ASSESSMENT, IN THE FRAMEWORK OF THE ELMED PROJECT, OF THE MAXIMUM ELECTRICITY PRODUCTION CAPACITY FROM NON-PROGRAMMABLE RENEWABLE ENERGY SOURCES (RES) CONNECTABLE TO THE TUNISIAN GRID IN ACCORDANCE WITH SECURITY AND QUALITY REQUIREMENTS

Objectives of the study

At the request of the company ELMED Etudes Sarl, CESI SpA carried out a study, the objectives of which are the following:

a) Definition of the network reinforcements necessary to guarantee static and dynamic security conditions following the commissioning of the ELMED Production Units (or "ELMED Production Cluster") and the realization of the new 1000 MW Tunisia-Italy High Voltage Direct Current (HVDC) transmission link;

b) Definition of the maximum power produced by non-programmable renewable sources (RES[1]) acceptable by the Tunisian production–transmission system in the reference configuration defined in objective a). The analysis shall take into account only the network reinforcements identified in the first phase of the study.

The thermal ELMED Production Cluster

To evaluate the impact of the thermal ELMED Production Cluster on the Tunisian transmission system, we examined various alternatives for the location of this power plant and different possibilities of fossil fuel, namely: gas and coal. In particular, the two extreme alternatives in terms of geographical location of the new power plant are:

- El Hawaria, 3x400 MW;
- Skhira, 2x660 MW.

We did not consider all the possible combinations of production technology for the realization of the ELMED power plant. Indeed, there are several technical solutions, even with the same fuel, being aware that the supply of fossil fuels in the different sites must take into account a variety of factors, including supply infrastructures, market conditions (fuel and technologies), logistic. These factors are not treated in this study, which is limited to identifying the necessary network reinforcements in the examined reference cases, only considering the electrical point of view.

The ELMED Production Cluster shall satisfy the internal demand in Tunisia up to 400 MW, while the surplus will be exported to Europe through the undersea HVDC link.

In a second phase, we carried on a detailed analysis, which addressed the performances of the Tunisian system at the occurrence of important contingencies; the simulations were executed considering the assumption of the ELMED Production Cluster located in Skhira, which requires the heaviest network reinforcements for the Tunisian transmission system.

[1] Renewable Energy Sources

All simulations were executed with reference to the horizon year 2016; at that date the HVDC link with Sicily was assumed in service. Two extreme operating conditions were considered: the yearly peak load (or maximum) of about 4000 MW and the yearly low load (or minimum) of about 1400 MW.

In addition to the HVDC link with Sicily, the adopted model for the Tunisian system is characterised by five tie-lines with Algeria (including the 400 kV line Chefia-Jendouba), whilst the interconnection with Libya has always been considered out of service; this is the less favourable situation in terms of system stability.

The results of the analyses can be summarised as follows:

- To comply with the N-1[2] security criteria, two 400 kV lines are necessary to connect the ELMED power plant and the HVDC converter to the Tunisian transmission system,
- The location of the ELMED power plant in El Hawaria requires the construction of two 400 kV lines (each with a length of about 150 km) connecting this power plant, to supply the internal demand of Tunisia.
- The location of the ELMED power plant in Skhira needs the doubling of the south-north 400 kV corridor until to Mornaguia (length about 450 km) and a 400 kV double circuit Skhira-Maknassy (length about 70 km), in addition to the 400 kV corridor from Mornaguia to El Hawaria to export power to Sicily. A 225 kV connection on the double circuit Bouchemma-Sidi Mansour has been proposed to increase the flexibility for the supply of the internal demand in Tunisia.

The reinforcements mentioned above are the additional reinforcements with respect to those already planned by STEG for the horizon year 2016.

The analyses of the performances of the power system in case of large perturbations are related to the location of the ELMED power plant in Skhira, which is the farthest site from the barycentre of the Tunisian internal demand, mainly located in the area of Tunis, as well as from the alternating-direct current converter located in El Hawaria. In particular, the following faults have been examined:

a) three-phase short circuit without fault impedance on the 400 kV line Skhira – Maknassy;
b) loss of one Skhira generator;
c) loss of one pole of HVDC system.

The most critical perturbation is the three-phase short circuit on the 400 kV line Skhira–Maknassy outcoming from the ELMED Production Cluster. To ensure an adequate stability margin, particularly in situations of maximum generation of the ELMED power plant, a series of measures have been recommended, such as the Power System Stabilizer (PSS), the Fast Valving device for both high and medium steam pressure valves and an independent supply of the excitation system.
The loss of one unit in Skhira has a moderate impact on the Tunisian power system when it is interconnected with Algeria and the HVDC link is equipped with a frequency regulator.

[2] N-1 security criterion: the electric system must be operated to cope with failure of a component (transmission element or generating unit) without violates any operational constrained fixed for the operation of the system.

