Africa-Europe Electrical Interconnection and Prospects of Worldwide Interconnections

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1. INTRODUCTION

Interconnected electric power systems exist in different parts of the world. They differ in size, whether in total generating capacity or in geographic area covered. Some of the systems operate within the political boundaries of a certain country while others include more than one country.

The advantages of the power systems interconnection are well known and we are not going to repeat whatever has been said or proven in this field

There are certain technical and economical limits for the size of the interconnections systems. However extending the size or the surface area covered may have some advantages tot he systems at the peripheries of the interconnected system. Certain advantages may also be gained by connecting two neighbouring interconnected systems

Ways and means have been developed to everyone the technical limits of synchronous interconnection. These include the direct current (DC) links and the flexible alternating current transmission system (FACTS). With these developments, neighbouring synchronous interconnected systems are being advantages of interconnection, mainly the exchange of reserve during emergencies and the transfer of low cost energy from one system to its neighbours. Other synchronous interconnections and flexible links are being studied, investigated or are still in future vision.

It is the hope of many power system engineers that a worldwide power system is realized, whether synchronously or flexibly interconnected. Low cost electric energy and peak time power could be transferred from one part of the world to the other.

The following is a short overview of some of the main interconnected systems

- Union for the Cooperation of Production and Transmission of Electricity (UCPTE), which includes the electric utilities in the western European countries involving about 14% of the world installed capacity and covers an area of about 2.28 million km^2.

- The interconnected Power System (IPS)/(CMEA), including the power systems of the eastern European countries, involving about 5% of the world installed capacity and covers an area of about 1.25 million km^2.

- The United Power System (UPS), including the power systems of the CIS countries with about 15% of the world installed capacity and covers an area of the about 11.25 million km^2. The UPS system is synchronously operated with the (IPS)/(CMEA) system under normal operating conditions.

- Nordic Countries Interconnection (NORDEL), which includes the electric the electric utilities in Scandinavian countries involving 2.8% of the world installed capacity and covers an area of about 1.23 million km^2. NORDEL system is connected with UCPTE and UPS systems via DC links.

- The continent of North America includes two main interconnected systems, each of them operates synchronously. The Eastern System including the east of the United States and the central provinces of Canada. The Western System including west of the United States and western provinces of Canada. Both systems involve 29% of the world installed capacity and cover about 8.26 million km^2

In this presentation, I shall illustrate the existing and prospected power systems in our region of the Middle East and how it is developing into interconnected systems which would be linked with each other and with neighbouring systems in Africa, Asia, and then to Europe.

2. EVOLUTION OF THE EGYPTIAN POWER SYSTEM

The first electric power system in Egypt was introduced about one hundred years ago when a private company was given the concession to generate and distribute electricity for lighting purposes in Cairo city and then was given another concession to operate an electricity system in Alexandria. The transmission voltages at that time were within the medium voltage range of 2000 - 6000 volts. At later stages of development, diesel plants with low voltage distribution network were installed in the main cities for lighting purposes.

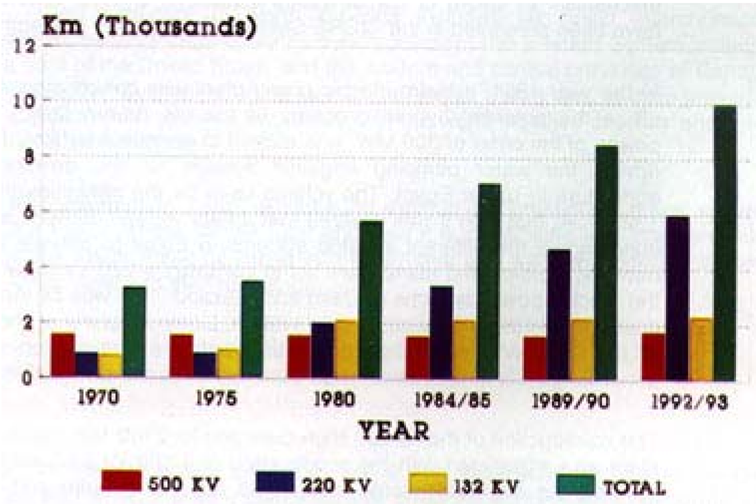
In the early 1930's, the Egyptian government started land reclamation programs, where electrically driven pumps were needed for water drainage in the Delta region in north Egypt and for lifting water from the Nile river to irrigate the reclaimed land in upper Egypt. Small steam turbine plants were installed with ratings of the order of 1000 - 2500 kW. Long transmission lines were designed and constructed to operate at the voltage level of 66 kV. However, it was then realised that insulators for the transmission lines and outdoor switchgear, which were designed according to the European experience, were not suitable for operation in the prevailing environments in Egypt and the transmission system had to be operated at 33 kV instead of 66 kV.
Field investigations were carried out to study this environmental phenomenon. This was followed by laboratory investigations and testing on transmission line insulation which resulted in the development of pioneer theories on the mechanism of failure of contaminated insulators. Several reports in this field have been presented in the CIGRE Sessions by Egyptian research workers.

In the year 1961, a hydroelectric power plant was commissioned at Aswan to utilize the potential hydraulic energy of the old Aswan dam. The available power, of the order 300 MW, was utilized to operate a fertilizer factory and for driving the water pumping irrigation system for the development of the agriculture in Upper Egypt. The voltage used for the transmission network was 132 kV. At that time it was realized that a high voltage network is necessary to interconnect the different isolated systems in Egypt to operate in one unified network. Studies and plans were set to construct a 220 kV network to connect the electric power systems of Cairo and Alexandria as well as the irrigation and drainage electricity network in one system. Commissioning of the first sections of this 220 kV system began in 1967 with the commissioning of the first generating units of the Aswan High Dam hydroelectric power plant.

