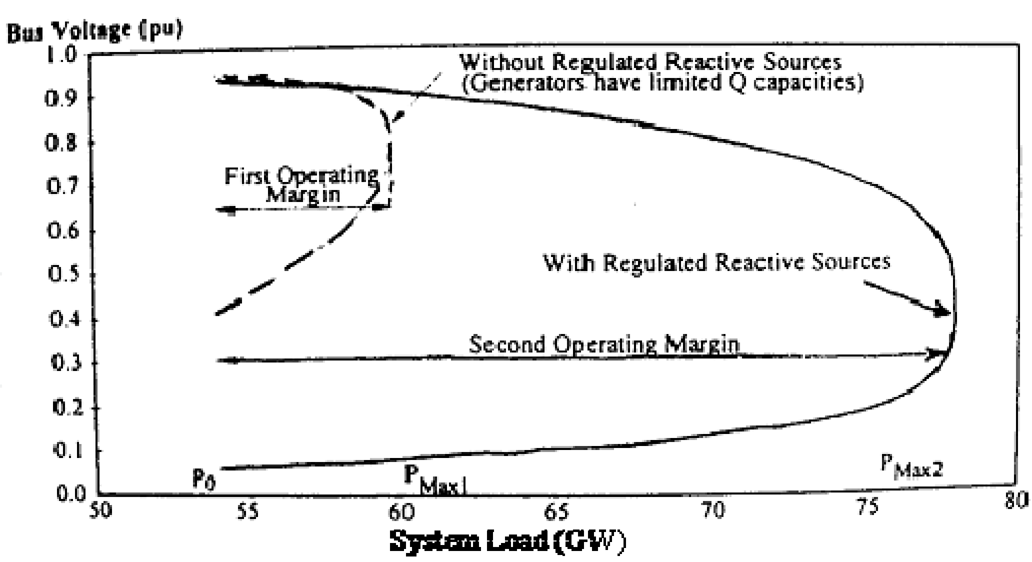


Figure 19.10. PV Curve of a Power System

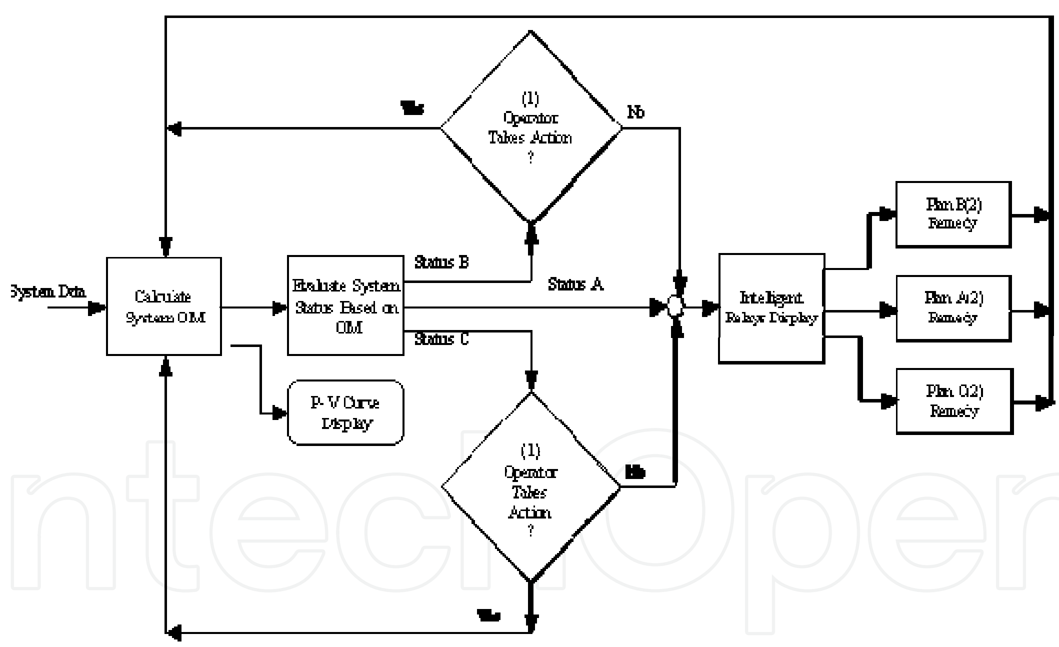
Power failures caused by voltage instability or so called voltage collapse that lead to power system blackouts have been reported in many countries, such as Sweden, France, Japan and USA (including the August-2003 blackout). The affected area, because of voltage instability, can be metropolitan or nationwide. The effects are not only in power interruption to customers, but also in mass transportation and industrial manufacturing. The losses to the power utility are in both finance and customer service.

Increasing load and deficient reactive power supply generally causes voltage collapse. It is a combinatorial problem affected by both system and load characteristics. The power-voltage characteristics of a power system are represented by a P-V curve (Figure 19.10).

It is clear that the degree of stability cannot be judged based on how close the bus voltage is to the normal level. The power industry is basically just using the magnitude of bus voltage as a measurement of voltage stability.

19.4.4 Today's Congestion Management

- Only check the thermal limit
- Real-time limit is not there
- No voltage stability limit
- No transient stability limit
- No dynamic stability limit
- The responsibility of system congestion due to single contingency is not clear.



Note: (1) Preventive actions include Re-dispatch, Shedding interruptible loads, Shedding weak bus loads, etc.
(2) Plans A, B, C remedies

Figure 19.11 Conceptual Design of an Intelligent Control-Room Operating System

If the detailed story of the August 2003 US. blackout is examined; the security issues of power system must be handled using a different approach. As a result of market driven dynamics introduced under deregulation in today's control room, the power system operator may not know the system margin. All utility operation control systems should provide the following:

- Real-time data of system margin
- Tools to ensure the Operator is informed and involved
- System identifies weak bus(es) of system
- Dynamic load-shedding (if necessary)
- An intelligent system should be installed immediately at all ISO facilities.

A conceptual design of an intelligent control room operating system is illustrated in Figure 19.11.

19.5 Area Control Considerations for the Emerging WAPP [16]

The full implementation of the WAPP project will be staggered over four phases over a period of more than 20 years. Each phase comprises an institutional development component and an infrastructure component.

The ECOWAS countries have been divided into two main zones: Zone A includes Benin, Burkina Faso, Côte d'Ivoire, Ghana, Niger, Nigeria and Togo, and Zone B includes Cape Verde, the Gambia, Guinea, Guinea Bissau, Liberia, Mali, Senegal and Sierra Leone (Figure 19.12).

Phase 1 covers most of the Zone A countries (except Niger, Nigeria and Togo) and Mali from Zone B

Benin, Burkina Faso, Mali, and Togo have been identified as the main prospective importers of electricity due to high generation costs, while Côte d'Ivoire and Ghana have been identified as the main prospective exporters of electricity in the region during phase 1 implementation.

Note: WAPP Demonstration Results only

Figure 19.12. WAPP Zone A and B countries: WAPP MW reserve exports, period 2

19.5.1 Financial Issues

In general, synchronous interconnection must be accomplished through multiple large capacity transmission paths placed in service simultaneously. A thorough analysis of the optimal number of lines necessary to accomplish reliable interconnection depends upon the anticipated transfers over the lines and requires engineering and economic analyses. For those originally isolated systems, construction of new transmission facilities and improvement of existing transmission facilities would be necessary to provide the infrastructure to facilitate desired power transfers. Investments in transmission facilities have historically been funded by utilities. The facilities for interstate connection and the required infrastructure improvements may fall outside the traditional paradigm of transmission funding by utilities. The investment for the construction of the required facilities must have a reasonable expectation of recovering the associated costs from their customers or users of the facilities. The issue of providing the necessary economic incentives for construction of new transmission facilities in an environment where transmission owners must provide open access is common to synchronous interconnection investments. However, incentive for cost recovery and profit for investment may defeat the purpose of interconnection to provide cheap and clean energy in Africa.

Synchronous interconnection could impose additional operating cost on utilities and other owners of electric generating facilities. In order to maintain reliability, generators may have to adjust operations to accommodate those of utilities elsewhere on the interstate grid. The magnitude of these additional costs is difficult to quantify due to uncertainties over the operating characteristics of the interconnected grid. Any additional operating costs caused by synchronous interconnection raise two issues. First, the additional operating costs must be offset against estimates of gains from trade considered as benefits from synchronous interconnection. Second, there must be some mechanism for beneficiaries of power flows to compensate those entities that are forced to bear additional costs to accommodate those flows. Though initial evaluations suggest that any additional operating costs are probably not very large, there is considerable uncertainty and controversy over the significance of these costs and it would probably not be prudent to ignore them.

19.5.2 Technical Issues

Interconnection enhances the ability to import power when there is a shortage due to extreme weather or generator outages is a reliability benefit. However, interconnect AC network will increase the complexity of the system that is subject to various reliability, security, and stability problems due to the interactions among the increasingly prevalent automatic generator voltage and speed controls, system frequency, tie line flow, and critical bus voltages. The analysis of system dynamic performance and the assessment of power security margin have correspondingly become more complex. This may threaten reliability and lead to wide area power outages. The social and economic cost of power outages, especially extended outages over a wide geographic area can be significant, as was learned in the North America Northeast blackout in August 14, 2003. It took only nine (9) seconds for the blackout to spread across Canada and several states in the US, effecting more than 50 million people. Some went without power for more than three days. Understanding the behavior and fundamental characteristics of the system are critical for secure operation.

19.5.3 Cascade Failure and Protection Coordination

If the failure of equipment may trigger other events and cause other devices to trip out of service, the system is threatened by the possibility of cascading outages. As an example, the condition might be precipitated by a transmission line failure caused by a falling tree branch. In response to the outage, all remaining transmission line flows adjust to carry more loads. This may result in tripping another overload line and worsen the system situation that lead to system blackout. The interconnected system is more susceptible for this type of situation since the under-frequency protection may not function properly. These cascading overloads are a threat to secure system operation, and were the main reason for the spread of the Great Northeast Blackout in the 2003. Regular evaluate and update the protection scheme is necessary when expanding the interconnection networks.

Interconnecting these planned AC network and or HVDC networks will increase the complexity of the system that in turn will increase system reliability, security, and stability problems due to the interactions of equipment and control actions. Therefore the primary reliability threats in a transmission system of Voltage stability, Dynamic/Transient stability, and Cascading failure and protection coordination as discussed in 19.4 should remain predominant during the planning phases particularly for emerging economies with marginal system parameters.

19.6 Hydropower and African Grid Development: Rights Based Perspective

19.6.1 Hydropower and African Grids

African energy needs are indeed vast. Africa is home to 13% of the global population, but has the lowest energy consumption per capita of any continent. Most grid energy generation is in three countries: South Africa, Egypt, and Nigeria. Even then, a disproportionate amount of those using grid based energy live in urban areas. Vast disparities exist between grid energy available for commercial and non-commercial use. Grid based energy continues to be available overwhelmingly in urban areas, benefiting commercial use and those able to afford it. Concerns exist that financing grid-based development displaces resources available for energy development that could better promote poverty alleviation.

Hydropower is a significant source of existing and planned grid-based energy in Africa. Statistics are often used declaring that Africa's hydropower potential has gone virtually unexploited. While hydropower can generate significant electricity for grid systems and provide effective peak load power, hydropower projects are often proposed with overstated benefits and understated costs. Hydropower projects also have a history of poor implementation that has resulted in inequitable sharing of project costs and benefits. Beneficiaries of hydropower projects tend to live away from the hydropower site, and receive the grid based electricity, generally in urban areas or large towns. Those bearing the costs of hydropower projects may be directly displaced, have negative impacts to their livelihoods (such as fishing or agriculture), have increased health risks from water-borne disease, and face disruptions to social systems by temporary migration into the area during project construction. Those bearing the costs often do not benefit directly from the projects, or receive adequate compensation that recognizes all the social costs endured. Without genuine participation in the decision making process, communities often do not receive project benefits that outweigh their share of the costs.

