Deliverable 2.1.2

Detailed Project Description

06 - TNIT2 Tunisia - Italy

EC DEVCO - GRANT CONTRACT: ENPI/2014/347-006

"Mediterranean Project"

Task 2 "Planning and development of the Euro-Mediterranean Electricity Reference Grid "

Med-TSO is supported by the European Union.

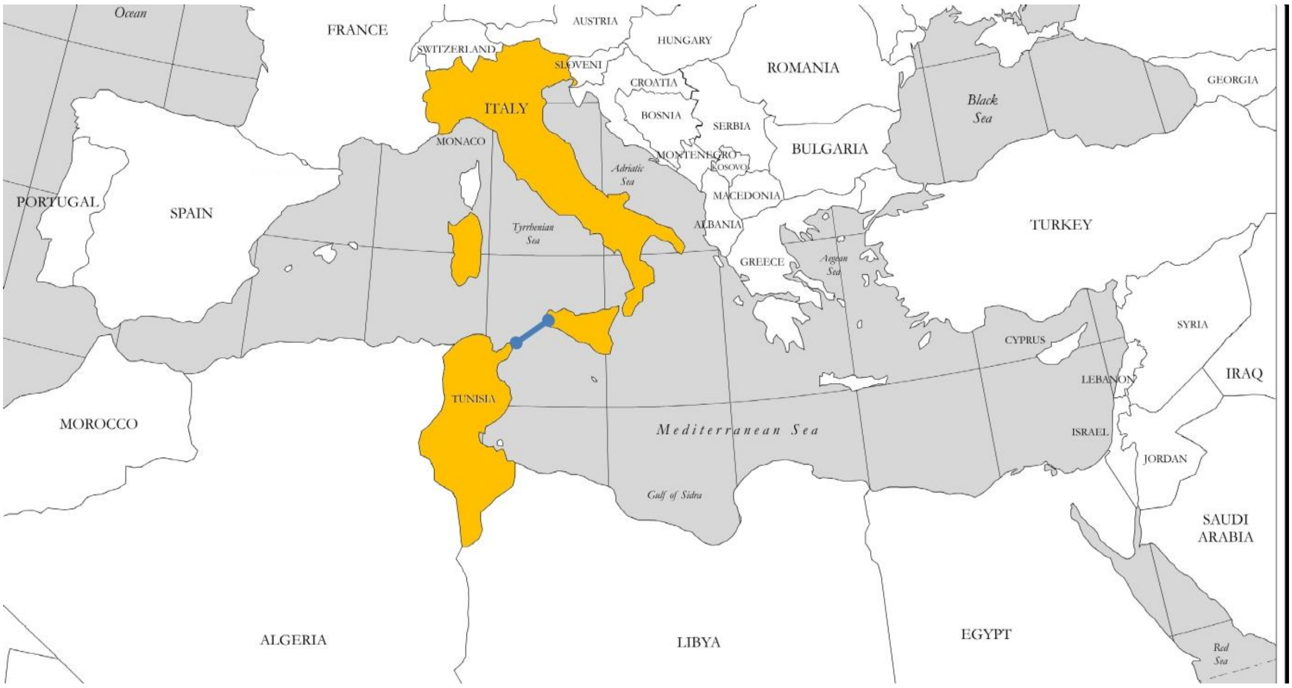
INDEX

1 Introduction

The present document contains the studies on project TNIT2, in the context of the Mediterranean Master Plan of Interconnections. Project TNIT2 consists of an interconnection between Italy and Tunisia (+600 MW DC).

The document is structured as follows. Section 2 describes in detail the interconnection project and the different sources for data employed. Section 3 presents the definition of the different snapshots to be considered and the description of the building process followed. Section 4 comprises the criteria and results of the security analysis. Section 5 summarizes the results on security analysis and reinforcements' assessment. Section 6 contains the estimations made for the active power losses. Finally, section 7 comprises the estimation for the different investment costs.

2 Project description and data acquisition



The project involves the reinforcement of the first interconnection (600 MW) between Tunisia and Sicily to be realized through an HVDC submarine cable. The project may contribute to reduce present and future limitations to the power exchanges on the northern Italian border under specific conditions, and therefore it may allow to increase significantly the transmission capacity and its exploitation by on that boundary.

Project details

Description	***Substation (from)***	***Substation (to)***	***GTC contribution (MW)***	***Present status***	***Expected commissioning date***	***Evolution***	***Evolution driver***
New interconnection between Italy and Tunisia (HVDC)	Sicily (IT) Partanna	Tunisia (TN) Hawaria	600	Mid-term project	2025	Investment on time	Increase the interconnection capacity of the Euro-Mediterranean system and reduce present and future limitations to the power exchanges on the northern Italian border
Reinforcement of interconnection between Italy and Tunisia (HVDC)	Sicily (IT) Partanna	Tunisia (TN) Hawaria	600	Long-term project	Post 2030	*n.d.*	

The system defined for project TNIT2 is described in the table and figure below.

