21st International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

The Power Link Caribbean Project

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Abstract. The PWRLINKCAR (Power Link Caribbean) is a research project that has the aim of promoting the renewable energies in the Caribbean area. The use of a submarine cable is proposed for the union of the electric markets of Greater and Lesser Antilles. The goal of the project is to extend the renewable energies to the markets of the Caribbean Area by studying, designing, and modelling the interconnectivity of the markets. It is proposed the use of direct current in order to transmit the electricity energy power using HVDC (High Voltage Direct Current) and HVAC (High Voltage Alternating Current) through submarine cables. Regulatory provisions of the different markets are considered. Energy stocks and electricity price reduction are benefits expected by implementing the power link proposed in this work. Moreover, the power link can include optical cable for promoting telecommunications possibilities in the Caribbean area.

Key words. Power Link Caribbean, Renewable Energies, High Voltage Direct Current, High Voltage Alternating Current, Voltage Source Converter, Interconnectivity of Electricity Markets.

1. Introduction

Energy market interconnectivity is considered as an important factor when economies of scale, reduction of reserves, and more efficient operation of electrical systems, are considered [1]. Therefore, more optimal use of the natural resources of each country or region, as well as the strengthening of relations between the countries that participate in regional electricity markets are achieved.

Caribbean and South America regions have the right conditions for becoming a renewable energy hub with great potential [2]. Supply of energy to the region can be made from solar, wind, hydro, biomass, and tidal energy, among others.

This paper presents the PWRLINKCAR (Power Link Caribbean) project based on the interconnectivity of Caribbean and American Areas. The interconnectivity will provide robustness to the system when security, stability, and reduction of the reserves are considered.

The PWRLINKCAR project started at 2021 and will end at the end of 2023. It is led by researchers of Dominican Republic and includes researchers of South America and Europe.

The expected benefits of this project are focused on the fact that interconnectivity will add security and stability to the electricity system because access to energy is possible when a lack of generation is produced.

Regarding Dominican Republic, the following facts are pointed out:

- The present situation includes thermo-electrical centrals as well as renewable sources of energy. Dominican Republic can be considered as a potentially net exporter of energy.
- Due to the major robustness of the system that will be achieved, new legislation that will increase the actual generation percentage of renewable energies is expected.
- By joining the generation centrals to the projected link, straightening of the connectivity will be achieved.
- Investment attraction according to the market possibilities is expected.
- The use of the link for telecommunications can offer new possibilities because voice and data can be transmitted.

In this way, the project is performing the following objectives:

- To study the energy demand of the covered area.
- To analyze the potential of the Caribbean area when renewable energy is considered.
- To evaluate the technological possibilities AC or DC current concerning the energy to be transmitted and distances between points.
- To study the bathymetry of the Caribbean Sea.
- To analyze and study the different submarine cable possibilities according to the topology of each region and the market technology.
- To consider the telecommunication possibilities of embedding optical cable within the power link.
- To study and to analyze the different legislations of the covered area. The objective is to adapt the laws to a new framework with a unique electrical market.
- To promote the creation of a Caribbean Control Energy System for real-time control of the different operations concerning the interconnectivity of the link.

- To prove the economic and technical feasibility when interconnectivity between Caribbean and American countries is considered.
- To design the link according to the studies developed.

Next section presents some of the available technical solutions when submarine electric power is transmitted. Section 3 outlines the work carried out within the PWRLINKCAR project. Finally, section 4 presents the conclusion of this research.

2. Electrical Power and Submarine Interconnectivity

In this section it is shown and compared different submarine interconnections. Table I depicts three submarine interconnections and some of their features.

Table I. - Examples of submarine interconnections

HONSHU AND SHIKOKU ISLANDS (JAPAN)			
Name	Capacity	Voltage	Length
Kii Channel HVDC	1,200 MW	500 KV	50 Km
INTERCONECTION BETWEEN EEMSHAVEN (NETHERLAND) AND FEDA (NORWAY)			
Name	Capacity	Voltage	Length
NorNed	700 MW	450 KV	580 Km
INTERCONNECTION BETWEEN FLUME SANTO (SARDINIA) AND LATINA (ITALY)			
Name	Capacity	Voltage	Length
SAPEI	1,000 MW	500 KV	435 Km

The analysis of the submarine power cables shows that most of the submarine energy links use HVDC technology, with voltage values around 500 KV. Different distances, from teens of km to hundreds of km, are suitable. According to [3], most submarine power cables are placed in Europe, see Figure 1.