Reservoirs of hydropower dams often displace thousands of people. The Kariba Dam shared by Zimbabwe and Zambia displaced 57,000 in the 1950s. These are people for whom adequate compensation has never been granted, and whose lives and livelihoods were expensed for this addition to grid development. Currently, the Merowe Dam is displacing 20,000 villagers in Sudan without receiving proper compensation. They have been denied participation and genuine access to the justice system. In the past 50 years, some 40-80 million people have been forcibly resettled for large dams, and millions more face such a fate as we speak.

There are many current proposed hydropower projects across Africa. The largest is the NEPAD-backed Grand Inga scheme, which would be the core of a continental grid system. Over-simplified statements are made that if only Inga could be developed, the whole continent would be lit up. There is little discussion occurring, however, about how to develop the demand in rural areas for this type of project. With fifty-two generating units, it would be the largest hydropower project worldwide. Including transmission, it would cost an estimated cost of $10 billion. Grid development like Grand Inga contradicts the goals of small-scale sustainable energy projects that were discussed at the World Summit on Sustainable Development in 2002.

In the SADC region, there are many other projects proposed or underway. Mphanda Nkuwa in Mozambique is another NEPAD backed project that would fulfill the country's effort to attract energy intensive business. Significant hydropower development, such as Tekeze and Gojeb, is occurring in Ethiopia with expectations to export power. Other significant projects include the 520 MW Capanda Dam in Angola, the Kafue Gorge Lower Dam in Zambia, and the 400MW Bui Dam in Ghana.

Current plans to develop the African grid system include the promotion of regional transmission lines in order to develop power pools and numerous large-scale energy projects that will feed specifically into grid systems. The grid system, as currently planned, primarily benefits industry and wealthy communities in urban areas. There is virtually no benefit to rural areas, or the urban poor. Local industry and small business generally do not benefit from grid development to the extent that major commercial and industrial customers do. These large businesses, often foreign-owned, benefit from increased power generation, but often wield enough power to receive electricity at rates providing little profit margin for the government, if at all. In some cases, major end users pay rates subsidized by residential customers.

Power grids are not designed to reach the hundreds of millions of Africa's rural poor. Grid systems can create a greater divide between those with and without access, generally increasing the disparity between rural and urban areas. Mass grid development may even encourage greater urbanization, causing cities to develop at increased rates, leading to other negative economic impacts that cities must then address (such as increased water, sanitation and other infrastructure needs, increased crime, and increased spread of HIV and other diseases). Many Africans live outside of the formal economy, living on subsistence and small enterprises that are often overlooked by development planners and policy makers. Designers of grid systems must be acutely aware of consumer demand and affordability. Whether in urban areas or in more distant communities, grid connection does not alleviate poverty for those unable to afford the electricity.

The New Partnership for African Development (NEPAD) has been described as a blueprint for Africa's self-determined economic propulsion out of poverty and toward sustainable development. NEPAD recognizes that half the Africa population lives on less than $1 per day, and that infrastructure is desperately needed to improve people's lives. However, NEPAD continues to be a top-down entity made up primarily of African elites with only token input from civil society. In a rush to promote foreign investment, economic growth, and NEPAD's political success, the body is virtually blind to the fact that its activities are in direct contradiction to its mission of African sustainable development.

Regional economic development planning and power pools are both gaining ground in Africa. More and more countries are receiving World Bank advisement to privatize their energy systems and promote competitive markets. Significant manipulation of market circumstances happens by those with the greatest market power: suppliers and major end-users. Civil society is rarely, if ever, in a position to benefit from the liberalized market. Where there is supposed to be greater consumer power, industrial consumers wield the most power, often to the detriment of residential and small business users.

World Bank and IMF loans are regularly conditioned to include privatization of government enterprises and promotion of free market systems, including liberalizing capital markets, promoting market-based pricing and free trade. Unfortunately, these measures only move political economic powers from government bodies and politicians to private, often foreign, companies. None of these changes provides increased political economic power to civil society.

19.6.2 Using a Rights-Based Approach

Utilizing a rights-based approach can bring more effective, more sustainable, more rational and more genuine development decisions. The inclusion of civil society in decision-making promotes transparency, which will likely decrease corruption. It will ensure that poverty alleviation happens, rather than poverty displacement, or even poverty generation. It will ensure appropriate solutions are found that fit the problems at hand because project analysis will be more complete. Most importantly, local participation and ownership of decisions helps safeguard against harm done by development projects, and will promote the sustainability of solutions found.

A rights-based approach allows for a positive transformation of power relations between various stakeholders involved in decision-making. There are four primary criteria to a rights based approach. First, it must include a linkage to human rights and accountability. Second, it includes equity of benefits and costs allocation. Third, it also includes empowerment and public participation, with attention to marginalized groups. And finally, it includes a transparent process. A primary concern over development projects in Africa is the external control of projects that affect internal peoples. Those within Africa need to be given decision-making control in their own development.

19.7 Targets and Technologies for African Electrification

19.7.1 Global Energy System Vision

Over the next 50 years, universal access to at least a minimum level of electricity and related services can contribute to dramatic improvements in the quality of life (education, economic justice, public health and safety, and environmental sustainability for the world's under-served populations). In 2000 the United Nations General Assembly adopted a comprehensive set of "*Millennium Development Goals*" to help create a more coherent worldwide focus on the truly pressing tasks for the coming fifteen years [18]. Global electrification can greatly assist the effort to achieve those UN goals, such as halving the incidence of extreme poverty or reducing the waste of material resources.

The World Summit on Sustainable Development held in Johannesburg reaffirmed those goals and gave particular attention to the need for assuring a greater supply of modern energy services, notably electricity, electricity, to the entire world's population [19]. This report affirms and adopts that goal. For the benefits we envision, electricity will have to meet reasonable standards of quality and reliability be available for commercial, industrial and residential uses, be affordable, and cause minimal environmental impact. A diverse portfolio of generation options will be required, including advanced clean fossil, renewable, hydroelectric, and nuclear power sources, plus high-efficiency end-use technologies and applications to support both environmental and economic sustainability. Our vision for the 2050 global energy system is therefore one of worldwide new capabilities and opportunities for quality of life, dignity, and environmental sustainability, enabled by universally available electricity.

What is needed is a global vision for realizing electricity's essential value to 21st century society, a plan to set strategic technological priorities, and an outline of the associated research, development, and delivery requirements needed to achieve this vision. In this context, EPRI's Electricity Technology Roadmap outlines a vision for the future based on broad stakeholder input to spur debate, consensus, leadership, and investment that will enable electricity to continue to fulfill its potential for improving quality of life on a global scale. The initial version of the Roadmap, released in 1999, describes a series of destinations for the power system of the 21st century [20]. A companion volume that supplements the initial report is now available [21]. This report expands the original by identifying three comprehensive high-priority goals that are most essential to assuring global economic and environmental health. They are:

- **Smart power** – the design, development, and deployment of the smart power system of the future
- **Clean power** – the accelerated development of a portfolio of clean energy technologies to address climate change
- **Power for all** – the development of policies and tools to ensure universal global electrification by 2050.

These characteristics reinforce the Roadmap's original destinations and provide a basis for a new planned initiative to include a series of detailed recommendations for technology development.

19.7.2 Improving Efficiency of the Energy Supply Chain

As societies strive to improve access to modern energy services, they must also find ways to make the energy system more efficient. The efficiency of the full energy supply chain (extraction, conversion, delivery, and consumption) has only reached about 5%; therefore, large opportunities for improving efficiency remain at every stage in this chain. For example, using today's energy sources and technology, achieving universal supply of at least 210 Mega Joules per day per capita by 2050 would approximately triple the current global rate of energy consumption. Fortunately, realizing technological advancements that are now visible throughout the energy supply chain could reduce the 210 Mega Joules per day threshold by 2050 to as little as 125 Mega Joules per day with no loss in economic productivity or quality of life potential. The efficiency of electricity generation, for example, now typically in the 30% range, could easily reach, on average, 50–60% by 2050, based on modest technology improvements over current practice. Even greater performance is possible if step function technology advances occur, as seems likely. For example, the emergence of low wattage lighting and appliances aimed at the developing world suggests rapid technological progress in household energy efficiency. Even the automobile is on the threshold of tran formative change.

19.7.3 Electrifying the World

As a practical matter, electricity must form the backbone for the transition to a globally sustainable energy system and the modernization process it enables. Electricity's ability to transform the broad array of raw energy and other natural resources efficiently and precisely into useful goods and services, irrespective of scale, distinguishes it from all other energy forms. Electricity also serves as the unique energy prime mover enabling technical innovation and productivity growth—the lifeblood of a modern society. One need look no further than rural North America in the 1920s and 1930s — regions that were transformed from economic backwaters through active rural electrification programs — to see the importance of electrification as the precursor to economic opportunity and well-being. Further, as electricity's share of "*final energy*" in USA. increased from 7% in 1950 to nearly 20% today, the energy required per unit of GDP dropped by one third. Such important achievements, which occurred throughout the industrialized world, remain elusive in the least developed world regions. Over the last 25 years, about 1.3 billion people have been connected to electric service, but even this achievement has not kept pace with global population growth. Today, the International Energy Agency estimates that 1.6 billion people lack access to electricity. To keep pace with the world's growing population, electrification must reach at least an additional 100 million people per year for at least the next 50 years. This is about twice the current rate of global electrification.

A roadmap for destinations is indicated in Table 19.8.

Destination	Summary
Strengthening the Power Delivery Infrastructure	An advanced electricity delivery system that provides additional transmission and distribution capacity and "*smarter*" controls that support dynamic market activity and the rapid recovery from cascading outages, natural disasters, and potential terrorist attacks
Enabling the Digital Society	A next-generation power system that delivers the power quality and reliability necessary for sophisticated digital devices and seamlessly integrates electricity systems with communications systems to produce the "*energy web*" of the 21st century
Enhancing Productivity and Prosperity	New and far-reaching applications of the energy web that increase productivity growth rates across all sectors of the economy
Resolving the Energy/ Environment Conflict	Clean, cost-effective power generation technologies combined with workable CO_2 capture, transport, and storage options
Managing the Global Sustainability Challenge	Universal access to affordable electricity combined with environmentally sound power generation, transmission, and delivery options

Table 19.8. Roadmap Destinations

19.7.4 Setting Electrification Goals

Equally important as universal access to electricity is assuring adequate levels of electric service for those who have access. Our work suggests 1,000 kWh per person per year as a benchmark goal for minimum electric services—an essential milestone in the pathway out of poverty. This target is similar to the electric consumption in emerging modern societies that use a mix of fuels (some directly, others via electricity carrier) to satisfy their needs. It lies between very low levels of electrification (100 kWh per person per year) insufficient for measurable economic benefits and the 10,000+ kWh per person per year of the current US economy. Achieving this target can help meet personal needs for basic lighting, communication, entertainment, water, and refrigeration, as well as provide electricity for the efficient local production of agriculture and goods and services.

In choosing the 1,000 kWh per capita per year goal, we are mindful that improved energy efficiency and complementary innovations would allow delivery of basic energy services using less electricity. Nonetheless, the benchmark reveals that, under current trends, perhaps 90% of the world's population in the next 50 years will be born into conditions that fall short of the 1,000 kWh goal. Based on country averages, about 3.7 billion people today live in countries where the average per capita consumption of electric power is below the 1,000 kWh threshold. Over the next 50 years, it is likely that another 3 billion people will be added in these electricity-deficient areas.