Full models	**Boundaries**
Italy IT	France FR
Tunisia TN	Switzerland CH
Algeria DZ	Austria AT
	Slovenia SI
	Montenegro ME
	Greece GR
	Libya LY
	Morocco MA

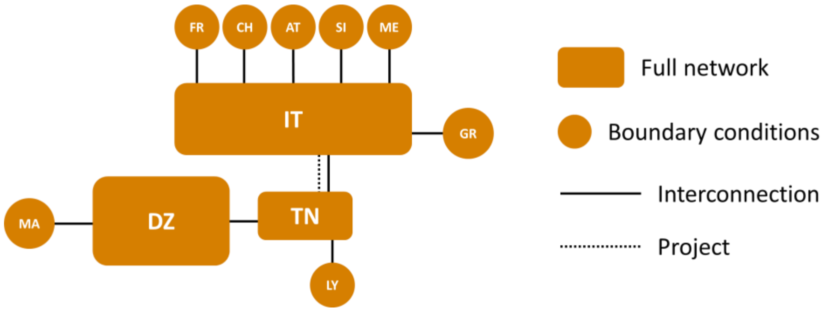


Table 1 – Participation of each of the systems involved in project TNIT2

For this project, the Algerian, Tunisian and Italian systems have been considered as full represented by their transmission network models. Boundary systems, i.e. Morocco, Libya, France, Switzerland, Slovenia, Montenegro and Greece, are considered as external buses with loads to simulate energy interchanges.

In the snapshots definition, 4 scenarios (S1, S2, S3 and S4) and seasonality (Winter/Summer) are distinguished. Models provided:

- For the Algerian system, a set of eight models have been provided, corresponding with 4 scenarios (S1, S2, S3 and S4) and seasonality (Winter/Summer).
- For the Tunisian system, a set of four models have been provided, corresponding with 4 scenarios (S1, S2, S3 and S4)
- For the Italian system a set of two models have been provided, one for scenarios S1 and S2 and the other for scenarios S3 and S4.

Full list of provided files is included in [1].In all models provided interconnected Areas are well identified. Generating technologies are identified in the 'Owner' field for Machines. Concerning merit order list, all generating units are considered with the same rank. Certain particularities in the models provided for the three systems involved in the project are mentioned below:

DZ: The file '0.DZ_Database guidline&Market data_Common cases_S&W-Peak.xlsx' provided contains a complete guideline for the format used to collect network information, plus the generation dispatch by technologies, demand and energy interchanges for S1-S4 and S/W. Concerning Algerian areas (4th character in bus code), from 1 to 7 have been identified as Algerian areas. Rest of them represent boundary countries, i.e. 'M' for Morocco and 'T' for Tunisia. Finally, 'S' represents the Algerian bus for DZES project, while 'I' represents the Algerian bus for DZIT project. Finally, in the uploaded EXCEL files, generating technologies are identified using numbers. The following table identifies the Algerian nomenclatures and the standard:

Technologies Identified in EXCEL networks	Standard technologies
NUCLEAR	1 – NUCLEAR
CCGT - OLD	13 - GAS CCGT OLD 2 (45% - 52%)
CCGT - NEW	14 - GAS CCGT NEW (53% - 60%)
OCGT- OLD	17 - GAS OCGT OLD (35% - 38%)
WIND	26 - WIND ONSHORE
PV	23 - SOLAR PHOTOVOLTAIC
CSP	24 - SOLAR THERMAL
Hybrid	24 - SOLAR THERMAL
SVC	(Static Var Compensator → 99-UNKNOWN)
SLACK	Connection with Morocco (slack of the system)

TN: the file ‘Mapping_file_for_TN.XLSX’ provided contains information on generating units’ characteristics and dispatch for the four scenarios.

IT: Additionally, the file ‘Generators technology.xlsx’ provided contains basic information on generating units of the Italian system. Generating technologies are well identified in the ‘Owner’ field for Machines, but using ENTSO-E codes. File ‘Generators technology.xlsx’ includes the matching between ENTSO-E codes and Med-TSO codes. Concerning merit order list, all generating units are considered with the same rank. Finally, the file ‘IT_interconnections.xlsx’ provided comes with basic information on interconnections of the Italian system.

Merging process consists of joining the different networks using the connecting buses defined in the next tables. First, Table 2 summarizes the interconnections between systems, which correspond with pairs of modelled systems, thus two interconnection buses must be identified, one for each of the systems in the interconnection.

Bus	Area	Substation	Bus	Area	Substation
CHE3112	Algeria DZ	Chefia	JENT112	Tunisia TN	Jendouba
EAO3212	Algeria DZ	El Aouinet	TAJT211	Tunisia TN	Tajerouine

Table 2 – Points of merging between systems in the TNIT2 project

Table 3 shows the set of interconnections that correspond with pairs formed by a modelled system and a boundary system, thus only one bus in the modelled system needs to be identified.

Bus	Area (from)	Substation	Area (to)
BOUM111	Algeria DZ	Boussidi	Morocco MA
OUJM211	Algeria DZ	Oujda	Morocco MA
XWU_SO21	Italy IT	Soverzene	Autria AT
XNA_GL21	Italy IT	Glorenza	Autria AT
XLI_PO21	Italy IT	Pordenone	Autria AT
XGR_TA41	Italy IT	Taio	Autria AT
XSO_ME11	Italy IT	Mese	Switzerland CH
XSI_VE1I	Italy IT	Verderio	Switzerland CH
XSE_PA21	Italy IT	Pallanzeno	Switzerland CH
XRO_SF11	Italy IT	S. Fiorano	Switzerland CH
XRO_GO11	Italy IT	Gorlano	Switzerland CH
XRI_VA21	Italy IT	Valpelline	Switzerland CH
XRI_AV21	Italy IT	Avise	Switzerland CH
XME_CA11	Italy IT	Castasegna	Switzerland CH