The construction of the Aswan High Dam and its 2100 MV hydroelectric power plant was associated with the construction of a 500 kV transmission system to transmit the available energy to the load centers in Cairo and other parts of Egypt where the 200 kV and 132 kV networks distribute the energy to the subcenters. It is worthy to mention that at the mid 1960's the 500 kV voltage level was the highest voltage used in the world and Egypt was one of the pioneers in this voltage level besides USA & USSR.

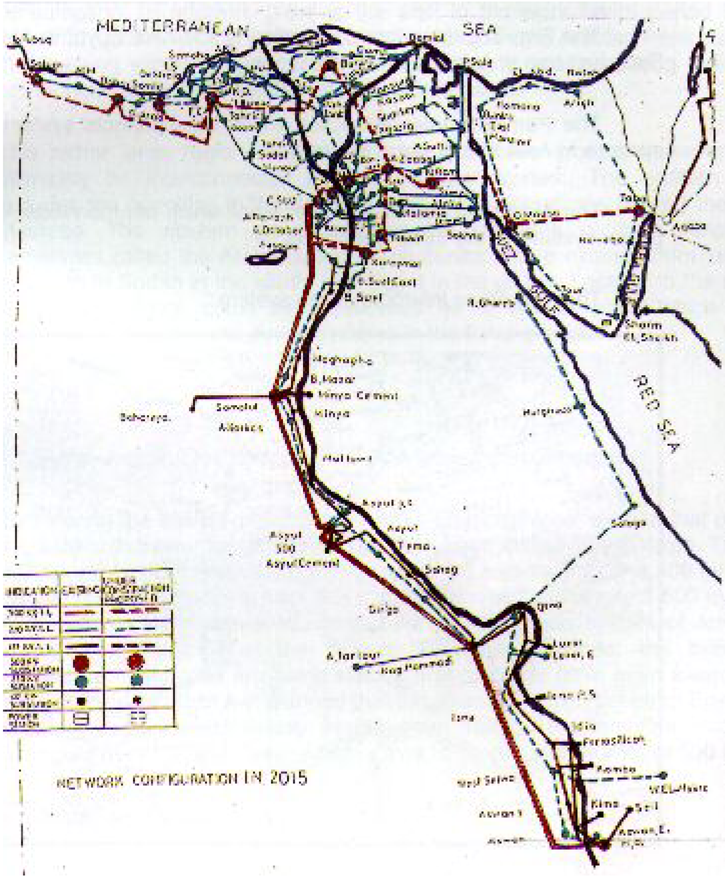
Because of the localization of the inhabited area within the valley of the Nile river, the high voltage transmission system was also limited to the valley and the Nile Delta in the north. However, with the plans of economic and social development, extensions of the high voltage networks are being implemented to reach most of the country. In the east, 500 kV lines are under construction to reach the borders of Egypt to interconnect to Jordan. In the west, 220 kV lines are under construction along the Mediterranean Sea coast to reach the borders of Egypt with Libya.

In the year 1993, the total length of the high voltage transmission system (500 kV, 220 kV, and 132 kV) was about 10000 km. The total demand on this system was about 7000 MW.



Evolution of Transmission Lines Lengths (1970 - 1992/93)

The Egyptian power system went through fast developments during the 1980's and 1990's. Several power plants have been installed bringing the total installed capacity to about 12000 MW. Other power plants are being constructed in order to cope with the increase of the future demand with a unit capacity of 600 MW. Transmission lines extensions will be implemented in order to supply the existing load centers and also reach most of the isolated systems. It is forecasted that the electric energy requirements would be about 113 TWh, in the year 2015, while the corresponding maximum demand would be about 17300 MW.



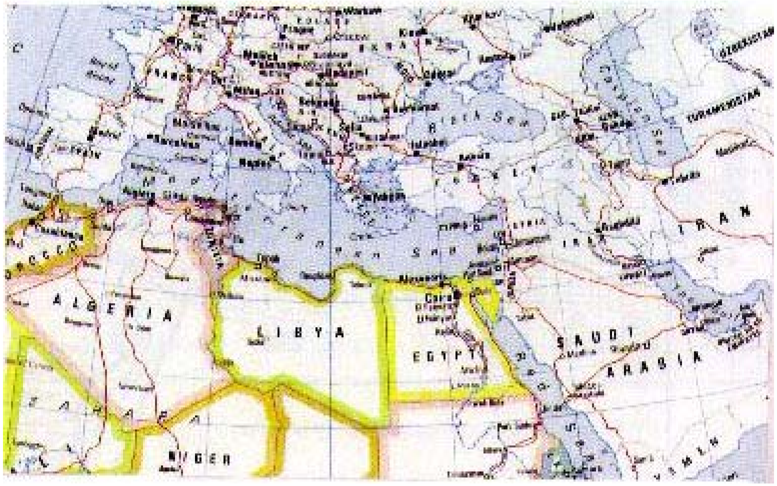
Development of Egyptian Power System up to 2015

3. EGYPT WITHIN REGIONAL INTERCONNECTIONS

Egypt is at the meeting point of the three continents: Africa, Asia, and Europe.