Finally, the loss of one pole in the HVDC converter station (500 MW with a bipolar configuration), which is equivalent to the sudden disconnection of a load, doesn't show any transient stability problems; only with Tunisia isolated from Algeria, the frequency, particularly in minimum load conditions, increases in a significant way. In this case, a high value of power exported to Italy in pre-fault conditions exposes the Tunisian grid to possible over-frequency problems at the occurrence of the loss of one HVDC pole, if the tie-lines with Algeria are out of service[3].

The non-dispatchable renewable source production

The scope of this phase of the study is the assessment of the maximum non-dispatchable generation, connectable to the Tunisian system.

The study has been split in three phases that can be summarised as follow:

a) *Global analysis ("single bus-bar analysis")*, the scope of which was to determine the non-programmable renewable generation considering only the constraints of the conventional generating units (e.g. frequency regulation reserve), disregarding the constraints of the transmission system.
   The analysis concerned both minimum and peak load conditions, in order to assess a value acceptable by the grid in each loading condition.

b) *Static analysis*, that allows to determine the grid configurations with the schemes required for the renewable power plants connection.

c) *Dynamic analysis*, where two sets of analyses have been carried out:
   - sensitivity analysis, where the effects of renewable generation fluctuations have been investigated in terms of voltage and frequency oscillations;
   - fault analysis, where the stability of the system in case of main grid contingences (i.e. three phase short circuit) has been tested to verify the behaviour of renewable power plants.

All analyses have been carried out starting from the grid configuration determined with the ELMED Production Cluster located in Skhira without any additional network reinforcements except those strictly necessary for the renewable power plant connection.

The simulations showed that the binding condition is related to the minimum loading level in the system, where the difference between the power generated by the conventional power plants provided by STEG for the year 2016 and their technical minimums are very low, keeping the assumption not to shut down the generating units indicated by STEG, that is to say: unchanging the unit commitment.
In the yearly minimum load conditions (1400 MW), with the presence of the direct-current link to Sicily (1000 MW) and considering the generation of conventional units provided by STEG together with the associated reserve (1330 MW), we obtain a maximum generation from non-dispatchable renewable sources of about 530 MW, corresponding to an installed capacity of about 660 MW, considering a generation rate equal to 80%, and taking into account the need for additional reserve in the system to cope with the variability of the production of renewable non-programmable sources.

[3] This is indeed a very rare operation mode.

The previous result is valid under the assumption of a thermal generation at the ELMED power plant equal to 400 MW in low load conditions. However, if the level of thermal generation at the ELMED power plant exceeds 400 MW, the non-dispatchable RES generation shall be reduced according to the following table.

Tab. E-1 – Maximum non-dispatchable RES generation and installation in function of thermal ELMED production

Production of ELMED power plant [MW]	Maximum RES power generation [MW]	Installed RES power (*) [MW]
400 *(limit condition)*	530	660
500	450	560
600	370	460
700	285	355
800	205	255

(*) generation rate equal to 80%

To investigate the impact on the Tunisian electric system of the production from non-dispatchable renewable sources up to a value of 530 MW, we necessarily had to introduce assumptions on the geographic distribution of such a form of generation, on the type of technology and the possible connection substations. These assumptions were agreed with "ELMED Etudes" and STEG and can be summarized as follows: the production of non-programmable renewable sources is located in the northern part of Tunisia, the technology of generators is referred to that adopted in the case of wind generation that is characterized by the highest intermittency.
We have verified that with an appropriate selection of connection solutions for the RES generation to the Tunisian power system for the year 2016, it is possible to comply with the N (all network components in service) and N-1 (one component out of service due to a fault) security conditions.
Concerning the performance of the power system in dynamic conditions, we verified that the intermittency of the non-programmable renewable generation doesn't excessively affect the system performances, since the variations of frequency and voltages remain within the acceptable limits, thanks to the frequency regulation of the HVDC converter station and the interconnection with Algeria. Indeed, it is recommended that the converter alternating-direct current (HVDC converter) is equipped with a system of frequency control.
In case of large contingencies, such as three-phase short circuits, to avoid a cascade effect of renewable generation unit tripping, we recommend not to equip these generators with relays of frequency derivative. Three-phase short circuits very close to a RES power plant can cause its tripping.
The frequency control in the HVDC converter is important to improve the system performances (in terms of frequency control) after a fault in the system.
Finally, to avoid attaining too high voltage values, especially in low load condition, we recommend to set the absorption of reactive power equal to 20% of the rated power for each generator RES. Therefore, the power factor would be about 0.97 lagging.

The benefits of the link between Tunisia and Italy for the Tunisian power system
The connection between Tunisia and Italy provides benefits for improving the performances of the Tunisian power system in terms of:

- better frequency stability thanks to the contribution to frequency control by means of the control system in the converter alternating-direct current,
- possibility to cope with extreme contingencies (e.g. loss of a transmission line followed by the tripping of a large size group), thanks to the sudden reduction of power export to Sicily or, if necessary, rapid reversal of power flow on the HVDC link with the supply of power from Italy to Tunisia.