Bus	Area (from)	Substation	Area (to)
XLA_MU11	Italy IT	Musignano	Switzerland CH
XGO_ME21	Italy IT	Mese	Switzerland CH
XCA_ME21	Italy IT	Castasegna	Switzerland CH
XAL_PO21	Italy IT	Ponte	Switzerland CH
XVL_VE12	Italy IT	Venaus	France FR
XGR_PI9I	Italy IT	Piossasco	France FR
XB._CA21	Italy IT	Camporoso	France FR
XAL_RO12	Italy IT	Rondisone	France FR
XAL_RO11	Italy IT	Rondisone	France FR
XAR_GA1I	Italy IT	Galatina	Greece GR
XVI_TI9I	Italy IT	Villanova	Montenegro ME
XRE_DI11	Italy IT	Redipuglia	Slovenia SI
XPA_DI21	Italy IT	Padriciano	Slovenia SI
XBE_SA1S	Italy IT	Salgareda	Slovenia SI
ABOU KAMMECH	Tunisia TN	Abou Kammech	Libya LY
ROUIS	Tunisia TN	Rouis	Libya LY

Table 3 – Points of merging between systems and external buses in the TNIT2 project

For the interconnection between Algeria and Morocco (boundary), two buses have been identified in Algerian networks, BOUM111 and OUJM211. However, it is important to remark that bus OUJM211 appears disconnected, since all the energy transfers between Morocco and Algeria are through BOUM111.

Finally, Table 4 presents the new interconnections associated to the TNIT2 project.

PROJECT	Bus	Area	Subs.	Bus	Area	Subs.	LINK
DZIT	HAWARIA	Tunisia TN	Hawaria	XPA_EL9I	Italy IT	Partanna	HVDC

Table 4 – Points of merging in the Projects in the TNIT2 project

Projects TNIT2 involve two HVDC links between Tunisia and Italy. Buses in the Tunisian side (HAWARIA) and the Italian side (XPA_EL9I) have been identified.

3 Snapshots definition and building process

For the project TNIT2, a total number of eight Points in Time (PiT) have been defined [2]. Each of the PiT contains, for each of the systems considered, the active power generated, demanded and exported to the other systems. Active power production comes with a breakdown of technologies. Next table shows the power balance for each of the PiTS in TNIT2 project.

```
project TNIT2 PiT 1 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  2543.3  3543.3 -1000.0     0.0 -1200.0 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   53276.4 49780.1  3497.2  1200.0     0.0    0.0     0.0  1736.3     0.0 -1139.1  1200.0  500.0   0.0     0.0
Algeria DZ 19134.3 19679.6  -545.3   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0  -845.3

project TNIT2 PiT 2 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  1671.8  2618.3  -946.5     0.0 -1200.0 -246.5     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   38039.3 33446.5  4592.8  1200.0     0.0    0.0     0.0  2941.2  1071.9     0.0  -198.5 -421.8   0.0     0.0
Algeria DZ 14299.8 14486.2  -186.3   246.5     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0  -432.8

project TNIT2 PiT 3 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  3910.7  4910.7 -1000.0     0.0 -1200.0 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   48939.5 42919.8  6019.7  1200.0     0.0    0.0  2026.6     0.0   213.2  1380.0  1200.0    0.0   0.0     0.0
Algeria DZ 21280.4 21980.4  -700.0   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0 -1000.0

project TNIT2 PiT 4 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  4624.4  5624.4 -1000.0     0.0 -1200.0 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   54884.8 56777.4 -1892.6  1200.0     0.0    0.0 -1293.6  -900.6 -1068.5 -1530.0  1200.0  500.0   0.0     0.0
Algeria DZ 19810.8 18510.8  1300.0   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0  1000.0

project TNIT2 PiT 5 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  5193.6  5997.9  -804.3     0.0 -1004.3 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   53328.7 60483.7 -7155.0  1004.3     0.0    0.0 -2279.5 -2391.6 -1655.0  -633.1 -1200.0    0.0   0.0     0.0
Algeria DZ 22849.8 21549.8  1300.0   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0  1000.0

project TNIT2 PiT 6 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  5723.4  6445.7  -722.3     0.0  -922.3 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   49773.0 55144.4 -5371.4   922.3     0.0    0.0 -4299.0 -2932.9     0.0    46.4   391.8  500.0   0.0     0.0
Algeria DZ 28948.4 28294.9   653.5   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0   353.5

project TNIT2 PiT 7 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  5743.1  4343.1  1400.0     0.0  1200.0 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   48420.1 57550.9 -9130.9 -1200.0     0.0    0.0 -4339.7  -663.5 -1082.5 -1345.2     0.0 -500.0   0.0     0.0
Algeria DZ 21645.7 20345.7  1300.0   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0  1000.0

project TNIT2 PiT 8 - Power Balance [MW]
sys             PG      PD  Pexport      TN      IT     DZ      FR      CH      AT      SI      ME     GR    LY       MA
Tunisia TN  3501.3  3488.3    12.9     0.0  -187.1 -300.0     0.0     0.0     0.0     0.0     0.0    0.0 500.0     0.0
Italy IT   37638.9 33959.8  3679.1   187.1     0.0    0.0 -4350.0  3836.3  1385.0  1372.8   748.0  500.0   0.0     0.0
Algeria DZ 20963.9 19663.9  1300.0   300.0     0.0    0.0     0.0     0.0     0.0     0.0     0.0    0.0   0.0  1000.0
```

Table 5 – Power balance for each of the PiTS defined in the TNIT2 project

4 Power flow and security analysis

This section presents the criteria agreed to run the power flow and N-x contingency analysis over the different snapshots built for project TNIT2. Details on the methodology used for the security analysis are compiled in [3].

Algeria

For the Algerian system, the N-1 will be focused on the transmission levels. Therefore, the branches considered for the N-1 analysis are only those at 220 kV and 400 kV. Also, overloads will only be checked for branches at 220 kV and 400 kV.

