

PROSPECTS FOR 400 kV SUBMARINE INTERCONNECTION BETWEEN CROATIAN AND ITALIAN POWER SYSTEMS

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ABSTRACT

Croatian power system was located between two synchronous UCTE zones and subject to numerous power exchange programs expected after UCTE reconnection performed in October 2004. Due to neighbouring Italian system which is a large power importer, many players are very interested in regional electricity market. Consequently, steady state analysis is performed in order to evaluate prospects for transmission interconnection between Croatia and Italy. Study results presented in this paper give a clear picture of Croatian transmission system throughput with respect to this interconnection. Maximum possible power transits are evaluated. This case study is of utmost interest for different players as detailed evaluation of power supply from South - Eastern Europe was not reachable so far due to UCTE separation.

KEYWORDS

Interconnection lines, Croatian and Italian power system, steady state analysis, UCTE reconnection, power transit

1. INTRODUCTION

Till 1988 almost all power companies in the world were vertically integrated. Generation, transmission and distribution were simultaneously controlled from a state level. Generally, transmission control responsibility was divided between national dispatching centre (generation and transmission) and regional distribution centres (distribution). In vertically integrated utilities transmission system was planned and developed on the base of reliability and total generation evacuation requirements. Today, transmission systems are called to do much more. Power sector liberalization process has established new role of transmission network. They must serve dynamic and rapidly expanding markets with lots of variables. Newly liberalized market environment introduced significant raise of power exchange programs between different systems.

As many others, Croatian power sector is currently under process of restructuring. Along the way, several locally

specific features have appeared as a consequence of simultaneously integrated processes of restructuring and market opening. At the same time, reparation of wartime damages and major constructions in power systems are taking place. Reconnection of the 2nd synchronous UCTE zone to the main UCTE grid is also actual technical issue lately.

After 12 years of isolated operation and rebuilding of major infrastructure in Croatian and Bosnian transmission networks that has been seriously damaged by the war, additional 30,000 MW of peak load belonging to the 2nd UCTE synchronous zone is reconnected to the main UCTE grid. The role of Croatian transmission network is found to be very important in the UCTE reconnection process. It assumes two 400 kV reconnection points and five 220 kV ones. It certainly contributes to a necessity for conducting additional analysis of Croatian transmission network.

After reconnection of the 2nd UCTE synchronous zone to the main UCTE grid, position of Croatian transmission network is expected to change considerably. Before UCTE reconnection, Croatian transmission network is being at the border between two non-synchronized zones without any East↔West power transit possibilities. Upon reconnection, it will become a central part of South-Eastern European network with enormous expectations to satisfy various demands for power transits in these newly liberalized market conditions. Therefore, this paper presents prospects for direct interconnection between Croatian and Italian transmission network. Not only that this work presents new insight over conditions of Croatian transmission network, but it also points out necessity for precise definition of planning criteria in the region with respect to reliability and commerciality.

2. CROATIAN POWER SYSTEM SPECIFICS

Croatian population of 4.5 million dispersed on the ground of 56,538 km² consumed 15.5 TWh in 2003 with its peak load of 2673 MW. Total installed generating capacity is 4032 MW with 650 MW out of Croatian

borders as ex-Yugoslavian projects. Half of nuclear power plant Krško ($P_{total} = 676$ MW) located in Slovenia is considered as Croatian ownership. Hydro power plants capacity share is 43% of total generating capacity. Power import was covering 14% of total system demand in 2003. High level of import is determined by market possibilities. At the same time Croatian power system is built as self – sufficient and nominally, if there are no extreme unfavorable hydrological conditions, it is capable to cover its demands. Due to specific shape of the country, Croatian power system is extremely well connected to the neighboring power systems. Also, this is a consequence of unified transmission system development in ex Yugoslavia that considered all inter-federal lines as internal ones. Today, Croatian power system is sharing 7,465 MVA of total installed interconnection capacities. After total network recovering and UCTE reconnection it is increased to 13,487 MVA, as shown in Table 1.

Table 1 Thermally rated total installed interconnection capacities, *TIIC* (MVA)

Interconnection	TIIC (MVA); 2003	TIIC (MVA); 2005
CRO-HUN	1318	2636
CRO-B&H	1512	4898
CRO-SLO	4635	4635
CRO-S&MN	/	1318
TOTAL	7465	13487

Till 1998 Croatian power system was typical vertically integrated power system. In 1998 Energy development strategy was conducted and approved by the Parliament. Two years later, in 2000, energy sector restructuring concept was defined and set as a base for Energy law package that was conducted in 2001 when Croatian Energy Regulatory Council was established. Finally, in 2002 the process of Croatian Power Company (HEP) unbundling started with ISO model orientation. It means that overall structure of HEP-Group with its generation, transmission, distribution and supply daughter-companies remains under single organizational unit as vertically integrated company, while system and market operators are completely independent. In 2003 market was opened for customers with yearly energy consumption higher than 40 GWh. In November 2004 new energy law package was adopted by the Parliament. Secondary legislation is still to be done. New energy laws assume getting back of independent system operator inside vertically integrated company – HEP and independent market operator. Also, status of eligible customer is lowered to 16 GWh of annual consumption.