Egypt will be a main partner in the following future interconnections which will be described in detail:

- The Five-Countries Interconnection which links Egypt in Africa to Jordan, Syria, and Iraq in Asia to Turkey in Europe.
- The Pan-Arab Interconnection which interconnects systems in Africa to systems in Asia with Egypt at the center.
- The Mediterranean Sea Power Pool which interconnects Mediterranean power systems in the three Continents.
- The Pan-Africa interconnection system.



Egypt within the Middle East

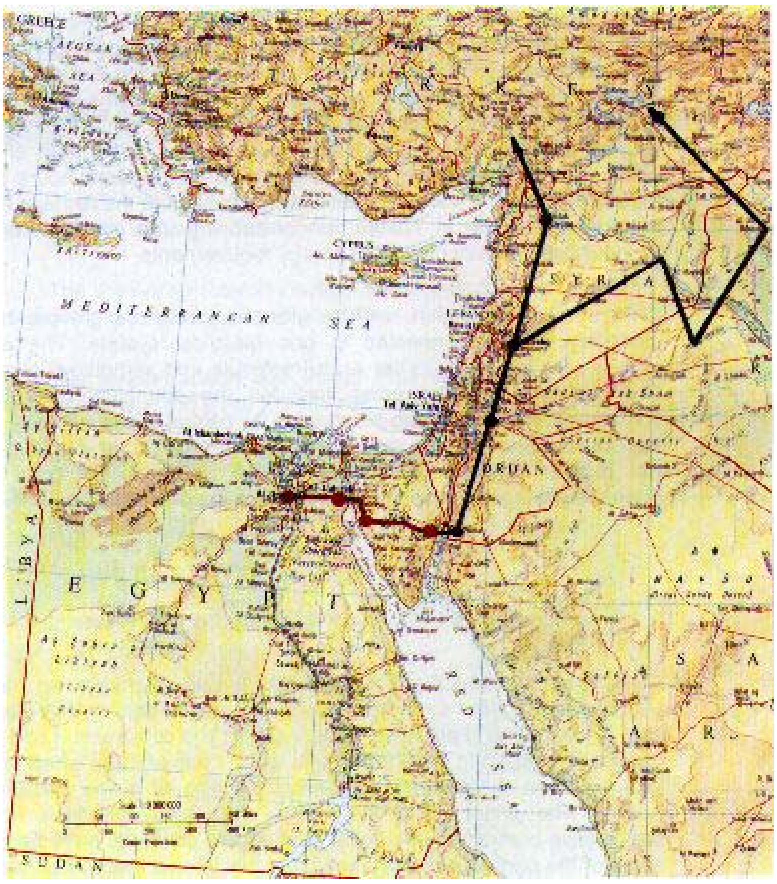
There are many definitions for the boundaries of the Middle East. In this presentation, it will be considered as including the countries extending from the Gulf on the east to the Atlantic on the west, and extends northwards to Turkey and southwards to Sudan. It extends from east to west including five time zones indicating one of the main advantages of power systems interconnection which is the diversity of maximum demand. Domestic and lighting loads which depend on day time and evening time represent a large percentage of the electricity consumption. In addition, there is the shift in the work hours period for the industrial loads. With the very hot summer season in the Arabian Peninsula, and the freezing winter in Turkey, air-conditioning and space heating indicate a pronounced diversity of electric energy requirements.

This rather large region may be grouped into three groups, however could ultimately be interconnected in one electrical system. The eastern group includes the countries in the Arab Peninsula and sometimes termed the Arab-Mashreq. The western group includes the countries in north Africa and sometimes called the Arab-Maghreb. The central group extends from Turkey in the north to Sudan in the south, with Egypt in the center. Looking to the map of the region, Egypt could be considered as a central point which would interconnect together the power systems in the three groups.

3.1 Egypt-Jordan Link and the Five Countries Interconnection

Considering the central group of the Middle East countries, we find that positive steps towards power system interconnection have actually been taken. The first step is now being implemented and includes the construction of a 500 kV transmission line crossing Sinai from Suez to the town of Taba where a 500 kV / 400 kV step down substation is to connect the 400 kV power system of Jordan at Aqaba. The financing of the project has been obtained, the bids from prospective contractors are being studied and contracts have been awarded for some of the packages. It is planned that this interconnection between Egypt and Jordan will be commissioned in the year 1997. This interconnection will eventually permit power transfer from Egypt to Jordan of the order of 500 MW.

A feasibility study was carried out to evaluate the viability of interconnecting the power systems of the five countries; Egypt, Iraq, Jordan, Syria and Turkey. The study has shown that the interconnection would be advantageous to all the 5 countries, as it would allow savings in the reserve generating capacity at the order 2000 MW on the basis of reducing the reserve margin, now kept in each of the five countries, by 5 percent, in order not to depend largely on it's neighbours. The study recommended the use of 400 kV AC for the transmission system rather than the use of d.c. The 400 kV level is



Egypt - Jordan Link and 5 Countries Interconnection

already adopted in Jordan, Iraq, and Turkey. That is why the interconnection with Egypt will be through the 500 kV / 400 kV transformers at Taba. The total length of the 400kV transmission lines interconnecting the power systems across the political boundaries is estimated to be about 650 km, in addition to the transmission lines which would be required to strengthen and complement the power systems within each one of the countries. It is worth to mention that most of the power system in Lebanon is connected to the power system in Syria at a lower voltage level.