Concerning rates and tolerances, PSS/E files come with three different values, i.e. rateA, rateB and rateC. For lines, rateA will be considered for Winter, rateB will be considered for Summer, and rateC will be unused. For transformers, rateA will be considered as unique rate, thus rateB and rateC will be unused. The tolerance for overload will be 0% for all branches, in N and N-1 situations.

Regarding the loss of generating units, the energy lost will come from the Moroccan interconnection, until rate. Then, if it is necessary, the rest of the energy lost will come from Italy through Tunisia, via the TNIT interconnection.

Finally, no N-2 situations have considered for Algeria.

Tunisia

For the Tunisian system, the N-1 will be focused on the transmission levels. Therefore, the branches considered for the N-1 analysis are only those at 150 kV, 225 kV and 400 kV. Also, overloads will only be checked for branches at 150 kV, 225 kV and 400 kV.

Concerning rates and tolerances, PSS/E files come with three different values, i.e. rateA, rateB and rateC. For lines and transformers, rateA will be considered all snapshots, thus rateB and rateC will be unused. The tolerance for overload will be 0% for all branches in N, and +20% in N-1 situations.

Regarding the loss of generating units, the energy lost will come first from Italy, via the TNIT interconnection, until rate. Then, if it is necessary, the rest of the energy lost will come from Morocco through Algeria.

Finally, no N-2 situations have considered for Tunisia.

Italy

For the Italian system, the N-1 will be focused on the transmission levels. Therefore, the branches considered for the N-1 analysis are only those at 150 kV, 220 kV, 400 kV and 500 kV. Also, overloads will only be checked for branches at 132 kV, 150 kV, 220 kV, 400 kV and 500 kV.

Concerning rates and tolerances, PSS/E files come with three different values, i.e. rateA, rateB and rateC. For lines and transformers, 1.2 times the rateA will be considered for Winter and 0.8 times the rateA for Summer. Thus, rateB and rateC will be unused. The tolerance for overloads in lines will be 0% for N and N-1 situations. The tolerance for overloads in transformers will be 0% for N and +10% for N-1 situations.

Regarding the loss of generating units, each area will provide with its own internal resources.

Finally, the set of N-x outages is defined by considering simultaneous outage of each couple of branches with a degree of separation from the interconnections less or equal to two.

AC security analysis of selected PiTs

In the context of the TNIT2 project, PiT 4 has been selected to be analyzed using the full AC power flow. The objective of this analysis are the voltages at the transmission network and, in case of problems, study potential solutions.

Next table contains the reactive power balance for this PiT

area	Algeria DZ	Tunisia TN
generators (+)	2127.4	1513.8
demand (-)	7951.9	1860.3
bus shunt (+)	0.0	111.5
series reactance of lines (-)	1679.1	648.3
shunt charging of lines (+)	9811.8	1606.6
reactance of transformers(-)	2180.6	837.7
exporting (-)	127.7	-114.4

Table 6 – Reactive power balance for PiT 4 in the Algerian and Tunisian systems

Table 6**Errore. L'origine riferimento non è stata trovata.** shows how the most of the reactive power generation comes from the shunt charging of lines, especially in the case of Algeria where generating units provide only the 30% of the reactive power demanded by loads. However, despite this is a good indicator for

QV analysis, some problems with bus voltages arise from the N and N-1 security analysis. Next tables depict all those voltage problems.

bus	area	Vbase [kV]	Vmin N [pu]	Vmax N [pu]	Vmin N-1 [pu]	Vmax N-1 [pu]	BASE CASE	lin DZ GST5212@ BLH5212@ 1 220kV	lin DZ BLH5212@ HMO5222@ 1 220kV	lin DZ OOM3111@ AB23112@ 1 400kV	lin DZ HMO5222@ GSH7212@ 1 220kV
GST5212	ALGERIA DZ	220	0.932	1.068	0.900	1.100		-1.67%	-1.65%		
BLH5212	ALGERIA DZ	220	0.932	1.068	0.900	1.100			-1.69%		
OOM3111	ALGERIA DZ	400	0.950	1.050	0.950	1.050				1.14%	
MLN7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100	-4.47%	-6.52%	-6.52%	-1.27%	-5.69%
HBS7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100	-4.23%	-6.26%	-6.27%	-1.04%	-5.44%
ORD7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100	-3.98%	-5.98%	-5.99%		-5.16%
HBK7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100	-2.98%	-4.91%	-4.92%		-4.10%
GSH7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100		-1.29%	-1.33%		
BRN7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100	-4.84%	-6.92%	-6.93%	-1.64%	-6.09%
RHS7212	ALGERIA DZ	220	0.932	1.068	0.900	1.100		-4.35%	-4.39%		-4.01%

