A Load Flow Study in European Super Grid Using High Voltage Alternating Current (HVAC), High Voltage Direct Current (HVDC) and Flexible AC Transmission System (FACTS)

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Abstract—The effective solution for the bulk power transmission to a larger distance is only possible with the utilization of the three technologies. Firstly, High Voltage Alternating Current (HVAC) which gives us fewer losses in order to cover larger distances. Secondly High Voltage Direct Current (HVDC) Voltage Source Convertor (VSC) which converts the AC Power into DC power and which provide better active and reactive power compensations during transmission of an electrical power to a large distance. Third one is the FACTS (Flexible AC Transmission system) which is actually the combination of series and shunt convertors and can provide better voltage and power stability, and allow the electrical power to be transmitted to a larger distance with fewer losses as compared to simple AC transmission lines. The main idea behind this research is the Load Flow model implementation of the future European super grid technology, using High Voltage Alternating Current (HVAC), High Voltage Direct Current (HVDC) using voltage source convertors (VSC), and FACTS (Flexible AC Transmission system), and then compare these models with one another in order to prove different facts which will lead us to the conclusion than instead of using Ultra-High Voltage AC we can used Ultra-High Voltage DC as an effective solution for bulk power transmission (Active Power) especially of Renewable energy for Covering larger distances. This Research work also Summarizes an overall picture of the European Super Grid Technology which will be completely implemented in a Practical way in 2050 and which will used these above technologies in order to provide a secure and sustainable Electrical Energy to different European Countries.

Index Terms— High Voltage Alternating Current (HVAC), High Voltage Direct Current (HVDC), Flexible AC Transmission System (FACTS), Unified Power Flow Controller (UPFC).

1 INTRODUCTION

European Countries have much to worry about, when it comes to the consumption of an Electrical Energy [1].

There is a need to reevaluate the design of current electrical power system in Europe in order to provide secure and sustainable supply of electrical power to European countries. Europe's growing demand on imported energy puts it in a difficult situation. Estimates suggest that, by 2025, 70% of Europe's energy will be imported, As Europe becomes more dependent on countries like Russia for gas resources. But the recent new project proposed by Irish renewable energy firm Airtricity offers a possible solution. This company planned a new renewable energy resource project (Super Grid), that takes electrical energy produced from an offshore wind resources and provide it to onshore load centers in different European countries. The Project offers potential benefits for all participants (at the moment, the UK, Germany and Holland). Such a super grid is likely to build using High Voltage Direct Current (HVDC) Voltage Source Convertor (VSC) technology, especially when considering that a significant part will be offshore [2].

As an increasing demand for electricity generation is growing day by day, so the best and reliable option is to generate electrical energy with renewable energy sources. Electrical Energy generated from renewable energy resources helps us to keep the environment clean and also provide benefit to their customers in terms of providing cheap electricity [3]. On basis of these facts, the European Super Grid is totally dependent on renewable energy resources i.e. Offshore Wind Turbines. These Offshore Wind Turbines are interconnected with the help of Super Node in the form of clusters.

As we know the fact that, wind turbines continuously need wind for generation of its electrical Energy .So, therefore Installation of a new renewable projects on land becomes scarce, as on land, the need i.e. wind for the continues generation of electrical energy from wind turbines is not always available. So, therefore the best scenario to generate electrical energy from wind turbines lies in offshore wind farms [4].

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As the planning stage of future European super grid is over 100 GW, so it is expected that this European super grid constitute a sixteen percent of renewable energy from all the renewable energy resources in the continent[5–7].

As the rating of wind turbine is increasing day by day, with (Seven and the half Mega Watt) units are already available, and (Ten Mega Watt) Units are also under development [8], so therefore it is estimated, that offshore wind farms installing capacity should be increased in the nearby future [9].

Different Studies about offshore wind farms realized the fact that multi-terminal DC grid network is the most effective and efficient method of connecting large amount of wind farms with one another [7-9]. Moreover, these Multi Terminal DC Grid Network will also increase the electricity market between different European countries [10].

However, before implementing this type of multi-terminal DC Grid network in order to implement the future European super grid, there must be some technical issues that should be keep in mind [11]. And the most important one is the choice of HVDC converter topology, i.e. which type of convertor topology is used for HVDC convertor station, so in order to maximize the overall efficiency of the system [12–15], The second one is the need of dc to dc converters [16-17], The third one is the need for protection schemes [18–23], Fourth one should be a dynamic stability issues in European super gird [21–23], and the final one will be Load flow Study strategies of MTDC Grid Network.

The focus of this research work is the Load flow Study Strategies that will help us to improvise the power flow or load flow in European Super Grid.

2 IMPLEMENTATION OF EUROPEAN SUPER GRID

2.1 Wind the European Energy Resource

The European Super Grid Concept is inherently based on the nature of wind. Offshore wind is the major European Energy Resource, wind is clean, i.e., the conversion of wind energy into electrical energy emits no CO_2 and other greenhouse gases, moreover once the construction of wind farm is completed, and it can go on producing electricity indefinitely [24].

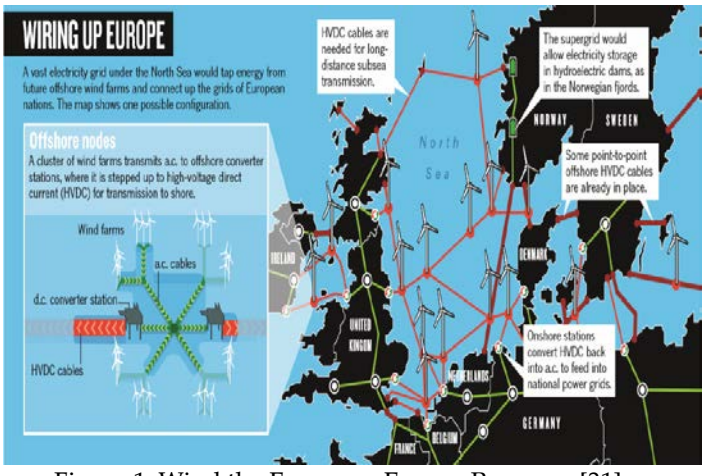

Figure.1. Wind the European Energy Resource [31]

2.2 Super Node Concept

The concept of super node is used in the European Super Grid Technology is basically for the continuity of electrical energy supply to their on-shore AC grid Station i.e. If there is a fault occurred in one part of the system, and its generation goes down, than with the help of a Super Node Concept, we can accommodate that part of the system without interrupting the Electrical Energy Supply.