Table 19.9 below presents anticipated trends in energy and economic statistics over the next 50 years for Africa and other parts of the globe. Actual data for the year 2000 are presented along with two projections, one representing a "*business as usual*" scenario and the other a world driven by sustained efforts to use electricity as the engine of economic growth in Africa and around the world. These data are derived from the US DOE Energy Information Agency International Energy Outlook for 2004[22], from a World Energy Council study of energy futures [23], and from other sources. Africa trails all other regions in economic growth, in energy and electricity growth, and in carbon emissions. Moreover, Africa attains the target of 1,000 kWh per person only in the electrified case. The extreme poverty of much of Africa is a key factor in limiting the pace of electrification, but the failure of reforms and other political issues also play a role.

Providing power to a global population in 2050 of 9 billion—including minimum levels of 1,000 kWh per person per year to the very poorest people—will require roughly 10,000 GW of aggregate global generating capacity, or three times the current level, based on today's technology. That corresponds with at least a 3% annual rate of increase in global electricity supply. Even with major efficiency gains in the generation and use of electricity, the aggregate global requirements for electricity generation will still be prodigious. Therefore, a critical priority is the development and deployment of an advanced portfolio of clean, affordable, generating technology options—fossil, nuclear, and renewables—that reflects the diverse resource, environmental, and economic realities of the world, while enhancing efficiency and productivity throughout the energy supply chain.

19.7.5 Crucial Issues in Global Electrification

Global Electrification Prospects in Africa are summarized in Table 19.9. To build the necessary momentum toward global electrification, research initiatives must address the whole electricity supply chain—from market policies through generation, transmission and distribution. In some cases, technology development will be required, but first some improvements in basic understanding are essential to meeting global electrification goals. Studies are urgently needed to quantify the value proposition of electrification under a variety of policy and technology scenarios. This information will play an important role in helping policymakers develop incentives as well as regulatory and market frameworks that will encourage private sector investment in electricity infrastructure for underserved areas. Also necessary are analytic tools that can improve this understanding and lead to development strategies specific to individual regions, to accommodate the differences in resources, human needs and cultural norms. The availability of these and other analytical tools will help avoid the mistakes that have occurred in recent African electrification initiatives. This body of work is beyond the scope of this chapter, but significant problems in African electrification have arisen due to poor management practices, political corruption, counter-productive cross subsidies, ineffectual reform programs, among others [24,25].

These issues must be resolved to assure the success of electrification programs.

	GDP per capita (10^3 US $PPP per year)	Primary Energy per capita (10^6 J per day)	Electricity Consumption per capita (kWh per year)	Electricity (% of Final Energy)	Carbon Emissions (MTC/yr)
2000					
Sub-Saharan Africa	1.7	70	840	7	140
3rd World	2.4	70	1,550	7	900
Industrialized World	28.0	650	7,300	18	3,200
2050 Reference Case					
Sub-Saharan Africa	2.0	90	900	10	400
3rd World	3.5	110	1,900	11	2,700
Industrialized World	39.0	690	11,000	3	2,950
2050 Electrified Case					
Sub-Saharan Africa	4.0	120	1,460	31	350
3rd World	5.3	130	2,930	31	2,300
Industrialized World	39.0	460	16,100	48	1,420

Table 19.9. Global Electrification Prospects in Africa

19.7.6 Highest Priority Actions

The highest priority should be assigned to activities in two areas. First, additional research is needed on the "*value equation*"—the costs and benefits associated with universal electrification. This section proposes some global goals and strategies, but work is needed to understand the implications of those global goals for particular localities and regions and to outline specific strategies for achieving the goals. For example, the goal of 1000 kWh per person per year will vary with local conditions (e.g., heating requirements) as well as the potential for increasing efficiency and the competition between electricity and other energy carriers.

These questions require local and regional attention. Such analytical work must be done in a way that reflects appropriate local policies and the emerging new reality that electrification is increasingly funded with private capital and operated as a partnership between private firms and public institutions. In that emerging market, assessing the value equation requires attention to public values and policies as well as private incentives.

Second, work is needed on specific technologies that will be essential to meeting the goal of universal electrification. Improvements across a broad portfolio of generation and delivery systems will be needed. Especially for service in remote rural areas there is a need to create or adapt relatively clean, low-cost, and readily deployable off-grid distributed generation options. For service in most other areas improvement of grid-based systems will be needed, with special emphasis on improving the reliability of distribution infrastructure.

Work on these topics will require attention to the interplay between technological capabilities, the goals that particular regions and localities may set for electrification, and demographic change. Low-power distributed generation may be adequate for achieving universal access to electricity. But if the goal is extended to include large consumption of high quality electricity then today's rural distributed generation systems may be unable to supply the level and quality of power demanded. New higher power systems with intelligent metering that complement distributed and grid-based power may be required.

19.7.7 Outlook for Generation Technologies in Africa

The electrification of Africa offers the opportunity for a fresh look at designing a 21st century power system. For example, systems for the developing world are expected to rely on distributed generation for many applications, rather than the focus on central generation that is typical of countries that electrified during the 20th Century. Distributed designs may be the least costly and quickest way to get power to rural areas in developing countries using readily available indigenous resources. Distributed energy resources will also have a role in supplying the electricity needs of urban areas in developing countries. Note, however, that the markets for power in urban areas of the developing world dwarf the demand in rural areas. This suggests that there will be a continued role for central station generation in many developing countries that must necessarily rely on indigenous resources to control costs.

The distributed generation portfolio for developing countries is essentially the same as for the developed world. Moreover, petroleum-based liquid fuels may have an advantage in rural settings, because of the high volumetric energy density and the potential for upgrading existing refineries and building new ones to refine coal and crude oil into clean fuels. Liquid fuels are also valuable because they can be used both for stationary power requirements and for motor fuels (e.g., synthetic diesel oil).

Renewables will have an especially important role in developing countries. In general, technologies addressing the needs of the developed world can be adapted for use in developing countries. Examples include solar photovoltaic, wind generation, and biomass. To use these technologies effectively in the developing world, technology advances are needed in several areas, such as reducing the capital and operating costs of the equipment, reducing maintenance requirements, and improving the efficiency of end-use technologies. End-use efficiency improvements can lead to substantial reductions in the power requirements and capital cost of the generation equipment. Work is also needed to develop low-cost storage options—batteries, flywheels, and ultra capacitors for example—to deal with the intermittency problems of wind and solar power.

In many circumstances, power systems in developing countries will be designed to fill the needs of single users. However, village systems will probably require some version of a multiply connected mini-distribution grid, because simple radial distribution schemes will be unable to handle more than one generator on a system.

End-use technologies can also be designed to meet the needs of rural settings. Direct current end-use equipment—lights and power supplies for electronic applications—can be connected directly to DC generators, such as PV systems and fuel cells, without the need for

AC inversion of the generator output, and conversion back to DC at the point of use. Other considerations include the need for standardization of voltage levels, interconnection standards, and safety measures such as current limiters. Finally, guidelines for the initial electrification of developing countries can speed the process by summarizing the case histories of other organizations and countries, recognizing that no single solution will suffice for all applications.

19.7.8 Technology Portfolio

African power producers, transmission companies, and distribution companies have several options for introducing electricity and expanding its reach. There are two principal options. The first is to implement current technologies. The advantages of this approach are low initial cost, a reliable, proven technology, and technicians skilled in operation and maintenance requirements. However, these advantages are mitigated to a degree by the relatively low efficiency and high emissions of some designs. In addition, purchasing today's technology may lock the purchaser into yesterday's solutions, and in the future it may be difficult to retrofit a more modern solution. A second class of power systems incorporates new technologies with higher efficiencies, better environmental performance, and lower life-cycle cost. Frequently, the superior performance and low life-cycle cost may be offset by a higher initial capital cost.

One key attribute of new technologies is the potential to address climate change concerns through the implementation of a portfolio of zero- or low- carbon emitting generation systems. In the African context, this suggests a growing reliance on distributed generation, fueled by natural gas or renewable primary energy sources, in addition to clean coal technologies and nuclear generation.

The portfolio strategy offers the greatest flexibility and resiliency in meeting the uncertainties of the future, as well as the opportunity for different regions of the world to adjust the portfolio balance to suit their circumstances. A number of factors can shift the balance of the portfolio, including the availability and price of fuels, the pace of technological advancement, capital requirements, regulation, and policy. One critical factor will be the growing pressure to internalize the environmental costs of fossil energy, which will increase the relative importance and attractiveness of renewable and nuclear energy.

There is general agreement that we will have to continue to use coal as a fuel resource in South Africa. The issue here is the design of the next generation of coal plants. There is a significant opportunity to improve the environmental performance of coal by "*refining*" it into clean gaseous fuel or chemical feedstock. The gasification process can provide both high-efficiency power generation and hydrogen. This process is also amenable to carbon capture and sequestration.

Natural gas is also an option for African electrification. The reserves in Algeria and Nigeria can be tapped to provide fuel for gas turbines, and ultimately for fuel cells. Gas imports can supplement the indigenous reserves. Key technological issues include the need for liquefied natural gas (LNG) infrastructure for shipping and handling.

Distributed Energy Resources (DER), which includes generation, storage, and intelligent control, will become an integral asset in the African electricity supply system. As DER grows, it could fundamentally change the relationship between power supplier and consumer, and over time, the network architecture of the distribution system.

The portfolio of DER generation technologies includes reciprocating internal combustion (IC) engines (500 kW–5 MW), small combustion turbines (5–50 MW) and even-smaller micro turbines (kW-scale), and various types of fuel cells. Photovoltaic, small wind turbines, and other renewables are often considered DG technologies. Commercial DER storage technologies include batteries and capacitor banks. These technologies should find ready application in the African context. Advanced and novel DER concepts under development include Stirling engines, various generating technology hybrids, flywheels, "*ultra capacitors*," and super conducting magnetic energy storage systems. Related R&D is addressing DER-specific power conditioning equipment. Implementation of these technologies in Africa will require substantial site-specific evaluations. "*Ruggedized*" equipment that resists breakage and has minimal maintenance and repair requirements is likely to capture much of the market for rural areas.

19.7.9 Mitigating Greenhouse Gas Emissions

Addressing potential global climate impacts is becoming an urgent priority for the energy industry and policymakers alike. This reflects the fact that atmospheric CO_2 concentrations have increased 33% over the last 200 years, and are continuing to increase.

Changing from a global system where more than 85% of the energy used releases CO_2 to a system where less than 25% is released requires fundamental improvements in technology and major capital investments. A robust portfolio of advanced power generation options—fossil, renewable, and nuclear—will be essential to meet the economic aspirations of a rapidly growing global population.

There is no single solution to the climate change conundrum. Activities on all nodes of the electricity value chain—from fuel extraction to power generation to end use—are contributing to the buildup of CO_2 and other greenhouse gases (GHGs) in the atmosphere, with a potential impact on precipitation and other important climactic factors.

Addressing today's and tomorrow's complex climate issues will require a multidisciplinary carbon management strategy on three broad fronts:

1. Decarbonization, defined as reducing the carbon content of the fuel. Renewable generation, biomass, and nuclear power are the principal means for decarbonization. However, some petrochemical processes are available that produce liquid fuels with a high hydrogen content that could be used in gas turbine generators.
2. Sequestration, which consists of removing CO_2 from the product stream at the point of production, is a commercially available technology, but reducing the high costs of the technology would probably be required to make sequestration a viable alternative in developing countries.
3. Efficiency improvements reduce the energy required to produce a dollar of economic output. Efficiency improvements can be found throughout the energy supply chain, from mining and transporting fuel, converting the fuel to electricity or other energy carrier, power delivery, and end-use efficiencies.