Table 7 – N and N-1 results on AC analysis for the Algerian system

bus	area	Vbase [kV]	Vmin N [pu]	Vmax N [pu]	Vmin N-1 [pu]	Vmax N-1 [pu]	BASE CASE	AClink DZ-TN XTAJEEAL@XTAJEEAL 220kV	lin TN XTAJEEAL@TAJEROUI@1 220kV	lin TN JENDOUBA@KEF @1 220kV	lin TN MAKNASSI@BOU SAID@1 220kV	lin TN MSAKEN2 @EL JEM @1 220kV	lin TN MSAKEN2 @ZAAFRANA@1 220kV	lin TN THYNA @TAPARURA@1 150kV	lin DZ EAO3212@XTAJEEAL@ 1 220kV	gen TN HAWARIA @IT
XTAJEEALO___	TUNISIA TN	220	0.950	1.095	0.918	1.127		-1.18%							-1.18%	
KAIROUAN	TUNISIA TN	220	0.950	1.095	0.918	1.127							-1.46%			
TAJEROUI	TUNISIA TN	220	0.950	1.095	0.918	1.127		-1.23%	-1.41%						-1.23%	-1.78%
MAKNASSI	TUNISIA TN	220	0.950	1.095	0.918	1.127					-4.65%					
C.KAIRON	TUNISIA TN	220	0.950	1.095	0.918	1.127	-1.07%						-1.65%			
HAJEB	TUNISIA TN	220	0.950	1.095	0.918	1.127					-1.18%					
KEF	TUNISIA TN	220	0.950	1.095	0.918	1.127				-1.15%						
EL JEM	TUNISIA TN	220	0.950	1.095	0.918	1.127						-2.95%				
ZAAFRANA	TUNISIA TN	220	0.950	1.095	0.918	1.127							-2.02%			
BIR CHAABANE	TUNISIA TN	220	0.950	1.095	0.918	1.127	-5.05%	-5.24%	-5.40%	-4.83%	-2.63%	-2.55%	-2.30%	-1.85%	-5.24%	-6.48%
FERIANA	TUNISIA TN	220	0.950	1.095	0.918	1.127	-5.07%	-5.24%	-5.41%	-4.84%	-2.65%	-2.57%	-2.32%	-1.87%	-5.25%	-6.49%
OUED EDDARAB	TUNISIA TN	220	0.950	1.095	0.918	1.127	-5.06%	-5.24%	-5.41%	-4.84%	-2.64%	-2.56%	-2.31%	-1.86%	-5.24%	-6.49%
FERIANA	TUNISIA TN	150	0.927	1.073	0.900	1.100	-8.70%	-7.19%	-7.25%	-7.05%	-6.97%	-6.41%	-6.21%	-6.06%	-7.19%	-7.76%
KASSERIN	TUNISIA TN	150	0.927	1.073	0.900	1.100	-10.74%	-9.31%	-9.37%	-9.16%	-9.07%	-8.48%	-8.27%	-8.11%	-9.31%	-9.90%
KEBILI	TUNISIA TN	150	0.927	1.073	0.900	1.100	-5.83%	-3.32%	-3.33%	-3.32%	-3.46%	-3.14%	-3.22%	-3.21%	-3.32%	-3.15%
MAKNASSY	TUNISIA TN	150	0.927	1.073	0.900	1.100	-4.73%	-2.68%	-2.71%	-2.62%	-6.34%	-2.48%	-2.38%	-2.34%	-2.68%	-2.47%
METLAOUI	TUNISIA TN	150	0.927	1.073	0.900	1.100	-10.10%	-7.76%	-7.77%	-7.71%	-7.69%	-7.56%	-7.49%	-7.45%	-7.76%	-7.94%
C.FERIAN	TUNISIA TN	150	0.927	1.073	0.900	1.100	-8.76%	-7.26%	-7.32%	-7.11%	-7.03%	-6.47%	-6.28%	-6.12%	-7.26%	-7.82%
S.BOUZID	TUNISIA TN	150	0.927	1.073	0.900	1.100	-9.68%	-7.89%	-7.93%	-7.81%	-10.45%	-7.40%	-7.31%	-7.24%	-7.89%	-7.78%
TOZEUR	TUNISIA TN	150	0.927	1.073	0.900	1.100	-11.78%	-9.32%	-9.33%	-9.29%	-9.28%	-9.19%	-9.15%	-9.12%	-9.32%	-9.43%
GAFSA	TUNISIA TN	150	0.927	1.073	0.900	1.100	-8.60%	-6.12%	-6.12%	-6.10%	-7.00%	-6.03%	-6.02%	-6.01%	-6.12%	-6.01%
TAPARURA	TUNISIA TN	150	0.927	1.073	0.900	1.100								-3.29%		
BIR HFAI	TUNISIA TN	150	0.927	1.073	0.900	1.100	-10.44%	-8.79%	-8.83%	-8.68%	-10.23%	-8.16%	-8.02%	-7.92%	-8.79%	-8.97%
NOYEL	TUNISIA TN	150	0.927	1.073	0.900	1.100	-3.81%	-1.35%	-1.35%	-1.35%	-1.50%	-1.12%	-1.21%	-1.20%	-1.35%	-1.13%
AL ITIZAZ	TUNISIA TN	150	0.927	1.073	0.900	1.100	-5.13%	-3.02%	-3.04%	-2.97%	-6.31%	-2.83%	-2.74%	-2.71%	-3.02%	-2.82%
BOUCHEMA400	TUNISIA TN	400	0.950	1.050	0.930	1.070	1.80%									
XBOUCSOSM___	TUNISIA TN	400	0.950	1.050	0.930	1.070	6.20%	4.07%	4.06%	4.08%	4.61%	4.02%	4.13%	4.10%	4.07%	4.25%
XBOUCSOSM2__	TUNISIA TN	400	0.950	1.050	0.930	1.070	6.20%	4.07%	4.06%	4.08%	4.61%	4.02%	4.13%	4.10%	4.07%	4.25%

Table 8 – N and N-1 results on AC analysis for the Tunisian system

Subvoltages presented in Table 7**Errore. L'origine riferimento non è stata trovata.** and Table 8**Errore. L'origine riferimento non è stata trovata.** are located at 220 kV and 150 kV levels, and are mainly due to the large amount of power transferred in some areas. One possible solution is to redispatch the generation and connect some of the generating units that are offline. In the case of Algeria, the unused reactive power capability available is close to 10000 MVAR, while in Tunisia that unused capability is over 2200 MVAR. Another possible solution is to install QV control devices, such as shunt capacitors. Next tables show the voltages problems found in the base case.