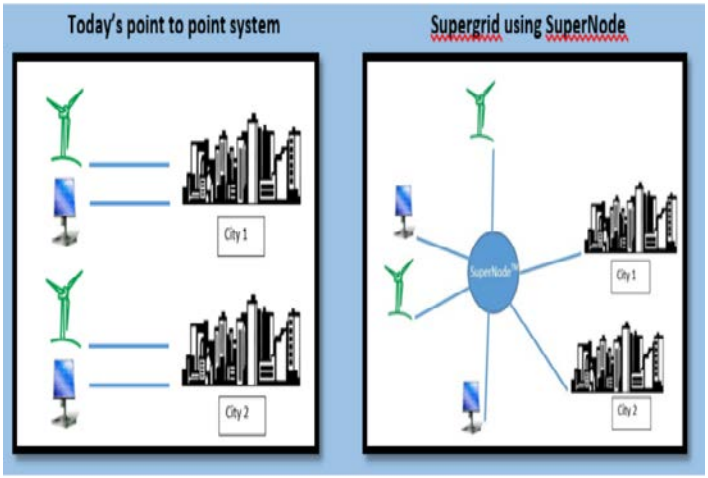

Figure.2. European Super Grid using the concept of Super Node [32]

3 TECHNOLOGY

Deregulation and privatization are posing new challenges to high voltage transmission lines. High-voltage Transmission Scenario, such as High Voltage Alternating Current (HVAC), High Voltage Direct Current (HVDC) and Flexible AC Transmission System (FACTS), provide the necessary features to avoid technical problems in heavily loaded power systems, thus increase the transmission capacity and system stability very efficiently and assist in preventing cascading disturbances [25]. The future European Super Grid is based on these three technologies, thus allowing the transport of electricity over very long distance, when and where it is needed.

3.1 Flexible AC Transmission System

A flexible alternating current transmission system (FACTS) is generally a power electronic based system that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability [26]. In this research work, I will be highlighting this idea by using one of the technology of Flexible Alternating current transmission system (FACTS) in order to implement the load flow Model of European Super Grid i.e. Unified Power Flow Controller (UPFC). Unified Power Flow Controller (UPFC) is more versatile flexible AC transmission system device ever applied to improve the power system operation and delivery. It can control various parameters, such as bus voltage and line flows.

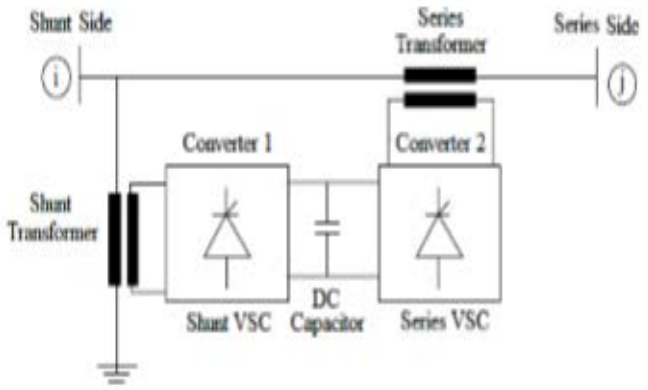

Figure.3. FACTS Technology (Unified Power Flow Controller) [33]

3.2 HVAC vs HVDC Technology based on (Break-Even Distance)

The table below compares the High Voltage Alternating Current (HVAC) & High voltage direct current (HVDC) Technology for implementing a Super grid. It is clearly observable from the below table that for covering larger distances, High voltage direct current (HVDC) Technology is more favorable as compared to High Voltage Alternating Current (HVAC) Technology due to following Reasons [27].

Table 1. Comparison of HVAC with HVDC

HVAC	HVDC
1) Inductive, Resistive and Capacitive Losses.	1) Only Resistive Losses.
2) Skin Effect.	2) No Skin Effect.
3) Frequency Issue.	3) No Frequency issue.
4) Not Suitable For longer distance Transmission.	4) Suitable For longer distance Transmission.
5) Suitable for Low Power Transmission.	5) Suitable for High Power Transmission.

The generation of electrical energy is always in AC form. Similarly, before providing it to the end user, it must be in AC form. The losses and costs incurred in the power transmission are proportional to the distance of transmission, i.e., they are relatively small for the small distance power transmission and increase with the increase in the distance required for the transmission. To overcome these loses (both electrical power and transmission line cost) the electrical power must be converted to DC and later back to AC. However, these converter stations have the cost of their own. Therefore, it is required to know the minimum transmission distance where the AC transmission is no longer feasible.

Figure.4. describes the break-even distance point where High voltage direct current (HVDC) is more favorable as compared to High Voltage Alternating Current (HVAC), graphically.

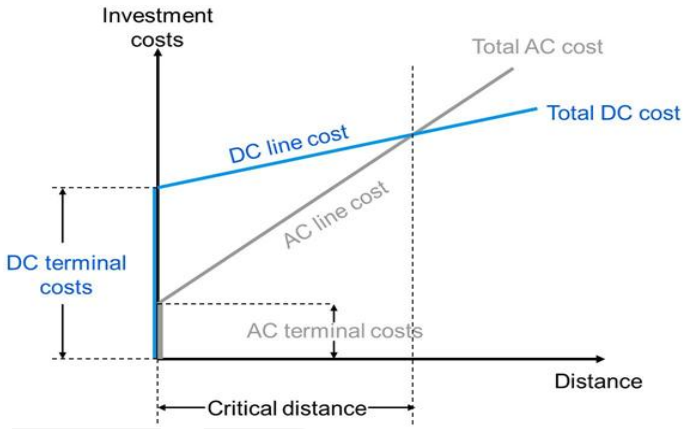

Figure.4. Comparison between HVDC and HVAC (over-head Transmission) [34]

In over-head transmission line this break-even distance is generally 400 km to 600 km, But the transmission system based on sub-marine cables (Super Grid), this break-even distance is much less than over-head transmission i.e. approximately 50 km. So therefore DC cable transmission system is suitable to connect distant energy sources (wind farms) to the network.

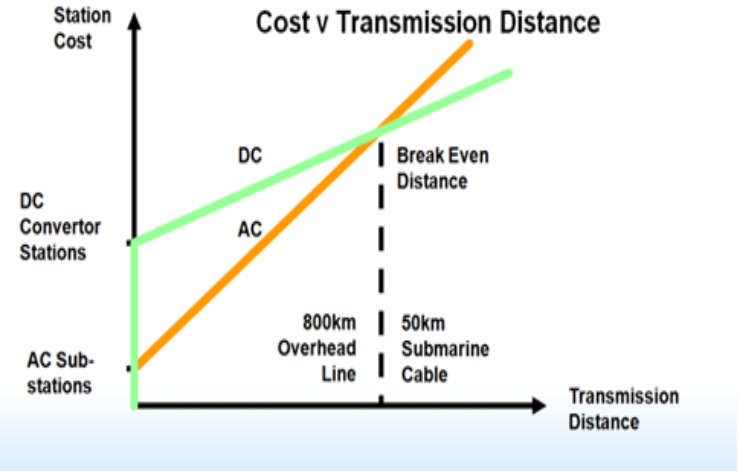

Figure.5. Comparison between HVDC and HVAC (Sub-Marine Cable Transmission) [35]

4 EUROPEAN SUPER GRID LOAD FLOW MODELS

4.1 European Super Grid HVAC Load Flow Model

As we discussed previous, that if the distance between offshore wind farms and On-Shore AC Grid station is less than approximately 50 km, than the best way to implement the European Super Grid is with the utilization of HVAC Technology.