Relative slowness of restructuring process and market opening in Croatia was partly caused by objective reasons (wartime in 1990-ies, economy transition process, lack of know-how professionals) as well as by subjective ones (insufficient dedication of decision making personnel).

All these facts have a great influence on building electricity market conditions in Croatia which is highly

connected to status of new projects and foreign investments.

3. ITALIAN POWER SYSTEM SPECIFICS

Italian population of about 58 million consumed 310.4 TWh in 2003 with its peak load of 51,980 MW. Average consumption per capita is equal to 5,351 kWh/capita compared to Croatian average consumption of 3,288 kWh/capita. Total installed generating capacity in Italy is about 78,000 MW, but almost 30,000 MW is continually out of operation due to different reasons [1]. Energy import in 2003 was equal to 50.6 TWh or 16.3% of total demand. As a long peninsula, Italy also has a specific shape that disables more suitable interconnecting to the neighboring systems. Total installed interconnection capacity of Italian power system is equal to 6,300 MW plus 300 MW of available submarine cable capacity between Italy and Greece [1]. In last three years total installed interconnection capacity was growing at an average rate of 6.9%. Also, there exist a number of planned new interconnections that will be discussed later. But, at the same time the increase of significant import share is expected as shown in Table 2.

Table 2 Import share increase in Italian power system in the period 2001-2005 (%) [1]

Year	Import share increasing (%)
2001	4.6
2002	5.7
2003	6.6
2004	7.0
2005	9.8

If planned import share is compared to the realized ones presented in Figure 1 [2], it is obvious that Italian power system will face serious supply problems in near future.

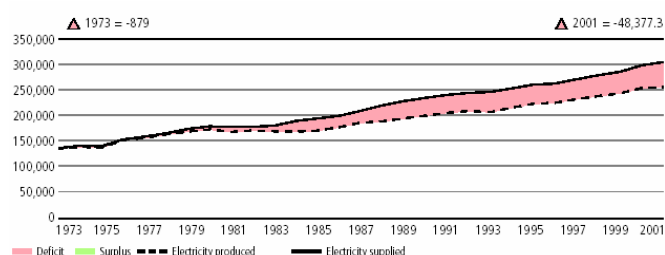


Figure 1 Power consumption, production and deficit (MWh) in Italian power system in the period 1973–2001

4. SUBMARINE CABLE BETWEEN CROATIA AND ITALY

Many solutions are offered to solve this unenviable position of Italian system operator and Italian consumers.

At the moment approximately 15,000 MW of new generating capacities are offered to system operator (GRTN) for approval [1]. Also, many new interconnection projects are nominated as shown in Table 3 and Figure 2.

Table 3 New interconnection candidate characteristics [1]

New interconnection from Italy to	Number of initiatives	Installed capacity (MVA)	Investment (M€)
France	3	1150	400
Swiss	14	5910	1479
Austria	14	2720	624
Slovenia	10	3278	576
Croatia	1	500	145
TOTAL	42	13558	3224

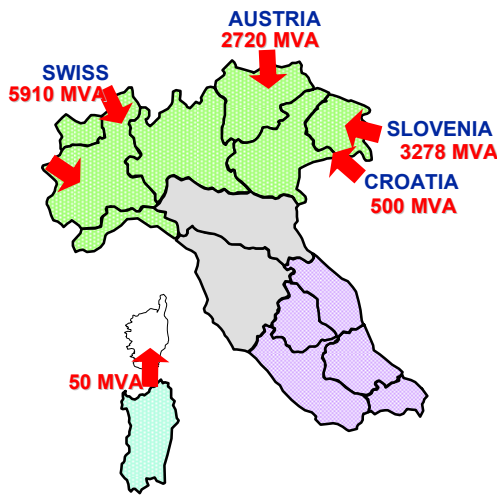


Figure 2 New interconnection candidate capacities in Italian power system [1]

Naturally, some of those projects are not likely to be realized soon because of different restrictions (environmental, procedural, financial etc). Even though not all projects are at the same stage, generally it shows large initial interest of all neighboring countries for construction of new interconnection lines. This interest is even more intensified after total blackout in Italy that happened on September 28, 2003 when almost 60 million people with consumption of 27,500 MW were cut off. At that time Italy was importing 24% of its total demand.