bus	area	Vbase [kV]	V [pu]	Vlim [pu]	V-Vlim [%]	dV/dQe [%/100MVAR]
MLN7212	Algeria DZ	220	0.887	0.932	-4.471	14.09
HBS7212	Algeria DZ	220	0.889	0.932	-4.234	12.89
ORD7212	Algeria DZ	220	0.892	0.932	-3.978	12.27
HBK7212	Algeria DZ	220	0.902	0.932	-2.983	9.96
BRN7212	Algeria DZ	220	0.883	0.932	-4.838	15.25

Table 9 – AC results on base case for the Algerian system, and reactive power sensitivities

bus	area	Vbase [kV]	V [pu]	Vlim [pu]	V-Vlim [%]	dV/dQe [%/100MVAR]
C.KAIRON	Tunisia TN	220	0.939	0.950	-1.073	6.83
BIR CHAABANE	Tunisia TN	220	0.899	0.950	-5.053	7.26
FERIANA	Tunisia TN	220	0.899	0.950	-5.065	7.28
OUED EDDARAB	Tunisia TN	220	0.899	0.950	-5.059	7.27
FERIANA	Tunisia TN	150	0.840	0.927	-8.696	8.33
KASSERIN	Tunisia TN	150	0.819	0.927	-10.744	21.90
KEBILI	Tunisia TN	150	0.868	0.927	-5.831	15.39
MAKNASSY	Tunisia TN	150	0.879	0.927	-4.731	8.50
METLAOUI	Tunisia TN	150	0.826	0.927	-10.105	6.10
C.FERIAN	Tunisia TN	150	0.839	0.927	-8.761	9.25
S.BOUZID	Tunisia TN	150	0.830	0.927	-9.677	17.67
TOZEUR	Tunisia TN	150	0.809	0.927	-11.781	12.90
GAFSA	Tunisia TN	150	0.841	0.927	-8.599	6.28
BIR HFAI	Tunisia TN	150	0.822	0.927	-10.436	18.90
NOYEL	Tunisia TN	150	0.889	0.927	-3.809	16.70
AL ITIZAZ	Tunisia TN	150	0.875	0.927	-5.128	9.45
BOUCHEMA400	Tunisia TN	400	1.068	1.050	1.802	1.94
XBOUCSOSM___	Tunisia TN	400	1.112	1.050	6.204	7.01
XBOUCSOSM2__	Tunisia TN	400	1.112	1.050	6.204	7.01

Table 10 – AC results on base case for the Tunisian system, and reactive power sensitivities

Table 9**Errore. L'origine riferimento non è stata trovata.** and Table 10**Errore. L'origine riferimento non è stata trovata.** also show first order sensitivities of bus voltages with respect to the injection of 100 MVAR at the same bus. All problems need less than 100 MVAR of reactive power to be solved locally. For example, the largest subvoltage in the Algerian system (bus BRN7212 220 kV, deviation -4.8%) presents a sensitivity of +15.3 %/100MVAR, which means that the deviation could be solved with only 32 MVAR of reactive power injected in that bus. In the case of Tunisia, the largest subvoltage (bus TOZEUR 150 kV, deviation -11.8%) presents a sensitivity of +12.9 %/100MVAR, which means that the deviation could be solved with only 92 MVAR of reactive power injected in that bus.

All these results indicate that an adequate redispatch and by connecting some offline units, voltages profile in both of the systems should be within limits.

5 Assessment of reinforcements

For this project, only the Tunisian system has defined a set of reinforcements to be analyzed. Between 400 kV substations of Hawaria and Mornaguia, two 400 kV lines are planned to be commissioned together with the first 600 MW of the project, each of them with double circuit configuration and almost 1000 MW of rate that can support the interconnection capacity (1200 MW) in N situations. However, if one of them is under outage, then the other becomes overloaded. To overcome this, the two lines Hawaria - Mornaguia are going to be considered as triple circuit configuration (i.e., consider impedance as 2/3 times the original and rate as 3/2 times the original). Reinforced Mornaguia - Hawaria link presents no overloads. In addition, a new 400 kV circuit between Mornaguia and Oueslatia (140 km) and three (3) 400 MVA 400/220 kV transformers at the Oueslatia substation have been also considered as reinforcements for the Tunisian network.

Next figure shows the map of the projected interconnection (yellow line), and corresponding reinforcements (green line).