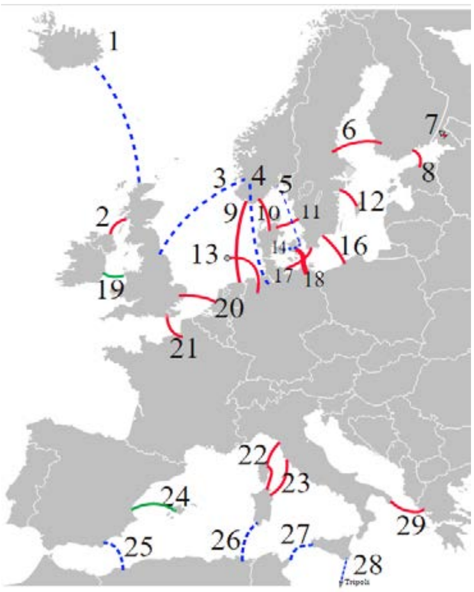

Fig. 1. Submarine HVDC links in Europe (red) Courtesy: J.JMesserly.

The islands that are near the continental coasts are appropriate for using HVDC submarine power cables [3]. For this reason, we consider that Greater and Lesser Antilles can be interconnected between them and with continental countries as Venezuela and Colombia by using such technology. Moreover, The PWRLINKCAR project also considers the submarine energy connection of the south of Florida with Cuba.

The submarine cable technology is based on previous studies developed for the interconnection between Dominican Republic and Puerto Rico [4]. From the studies done, the use of XLPE cables is proposed. XLPE is an abbreviation for cross-linked polyethylene and refers to a process where the molecular structure of polyethylene changes because of including additives. As result a material more robust when heated. Figure 2 shows an example of the HVDC cable used in submarine interconnections.

Fig. 2. HVDC submarine power cables.

We should also consider the need of AC (Altern Current) conversion when HVDC submarine cables are used. Therefore, CLC (Commuted Line Converter) and VSC (Voltage Source Converter) are technologies that can be used [3]. The advantages and disadvantages of each converter are pointed out in Table II.

Table II. - Advantages and disadvantages of CLC versus VSC

CLC Converters	
Advantages	Disadvantages
Less number of cables (lighter) Without distance limit Low electrical losses Easy Power Control High Power Transmission	Need of Strong AC lines Not suitable for isolated loads Polarity changes with the flux Need of large space Specific hardware (filters…)
VSC Converters	
Advantages	Disadvantages
Can feed isolated loads. Scalable solution Less space when compared with CLC No polarity changes with the flux Standard Hardware	High Losses during the conversion process Limited experience. Limited Power.

Smart Grid is proposed for controlling the Energy System. A Smart Grid is an electricity network that can

intelligently integrate the actions of all users connected to it - generators, consumers and those that do both-in order to efficiently deliver sustainable, economic, and secure electricity [5]. Connection to onshore AC power link can be done using VSC-HVDC (Voltage Sources Converter, High Voltage Direct Current). The design and implementation of a Multi-terminal VSC-HVDC has been tested on an experimental platform [6]. The research developed shows different operational points by considering intermittent power sources as offshore wind farms. The experimental platform has been tested under several conditions such as: normal operation, grid side converter disconnection and wind farm converter disconnection. Current Flow Controllers (CFCs) are proposed for managing line power flows and protection against DC faults. The integration of LCS (Load Commutation Switch) and Circuit Breakers for CFCs is proposed in [7].
Installation of submarine cable is an expensive challenge. The expected useful life of teens of years and difficulty to repair are also important issues to be considered. In this context, environment impact reduction and placement selection that take care of cable protection should be considered.
Figure 3 shows the process of installing submarine cable. Exist different private companies that have equipment and technology to perform the installation of submarine cable.

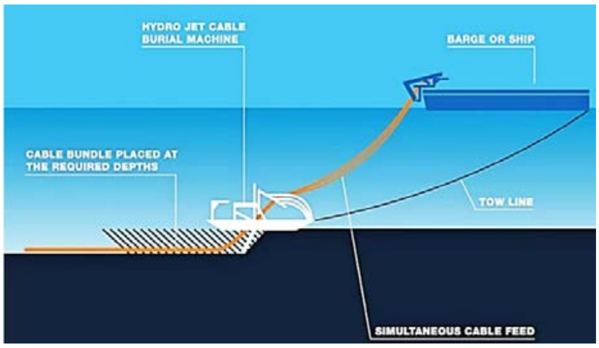

Fig. 3. The process of installing submarine cable
Courtesy: Electric Engineering Portal

Installation of submarine cable must consider the following aspects:

- Selection of a trajectory.
- Obtaining permits from the corresponding authorities
- Evaluation and study of the trajectory selected.
- Cable selection according to the trajectory selected.
- Cable placement that can be buried cable where it is required.
- Once cable is placed, a need of a later stage can be necessary.
- Notification to sea users concerning the submarine cable location must be done.