This paper presents study results obtained for nominated Croatian – Italian candidate line. Not going deeper into feasibility details or project finance, this study consists of preliminary technical steady-state analysis including evaluation of maximal possible transits through Croatian network for Italian import needs. There have been four studies performed in the Energy Institute Hrvoje Pozar, Zagreb in last four years that cover this issue [3, 4, 5, 6]. Figure 3 shows existing and potential 400 and 220 kV interconnection lines between Croatian and neighboring

systems as well as some other interconnections in the neighborhood. Dotted lines present candidate lines.

Obviously, there are two possible new 400 kV interconnections in Croatian power system: Ernestinovo (CRO) – Pecs (H) and Savudrija (CRO) – Planais (I). Before presenting study results it is necessary to announce that some significant topology changes should happen in Croatian network as a precondition for realization of submarine connection between Croatia and Italy. As shown in Figure 4 it is necessary to develop 400 kV network in western part of Croatia (Istria region). 400 kV network through Istria can be realized by interpolation into existing interconnection line Melina (CRO) – Divaca (CRO). Besides, it is necessary to build new 90 km of 400 kV line from interpolation point Klana to OHL/cable (or converter) station Savudrija.



Figure 3 Existing and possible interconnections in Croatian neighborhood

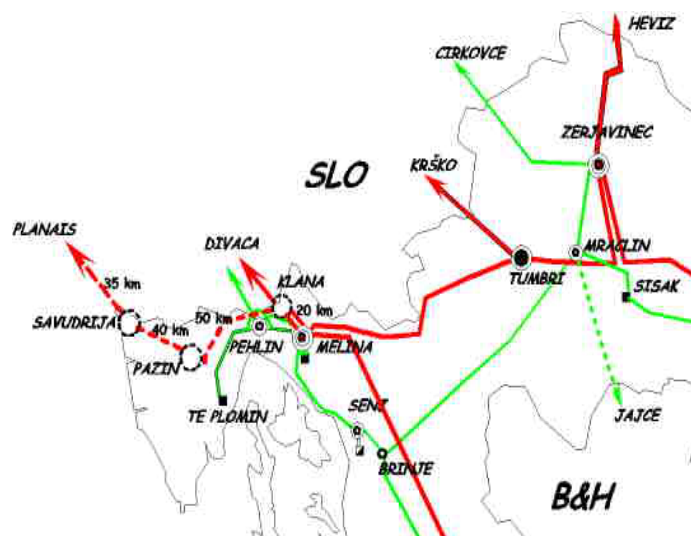


Figure 4 Necessary preconditions in Croatian transmission network that enable CRO-IT interconnection

Transformer station 400/110 kV Pazin is included in official long term development plans of Croatian power company. However, it is not a precondition for the interconnection. Submarine interconnection cable length is about 35 km. It can be realized as HVDC or regulated AC interconnection. Both solutions are analyzed and results are presented in next chapter.

5. STUDY RESULTS

Time horizon analyzed in this study was set to year 2005. Study was performed by using PTI PSS/E software package, version 29. European power system was modelled completely, from Portugal to Greece. Croatian transmission network is modelled at 400 kV, 220 kV and 110 kV levels, while the rest of the UCTE network is modelled at 400 kV and 220 kV levels (in Greece 150 kV also). Total power system model consists of 2,936 busses, 4,247 branches, 578 machines, 981 transformers and 1,452 loads. The western UCTE part (the 1st synchronous zone) is modelled according to official annual UCTE reports, while the model of the eastern one (the 2nd synchronous zone) is based on database defined in [7]. It is also assumed that all war damages in this region will be completely rebuilt and in operation [8].

Table 4 Exchange scenarios for 500 MW transit to Italy through regulated connection Savudrija – Planais

Transit 500 MW from	Hydrology in Croatia	Balance of Croatian power system
- *	Normal	Balanced**
- *	Normal	Import 600 MW from BH and SMN
- *	Normal	Import 800 MW from SK and D
- *	Extremely dry	Base case import 400 MW from SK and D
- *	Extremely dry	Additional import 600 MW from BH and SMN
- *	Extremely dry	Additional import 800 MW from SK and D
- *	Extremely wet	Balanced**
- *	Extremely wet	Export 500 MW from CRO to I
SK and D***	Normal	Balanced
SK and D***	Normal	Import 600 MW from BH and SMN
SK and D***	Normal	Import 800 MW from SK and D
SK and D***	Extremely dry	Base case import 400 MW from SK and D
SK and D***	Extremely dry	Additional import 600 MW from BH and SMN
SK and D***	Extremely dry	Additional import 800 MW from SK and D
SK and D***	Extremely wet	Balanced**
SK and D***	Extremely wet	Export 500 MW from CRO to I
Ukraine	Normal	Balanced
Ukraine	Normal	Import 600 MW from BH and SMN
Ukraine	Normal	Import 800 MW from SK and D
Ukraine	Extremely dry	Base case import 400 MW from SK and D
Ukraine	Extremely dry	Additional import 600 MW from BH and SMN