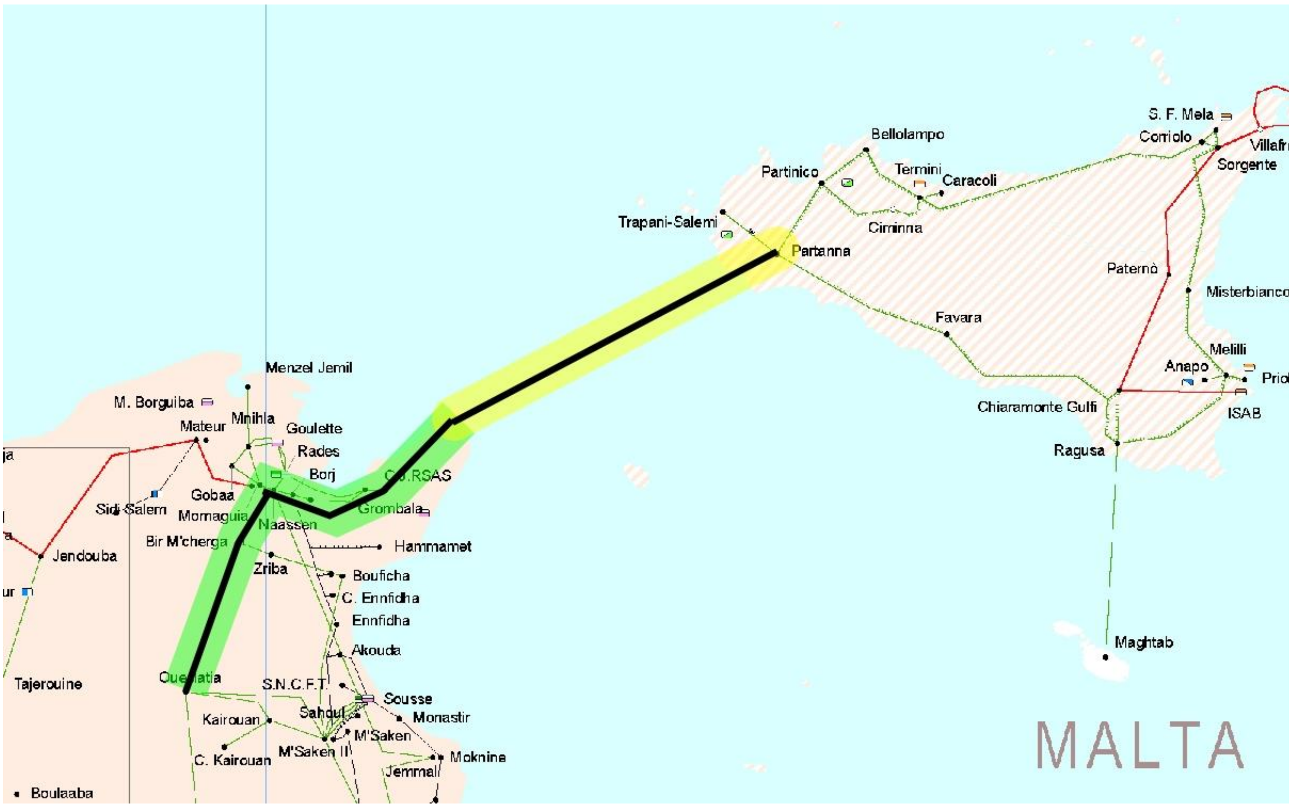


Figure 1 – Map of interconnections and reinforcements for project TNIT2

6 Estimation of Active Power Losses

Internal losses in each country

To evaluate the performance of the new interconnection projects plus the planned reinforcements, the active power losses have been computed for 1) the snapshots built with the specified reinforcements considered, and for 2) the snapshots without interconnection projects and without reinforcements. Next tables show the active power losses summary for each of the PiTs, Table 11 with the results for the Algerian system, Table 12 with the results for the Tunisian system and Table 13 with the results for the Italian system.

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
1	436.9	438.6	1.7
2	195.5	155.5	-40.0
3	313.0	314.4	1.3
4	211.9	215.4	3.5
5	301.4	302.8	1.4
6	407.5	406.9	-0.6
7	357.3	355.4	-1.9
8	218.7	253.1	34.3

Table 11 – Comparison of the active power losses for each snapshot, with and without interconnection projects and reinforcements, for the Algerian system

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
1	25.9	63.0	37.1
2	109.5	84.4	-25.2
3	33.1	81.6	48.5
4	53.0	91.3	38.2
5	57.9	92.4	34.5
6	64.1	97.4	33.3
7	106.9	137.4	30.5
8	68.6	75.5	6.8

Table 12 – Comparison of the active power losses for each snapshot, with and without interconnection projects and reinforcements, for the Tunisian system

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
1	504.8	418.7	-86.1
2	414.7	405.6	-9.1
3	371.9	392.9	21.1
4	604.5	524.2	-80.3
5	530.0	558.4	28.4
6	541.5	707.8	166.3
7	703.7	763.1	59.4
8	272.2	774.8	502.6

Table 13 – Comparison of the active power losses for each snapshot, with and without interconnection projects and reinforcements, for the Italian system

Considering the time percentile (hours of the year) that each PiT represents, internal active power losses with and without the new interconnection project computed for each PiT have been converted to annual energy losses for each one of the 4 scenarios.

Losses in the new HVDC interconnection

Based on the hourly time series of exchange among countries provided by Market studies for each one of the 4 scenarios, with and without the new interconnection project, yearly losses on the interconnection have also been computed.

Computation of the losses in the new HVDC interconnection has been carried out for the four scenarios S1 to S4 and 8760 hours of estimated flows through the interconnections. The following table summarizes the values used for this estimation exercise, considering 400 kV and 500 kV as potential nominal voltage for the projected link:

V (kV)	r_1 (Ω/100km)	A (MW/kA)	B (MW)	d (km)
400	1.10	1.5	3.4	200
500	0.57	2.2	5.0	

Table 14 – Parameters for the TNIT2 HVDC link loss estimation

The following table shows the annual losses estimate for the HVDC link and scenario:

Scenario	Annual Losses (GWh)	
	400 kV	500 kV
S1	207	180
S2	127	132
S3	256	209

S4	145	142

Table 15 – Annual losses estimate for the new TNIT2 HVDC link

7 Estimation of Investment Cost

The new HVDC link between Tunisia and Italy consists of 200 km of VSC bipolar undersea cable. Using 1.24 M€/km for the cost of the cables including installation, the estimate for the cable cost is 248 M€. The estimated cost for the two converters is 270 M€. Finally, the total investment cost in the new HVDC interconnection is 518 M€.