The Figure Below shows the model of European Super Grid using HVAC Technology. This model includes three European Countries, Each Country Generating 1000 MW Offshore wind farm Energy and transmitting that power to their On-shore AC grid Station. Moreover these three European Countries have also connected with one another with the help of HVAC Inter-Connectors. These HVAC inter-Connectors will provide a secure and sustainable electrical energy to these three European countries i.e. if some amount of generation of one European country is lost due to some fault occurred in a system, than with the Utilization of HVAC Interconnectors, we can balanced the overall system in order to provide secure, sustainable and balanced form of electrical energy to each European country **[29].**

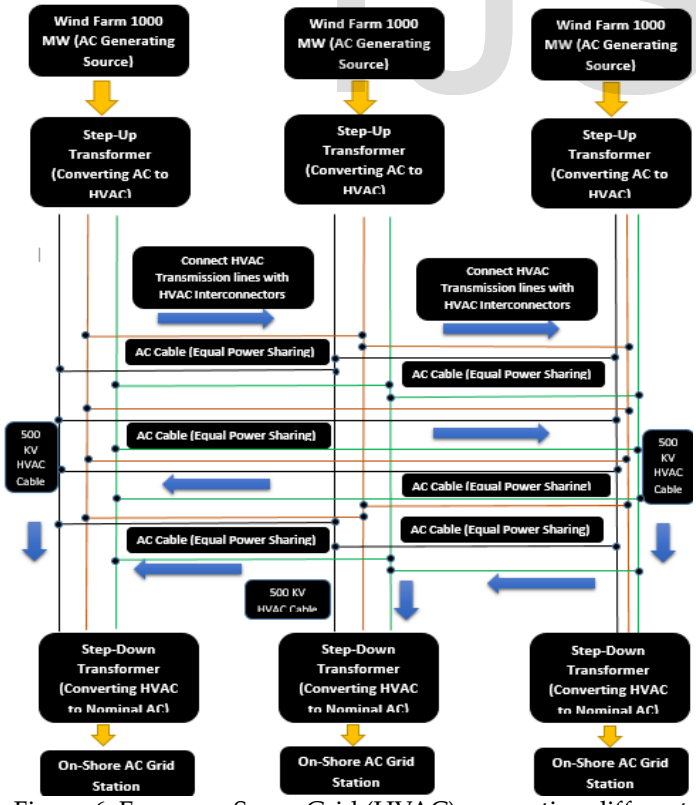

Figure.6. European Super Grid (HVAC) connecting different European Countries

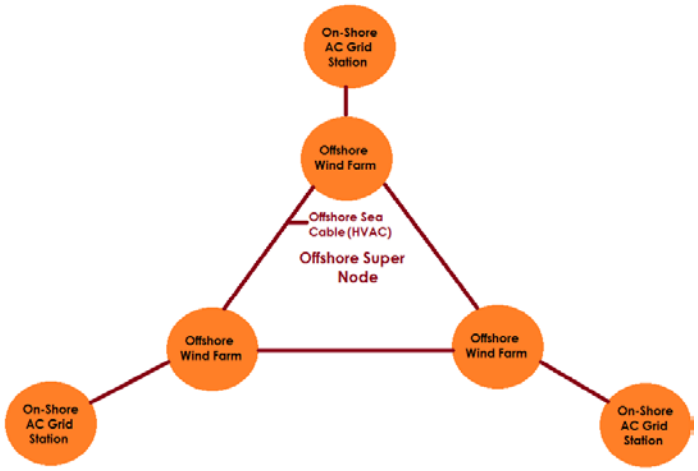

Figure.7. European Super Grid (HVAC) connecting different European Countries

4.2 European Super Grid HVAC Load Flow Model

The European Super Grid HVAC Load flow model as shown in above figures i.e. Figure.6 and Figure.7 is now constructed in MATLAB with assuming that, the distance between Offshore Wind Farm and On-Shore AC Grid Station is less than 50 Km.

We can also discussed different cases in MATLAB in order to analyze the fact, that how can we improvised the load flow i.e. Active power, While constructing the European Super Grid Using HVAC technology.

4.2.1 Each Wind Farm Generating 1000 MW (Case 01)

In Case No: 1, Each European Country has generating a power of 1000 MW from its offshore wind farms, and each European country has also have the capability of power sharing with the help of HVAC Interconnectors (Efficiency of Offshore Wind Farm in MATLAB is kept to be 90%).

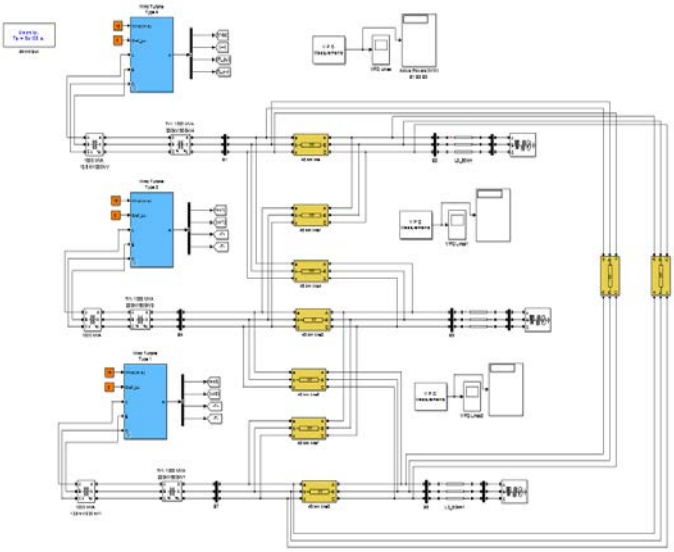

Figure.8. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01)

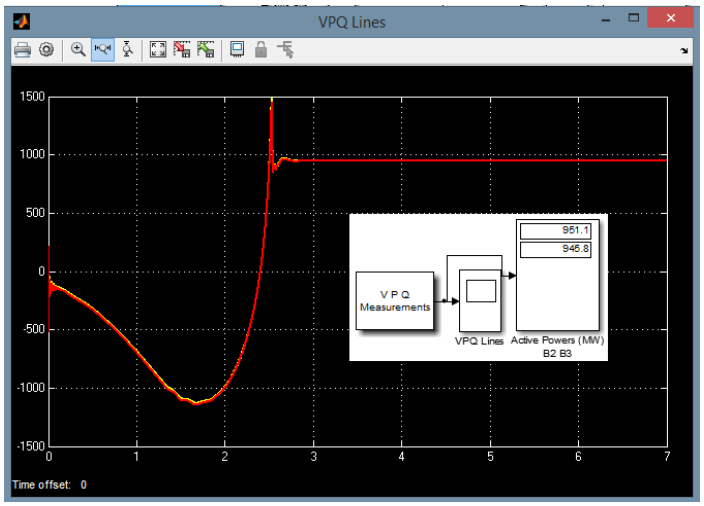

Figure.9. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01 Output Bus B2, B3)