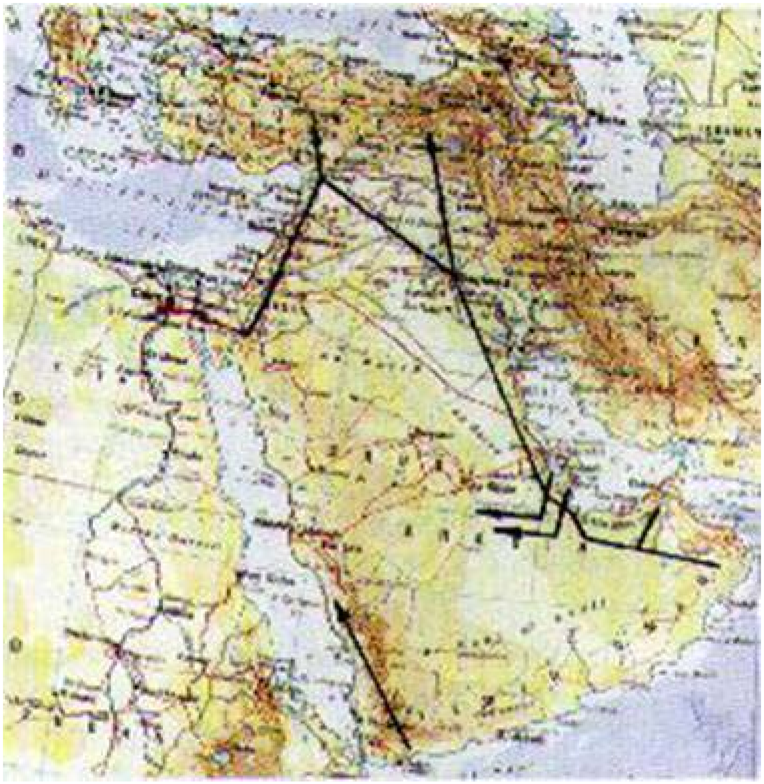
3.2 Arab-Mashreq Countries Interconnection

Arab-Mashreq countries imply those Arab countries which are in the east. The border line between the east and the west is not well defined geographically. In a recent feasibility study for the interconnection of the power systems of the Arab-Mashreq countries, the Arab countries which are east of the Mediterranean Sea and the Red Sea were grouped in four groups while Egypt was considered, in the said study as a group by itself but, however, a part of the Arab-Mashreq interconnection.

Starting from the east, we may consider the power systems of the countries within the Arab Peninsula as to develop in one interconnected system. It would include, mainly, the countries along the gulf, namely from north to south, Kuwait, Bahrain, Qatar, United Arab Emirates, and Oman and this group would eventually include Yemen.

The largest electric utility in this group is that of the Kingdom of Saudi Arabia. It includes four large electric utilities and several smaller utilities. Only two of the large utilities are at present interconnected by 380 kV transmission lines, while the others operate independently. Plans are being studied and when implemented the electric utilities in Saudi Arabia will operate as one interconnected system except for some isolated small systems. At present, about 4800 km of 380 kV transmission lines and a total installed capacity of about 20000 MW are in operation. It is to be pointed out that the operating frequency is 60 Hz while the operating frequency of other systems is 50 Hz and hence integrating Saudi Arabia within the Arab interconnection should be through a back-to-back DC system. This would be at Dhahran in Saudi Arabia.

The interconnection system would mainly be a 380 kV transmission line along the Gulf from Kuwait to Oman and tapped off to interconnect with Bahrain, Saudi Arabia, Qatar and the United Arab Emirates power systems.



Arab-Mashreq Countries Interconnection

The said feasibility study recommended that a transmission line would be extended northwards to Iraq to interconnect with the power systems of the countries of the northern group, including Iraq, Syria, Lebanon and Jordan. This would be then interconnected to the power system of Egypt. The highest system voltage at present is 380 kV in both Iraq and Jordan. However, strengthening of the networks within the countries would be necessary.

Accordingly, for this interconnection system, a 400 kV/500 kV transformation would be required to interconnect Egypt, and a 60 Hz / 50 Hz DC link transformation is required to interconnect Saudi Arabia. The first is a synchronous link, while the second would be an asynchronous link.

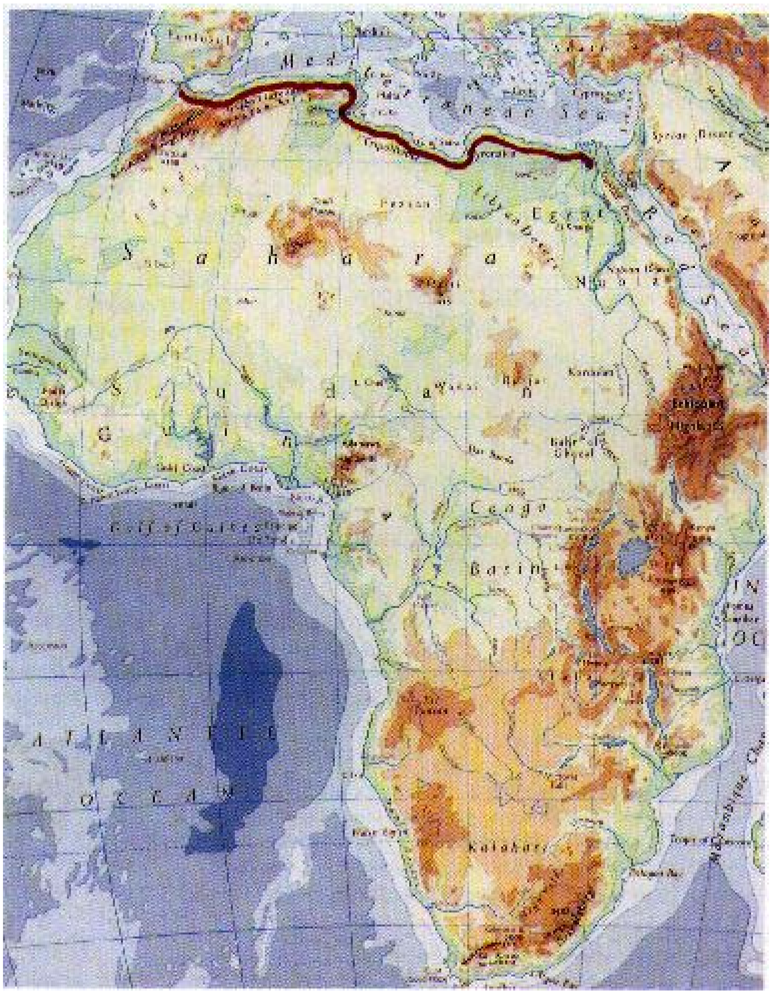
The interconnection study was based on the principle that each member country is to remain completely autonomous and solely responsible for electricity services within its own boundaries. The interconnection is to facilitate energy back-up in emergency situations for any member country without adverse effect on the other countries