The depth of the sea plays and important role when installation of the cable is done on the trajectory selected. For shallow water divers can be employed while for deep water the use of VORs (Vehicle Operation Remote) are required.

3. The PWRLINKCAR Project

Firstly, power link interconnections of Greater and Lesser Antilles are depicted. Renewable energies, under the connected link, are also commented.

A. *Summary of the power link*

The estimated total length of the submarine power link has near 3,500Km. Depth has different maximum values, from 25m to 5000m. It means a cost with a strong dependence with the trajectory, the cost can be computed using [1]:

$$C = \sum_{i=1}^{NSEC} L_i \qquad [1]$$

Where C denotes the total submarine cost of the power link, and *Li* is the cost of each sector and can be computed using [2].

$$L_i(GC_i, GC_F) = \int_{GCI}^{GCF} (L_{inst}(d) + L_C(d))\Delta d_{GCN\ GCW} \qquad [2]$$

Where $L_i\,(GC_i, GC_E)$ shows the cost of each sector, and is referred by using initial and final *GC* (Geographical Coordinates). *Linst(d)* denotes the link cost of installing the cable, it is function of the depth *(d)*, while *Lc(d)* denotes the cost of the cable which is also function of the depth. The depth is related to global coordinate north (*GCN*), and global coordinate west (*GCW*). The minimization of the total cost is being investigated by researchers.
The link includes the following 22 countries: South of Florida (USA), Cuba, Jamaica, Haiti, Dominican Republic, Puerto Rico, Virgin Islands (USA), Virgin Islands (UK), Anguilla (UK), Saint Kitts, Antigua, Montserrat (UK), Guadalupe (France), Dominique, Martinique (France), Saint Lucie, Saint Vincent, Grenade, Barbados, Trinidad and Tobago, and Venezuela. The start and end of the link, are placed at continental zones (USA and Venezuela). Figure 4 depicts the complete link proposal.
Regarding the flexibility, the power link is reversible. Furthermore, it can be initiated at any point by interconnecting any country.

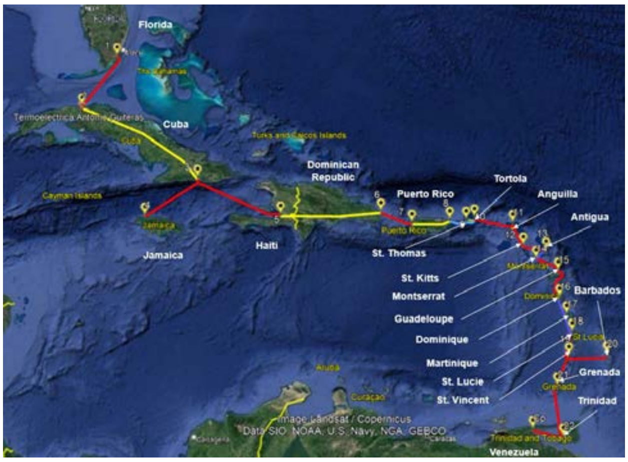

Fig. 4. The Power Link Project.

B. Power Energy Link and The Connecting Points

In this subsection, the technical features of the different connection points (CPs) are presented. The analysis is performed by considering Greater and Lesser Antilles. Table III and Table IV outline technical link issues.

Table III. - Power Energy Link at Greater Antilles

Florida Coast USA		
VSC at CP	Inland HVAC Voltage Length	Transformer
230 KVAC/ 230KVDC	230kV 0,6Km	NO
Cuba		
230KVDC/169KVAC		NO
169 KVAC/230KVDC	230kV 700Km	NO
Jamaica		
230KVDC/138KVAC	138kV 2,5Km	NO
Haiti		
230KVDC/115KVAC	345kV 250Km	115kV/345kV
Dominican Republic		
	With Punta Cana	
NO	138kV and 345kV 176Km	NO
345KVAC/230KVDC	Under-ground 345kVAC 5Km	345kV/230kV
Puerto Rico		
230KVDC/230KVAC	230kV 176Km	NO