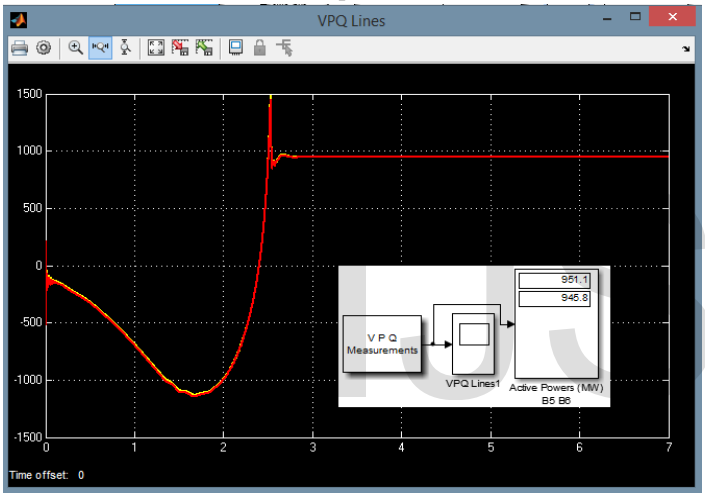

Figure.10. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01 Output Bus B5, B6)

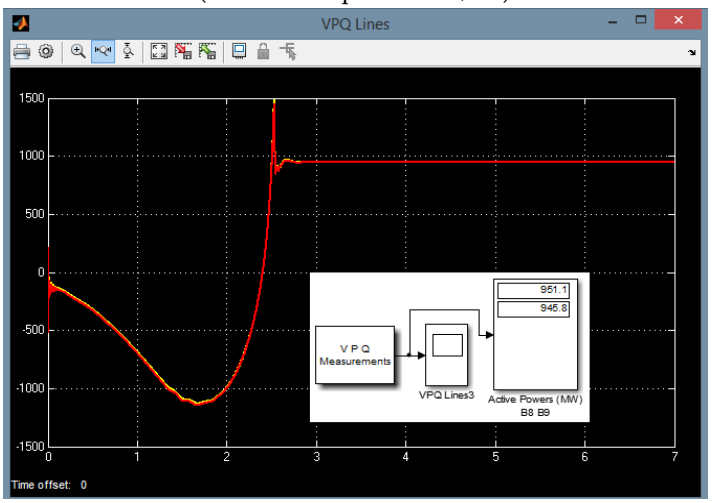

Figure.11. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01 Output Bus B8, B9)

4.2.2 One Wind Farm Generation drops to 800 MW (Case 02)

In Case No: 02, let's us consider, that one of the offshore wind farm generation drops to 800 MW due to some fault occurred in a system.

Now, due to well established inter connection between three European countries i.e. HVAC inter connectors, the power system i.e. (European Super grid) still generating a secure, sustainable and balances power or in other words we can say that, in spite of any generation fault occurred in a power system, the power system can still stabilized its self with the help of the interconnection between three European Countries.

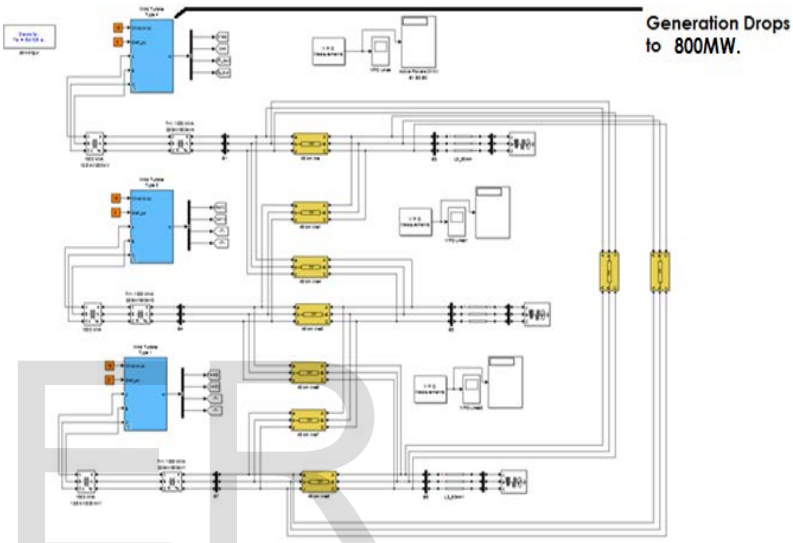

Figure.12. European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02)

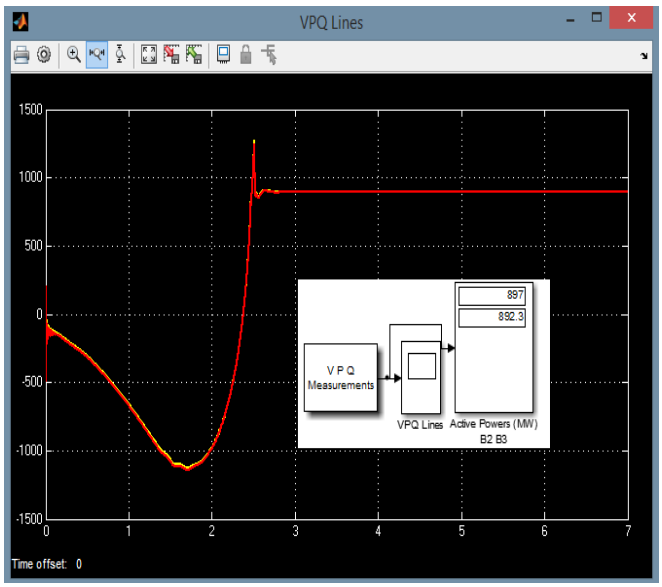

Figure.13. European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02 Output Bus B2, B3)

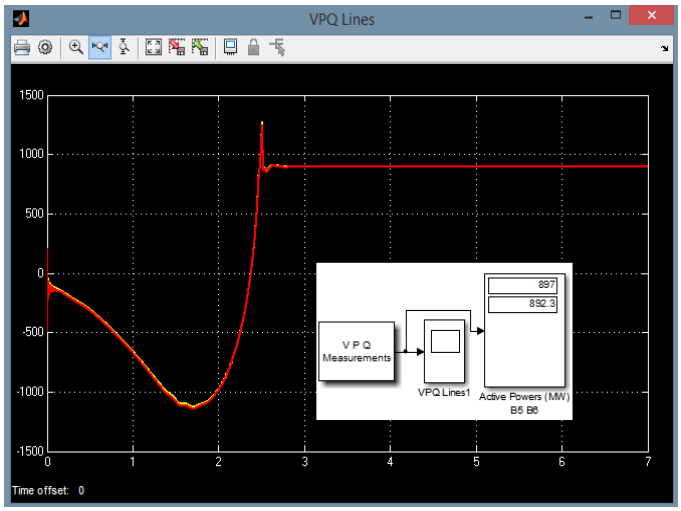

Figure.14. European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02 Output Bus B5, B6)

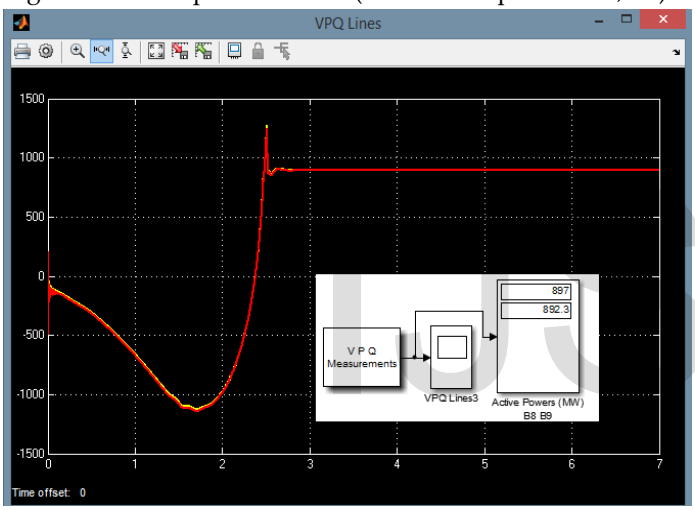

Figure.15. European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02 Output Bus B8, B9)

4.2.3 Two Wind Farm Generation drops to 800 MW (Case 03)

In Case No: 03, let's us consider, that Two of the offshore wind farm generation drops to 800 MW due to some fault occurred in a system.