The target dates for this Arab Mashreq interconnection were considered in the study as:

- Egypt - Jordan 1997.
- Northern (central) Group 1998.
- Gulf countries group after year 2000

3.3 Arab-Maghreb Countries Interconnection

High voltage transmission lines across the political boundaries of North African countries have started as early as 1952 when a 90 kV transmission line was built between Algeria and Tunisia. It has been followed by a 220 kV line which was commissioned in the year 1980 and a 150 kV line in the year 1984.



Arab-Maghreb Interconnection

Two transmission lines have been constructed between Algeria and Morocco, one commissioned in 1988 and the second 1992. According to jointly agreed agreements between the three countries, the maximum exchange is not to exceed 150 MW between Algeria and Tunisia and 200 MW between Algeria and Morocco.

A feasibility study is being updated for a project to interconnect the power systems in Tunisia and Libya, in order to exchange the power with a maximum of 150 MW in either direction. The project would include the construction of about 600 km of 220 kV transmission lines, most of it in the territory of Libya. It is planned that this interconnection be commissioned in the 1996.

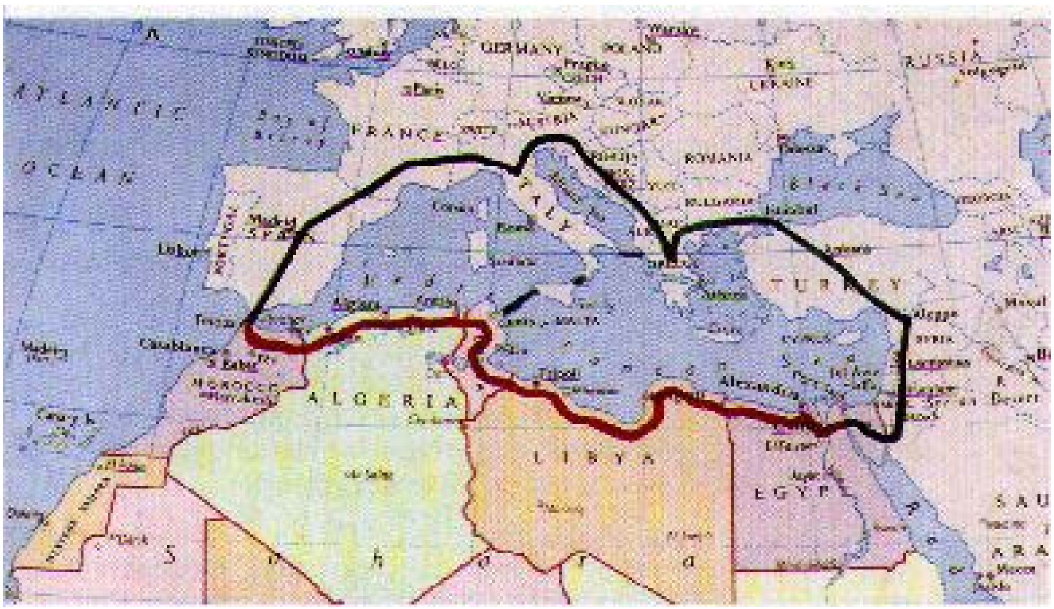
The interconnection between Egypt and Libya is being progressively implemented. Both countries are extending the 220 kV network to gradually reach the common borders.

Of course, full interconnection of the power systems of the five countries would be effected by the construction of a 500 kV (400 kV) transmission system superimposed on the 220 (150) kV transmission lines which are now used for the transfer or exchange of a certain amount of power.

4. AFRICA - EUROPE INTERCONNECTION

4.1 The Mediterranean Power Pool

The possibility of interconnecting and operating the power systems of the 17 Mediterranean Sea countries is interesting and challenging. These countries fall within three time zones and have different climatic conditions and in addition, the 380 million inhabitants have different living customs and habits. In fact many electrical connections exist or are under way between two or more neighbouring countries, however, a complete formation of an integrated power pool will surely prove beneficial.



Mediterranean Power Pool

Egypt, as one of the Mediterranean countries held in the year 1991 with the support of the Observatoire Mediterraneen de L'Energie (OME) and the Commission of the European Communities (CEC) a Seminar on "Cooperation through Electric Power Interconnection in the Mediterranean Region". The recommendation was to prepare a Master Plan study for the interconnection of the Mediterranean Sea countries. Since then, Egypt became an affiliated member of the UNIPEDE, sharing in all its activities.