Developing countries, including African countries, pose a particularly difficult challenge in addressing climate issues. As discussed earlier, the economic development of these countries depends on expanding electricity consumption, and most low-cost generation technologies emit greenhouse gases. However, as technologies are deployed in coming decades, solutions that meet the needs of the developing world will almost inevitably become viable.

19.7.10 Outlook for the Intelligent Power Delivery System

Although this Section focuses on the supply side of the electricity equation, the ultimate force pulling the electricity sector into the 21st century may turn out to be the technologies of electricity demand—specifically, intelligent systems enabling ever-broader consumer involvement in defining and controlling their electricity-based service needs. This will be true in developed and developing countries alike. It is important to remember that supply and demand in the electricity industry still rely on the same system design and much of the same technology in use since the dawn of electrification. This is a remarkable record of performance, but one that can no longer be sustained through merely evolutionary changes in the status quo.

Historically, the power delivery issues of security, quality, reliability, and availability (SQRA) have been measured and dealt with in a fragmented manner. In the future, they will almost certainly become a highly integrated set of design criteria to meet the evolving power requirements of consumers. Fortunately, the suite of advanced technologies that can be used to improve the security of the power delivery system can also be used to improve power quality and reliability, and transform the power system to meet the needs of the 21st century. These technology developments will first be manifested in the industrialized world, but developing countries will be able to leapfrog many of the intermediate steps in the development process. Consequently, their cost and time requirements to offer commercial solutions will compare favorably with the developed world.

The result will be dynamic technologies that empower the electricity consumer, stimulating new, innovative service combinations emphasizing speed, convenience, and comfort, with different quality levels and types of electric power. A vigorous, price-sensitive demand response from an increasing class of consumers whose energy choices reflect both electricity prices and power quality will become an integral part of the electricity marketplace.

The shorthand for this new system is the intelligent power grid, or "*Intelligrid*", conceived of as an electricity/information infrastructure that will enable the next wave of technological advances to flourish. This means an electricity grid that is always on and "*alive*", interconnected and interactive, and merged with communications in a complex network of real-time information and power exchange. It would be "*self-healing*" in the sense that it will constantly monitor its condition and self-correct at the speed of light to keep high quality, reliable power flowing. It could sense disturbances and counteract them, or recons the flow of power to cordon off any damage before it can propagate. It would also be smart enough to seamlessly integrate traditional central power generation with an array of locally installed, distributed energy resources (such as fuel cells and renewables) into a regional network.

The smart, self-correcting power delivery system will become the conduit for greater use of productivity-enhancing digital technology by all sectors of the economy, leading to accelerated productivity growth rates. The power system will enable new energy/information products and services across the board, and reduce or eliminate the parasitic costs of power disturbances characteristic of, for example, the US economy today.

To complete the picture, digital technology will also be able to open the industrial, commercial, and residential gateways now constrained by the meter, allowing price signals, decisions, communications, and network intelligence to flow back and forth through the two-way "*energy/information portal*". The portal will provide both the physical and logical links that allow the communication of electronic messages from the external network to consumer networks and intelligent equipment. For consumers and service providers alike, this offers a tool for moving beyond the commodity paradigm of 20th century electricity service. It will complete the transformation of the electricity system functionality, and enable a set of new energy information services more diverse and valuable than those available from today's telecommunications industry.

The Intelligrid may appear to be a distant dream when compared with the near-term needs of African electrification. However, the ability of the developing world to leapfrog intermediate technologies may allow implementation of elements of the Intelligrid system as they become available. In particular, a wireless information network will be able to provide much of the communications support needed for a power system based on distributed energy resources. The hardware and software needed for distributed energy systems in Africa are already available. Implementation of a distributed Intelligrid will be limited by financial considerations rather than technology considerations.

19.8 Providing Electricity Services to Rural Africa [26]

19.8.1 Understanding the Challenge

The communiqué from the G8 meeting in Gleneagles, Scotland in the summer of 2005 called for major action to support economic development in Africa. Even with the World Bank instituting a Clean Energy Investment Framework, the task is still daunting. The Action Plan for meeting Africa's energy service needs to include:

(a) Access to clean cooking, heating and lighting fuels, coupled with sustainable forest management
(b) Scaled up programs of electrification
(c) Additional generation capacity to serve newly connected households and enterprises, including through regional projects
(d) Provision of energy services for key public facilities such as schools and clinics, and
(e) Provision of stand-alone lighting packages for households without access to the electricity grid.

While ambitions to meet the Millennium Development Goals by 2015 are laudable, in terms of energy infrastructure design, finance and implementation, and developing the local capacity to operate and maintain those systems, 2015 is very close.

Several understated challenges that technology and finance companies, government agencies, and local communities face is how to design and implement new electricity services in time and space. For example, not all businesses and households in a village or town will receive electricity at the same time. Initially small village scale systems may only electrify community buildings, and then for only several hours per day from a diesel or biogas genset, or micro-hydropower system. However, we know that as communities develop, demand for modern energy services may begin to grow rapidly.

Several other daunting challenges have to do with a) how quickly can electric service be provided – at any level, b) what requirements are there from the viewpoint of grid extension, or the development of parallel fuel supply infrastructures to support generators, and how to maximize economic benefits/ and reduce cost and availability risks as local economies become more dependent on electric service. New tools for optimizing the configuration of village scale power systems, especially those that incorporate renewables are now readily available. However, energy demand is far from static and may vary significantly by time of year (climate, agricultural energy demand), as well as time of day showed how alternative configurations of wind-diesel systems could meet different levels of village electricity demand (with different economic values).

If local communities wish to tap multiple local energy resources, then their dynamics must also be taken into account. In the case of sun and wind, these may be more predicable than other resources, such as hydropower and biomass, especially if areas are drought prone–or worse–if vegetation is poorly managed.

So, if electricity is to be delivered to rural areas in the near-term, with factors of demand growth, resource dynamics, and system expansion taken into account, a new design approach is needed.

19.8.2 Designing Robust Solutions

Integrated energy technology demonstration projects must become models both for dissemination and training, recognizing full well that local communities must adapt these technologies and systems to suit their own needs and resources, including the ability to keep them running, and pay for operating costs. There are now good templates from small villages in India and elsewhere on how to collect costs from users, and task residents for routine maintenance tasks.

One challenge is to identify a range of "*basic systems*", based upon demand levels and pattern, and renewable resource dynamics that can then be adapted to actual village conditions.

19.8.3 Growing with Time

As hinted above, once electric service becomes available, demand for electric service is likely to grow rapidly. As illustrated in Figure 19.13, over time neighboring villages will install their systems, grow from intermittent to 24 hour service, and with enough planning and coordination, link up their villages to one another and where applicable linked to a centralized grid.

This poses a challenge to standards makers, so that "*plug and play*" village systems can easily be linked together and operated in a coordinated fashion without facing service quality impacts. The day of resistive loads has passed, and the power quality requirements of "*electrified*" villages must be respected, and planned for.

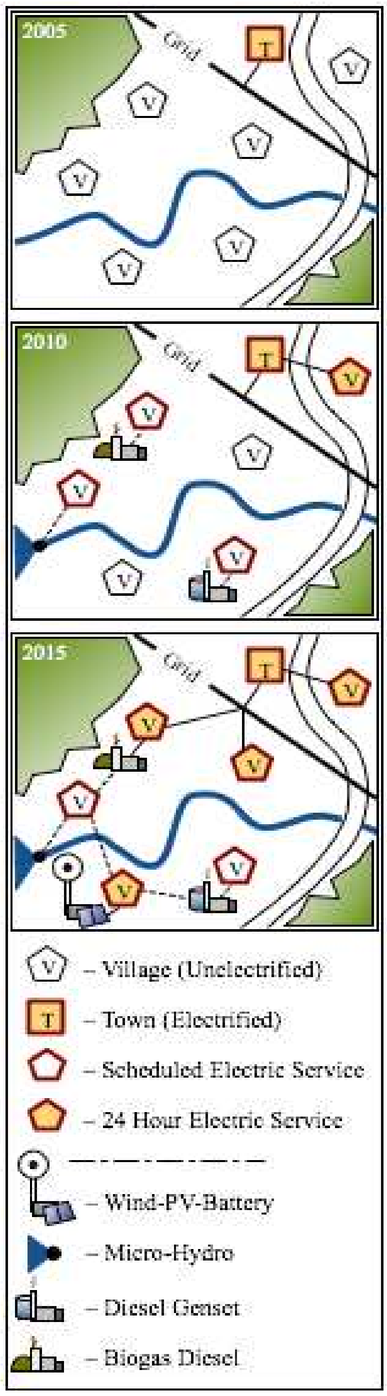


Figure 19.13. Diversity and Growth of Village Scale Power Networks over Time.

Concurrent with the development of design tools, on illustrative demonstration projects, is the need to collect quality information on changes in and drivers of electricity demand, as well as the patterns and variability in numerous renewable resources (wind, solar, hydro/precipitation, crop yields and forest productivity).

19.8.4 Building the Context and the Capacity

Taking the into consideration the various aspects of the challenge outlined above, it is clear that goals put forth by the UN and OECD can only be pursued by developing numerous "*capacities*" ranging from international finance and access to "*best practice*" technologies, to the development of operation, maintenance and small business skills down at the local level.

From a strategic planning viewpoint, "*context building*" is needed such that the initial provision of electric service cannot only be maintained, but expanded through time in a manner that maximizes both the use of local resources, and puts these new energy services to best economic use.

Building this integrated capacity to electrify 1.6 billion people, whether through grid extension to growing urban areas, to far from grid small population centers, is a very large task. It will take a huge commitment in time, people and money. However, with modern communications and information tools, "*best practices*" from design to operations should rapidly penetrate the industry and propagate from one local to another.

19.8.5 Modified Micro Grids Alternate Models [27]

Systems suitable for future grid connection should also be contemplated particularly in urban areas are in many cases just as deficient as the rural sector. This section proposes a concept of "*Olympic Ring*" type Micro grids to illustrate the bottom-up development. This Micro Grid power network architecture has incorporated the following power system and power electronics technologies:

- Advanced power network control techniques that allow for deployment of a wide range of DG and power network solutions into real-world applications.
- An advanced power converter system to enhance the capabilities of DG and storage systems. The distributed energy resources are able to interact directly over the power network to provide power sharing, power flow, and control.
- An open-platform energy management system that can provide remote monitoring, data collection, and aggregation of distributed power systems into "*dispatch able*" blocks of capacity.
- A static isolation switch system that manages the interface of Micro Grid power systems to the utility, and allows for seamless transitions between stand-alone and grid-connected operation.

Depending upon the loading condition and available resources, a single-ring (Figure 19.14) or double-ring (Figure 19.15) local node could be formulated. Each ring will be equipped with a local node controller for local optimization and control.