Now, due to well established inter connection between three European countries i.e. HVAC inter connectors, the power system i.e. (European Super grid) still generating a secure, sustainable and balances power or in other words we can say that, in spite of any generation fault occurred in a power system, the power system can still stabilized its self with the help of the interconnection between three European Countries.

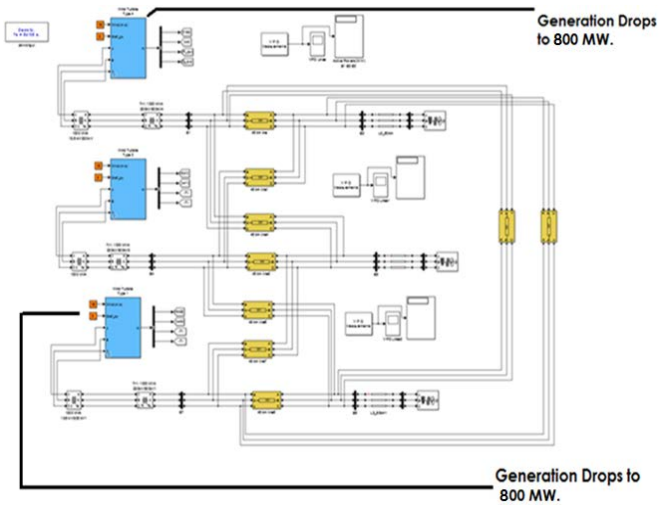

Figure.16. European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03)

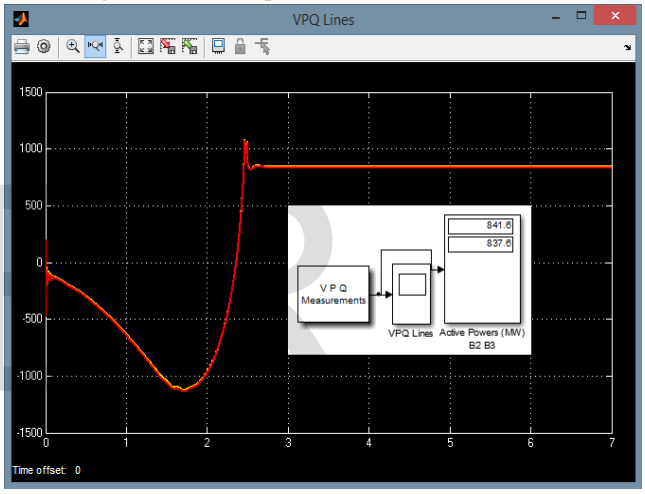

Figure.17. European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03 Output Bus B2, B3)

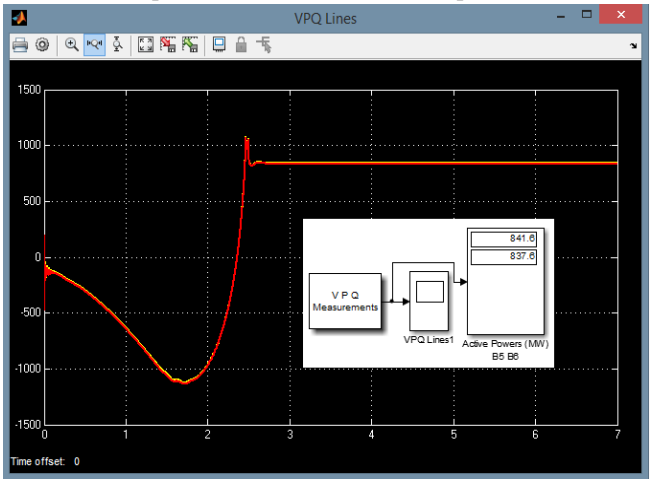

Figure.18. European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03 Output Bus B5, B6)

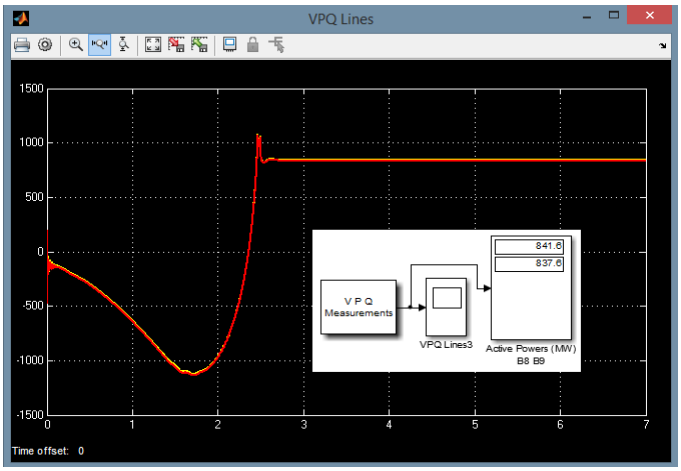

Figure.19. European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03 Output Bus B8, B9)

4.2.4 Three Wind Farm Generation drops to 800 MW (Case 04)

In Case No: 04, let's us consider, that Three of the offshore wind farm generation drops to 800 MW due to some fault occurred in a system.

Now, due to well established inter connection between three European countries i.e. HVAC inter connectors, the power system i.e. (European Super grid) still generating a secure, sustainable and balances power or in other words we can say that, in spite of any generation fault occurred in a power system, the power system can still stabilized its self with the help of the interconnection between three European Countries.