The "SYSTMED" which is the working group created from representatives of Mediterranean countries members of UNIPEDE has been entrusted to study the assessment of a framework of coherence for the long term development of the networks of the Mediterranean countries.

The horizon of the study is up to the year 2010 where a complete survey has been made by the group of experts for all existing, on-going or planned interconnection projects as well as on-going studies for interconnection projects up to the year 2000, this will be followed by the "Mediterranean Countries Interconnection Project" study for the year 2010.

According to national generation expansion plans, the total electrical production expected for the year 2000 will reach 1635 TWh and then 2200 TWh in year 2010.

The peak load of the interconnected Mediterranean power system is expected to reach 278 GW in 2010.

The required added capacities in the south and east Mediterranean countries up to the year 2010 are expected to be about 90 GW.

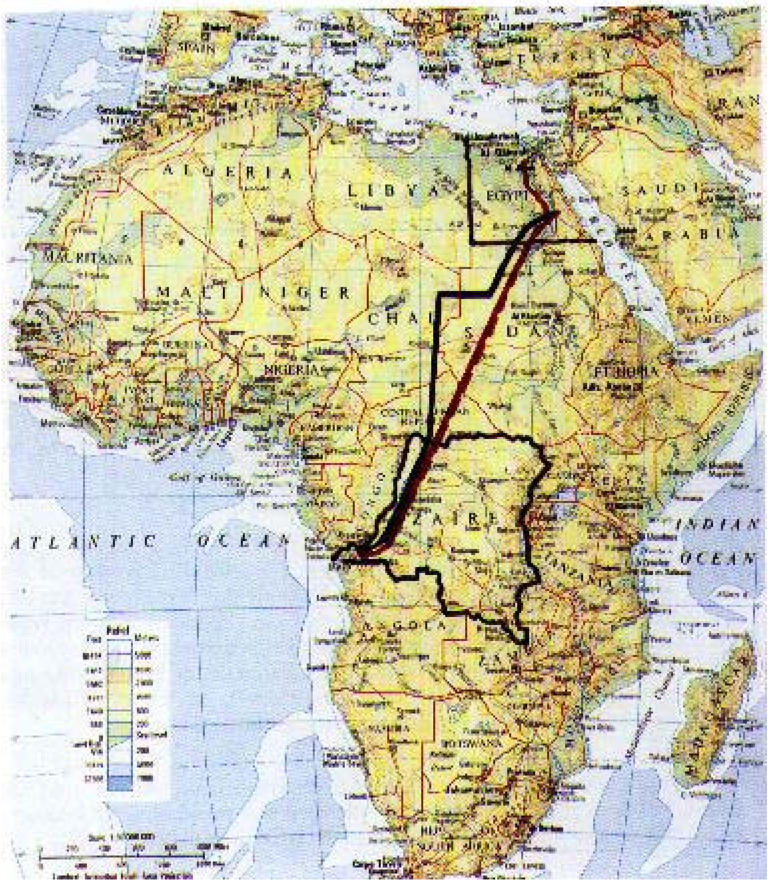
Although the study is in its earliest stage, primary basic indications on the order of magnitude of the fuel gains which may derive from an ideal pooled operation of the generating units of the Mediterranean power systems are well proving the economic interest of this interconnection.

With the implementation of this interconnection, Mediterranean countries in Africa would be interconnected to the countries of southern Europe.

4.2 Egypt - Zaire Power Systems Interconnection

The Zaire River in central Africa is one of the major hydroelectric potentials in the world and it remains as-yet largely not harnessed. Feasibility studies on this river have highlighted potential sites for the development of more than 40000 MW of firm, continuous electric power production. Further developments could achieve potentials of the order of 100 GW.

At the present time, there is no local need for such large quantities of electric energy. The surplus electric energy which is not locally needed could be utilized to complement the needs of some of the African countries and could also be exported to Europe.



Egypt-Zaire Interconnection Project

In 1987, an agreement has been signed by the Minister of Mines and Energy of the Republic of Zaire and myself, in which it was agreed to study the feasibility of the interconnection of the electric networks in both countries in order to make use of the huge hydroelectric potentials at Inga on the Zaire River. In 1988 the two Governments of Zaire and Egypt filed jointly a request to the African Development Bank to finance the feasibility study for the power system interconnection between both countries, involving also Central African Republic, Chad, and Sudan. The Bank approved a grant from eh African Development Technical Assistance Fund to finance the study.

The objective of the study is to identify the best electricity transmission schemes from a technical and economic stand point, which would be competitive with the local options for satisfying the electricity needs for Zaire and Egypt beyond the year 2005. It will also take in consideration possible tapping points in Sudan, Central African Republic and Chad.