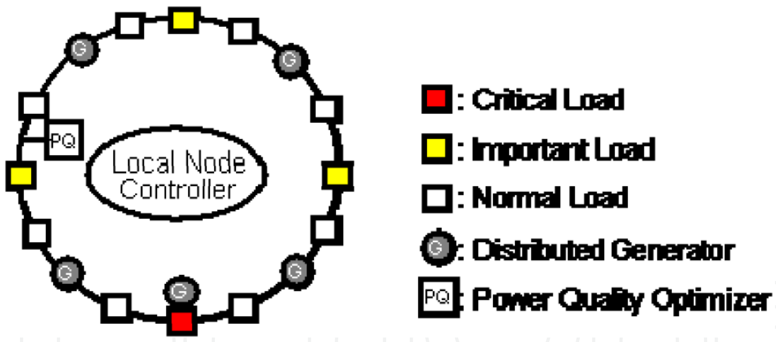


Figure 19.14. Formation of Single-Ring Local Node

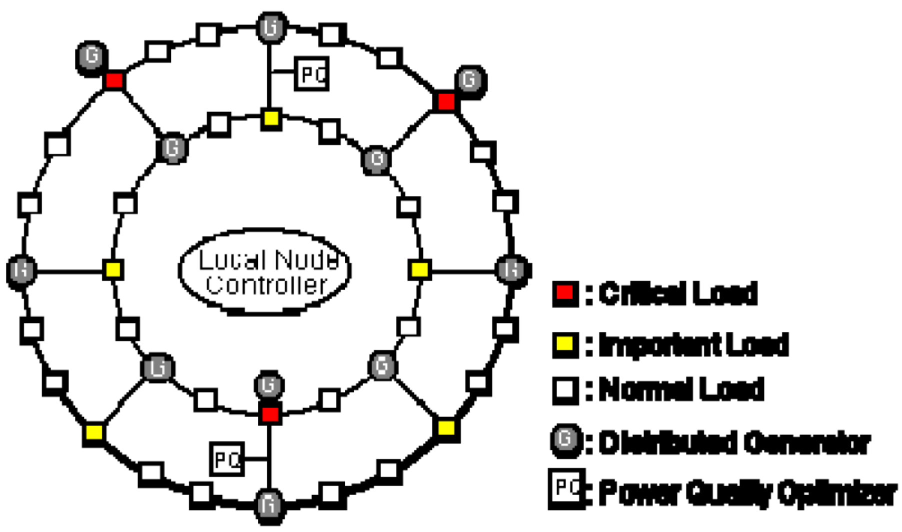


Figure 19.15. Formation of Double-Ring Local Node

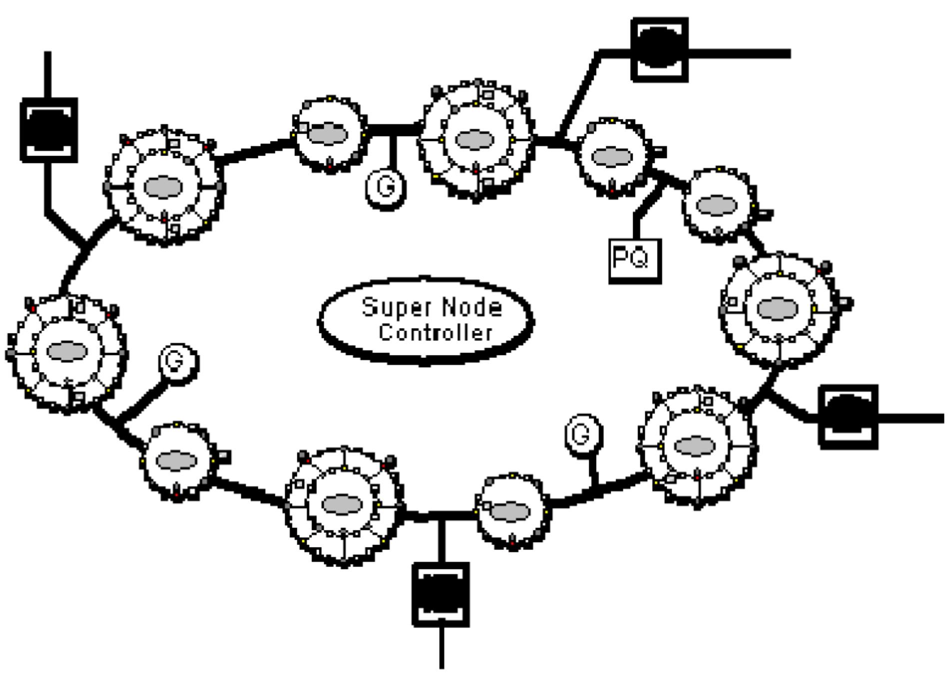


Figure 19.16. Formation of a Super Node and Grid Connection

Clusters of local nodes will then form a super node. As shown in Figure 19.16, a ring configuration is preferable since it offers higher system reliability. Super nodes may equip larger scale distributed generation facilities and power quality controllers. The protection schemes between local nodes are similar to the branch protection within the local nodes. Depends upon the operation condition, the super node can be either autonomous or non-autonomous. Super node controller will communicate with SCADA/EMD of the local utility or ISO, local node controllers, distributed generators, and PQ optimizers. Super node will serve as basic building block of the future "*Smart Grid*".

In summary, an uncontrolled unbundling of utilities and the resulting wave of growth in small distributed generation Independent Power Producers (IPPs), would lead to the creation of un-standardized meshed networks should the technical and economic planning associated with larger integration not be contemplated with today's technical standards. Building this integrated capacity whether through grid extension to growing urban areas, to far from grid small population centers, is a very large task. It will take a huge commitment in time, people and money. However, with modern communications and information tools, "*best practices*" from design to operations should rapidly penetrate the industry and propagate from one local to another [26].

19.9 The Kenyan Electric Power Sector –A Case Study [28]

In many African countries there is a tension between grid and off-grid electric service provision and it is unclear whether centralized or decentralized power system architecture will emerge. This Section explores some of the dynamics of system development in Kenya, where poor grid infrastructure has resulted in a thriving private market for photovoltaic panels and a growing number of industries are investigating shifting to on-site generation. The research is based on ethnographic interviews and observations in Kenya and uses System Dynamics modeling tools to analyze qualitative and quantitative feedback in the system.

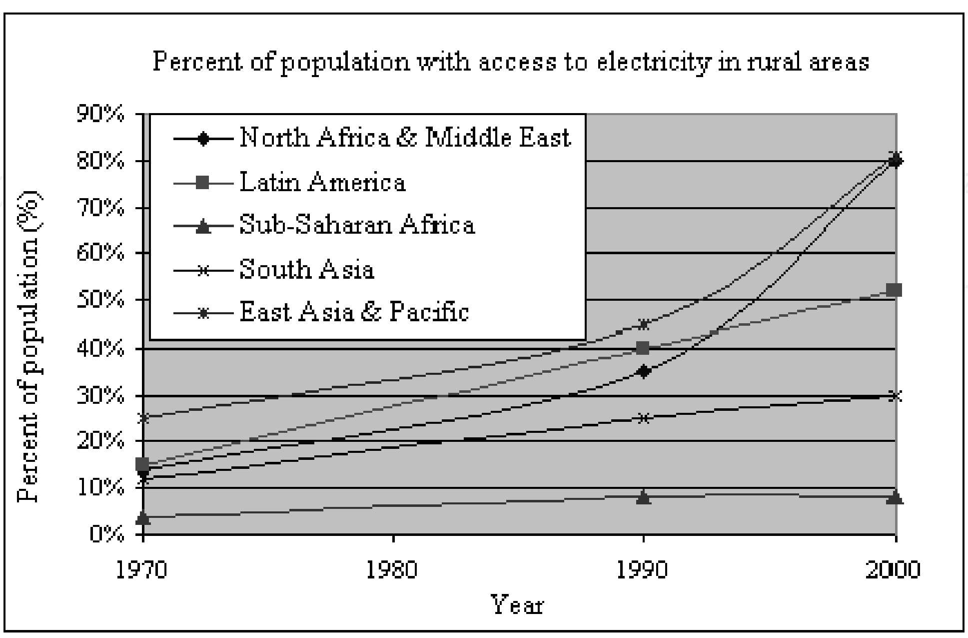


Figure 19.17. Percent of Rural Population with Access to Electricity by Regions

In the developing world Sub-Saharan Africa (SSA) and India are the least electrified regions of the world and they continue to fall further and further behind (see Figure 19.17). Although the lack of modern energy services in these regions is well documented, the underlying reasons are not well understood. The growth of the electric power system in the SSA country of Kenya is now focused on where both the dynamics that have led to the low availability of power as well as the drivers that could enable greater access in the future are explored.

Seventy percent of people in SSA live in rural areas and rural electrification rates are extremely low. This presents a challenge for electrification because it is expensive to connect a diffuse population. Both the line losses and cabling costs due to long transmission distances make installing the infrastructure very costly. This technical limitation, added to the fact that the majority of the rural population has little ability to pay for electric service, makes it economically impossible to extend the grid to all areas. The only justification for rural electrification has been the social necessity.

Lack of electricity and modern fuels can be linked to an increase in disease and environmental degradation, and economic stagnation. Homes without electricity continue to use biomass and kerosene for cooking and lighting, which leads to respiratory and eye infections. These households also deplete biomass resources, which can increase desertification and cause land erosion. Lack of modern energy sources can inhibit education due to poor lighting conditions and inhibit economic growth due to the time used gathering traditional fuels and the inability to expand businesses using more efficient energy sources.

Even in urban and industrial areas electricity access is low. While most industries are located near the central grid, many must invest in back-up power supplies and power smoothing equipment to manage the frequent outages and inconsistent voltage supply in the network.

19.9.1 Electricity in Africa as a Complex System

Discussions of complex systems usually focus on computer networks, transportation systems, or manufacturing logistics. However, African electric power systems are complex infrastructure where the architecture is not already determined. While most complex systems research focuses on existing complexity, in Africa there is an opportunity to study the system as it develops. So far there has been little research to understanding system development in this area. Karekezi and Kimani [29] and Pandey [30] have noted the lack of research in African power systems and the insufficient use of modeling in developing countries, respectively. Hammons has reviewed Recommendations for Power Pools in Africa [31] and Hammons et al. [32] also cite this need with reference to the World Bank, saying that "*[it] has not yet found a reliable model for dealing with the special needs of sub-Saharan Africa electricity infrastructure*".

Africa faces a choice between following the traditional model of centralized generation, and developing a decentralized model. There are benefits and detriments associated with both options. While a decentralized model may make it easier to provide service to remote populations, it may limit system growth in the future. Were an inexpensive bulk power supplier to come online, such as the Grand Inga hydropower station in the Democratic Republic of Congo, a country with a decentralized system might have difficulty benefiting from this source.

If the choice were simply a technical one, the system could be analyzed and optimized according to the least cost or most technically efficient model. However, there are several non-technical issues that add complexity such as most governments now seeing electricity as a social right. If an optimization model were to show it is uneconomical to provide any access to certain areas, this would not meet the desired goal of the system. There is also an issue of complexity due to corruption. Any planning which ignores the presence of corruption does not reflect the true cost of implementation. This problem of non-technical complexity highlights the need for new approaches to system analysis in Africa.

19.9.2 Selection of Case Study

Kenya typifies the difficulties of energy development in eastern Africa, with its low population density and an installed capacity of only 1147 MW. Kenya is also a regional economic and political anchor and ideally development in Kenya will positively impact Uganda and Tanzania [33][1], as well as other countries in the region.

The scope of this Section covers the range of electric power consumers and generators in Kenya, as well as the organizations that sell and regulate power. Kenya has privatized power generation with roughly 70% of generation by the Kenya Generating Company (KenGen). The remainder is provided by independent power producers (IPPs). Electricity is sold to Kenya Power and Lighting Company (KPLC), who sells to consumers, and the Electricity Regulatory Board (ERB) regulates the sale on both sides. Consumers who are not connected to the national power grid have the option to buy off-grid generating equipment from dealers. Figure 19.18 shows the scope of the case.