Table IV. - Power Energy Link at Lesser Antilles

Puerto Rico		
VSC at CP	Inland HVAC Voltage Length	Transformer
230 kVAC/230kVDC	230kV 176Km	No
Virgin Islands (USA)		
No	No	230kV/69 kV
Virgin Islands (UK)		
230KVAC/230KVDC	69kV 1Km	230 kV/69kV
Anguilla		
230KVDC/230KVAC	13.8kV 0.75Km	230kV/13.8kV
Saint Kitts		
230KVDC/11KVAC	11kV 5km	230kV/11kV
Antigua		
230KVDC/60KVAC	No	230kV/60kV
Montserrat		
230VAC/230VDC	11kV 0.12Km	230kV/11kV
Guadeloupe		
230KVDC/63KVAC	63kV 3.2Km	230kV/11kV
Dominique		
230KVDC/11KVAC	11kV 0.24Km	11kV/230kV
Martinique		
230KVAC/63KVAC	63kV 1Km	230kV/63kV
Saint Lucie		
230KVAC/230KVDC	66kV 0.2Km	230kV/66kV
Saint Vincent		
230KVDC/66KVAC	66kV 2Km	230kV/66kV
Grenade		
230KVDC/66KVAC	66kV 0.4Km	230kV/66kV
Barbados CP with Saint Vincent 230KVDC		
230KVDC/66KVAC	66kV 2.0Km	230kV/66kV
Trinidad		
230KVDC/220KVAC	220kV 0.8Km	230kV/220kV
Venezuela		
230KVDC/230KVAC	230KV 20Km	No

The link has 500 MVA of power but the union of Cuba with Haiti has only 400 MVA. For submarine distances, of more than 100 Km, 230 KVDC link is proposed but when distances are less than 100 Km, HVAC link of 230 kV is planned.

VSC are used to adapt the different HVDC of the submarine link with the HVAC required. A transformer may be needed for HVAC links adaptation. HVAC frequencies are 60 Hz but Martinique, Saint Lucie, Saint Vincent, Barbados and Grenada use 50Hz.

The final cable location is under study. Bathymetry studies are developed using data source provided by GEBCO (General Bathymetric Chart of the Oceans) [8].

C. Renewable Energy at Caribbean Area

Renewable energies can be reinforced under an interconnected power link. In table V, actual and future percentage of renewable energies (RE) is shown when Greater Antilles are considered [9]. The renewable energy sources are: solar (S), hydropower (H) wind (W), and bioenergy (B).

Table V. - Renewable Energy at Greater Antilles

Cuba			
Actual Energy Consumption	Actual RE percentage	Future RE percentage and year of the target	RE sources
109TWh	2.4%	37% (2030)	S, H, W, and B
Jamaica			
43TWh	14%	20%(2030)	S, H, W, and B
Haiti			
13TWh	11%	47%(2030)	S, H, W, and B
Dominican Republic			
123TWh	17%	30%(2030)	S, H, W, and B
Puerto Rico			
82TWh	4%	40%(2025)	S, H, W, and B

Regarding future percentage of Cuba, by 2030, aims to increase the proportion of clean energy to 37% [10]. Cuba plans to install solar photovoltaic and solar water heaters on private homes, factories, and hospitals. Cuba also plans to install wind parks with 700 MW of capacity.

Jamaica target is to ensure 20% of energy comes from RE sources by 2030 [11].

Haiti faces significant challenges in generating and distributing energy reliably, and lack of access to affordable and reliable power [12]. Haiti has a weak electricity grid that means it can integrate RE into its energy supply.

The target of Dominican Republic is to be getting a 25% of its electricity from renewables in 2025, and 30% in 2030 [13]. Foreign investors are incentivized to build clean energy plants from renewables [13].

Puerto Rico has committed to meeting its electricity needs with 100% RE by 2050, along with realizing interim goals of 40% by 2025, 60% by 2040 [14].

Regarding Lesser Antilles, Table VI outlines actual and future percentage of RE [9]**.** The RE sources are: solar (S), hydropower (H) wind (W), bioenergy (B), and Geothermal (G).