Ukraine	Extremely dry	Additional import 800 MW from SK and D
Ukraine	Extremely wet	Balanced**
Ukraine	Extremely wet	Export 500 MW from CRO to I
Bulgaria	Normal	Balanced
Bulgaria	Normal	Import 600 MW from BH and SMN
Bulgaria	Normal	Import 800 MW from SK and D
Bulgaria	Extremely dry	Base case import 400 MW from SK and D
Bulgaria	Extremely dry	Additional import 600 MW from BH and SMN
Bulgaria	Extremely dry	Additional import 800 MW from SK and D
Bulgaria	Extremely wet	Balanced**
Bulgaria	Extremely wet	Export 500 MW from CRO to I

* without interconnection Savudrija – Planais (initial system states)

** including NPP Krsko i HPP Dubrovnik (base case system balance -230 MW)

*** Slovakia and Germany (SK and D)

Study results for the year 2005 showed that the ($n-1$) security criterion becomes satisfied assuming all war damages being recovered [7]. In each system configuration only winter peak load is considered as the most indicative. Additional exchange scenarios East↔West are also included in the analysis [3]. Total number of analyzed scenarios is 56. The analysis is performed for Croatian power system scenarios presented in Table 4.

Initial active power exchanges are taken from official programmed exchange table of UCTE working subgroup for network models and forecast tools. Analysis is performed for two cases: 1) all network elements available and 2) $n-1$ network elements available.

This paper does not cover aspects of Var scheduling to facilitate the power wheeling through Croatian network because this project initially includes ideal total compensation at both cable ends. Also, feasibility aspects of the project such as reactive power compensation, dynamic analysis etc. should be analyzed in future project steps.

Interconnection line ending located in Croatian power system is practically supplied from a single point (Klana, Fig 4). This solution is not optimal but unfortunately in existing network there is no possibility for double supply points of the interconnection line to the internal network.

All study results and conclusions are conducted from Croatian power system viewpoint without considering any other power system point of view. Taking into account all preconditions mentioned above, it is found that:

- In all analyzed scenarios submarine cable is loaded with 500 MW from Croatia to Italy.
- In all analyzed scenarios with all elements in Croatian power system available there is no

overloading in Croatian network due to 500 MW transit to Italy.

- Considering only Croatian power system conditions (!) maximal possible transits (with all elements in Croatian power system available) is from 800 MW to 6,000 MW depending on direction.
- Considering only Croatian power system conditions (!) maximal possible transits from Slovakia and Germany to Italy (with n-1 elements in Croatian power system available) is from 300 MW to 2,400 MW depending on scenario.
- Considering only Croatian power system conditions (!) maximal possible transits from Ukraine to Italy (with n-1 elements in Croatian power system available) is from 400 MW to 1300 MW depending on scenario.
- Considering only Croatian power system conditions (!) maximal possible transits from Bulgaria to Italy (with n-1 elements in Croatian power system available) is from 300 MW to 1000 MW depending on scenario.
- In only three analyzed scenarios there is a limitation of 500 MW transit to Italy: two scenarios with extremely wet hydrology, 500 MW of export from Croatia to Italy and additional transit from Bulgaria/Ukraine to Italy are limited to 300 MW transit and one scenario of extremely dry hydrology with import of 400 MW from the north to Croatia simultaneously with transit Bulgaria – Italy is limited to 400 MW transit.
- Considering planned short-term investments in Croatian transmission system all restrictions mentioned above will be solved.
- Voltage profiles in Croatian power system in all analyzed scenarios are within allowed limits.
- This study presents preliminary static analysis, while dynamic simulations are not performed. Also, interconnection line influence on neighboring systems is not analyzed. Both aspects should be calculated in details in next project phase.
- Considering all study results it is obvious that Croatian transmission network can support 500 MW of transit to Italy from different directions with satisfied security criterion.
- All system scenarios assume significant power flow redirection from Croatia – Slovenia – Italy path to Croatia – Italy path. It is significantly reflected to Slovenian power system operation. Additionally, loop flow appears in some scenarios on the lines Klana (CRO) – Savudrija – Planais (I) – Redipuglia – Divača (SLO) – Klana. Loop flows are characteristic for high import from Slovakia and Germany.