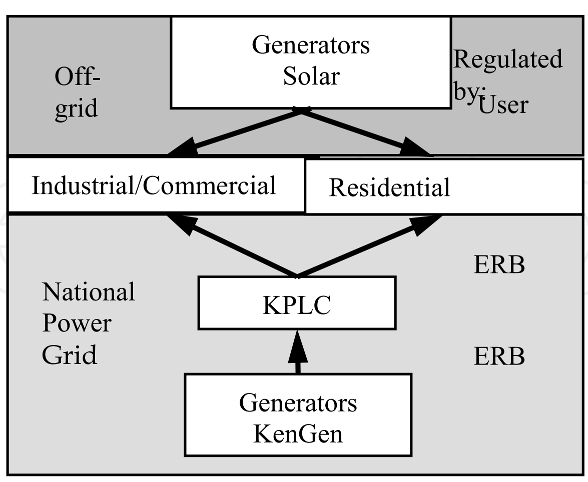


Figure 19.18. Scope of Analysis of Kenyan Electric Power System

[1] Kenya, Uganda, and Tanzania have existing cooperation agreements under the East African Community alliance. Kenya and Zambia are also working together to create a link that will bring power from the Southern African Power Pool into East Africa.

The case study concentrates on the interaction of the actors in the system and how their decisions feed back into the system and affect its development. The method used was selected because it seeks to understand qualitative, as well as quantitative, aspects of the system.

19.9.3 Method

The goal of the method is to understand why electricity access is stalled in SSA, and what can be done to enable growth. System dynamics modeling is appropriate method in this case because it can represent the range of technical and non-technical feedback in the system. For the model to be useful, however, it must be grounded in reality. Sterman [34] found participant interaction and interaction with clients essential to formulating the non-linear functions of a model, which points to the use of interviewing and observation as methods. The fieldwork for this study followed the standard method for system dynamics modeling [34]. This includes attention to stakeholder interaction, causal loop diagramming, calibration, and sensitivity analysis.

The interviews conducted in Kenya included residential and industrial consumers, representatives from KPLC, KenGen, and the ERB, and off-grid service providers. A final source of information was quantitative data collected in Kenya, both concerning the operation of the power system and the socio-economic status of the population. The data gathered from these sources are being used in the creation of the system dynamics model.

As stated earlier, this model is not intended to be predicted. Rather it could be used to identify points were policy could have an impact. Saeed and Prankprakma used system dynamics to study the link between technological development and economic growth [35]. They found that technological development has the potential to be a policy lever for economic growth in developing economies but only if a feasible path can be determined. Similarly, this study is attempting to find policies for inducing development in the energy system.

19.9.4 Preliminary Findings

The interviews have given some preliminary insight into the dynamics of the electric power system growth in Kenya. One of the key findings may be that Kenya, and Africa in general, is not so different from the rest of the world in terms of electrification. Instead of focusing on what makes Africa different, perhaps policy-makers should be focusing on how it is the same.

Grid infrastructure in Kenya is characterized by high fees and long waits for connections, large voltage fluctuations, and relatively common outages. Standby power supply in Kenya has become so common that commercial and residential customers accept frequent interruptions in the power supply. Even in very modern commercial centers or tourist hotels, power interruptions are not met with surprise, rather the customers simply pause while the generators automatically come online and then go about their regular activities. This is not the case with industrial consumers. Manufacturing and production processes frequently cannot simply restart if there is a power interruption. A food processing plant outside of Nairobi estimated that for every power interruption they lost four hours of productivity due to spoilage of the product and the need to reset and clean all processing equipment. In this case the feedback is that as power interruptions become more of a burden to the customer, the more likely they are to seek other sources of electricity.

Most commercial and industrial consumers that have been interviewed have said that if there were a standby power supply that could compete on cost with the grid, they would consider producing their own power. Already several large consumers, such as sugar, tea, and paper manufacturing companies, generate a portion of their own power. The Kenya Tea Development Authority (KTDA) has assessed the feasibility of on-site generation at 20 more of its tea factories and Mumias Sugar recently signed an agreement to expand its boiler capacity to generate 35 MW on site.

If a significant portion of industry disconnects from the grid, or generates the majority of their own power, it will reduce the revenue to the Kenya Power and Lighting Company (KPLC). If this happens, it could hinder KPLC's ability to invest in infrastructure, which would in turn encourage more consumers to move off-grid. This dynamic has already been seen in the telecom sector in Kenya. The national provider, Telkom, was ill equipped to manage the introduction of competition from mobile phones.

Residential consumers are similarly choosing to go off-grid. Estimates vary as to the total number of PV panels sold, but consensus says it is well over 100,000 units. In most rural cities the electrical appliance shops sell PV panels and systems and several large retailers and wholesalers operate across the country. According to interviews with dealers, customers choose PV in most cases because they are not close enough to the grid to be connected. However, some are buying PV even after having paid for a connection to KPLC, because after waiting several years they have still not been connected. Others decide to keep using PV even when the grid comes to their village since they have already made the investment.

Kenya, like many African countries, is at a critical point in its electric power infrastructure development. Depending on where investment is focused, the system could grow as an interconnected grid with generation flowing out of power stations, or it could become a decentralized system where industrial and residential power consumers generate power on-site. Even if the on-site generators remain connected to the grid, the technical and financial structure of the system will shift. In the US city of Chicago in the late 1800s, there was a surprisingly similar tension between dedicated power suppliers and industry and businesses generating their own power on site. In that case, the system shifted to a centralized utility when Samuel Insull was able to cut costs for power producers through increasing load factor and diversifying customer demand. In Kenya, it is important to understand how these types of policies and investments could impact the system development. Finally, this study will also question whether Africa is really all that different from other regions in its power system development. If the dynamics are similar to other regions which have already gone through this process, then that may lend insight into how to spur development.

19.10 The African Power Development Footprint: Accelerating the Technical Skills Factor

DEFINITIONS:
AAU - The Association of African Universities,
ICT - Information, Communications, Technology,
AVU - African Virtual University,
EPRI - Electric Power Research Institute,
SST - Strategic Science & Technology

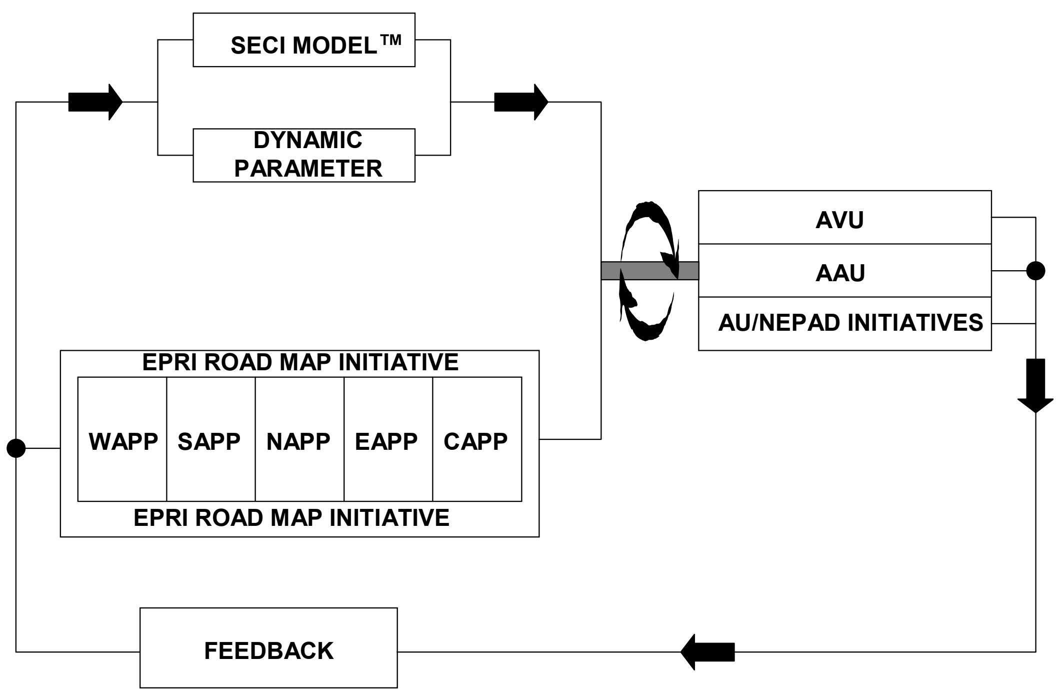


Figure 19.19. The African Power Development Knowledge Engine

The multidisciplinary nature of Power Generation and Transmission projects provide an interesting synthesis of knowledge generation and potential for its capture. This also includes the converging and diverging nature of geopolitical issues, humanitarian crises, infrastructure and human capital deficiencies. '*Think-outside-the-box-solutions*' (TOTB) is therefore necessary to effectively capture and apply this knowledge. The proposed African Power Development Knowledge Engine model Figure 19.19 is created in broad terms from an examination of various programs and studies from around the world and is then configured to synthesize elements from these various INPUTS to address an African context. The sheer ambition of attempting to converge such divergent disciplines into something practical leaves one open to skeptics were it not for the exigencies of disciplines such as System Dynamics and systems engineering broadly. To quote J.W. Forrester, the founder of system dynamics; "*Interest in System Dynamics is spreading as people appreciate its unique ability to represent the real world. It can accept the complexity, no linearity, and feedback loop structures that are inherent in social and physical systems*". In educating the individual, the objectives of a systems dynamics education might be grouped under three headings: 1) developing personal skills, 2) shaping an outlook and personality to fit the 21st century, and 3) understanding the nature of systems in which we work and live [36]. The subsequent sections and proceeding paragraphs will attempt to indicate the possibilities even though concrete models (simulation) that are at the core of the studies have not yet been tested specifically for this model.

19.10.1 Model Overview

The African Sectors of focus are the South African Power Pool (SAPP), West African Power Pool (WAPP) and the initiatives in North Africa with interconnections to the Middle East and Europe (NAPP). Studies such as the Purdue long-term economic model and R&D programs from EPRI's Road Map Initiative and SST are the proposed foundation candidates, from which interdisciplinary synthesis over a wide range of applications can be generated. The information density contained within these sector initiatives provides sufficient '*Synthesizing Capability*' for creating knowledge enabling infrastructures [37]. The Purdue University Power Pool development group commissioned by the Economic community of West African States (ECOWAS) and the Southern Africa Development Community (SADC) addresses regional and country specific power generation and transmission opportunities over a variety of economic scenarios and generation resources such as hydro, fossil fuel, thermal, natural gas etc. Other members of the African Union in North Africa also have large development foot prints as illustrated earlier in Figure.19.2 and are candidates for focusing on regional specific analyses and interconnections such as Egypt's ties with Jordan and the wider Mediterranean countries [38,39] (Figure 19.20). This Northern Grid will eventually interconnect with the Gulf Coordination Council states that have already implemented a successful multi grid integration plan with many firsts in the application of new technologies (Figure.19.21).