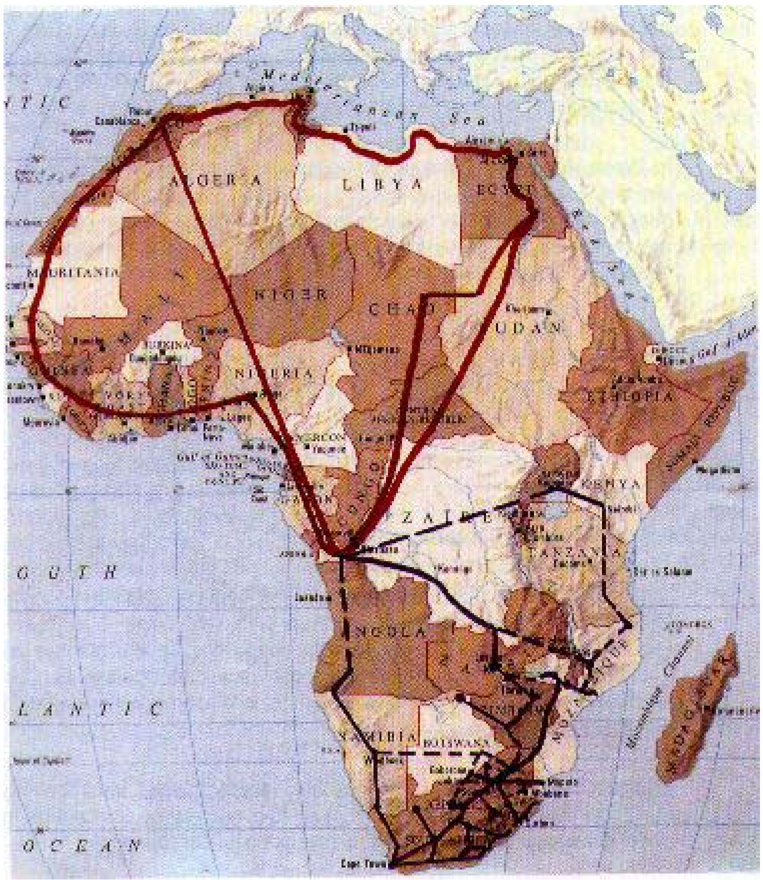
The stage of the pre-feasibility Study started in March 1993, the results of which are encouraging. The second phase of the study consists in optimizing the best three schemes selected during the pre-feasibility study and in further elaborating technical and economic evaluations, and the best scheme will be selected.

4.3 Prospects of Pan-Africa Interconnection

The African continent extends from about the Latitude 35 north of the equator to about the latitude 35 south of the equator. Whenever the electric power systems in Africa are interconnected, the resulting system would enjoy the advantage of exchanging the winter season peak and the summer season peak across the electricity networks. Africa also extends from east to west within four time zones, thus would enjoy the diversity of the daily maximum demand whenever the power systems are interconnected.

At the extreme north, are the Mediterranean countries Egypt, Libya, Tunisia, Algeria and Morocco. Existing and planned possibilities of interconnecting their power systems have been discussed in section 3.3.

The main power system in the south is that of the Republic of South Africa. The high voltage transmission system includes sub-systems with nominal voltage levels of 132 kV, 220 kV, 400 kV alternating current and also at +,- 533 kV direct current. The South Africa Electric Utility (ESKOM) exports power to Mozambique, Zimbabwe, Botswana, Namibia, Lesotho and Swaziland.



Pan-Africa Interconnection

Other transmission systems in southern Africa which cross the international boundaries include a 132 kV line from Cahora Bassa hydro-electric station in Mozambique to South Africa and a transmission line from Inga hydro-electric station in Zaire to Zambia.

Potentials at Inga falls on the Zaire River can generate 40000 MW with damming the river and could be extended to the order of 100 000 MW. Plans are being studied to construct a transmission line which will run southwards to Angola then connect to the network of Namibia which is, in turn, connected to the network of the Republic of South Africa. Visions for a southern African power grid also extend to include eastern and western Africa. In the east, interconnection between Mozambique, Tanzania and Kenya is a possibility.

In West Africa, the hydroelectric power of Inga falls in Zaire could be tapped off via the transmission line which is planned to go northwards to Morocco, to supply the West African countries. These include Gabon, and Cameroon, then the region from Nigeria to the Ivory Coast. This transmission system could also be tapped to supply the countries in the far west up to Mauritania.

The Inga hydroelectric power plant would thus be the main source of power which is common to the power network in southern Africa and to the power network of northern Africa. A pan Africa power network would thus be established.

4.4 Africa Europe Interconnection

The continued future development of the economies of the European Community member nations and others within the larger European continent will require extensive new electric energy resources. In the coming century, until a new energy resource or new energy conversion technology can be brought into production, the least expensive and most environmental sound existing forms of electricity generation will be used.

The economic advantage of importing electric power from the Inga Project on the Zaire River in comparison to operating nuclear or coal plants in Europe has been evaluated and discussed in international conferences.