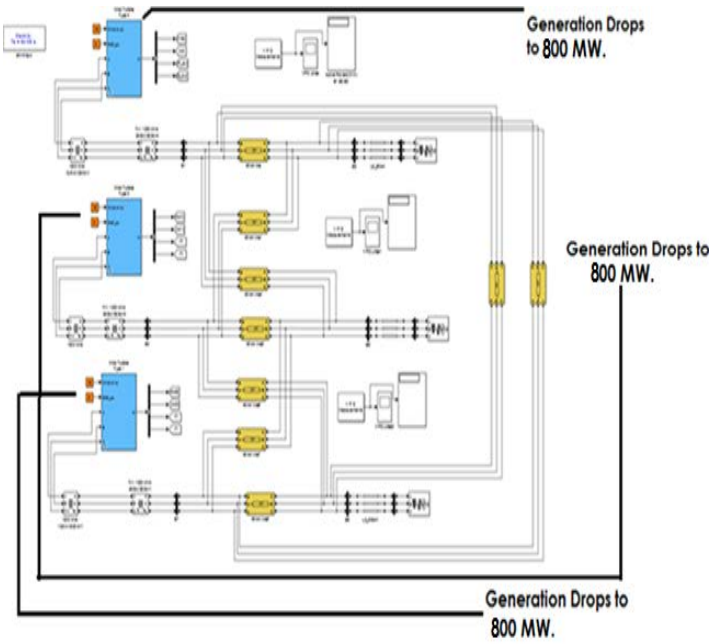

Figure.20. European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04)

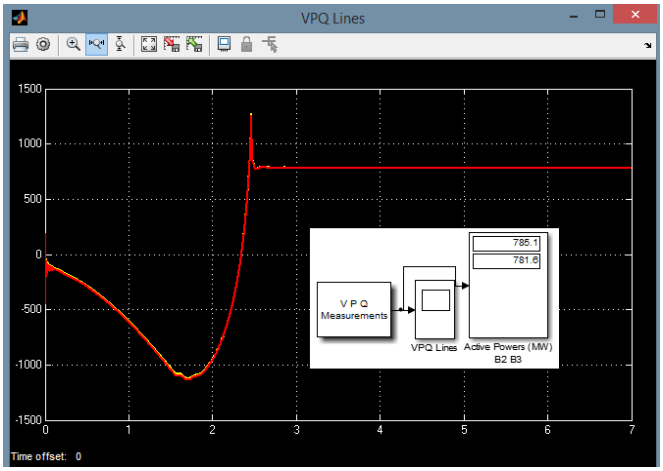

Figure.21. European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04 Output Bus B2, B3)

Figure.22. European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04 Output Bus B5, B6)

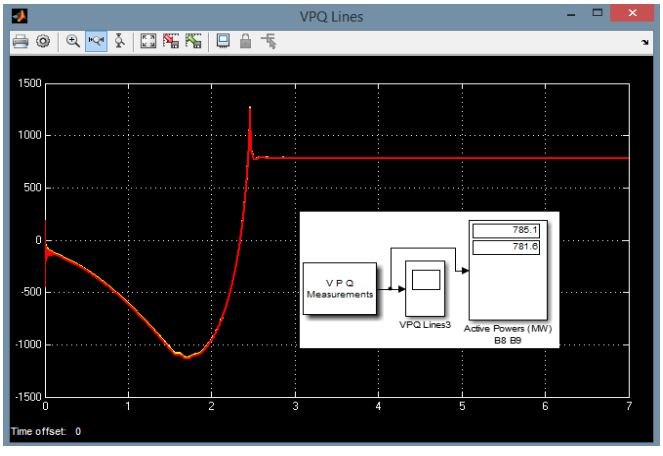

Figure.23. European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04 Output Bus B8, B9)

4.3 European Super Grid Optimized HVAC Load Flow Model

In Order to optimize the load flow model of European Super Grid using HVAC Technology, One Methodology is that, that we can also interconnect the on shore AC Grid stations of different European Countries with one another in order to optimize the Load flow on the Receiving side.

Same cases as we discussed above for European Super Grid using HVAC Technology can now discussed for Optimized European Super Grid using HVAC Technology, and then we can compare active power on a Bus at a Receiving side in all these cases in order to show that, that the optimized method will give us better result i.e. active power at the receiving side.

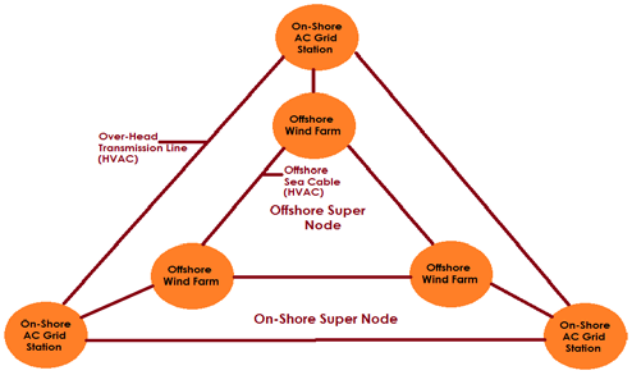

Figure.24. European Super Grid Optimized (HVAC) Model connecting Three European Countries

4.3.1 Each Wind Farm Generating 1000 MW (Case 01)

In Case No: 1, Each European Country has generating a power of 1000 MW from its offshore wind farms, and each European country has also have the capability of power sharing(Offshore as well as Onshore) with the help of HVAC Interconnectors (Efficiency of Offshore Wind Farm in MATLAB is kept to be 90%).

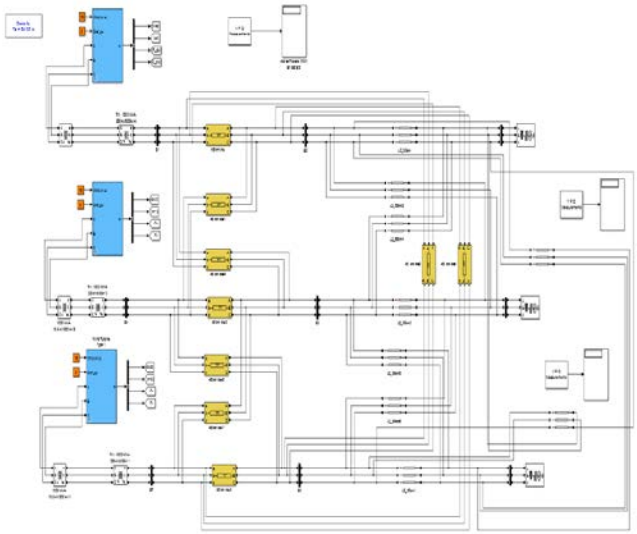

Figure.25. Optimized European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01)

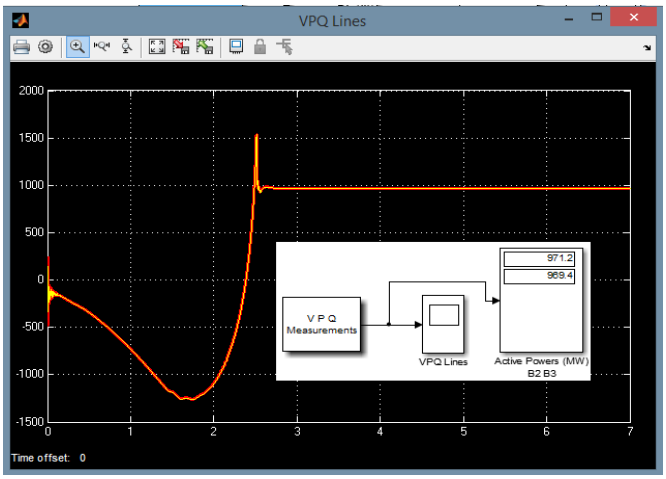

Figure.26. Optimized European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01 Output Bus B2, B3)