Table VI. - Renewable Energy at Lesser Antilles

Virgin Islands (USA)			
Actual Energy Consumption	Actual RE percentage	Future RE percentage and year of the target	RE sources
0.7TWh	2.86%	60%(2025)	S, H, W, and B
Virgin Islands (UK)			
0.14TWh	0.1%	60%(2030)	S, H, W, and B
Angilla			
0.1TWh	0.2%	30%(2030)	S, H, W, and B
Saint Kitts			
022TWh	5%	50% (2030)	S, H, W, B, and G
Antigua and Barbuda			
0.35TWh	5.7%	100%(2030)	S, H, W, and B
Montserrat			
0.02TWh	3,5%	60%(2035)	S, H, W, and B
Guadaloupe			
1.8TWh	20%	40% (2030)	S, H, W, B, and G
Dominique			
0.8TWh	23.53%	90% (2030)	S, H, W, B, and G
Martinique			
9TWh	24%	40%(2030)	S, H, W, and B
Saint Lucie			
0.35TWh	0%	50% (2030)	S, H, W, B, and G
Saint Vicent and Grenadines			
0.9TWh	25%	60% (2025)	S, H, W, B, and G
Grenada			
0.21TWh	0%	100% (2030)	S, H, W, B, and G
Barbados			
1,07TWh	7,48%	100%(2030)	S, H, W, and B
Trinidad and Tobago			
8.73TWh	0.11%	30%(2030)	S, H, W, and B

Due to the small size of the countries belonging to Lesser Antilles, they are grouped as a Caribbean community that share similarity and challenges [15].

RE possibilities of Lesser Antilles is also studied by the International Renewable Energy Agency (IRENA). In this way, a conference named "A path to prosperity: Renewable Energy for Islands" was held at Martinique [16]. It was remarked the potential of Lesser Antilles when RE are considered.

When future percentage of RE is analysed, values from 100% to 23% are obtained. In this way, regarding for instance Grenada, the target of 100% RE at 2030 is proposed. Therefore, the public program includes the wind energy project at Carriacau and the Mt. St. Catherine geothermal project [17]. Other islands as Saint Lucie develop an important challenge that reduce the fossil fuel use by increasing RE. The challenge is accomplished by creating an innovative renewable energy analytics platform that include the partnership of the Government of Saint Lucia and the UK based Institute for Environmental Analytics. This partnership has been made possible by investment from the UK Space Agency's International Partnership Programme (IPP), and reflects Saint Lucia's position at the forefront of promoting clean growth [18].

When RE sources are analysed, the geothermal energy potential is remarked. Thus, there are 19 potentially active volcanoes in Lesser Antilles. However, despite Guadeloupe, geothermal development is still in early stages. The main reason is that the markets are small, and also because promoting laws and financial projects should be favoured.

4. Conclusions

Among the benefits derived from the interconnection of electricity markets, we can mention the following:

- Immediate generation of economies of scale.
- Reduction of reserves, in terms of auxiliary or peak stations and emergency stations.
- More efficient operation of electrical systems.
- Optimum use of the natural resources of each country.
- Greater exploitation, with integrity, security, and stability of the renewable resources of each one of the countries that participate in the interconnection of their markets.
- Greater flow of investment in clean energy.
- Financial support from multilateral financing banks, such as the World Bank and the Inter-American Development Bank.
- Increase in the number of quality technological jobs.
- Greater income of foreign currency for the countries, by concept of the commercialization of the energy in the different electrical markets.
- Possibility of future interconnection with already existing interconnected markets, such as the Electrical Interconnection System of Central American Countries (SIEPAC) and integration into its Regional Electrical Market (MER).
- Creation of new companies that would participate in the new regional market of the Caribbean.
- The installed electric power capacity between the countries and territories under study reaches the value of 100,359 MW.
- The total installed capacity of renewable energy sources is 15,663 MW.
- It has been possible to identify that there is a certain vocation to expand the use of renewable energy, given that it is projected at 3,929 MW.
- There is significant geothermal energy potential in Dominica (300 MW), Guadeloupe (70 MW), Saint Kitts and Nevis (50 MW – 300 MW), Saint Vincent and the Grenadines (Upper), and Saint Lucia (170 MW), for a total of 840 MW.
- Finally, it is important to point out that the projections for the expansion of renewable energies in each country and territory have been made considering island electrical systems, from the geographical and energy point of view. In a market interconnection

scenario, higher projections would be achieved due to the advantages that such interconnection entails.

Acknowledgement

This work has been cofounded by the Ministerio de Educación Superior and Tecnología (MESCYT) of Dominican Republic through their National Founds for Innovation and Scientific and Technological development and the UFHEC (Universidad Federico Henríquez y Carvajal) of Dominican Republic.

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