Deliverable 2.1.2

Detailed Project Description

10 - TRIS Turkey - Israel

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.

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1 Introduction

The present document contains the studies on project TRIS, in the context of the Mediterranean Master Plan of Interconnections. Project TRIS consists of a new interconnection between Turkey and Israel (+2000 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 consists in one new interconnection between Turkey and Israel, to be realized through a submarine 2000 MW HVDC link. For this project, only the Turkish system has been considered as full represented by its transmission network model. Boundary systems, i.e. Greece, Bulgaria, Syria and Israel, are considered as external buses with loads to simulate energy interchanges.

Project *details*							
Description	***Substation (from)***	***Substation (to)***	***GTC contribution (MW)***	***Present status***	***Expected commissioning date***	***Evolution***	***Evolution driver***
New interconnection between Turkey and Israel (HVDC)	Turkey (TR) Mersini	Israel (IS) -	3000	Long-term project	Project under consideration		Develop a new corridor in the eastern Mediterranean

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

Full models	Boundaries
Turkey TR	Israel IS
	Greece GR
	Bulgaria BG
	Syria SY

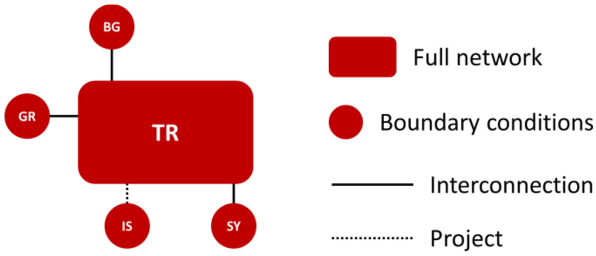

Table 1 – Participation of each of the systems involved in project TRIS

In the snapshots definition, 4 scenarios (S1, S2, S3 and S4) and seasonality (Winter/Summer) were distinguished, based on the distinctively different assumptions of future evolution considered in the Mediterranean project.

In data collection, a set of eight models were provided for the Turkish system, corresponding with 4 scenarios and seasonality (Winter/Summer). Full list of provided files is included in [1].

Technologies for generating units have been specified in all systems with respect to the generating technologies considered in the Mediterranean project, while all generating units of the same technology were considered with the same rank. In all models provided interconnected Areas were well identified.

Merging process consists of joining the different networks using the connecting buses defined in the next tables. Table 2 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. Finally, Table 3 presents the new interconnections associated to the TRIS project.

Bus	Area (from)	Substation	Area (to)
XNS_BA11	Turkey TR	Babaeski	Greece GR
XMI_HA11	Turkey TR	Hamitabat	Bulgaria BG
XMI_HA12	Turkey TR	Hamitabat	Bulgaria BG
XAL_BR11	Turkey TR	Birecik	Syria SY

Table 2 – Points of merging between systems and external buses in the TRIS project

Finally, Table 3 presents the new interconnection associated to the TRIS project, placed at bus XIS_ME11.

PROJECT	Bus	Area	Subs.	Bus	Area	Subs.	LINK
TREY	XIS_ME11	Turkey TR	Mersin	-	Israel IS	-	HVDC

Table 3 – Points of merging in the Projects in the TRIS project

3 Snapshots definition and building process

For the project TRIS, a total number of nine 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 TRIS project.

project TRIS PiT 1 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	33110.3	32516.0	14.0	608.4	0.0	-651.6	-1340.0	600.0	2000.0

project TRIS PiT 2 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	32857.4	29884.4	90.0	3063.0	0.0	463.0	0.0	600.0	2000.0

project TRIS PiT 3 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	26493.4	24397.8	106.0	2201.6	0.0	0.0	-398.4	600.0	2000.0

project TRIS PiT 4 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	63507.4	61323.3	123.0	2307.0	0.0	0.0	-293.0	600.0	2000.0

project TRIS PiT 5 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	34388.8	32589.5	100.0	1899.3	0.0	0.0	-700.7	600.0	2000.0

project TRIS PiT 6 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	81520.2	81023.2	103.0	600.0	0.0	-660.0	-1340.0	600.0	2000.0

project TRIS PiT 7 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	68369.5	66510.2	234.0	2093.3	0.0	-660.0	176.1	600.0	1977.2

project TRIS PiT 8 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	38703.8	37158.2	275.0	1820.7	0.0	-660.0	-119.3	600.0	2000.0

project TRIS PiT 9 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	IS
Turkey TR	81520.2	81023.2	103.0	600.0	0.0	-660.0	-1340.0	600.0	2000.0

Table 4 – Power balance for each of the PiTS defined in the TRIS project

In Table 4, the column 'Pextra', only non-zero for the Turkish system, represents extra energy that comes from Georgia, Iran and Iraq.