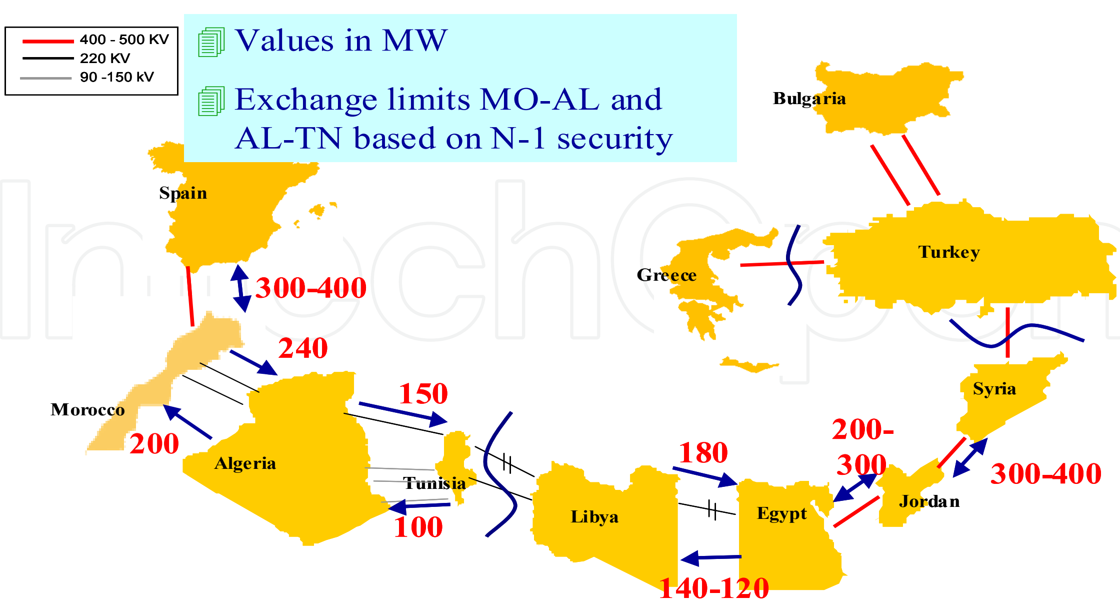


Figure 19.20. NTC Among SEMC Countries in the Year 2003 [39]

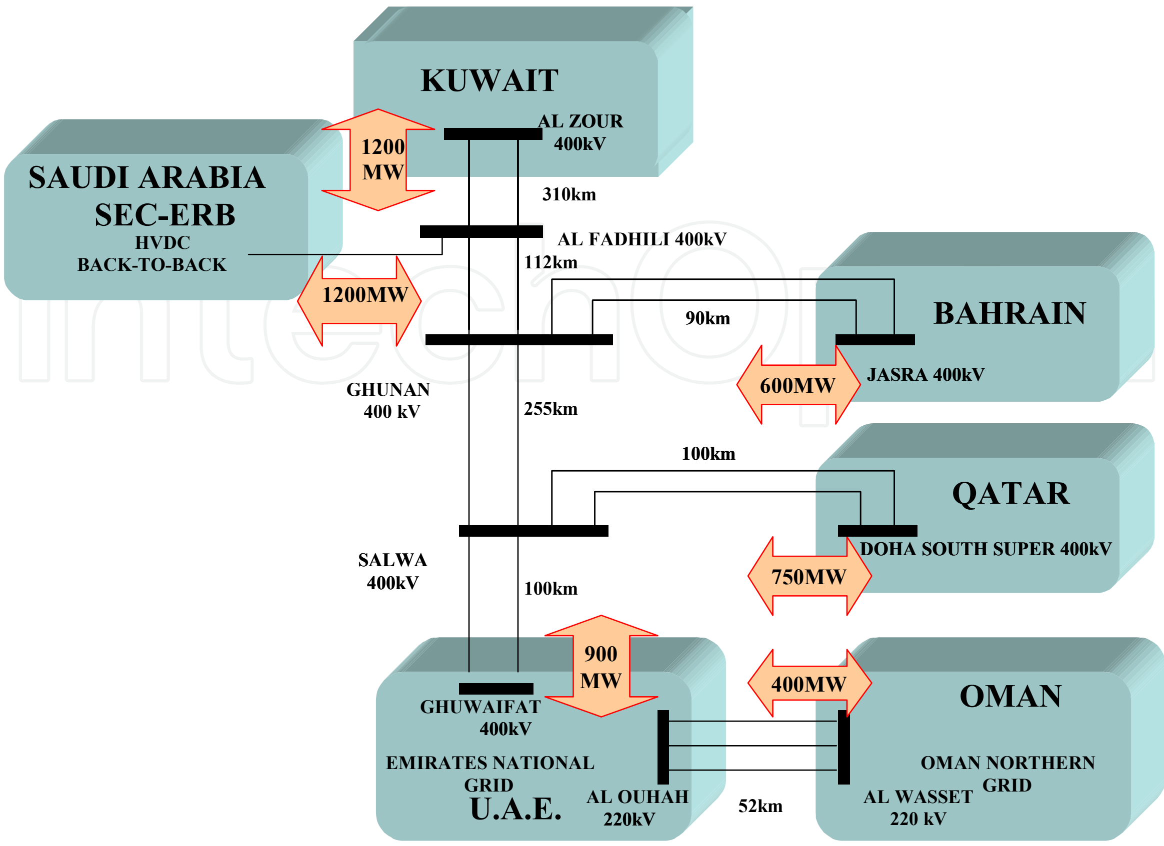


Figure 19.21. Conceptual Diagram of the Interconnection System of the Gulf States [39]

Within this context of knowledge capture, the EPRI Electricity Technology Road Map Initiative, The Alliance for Global Sustainability (AGC) and institutions such the Moscow Power Engineering Institute (MPEI) with an international focus on 21st century energy issues, represent a major convergence or synthesis of global Industry Experience and R&D. US-African organized programs hosted for example by the College of Engineering, Architecture and Computer Sciences (CEACS) and the Center for Energy System and Controls (CES&C) at Howard University have received prior research funding for supporting international workshops on power system operation and planning in Africa. Over the past ten years, the National Science Foundation (NSF) has supported the hosting of the International Conference on Power System Operation and Planning (ICPSOP) in various African countries namely, Nigeria, Ghana and Ivory Coast, Durban, South Africa and in Cape Verde [40]. Towards this end the importance of these advanced research institutions to enhance programs such as these cannot be overstated.

EPRI has over 150 participating electricity stakeholder organizations participating in the EPRI Road Map program [21]. The Roadmap Initiative seeks to develop a comprehensive vision of opportunities for electricity-related innovation to benefit society and business. The Roadmap also translates that vision into asset of technology development destinations and ultimately the needed R&D pathways. The Creation of the Roadmap began with the exploration of opportunities in five distinct topical areas:

- Sustainable global development
- Electricity and economic growth

- Power delivery Infrastructure
- Power Production
- Environmental Knowledge Base.

EPRI has also adopted a strategy whereby SS&T provides the strategic resources for EPRI's integrated R&D planning process, helping connect the specific technical objectives of EPRI's sector programs with the broad societal goals defined by the Road Map. SS&T concentrates on a set of 15 *limiting challenges* representing critical issues and opportunities facing the electricity enterprise and society along with the associated gaps in knowledge and technological capability. The limiting challenges link the destinations identified by the Road Map with the objectives of EPRI's sector programs.

The 15 limiting challenges are the following:

- Improved Transmission Capacity, Grid Control, and Stability
- Maintain and Strengthen Portfolio of Generation Options
- Accelerated Development of Carbon Capture and storage Technologies
- Creation of the Infrastructure for a Digital Society
- Improved Methods for Communicating and Applying Scientific Knowledge
- Improved Power Quality and Reliability for Precision Electricity Users
- Increasing Robustness, Resilience, and Security of Energy Infrastructure
- Advances in Enabling Technology Platforms
- Exploiting the Strategic Value of Storage Technologies
- Transformation of Electricity Markets
- Ecological Assessment Management
- High Efficiency End Uses of Energy
- Maintaining and Improving Water Availability and Quality
- Global Electrification
- Development of Electricity-Based Transportation Systems.

19.10.2 Standardizing Curricula as a Strategic Factor

For the ambitions set forward by the AU and NEPAD manpower development in the technological, health, agricultural and management field remain core to any kind of institutional integration. Previous IEEE PES International Practices for Energy Development and Power Generation presentations [41] have recommended creating Communities of Practices (COP) utilizing *knowledge creation* models such as the SECI™ Model from Japan (see Figure 19.22) which states that in order to "*make these things happen*", there must be "**Ba**" for knowledge creation [42]. **Ba** means internal communities of groups of technologists or knowledge workers who share the same interest or purpose. More specifically, they are cross-functional human networks or groups including virtual relationships on intranets, extranets or the Internet. These communities are called COP (communities of practice). Participants understand the contexts of others and oneself, and through interaction, change/create the contexts. Hence, it is constantly moving.

The key to understand context is <u>interaction</u>. Knowledge does not just reside in one's mind. Knowledge emerges through shared contexts that are created through interaction [42]. This author feels that further efficiency can be achieved from the proposed Knowledge Engine by incorporating systems dynamics to mine it's inherent complexity. In so doing a key objective would be the formulation of a "Renaissance Man" or woman as defined by Forrester [36].

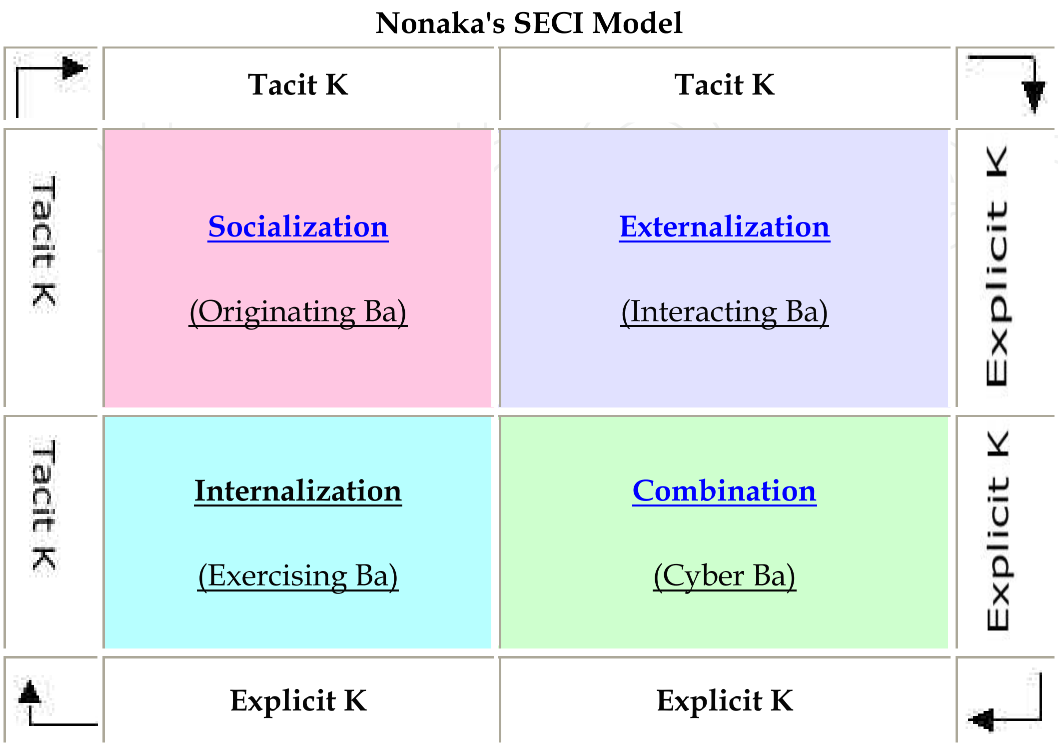


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Figure 19.22. SECI™ MODEL [41]

We have previously stated our proposed knowledge engine is introduced to create knowledge from local African and International continental conditions as a paradigm to improve efficiency. This we strongly believe can be achieved by strengthening institutional integration around specific and standardized curricula. With today's ICT advantages the challenge then becomes creating curricula that create Virtual Worlds used for improving the learning process Sterman [43]. Figure 19.23 is a basic representation of how a Systems Dynamics approach would initiate a basic level of evaluation of a system.