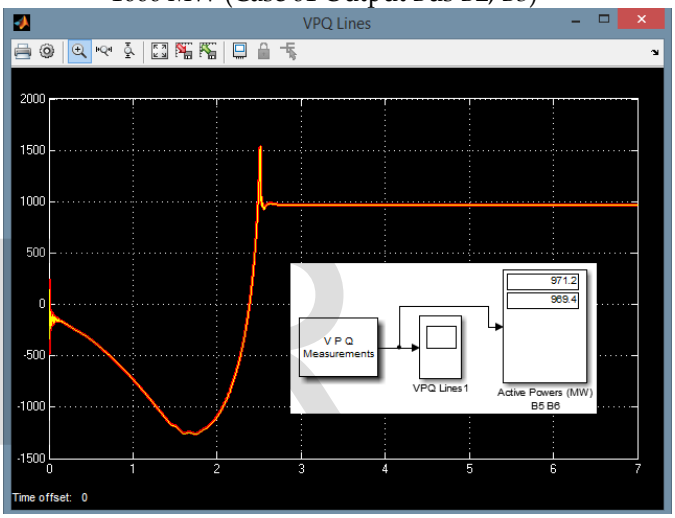

Figure.27. Optimized European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01 Output Bus B5, B6)

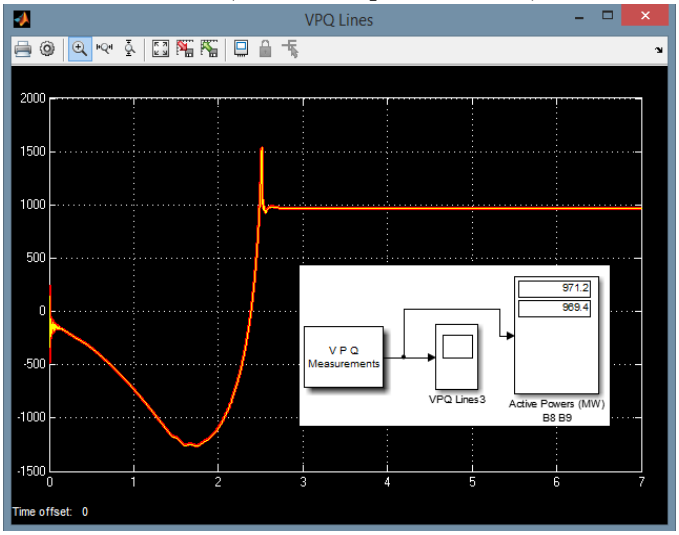

Figure.28. Optimized European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Case 01 Output Bus B8, B9)

4.3.2 One Wind Farm Generation drops to 800 MW (Case 02)

In Case No: 02, let's us consider, that one of the offshore wind farm generation drops to 800 MW due to some fault occurred in a system.

Now, due to well established inter connection between three European countries i.e. HVAC inter connectors (Offshore as well as On shore), the power system i.e. (European Super grid) still generating a secure, sustainable and balances power or in other words we can say that, in spite of any generation fault occurred in a power system, the power system can still stabilized its self with the help of the interconnection between three European Countries.

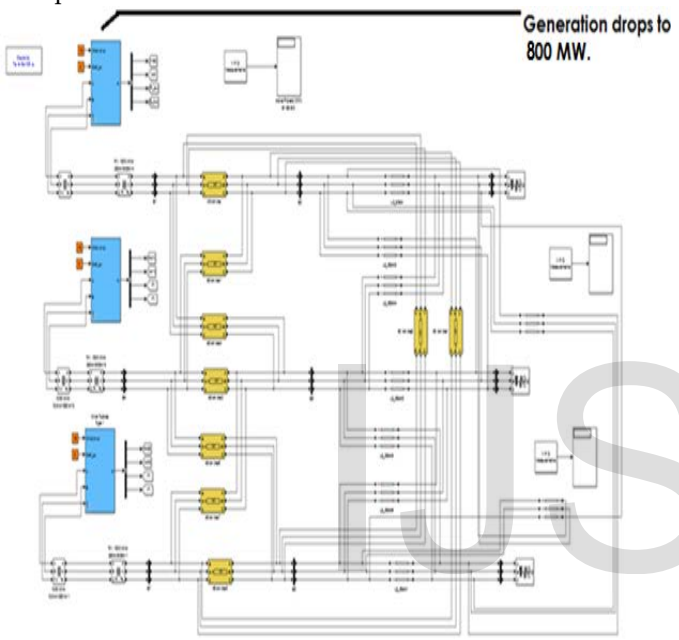

Figure.29. Optimized European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02)

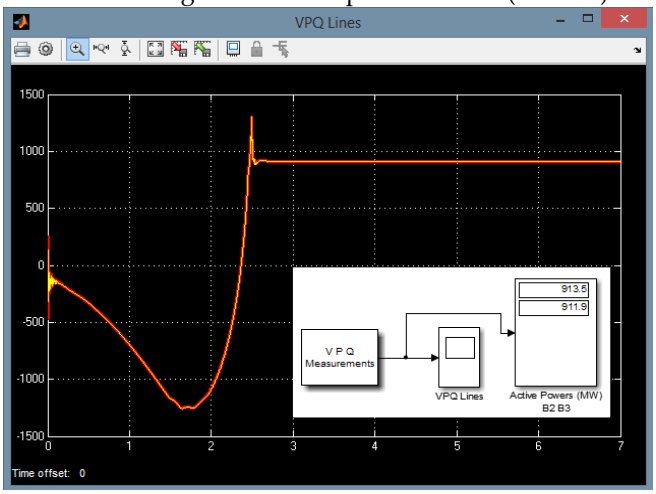

Figure.30. Optimized European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02 Output Bus B2, B3)

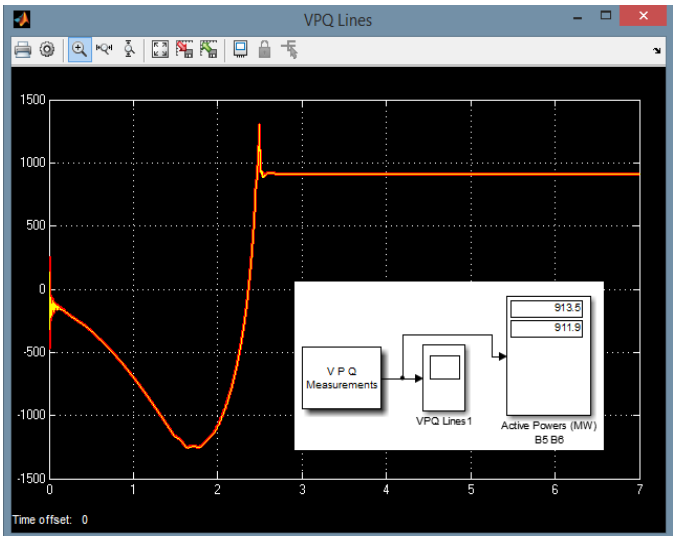

Figure.31. Optimized European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02 Output Bus B5, B6)