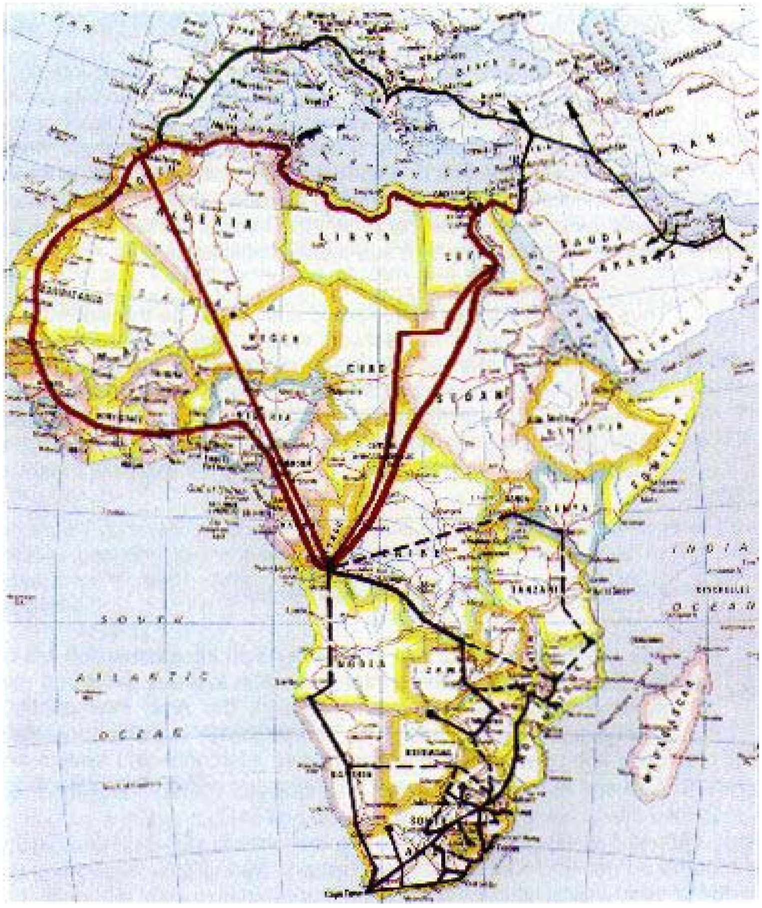
The interconnection between Egypt and Zaire is a unique opportunity to examine in detail for a real case, the practical feasibility of an interconnection between systems separated by very long distances.

Egypt has already adopted the philosophy of electrical interconnections with neighbouring countries. Towards the east, Egypt/Jordan interconnection projection project is now under execution and will be followed by the interconnection of the five countries (Egypt, Jordan, Syria, Iraq and Turkey). Towards the west: Egypt-Libya interconnection project is also now under execution and is followed by Libya interconnection with Tunisia then to Morocco. Morocco will be interconnected to Spain by a submarine cable in the Gibraltar Straights while Tunisia will be interconnected to Italy by a sub-marine cable to Sicily.

Thus the huge African hydroelectric energy can be transferred to the European Common Electrical Power Network via the links Egypt-Turkey, Tunisia-Italy and Morocco-Spain. This solution would represent the ecological accepted answer to Europe for the more and more pressing problem of the greenhouse effect, and would be a rightful investment for the environment protection. In fact, it would lead to a reduced use of fossil fuel for electric energy production in Europe.

4.5 The Three Continents Interconnection

The ultimate picture of this Euro-Afro-Asian interconnection will be realized by the completion of the three interconnection systems described earlier, in detail, namely; the 5-countries interconnection, the Arab interconnections and the Mediterranean power pool. The Turkish power network could also constitute a good link between the European future interconnected system and the UPS in Asia and at the same time will be connected within the Mediterranean system.



The Three Continents Interconnection

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 There are abundant potentials of hydroelectric energy in several parts of the world which are not yet harnessed. It is estimated that these potentials are of the order of 13000 TWh/yr., only about 15% are in operation. Development of these potentials and transmitting their energy to needy load centers, may prove to be more economical, in certain cases, than generation by thermal power plants. It is worthy to mention that the total world electric energy consumption is estimated to about12000 TWh during the year 1990, which is less than the potential hydro-energy.

5.2 The development of the world's hydroelectric potentials and the construction of long distance transmission lines for the transport of the bulk hydroelectric energy from its distant sources to the utilization centers is the aim of environmentalists as well as a hope for the peoples of developing countries.

The clean hydroelectric energy would replace electric energy produced by burning fossil fuels. The revenues from the export of the renewable hydro-energy would contribute to the sustained development of the producing countries.

5.3 In Northern Africa, the first step towards the fulfilment of these aims and hopes has started by the ratification of the agreement between Zaire and Egypt for the utilization of the potentials of the Zaire River for the benefit of the some African Countries. Exporting the excess energy to Europe is also considered.

5.4 It is proposed that successive steps should be taken for the development of the exploitable hydroelectric potentials in the Northern Africa, which are estimated at about 1000 TWh/year. A strong high voltage transmission system is to be built to interconnect the hydroelectric projects together, as well as to provide strong ties to neighbouring continents, (Europe, and Asia) for the export of blocks of electric energy.

Through the collective generation and export of hydroelectric energy, sustained development of countries in Northern Africa would be achieved. The revenues from electricity exports would pay back the investments in the power projects and also provide financing for sustained economic and social development.

5.5 Environmental issues caused by the combustion of fossil fuels are the present concern of the World. With the encouraging results of the Egypt-Zaire interconnection study, it has become interesting to extend the interconnection to Europe for the import of clean hydro electric energy to replace fossil fuel burning power plants.

5.6 The idea of the power pool of the Mediterranean Sea countries represents the first step in the integration of the European electricity system with the developing system of the countries of Northern Africa. The fulfilment of this integration will make it possible for increasing imports of clean electricity from Africa.

5.7 It is proposed that the electric utilities in the two continents of Europe and Africa should work closely and cooperate in the implementation of the hydroelectric projects in Northern Africa and the integration of the power systems of the two continents.

5.8 CIGRE, being the most important organization for large electric systems, would adopt the subject of the integration of the power systems within and the between continents for the transport of the hydroelectric energy from its far sources to the load centers. The objectives would be the alleviation of some of the world's environmental problems. The sustained development of countries in Africa, Latin America and Asia, where hydro potentials are available and could be exported to the industrialized countries, can be achieved.

5.9 It is proposed that the issues of inter-continent interconnection and long distance bulk power transmission be discussed in Working Groups within the CIGRE Study Committees. CIGRE may also organize symposia and conferences for the discussions of these issues.

5.10 Egypt Offers to host the first symposium on this subject.