4 Power flow and security analysis

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

Turkey

For the Turkish system, the perimeter of the security analysis was limited in the bulk transmission level. Therefore, the branches considered for the N-1 analysis but also as the monitored elements were only those at 400 kV.

Concerning rates and tolerances, from the three different values identified in the models provided, i.e. rateA, rateB and rateC, for lines, rateB was considered for Summer and rate A for Winter, while rateC was not taken into consideration. The tolerance considered for overload was 0% for all branches in N situations, and +10% in N-1 situations.

Regarding the loss of generating units, the energy lost was compensated internally, using the rest of Turkish generating units.

Finally, a set of N-2 outages has been specified for the project TRIS. This set is formed by two different clusters of lines:

'Sinop NPP' set			'Akkuyu NPP' set		
bus FROM	bus TO	IC	bus FROM	bus TO	IC
TALTIN11 400,00	TSINPN11 400,00	1	TKONYA11 400,00	TAKKYN11 400,00	1
TKURSN11 400,00	TSINPN11 400,00	1	TKRMND11 400,00	TAKKYN11 400,00	1
TKURSN11 400,00	TSINOP11 400,00	1	TSEYDS11 400,00	TAKKYN11 400,00	1
TSINOP11 400,00	TSINPN11 400,00	1	TERMEN11 400,00	TAKKYN11 400,00	1
TKSTMN11 400,00	TSINPN11 400,00	1	TMERSN11 400,00	TAKKYN11 400,00	1
TBARTN11 400,00	TKSTMN11 400,00	1	TMNVGT11 400,00	TAKKYN11 400,00	1
TBARTN11 400,00	TSINPN11 400,00	1			

Table 5 – N-2 outages considered for the Turkish system in project TRIS

From each of the sets, N-2 considered the simultaneous outage of two lines.

5 Assessment of the reinforcements

Reinforcements that are required to secure operation of Turkish grid with the TRIS interconnection project could be listed in two categories: 1. upgrade of existing OHL and 2. addition of new OHL/addition of new connection point to existing OHL.

To increase transmission capacity of an existing 2-bundle OHL, existing route need to be replaced with 3-bundle Cardinal or Pheasant OHL. Parameters of 3-bundle Cardinal and Pheasant OHLs are listed in the table below. In this study 3-bundle Cardinal OHL used in simulation for upgrade of existing 2-bundle OHLs.

	Rs [pu/100km]	Xs [pu/100km]	Bp [pu/100km]	rateA [MVA]	rateB [MVA]	rateC [MVA]
3-bundle Cardinal OHL	0,001306	0,016625	0,69266	1589	1334	2178
3-bundle Pheasant OHL	0,000994	0,016437	0,703719	1921	1604	2610

Table 6 – Parameters of 3-bundle Pheasant OHLs for the project TRIS

With the TRIS interconnection project 400 kV Tosçelik- Bastug OHL - 2bundle Cardinal, 4 km is required to be upgraded to to 3-bundle Cardinal.

To reinforce Turkish grid in the vicinity of TRIS interconnection project’s connection point, a new 400kV OHL is required between Mersin- Adana (3bundle Pheasant, 80km).

Relevant overloads were resolved with selected reinforcements. Next figure shows the map of the planned interconnection (yellow line), and corresponding reinforcements (green line).