The election of the VSC technology over the LCC technology are listed below [4]:

- Active and reactive power can be controlled independently. The VSC is capable of generating leading or lagging reactive power, independently of the active power level. Each converter station can be used to provide voltage support to the local AC network while transmitting any level of active power, at no additional cost;
- If there is no transmission of active power, both converter stations operate as two independent static synchronous compensators (STATCOMs) to regulate local AC network voltages;
- The use of PWM with a switching frequency in the range of 1–2 kHz is sufficient to separate the fundamental voltage from the sidebands, and suppress the harmonic components around and beyond the switching frequency components. Harmonic filters are at higher frequencies and therefore have low size, losses and costs;
- Power flow can be reversed almost instantaneously without the need to reverse the DC voltage polarity (only DC current direction reverses).
- Good response to AC faults. The VSC converter actively controls the AC voltage/current, so the VSC-HVDC contribution to the AC fault current is limited to rated current or controlled to lower levels. The converter can remain in operation to provide voltage support to the AC networks during and after the AC disturbance;
- Black-start capability, which is the ability to start or restore power to a dead AC network (network without generation units). This feature eliminates the need for a startup generator in applications where space is critical or expensive, such as with offshore wind farms;
- VSC-HVDC can be configured to provide faster frequency or damping support to the AC networks through active power modulation;
- It is more suitable for paralleling on the DC side (developing multiterminal HVDC and DC grids) because of constant DC voltage polarity and better control.

The following tables provide an estimate for the investment cost for the internal reinforcements, and the Cost Benefit Analysis (CBA) carried out based on the results of EES and TC1 activities of the Mediterranean Project. It should be noted that this is an estimation of the cost based on the best practices in the region.

P6 - TNIT2 - Investment Cost								
New Interconnections								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**GTC Contribution**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW**		
New Interconnection TN-IT	HVDC Submarine Cable	TN-IT		200	248	600		Long-term
	HVDC Converter Station	TN	1		135			Long-term
	HVDC Converter Station	IT	1		135			Long-term
Total Cost of New Interconnections (M€ / %total)					**518**	**89%**		
Internal Reinforcements								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**Capacity**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW / MVA**		
OHL 400 kV		TN	140		56		Mornaguia-Oueslatia	
Bays for OHL 400 kV		TN	2		3		Mornaguia,Oueslatia	
AutoTransformer 400/225 KV-400 MVA		TN	1		3		Oueslatia	
Bay AutoTransformer 400 kV		TN	1		2		Oueslatia	
Bay AutoTransformer 225 kV		TN	1		1		Oueslatia	
Total Cost of Internal Reinforcements (M€ / %total)					**65**	**11%**		
Total Project Investment Cost					**583**			

Table 16 – Investment costs of the project TNIT2

Assessment results for the Cluster P6 - TNIT2														
non scenario	GTC increase direction 1 (MW)		600											
	GTC increase direction 2 (MW)		600											
scenario specific			MedTSO scenario											
			1			**2**			**3**			**4**		
			Ref, Scenario	with new project	Delta	Ref, Scenario	with new project	Delta	Ref, Scenario	with new project	Delta	Ref, Scenario	with new project	Delta
GTC / NTC (import)		TN	1400	2000	600	1400	2000	600	1400	2000	600	1400	2000	600
		ITn	11225	11825	600	11225	11825	600	11225	11825	600	11225	11825	600
		ITs												
Interconnection Rate (%)*		TN	15,5%	22,1%	6,6%	14,6%	20,9%	6,3%	13,5%	19,2%	5,8%	10,9%	15,5%	4,7%
		ITn	9,4%	9,9%	0,5%	9,5%	10,0%	0,5%	8,2%	8,6%	0,4%	7,9%	8,3%	0,4%
		ITs												
Benefit Indicators	B1-SEW	(M€/y)	69			46			130			63		
	B2-RES	(GWh/y)	200			300			1170			640		
	B3-CO_2	(kT/y)	1000			-250			400			-350		
	B4 - Losses	(M€/y)	**-13,4**			**-2,2**			**-13,0**			**-4,0**		
		(GWh/y)	-314			-53			-455			-86		
	B5a-SoS Adequacy	(MWh/y)	0			0			0			0		
	B5b-SoS System Stability													
Residual Impact Indicators	S1- Environmental Impact													
	S2-Social Impact													
	S3-Other Impact													
Costs	C1-Estimated Costs	(M€)	583											

* considering the GTC for 2030 , the Install generation for 2030 and the GTC for importation (the same criteria used in the ENTSO-E)

Rules for sign of Benefit Indicators

B1- Sew [M€/year] =	Positive when a project reduces the annual generation cost of the whole Power System
B2-RES integration [GWh/Year] =	Positive when a project reduces the amount of RES curtailment
B3-CO_2 [kt/Year] =	Negative when a project reduces the whole quantity of CO_2 emitted in one year
B4-Losses - [M€/Year] and [GWh/Year] =	Negative when a project reduces the annual energy lost in the Transmission Network
B5a-SoS [MWh/Year] =	Positive when a project reduces the risk of lack of supply

Assessment	Color code
negative impact	🟥
neutral impact	⬜
positive impact	🟩
Not Available/Not Available	▨
monetized	🟨

Table 17 – Results of the Cost Benefit Analysis for the TNIT2 project

8 References

1	Snapshots building process	Share point
2	Guide for setting up grid models for Network studies V 5.0	Share point
3	Network Analysis and Reinforcement Assessment	Share point
4	D. Jovcic and K. Ahmed, “Introduction to DC Grids,” in High-Voltage Direct-Current Transmission, John Wiley & Sons, Ltd, 2015, pp. 301–306.	Share point

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