"System dynamics trains an individual to see the interrelationships in systems as being far more interesting and important than separate details. The interrelationships reveal how the feed back loops are organized that produce behavior. Students with a background in systems modeling should be sensitized to the importance of how the world is organized. They should want to search for interconnecting structure that gives meaning to the parts. System Dynamics provides a foundation underlying all subjects" [36]

Figure.19.23 represents an idealized learning process whereas effective learning involves continuous experimentation in both the virtual world and real world. Feedback from both informs the development of mental models, formal models and the design of experiments for the next iteration.

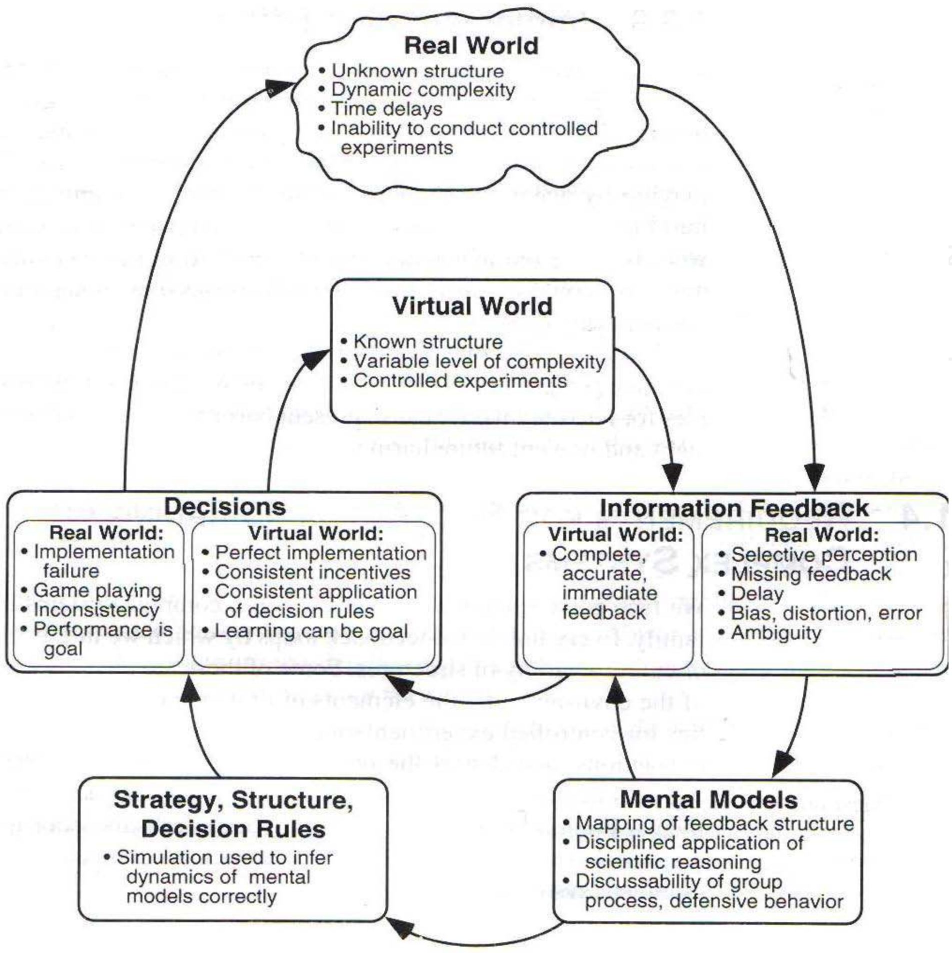

Figure 19.23. Systems Dynamics Representation []

19.10.3 The Dynamic Parameter Model [44]

In the Dynamic Parameter study a "*Dynamic Parameter*" is an evolved entity abstracted from any selected object (subject) that has significant information density or that lends itself to information convergence in a given sub domain or context as represented by Figures 19.24 and 19.25. In this study "*core*" **C** as shown represents the recommended curriculum to be derived from mapping the EPRI road map and its integration with models from other global experiences. In Figure 19.24. The different backgrounds represent different location contexts.

In this instance the object or context can also be projects within one of the power pools being looked at namely the WAPP, SAPP & NAPP. Figure 19.25 illustrates a given '*Domain*' where the continuous dynamics of relationships are created from knowledge exchange leading to constant flows of feedback and action. The resulting ICT network infrastructure or COP will produce behavior mimicking that of a neural network constantly under training/development/refinement. And while there is no precise agreed-upon definition among researchers as to what a <u>*neural network*</u> is, but most would agree that it involves a network of simple processing elements (neurons), which can exhibit complex global behavior, determined by the connections between the processing elements and element parameters [45].

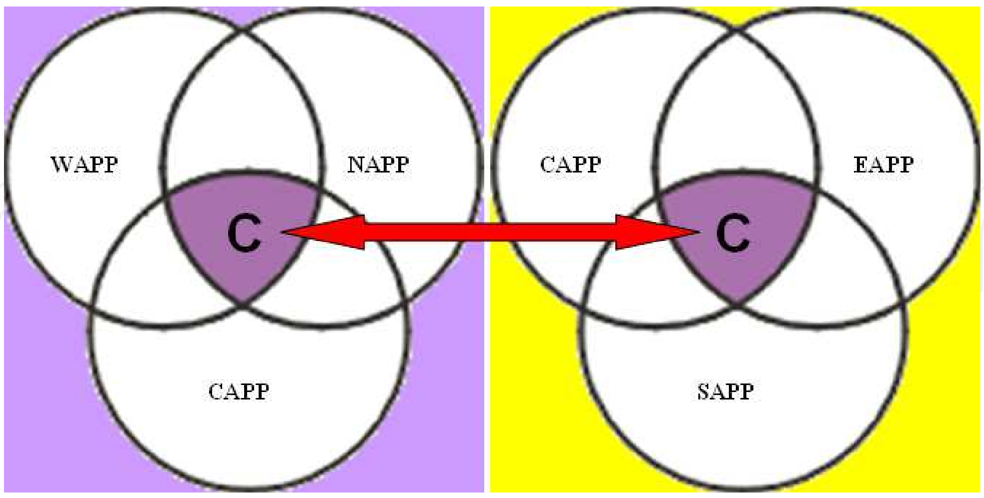

Figure 19.24. Dynamic Parameter Model

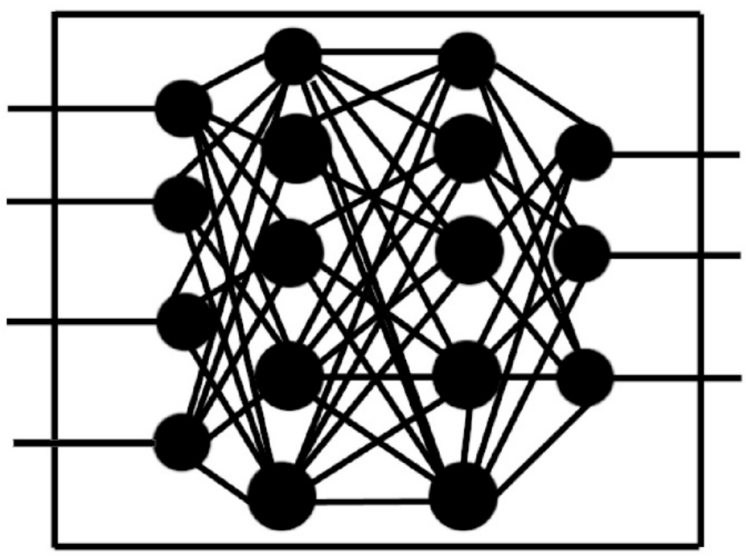

Figure 19.25. Dynamic Parameter-Sub Domain Relationships

As mentioned earlier specific programs such as the National Science Foundation (NSF) sponsored US-Africa Workshops produced a variety of dynamics from such collaborations as noted below [40]:

- US utility companies who attended have won opportunities to do business with Africa power industry as consultants, vendors, etc.
- Recruitment of outstanding doctoral students into United States universities with power programs, for example, Howard University, Tennessee Tech, Texas A&M, and Washington State University (WSU)
- Joint projects between United States power industry and African universities and industries. For example, joint projects between Howard University and Kwame Nkrumah University of Science & Technology (KNUST), Monsura University, etc.

- Exchange program between the United States and Africa
- US industry and power consultants have become interested in business in Africa. This includes K&M Engineering and Consulting Corporation and the US Education Institute, Inc. (AEI).

19.11 Further Reading

Further Reading on African Electricity Infrastructure is available in References [46-49].

19.12 Conclusion

The focus on power Generation as the driving knowledge base is because of the societal impact information generated before, during, and after its development. The simulation of societal impact to address societal problems is itself a contribution to the student body's social consciousness and source of ensuing feedback. Sharing that consciousness/knowledge among the body of coordinated participants in a local regional or international context creates a dynamic of new ideas and the potential for multiple solutions from a variety of sources and disciplines. The WESTCOR project in South West Africa is one such '*opportunity project*' whose large footprint covering a large resource laden geographical area can influence the training of a large student body in Systems Thinking throughout the continent and elsewhere. The same holds true for the North African and Middle Eastern systems. Within the same context of these larger projects, the development of less capital intensive Microgrids integrated with strategic new technologies, e.g. low heat input advanced refrigeration and heating such as the Thermosorber ™ , biomass plasma gasification, integrated solar thermal systems and wind power also become important economic development strategies. Micro grids in particular are an essential development '*growth incubator*' and can be setup as "*energy malls*" strategically placed for optimized development solutions such as Millennium goal villages and towns.

Further, the value derived from these small Distributed Generation micro grid systems for rural and urban development are no less complex as they too introduce logistics problems for systems installations, operations and maintenance (O&M) requirements, fuel supply dynamics in instances where renewable energy sources may not be easily accessible or available. Their often small-sizes being less capital intensive can be seen as being '*charity sustainable*' where applicable. The development of these small distributed generating systems can introduce a sustainable-strategic dynamic between charities, manufacturers, government agencies, NGOs and universities to penetrate society with greater efficiency and robustness. These small systems can also further the active role of universities and technical schools to provide '*energy peace corps*' in support of the development and maintenance of these systems.

19.13 Acknowledgements

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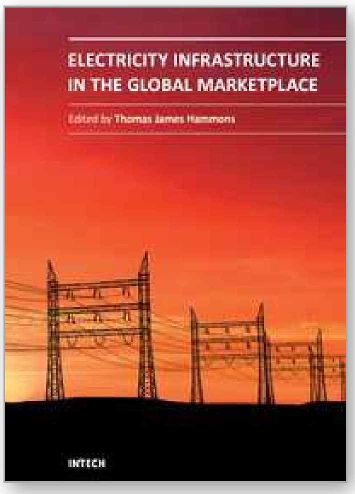

Electricity Infrastructures in the Global Marketplace
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This book discusses trends in the energy industries of emerging economies in all continents. It provides the forum for dissemination and exchange of scientific and engineering information on the theoretical generic and applied areas of scientific and engineering knowledge relating to electrical power infrastructure in the global marketplace. It is a timely reference to modern deregulated energy infrastructure: challenges of restructuring electricity markets in emerging economies. The topics deal with nuclear and hydropower worldwide; biomass; energy potential of the oceans; geothermal energy; reliability; wind power; integrating renewable and dispersed electricity into the grid; electricity markets in Africa, Asia, China, Europe, India, Russia, and in South America. In addition the merits of GHG programs and markets on the electrical power industry, market mechanisms and supply adequacy in hydro-dominated countries in Latin America, energy issues under deregulated environments (including insurance issues) and the African Union and new partnerships for Africa's development is considered.

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