6. CONCLUSIONS

This paper presents prospects of interconnections between Croatian and Italy and the fundamental corresponding power system facts. Calculation consists of steady state analysis performed in order to evaluate candidate interconnection line between Croatia and Italy. Study results presented in this paper give a clear picture of Croatian transmission system throughput for new interconnection and maximum possible power transits. All indicators show that Italian power system will face significant increase of import in near future. Accordingly, lot of market participants are deeply interested in regional electricity market. One of the candidate interconnection lines between Croatia and Italy is submarine cable Savudrija (CRO) – Planais (I). If Croatian and Italian system operator found it interesting, feasible and economic, realization of this interconnection would open a new importing direction for Italy, avoiding congested Slovenian network as well as on Northern and Western Italian borders. This paper attempts to report the outcomes of the power flow analysis of the proposed Croatian system with modification incorporating submarine cable link between Croatia and Italy, facilitating power exchange between Italy and South-Eastern European network, with Croatian system used for power wheeling.

Study results given in this paper present Croatian transmission system throughput for possible transits to Italy. 56 system scenarios were analyzed with respect to hydrology in Croatian power system, Croatian import/export and transits to Italy from North (Slovakia, Germany), East (Ukraine) and South-East (Bulgaria). General conclusion is that Croatian transmission system is capable to support 500 MW transit to Italy in all 56 analyzed scenarios if some short-term investments in Croatian transmission system are included. In other words, if submarine interconnection line is constantly loaded with 500 MW from Croatia to Italy, it would not cause any operational or security troubles in Croatian system within any of the analyzed scenarios. Detailed transit possibilities from North, East and South – East Europe through Croatian power system are given in Chapter 5. Additional contribution of this paper assumes analysis of synchronous UCTE operation (Europe as a whole) which includes around 3000 busses and more than 4000 branches from Portugal to Greece. This kind of operation is possible since November 2004 when regional system operators started with gradual allowance of power exchanges. Another contribution comprises analysis of all possible transit directions from Eastern and South-Eastern Europe to Italy. Projects of Greek-Italian and Spanish-Moroccan submarine interconnection help us a lot with its planning phase models and experience. Influence on neighbouring systems, loop flows, dynamic simulations and financial repercussions should be analyzed in the next project phases.

REFERENCES

[1] A. Seranni: "PROSPETTIVE DI POTENZIAMENTO DEI COLLEGAMENTI ELETTRICI TRA L'ITALIA E I PAESI CONFINANTI", Sinergy Conference 2003, Rimini, 5-8 November 2003

[2] GRTN Annual Report 2003, www.grtn.it

[3] G. Majstrovic, D.Bajs: "TRANSIT POSSIBILITIES THROUGH CROATIAN TRANSMISSION NETWORK IN SHORT AND MID-TERM PERIOD" Energy Institute Hrvoje Pozar, 2000

[4] G. Majstrovic, D. Bajs: "POSSIBILITIES FOR NEW CROATIAN INTERCONNECTIONS TO HUNGARY AND ITALY", Energy Institute Hrvoje Pozar, 2000

[5] D.Bajs, G. Majstrovic, M. Majstrovic, N. Dizdarevic "PRELIMINARY ANALYSIS OF CROATIAN TRANSMISSION SYSTEM THROUGHPUT FOR 500 MW OF DIRECT TRANSFER TO ITALY (SAVUDRIJA-PLANAIS)", Energy Institute Hrvoje Pozar, 2003

[6] D.Bajs, G. Majstrovic, N. Dizdarevic, M. Majstrovic "LOAD FLOW ANALYSIS OF MIDDLE ADRIATIC HVDC SUBMARINE CABLE LINK BETWEEN CROATIA AND ITALY", Energy Institute Hrvoje Pozar, 2004

[7] P. Miller, T. Cerepnalkovski, D. Bajs, G. Majstrovic, S. Mijailovic, M. Vukovic, P. Miksa, N. Gamov, N.Rusanov, "STUDY ON REGIONAL TRANSMISSION PLANNING PROJECT", *Study report commissioned by the Southeast European Cooperative Initiative (SECI) - Project Group on "Development of Interconnections of Electric Power Systems of SECI countries for better integration to European System"*, 2002

[8] "DEVELOPMENT OF CROATIAN POWER SYSTEM TILL 2030 – TRANSMISSION NETWORK, MASTERPLAN", Energy Institute Hrvoje Pozar, Zagreb, Croatia, 2001

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