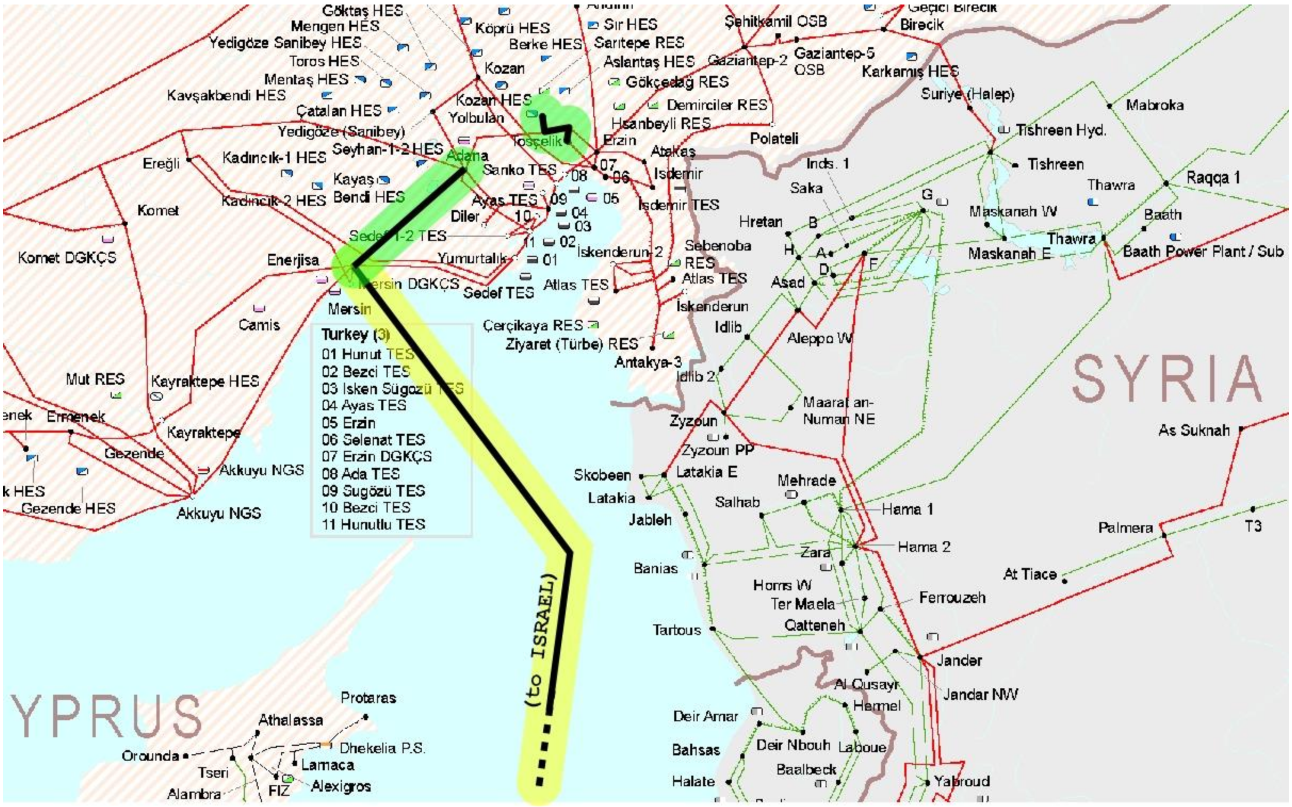

Figure 1 – Map of interconnections and reinforcements for project TRIS

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 table shows the active power losses summary for each of the PiTs.

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
1	212.3	262.5	50.2
2	342.5	351.9	9.3
3	276.0	299.3	23.3
4	1101.6	1060.5	-41.0
5	379.1	398.2	19.0
6	1534.9	1500.2	-34.7
7	844.4	814.1	-30.3
8	635.2	689.7	54.5
9	1198.3	1141.6	-56.7

Table 7– Comparison of the active power losses for each snapshot, with and without interconnection projects and reinforcements

Taking into account 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. The following table shows the annual internal delta losses estimate for the system of Turkey:

Scenario	Annual Internal Losses (MWh)
	TR

S1	81,432
S2	81,432
S3	81,432
S4	81,432

Table 8– Annual internal delta losses estimate for TR

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:

V_{nom} [kV]	r_l [Ω/100km]	A (MW/kA)	B (kW)	d (km)
500	0.600	2.2	3.1	700

Table 9 – Parameters for the losses estimation in the TRIS interconnections

The following table shows the annual losses estimate on the interconnection project for each scenario:

Scenario	Annual Losses on Interconnection (MWh)
	TR-IS
S1	622,483
S2	575,710
S3	483,343
S4	537,212

Table 10 – Annual losses estimate for the new TRIS interconnection

Both internal losses and losses on the interconnection were monetized for each scenario, taking into account the Annual Average Value of Marginal Cost, for the countries involved, as provided by the Market Studies. Results are presented in the following table:

Scenario	Annual cost of losses (M€)				Total Interconnection (M€)	Total System (M€)	Total (M€)
	TR			IS			
	Interconnection	System	Total	Interconnection			
S1	20.08	5.25	25.33	20.08	40.15	5.25	**45.40**
S2	24.63	6.97	31.59	24.63	49.25	6.97	**56.22**
S3	18.06	6.09	24.15	18.06	36.13	6.09	**42.22**
S4	24.19	7.33	31.52	24.19	48.38	7.33	**55.71**

Table 112 – Annual cost of losses estimate for the new TRIS interconnection

As a general remark, in addition to the losses on the HVDC interconnection the project results in a small increase also of the internal losses.

7 Estimation of Investment Cost

The new HVDC link between Turkey and Israel is expected to be implemented using VSC technology, which presents several advantages over the LCC technology that cannot be directly quantified but should be taken into account [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.

Based on the information on the interconnection project and the relevant internal reinforcements that were identified in the security analysis the total investment cost was estimated as presented in the following tables. As a general remark, internal reinforcements In Turkey associated with the project are rather shallow (close to the point of connection), representing a negligible part of the investment cost (0.03%).

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.

P10 - TRIS - 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 Turkey-Israel	HVDC Submarine Cable	TR-IS	-	600	1176	2000	S TR - E IS	Long-term
	HVDC Converter Station in Turkey	TR	1		281		S TR	Long-term
	HVDC Converter Station in Israel	IS	1		281		N IS	Long-term
Total Cost of New Interconnections (M€ / %total)					**1738**	**100.00%**		
Internal Reinforcements								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**Capacity**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW / MVA**		
Replacement of conductors AC OHL 400kV 2-bundle Tosçelik - Bastug	AC OHL 400kV - 3-bundle	TR	4	-	0.5	1589-2610	S TR	Long-term
Total Cost of Internal Reinforcements (M€ / %total)					**0.5**	**0.03%**		
Total Project Investment Cost					**1738**			

Table 12 – Investment costs of the project TRIS

Assessment results for the Cluster P10 - TRIS														
non scenario	GTC increase direction 1 (MW)		2000											
	GTC increase direction 2 (MW)		2000											
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)		TR	6200	8200	2000	6200	8200	2000	6200	8200	2000	6200	8200	2000
		IS	0	2000	2000	0	2000	2000	0	2000	2000	0	2000	2000
Interconnection Rate (%)*		TR	4.9%	6.5%	1.6%	4.9%	6.4%	1.6%	4.4%	5.8%	1.4%	4.1%	5.4%	1.3%
		IS	0.0%	10.9%	10.9%	0.0%	10.9%	10.9%	0.0%	10.9%	10.9%	0.0%	10.9%	10.9%
Benefit Indicators	B1-SEW	(M€/y)	630			270			360			240		
	B2-RES	(GWh/y)	0			0			0			0		
	B3-CO_2	(kT/y)	3200			1600			-1400			2000		
	B4 - Losses	(M€/y)	44.2			55.7			41.7			55.3		
		(GWh/y)	704			657			565			619		
	B5a-SoS Adequacy	(MWh/y)	0			0			500			20		
	B5b-SoS System Stability													
Residual Impact Indicators	S1- Environmental Impact													
	S2-Social Impact													
	S3-Other Impact													
Costs	C1-Estimated Costs	(M€)	1738											

* 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/Yea	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	red
neutral impact	light pink
positive impact	green
Not Available/Not Available	grey
monetized	yellow

Table 13 – Results of the Cost Benefit Analysis for the TRIS 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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