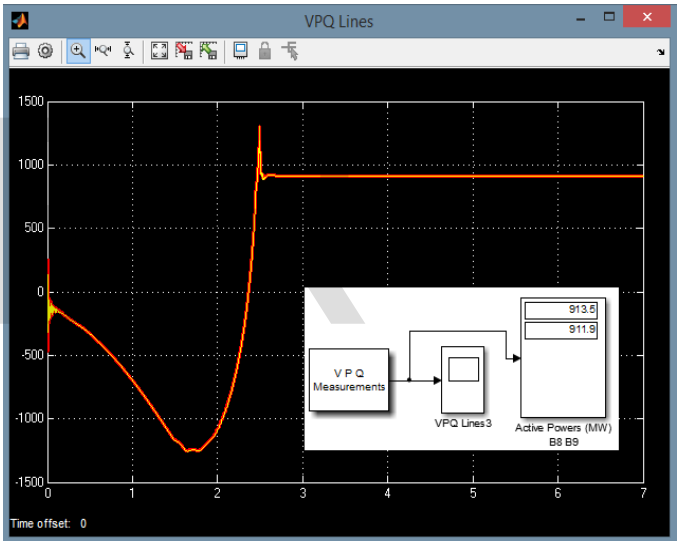

Figure.32. Optimized European Super Grid (HVAC) connecting Three European Countries with one European Country Wind Farm generation drops to 800 MW (Case 02 Output Bus B8, B9)

4.3.3 Two Wind Farm Generation drops to 800 MW (Case 03)

In Case No: 03, let's us consider, that Two of the offshore wind farm generation drops to 800 MW due to some fault occurred in a system.

Now, due to well established inter connection between three European countries i.e. HVAC inter connectors (Offshore as well as On shore), the power system i.e. (European Super grid) still generating a secure, sustainable and balances power or in other words we can say that, in spite of any generation fault occurred in a power system, the power system can still stabilized its self with the help of the interconnection between three European Countries.

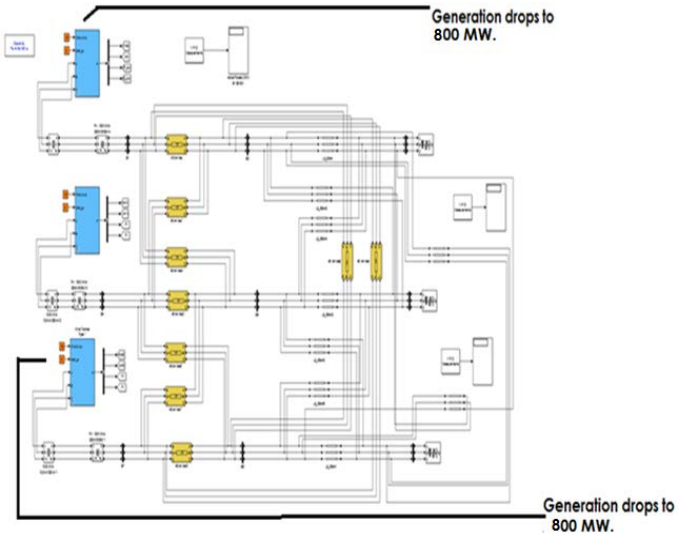

Figure.33. Optimized European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03)

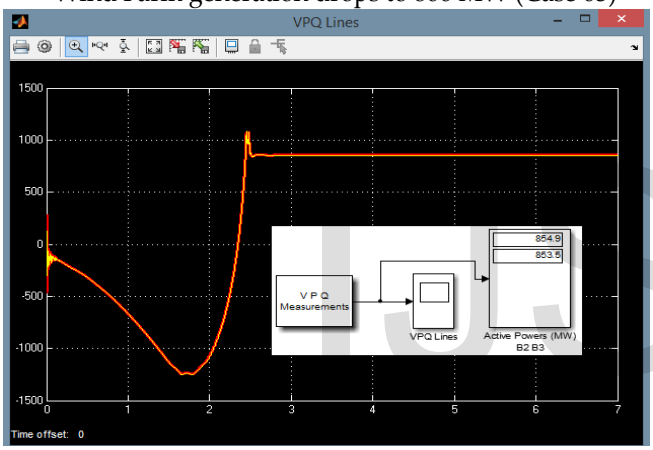

Figure.34. Optimized European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03 Output Bus B2, B3)

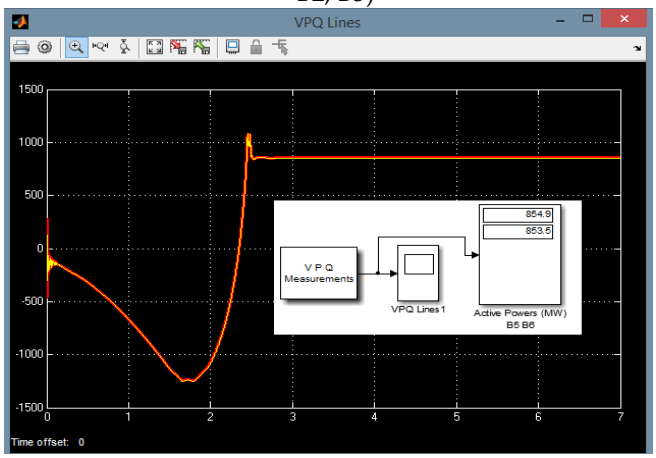

Figure.35. Optimized European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03 Output Bus B5, B6)

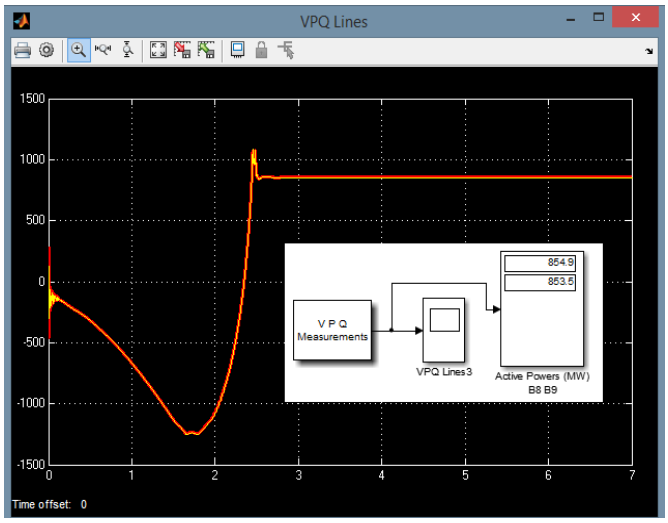

Figure.36. Optimized European Super Grid (HVAC) connecting Three European Countries with Two European Country Wind Farm generation drops to 800 MW (Case 03 Output Bus B8, B9)

4.3.4 Three Wind Farm Generation drops to 800 MW (Case 04)

In Case No: 04, let's us consider, that Three of the offshore wind farm generation drops to 800 MW due to some fault occurred in a system.

Now, due to well established inter connection between three European countries i.e. HVAC inter connectors (Offshore as well as On shore), the power system i.e. (European Super grid) still generating a secure, sustainable and balances power or in other words we can say that, in spite of any generation fault occurred in a power system, the power system can still stabilized its self with the help of the interconnection between three European Countries.

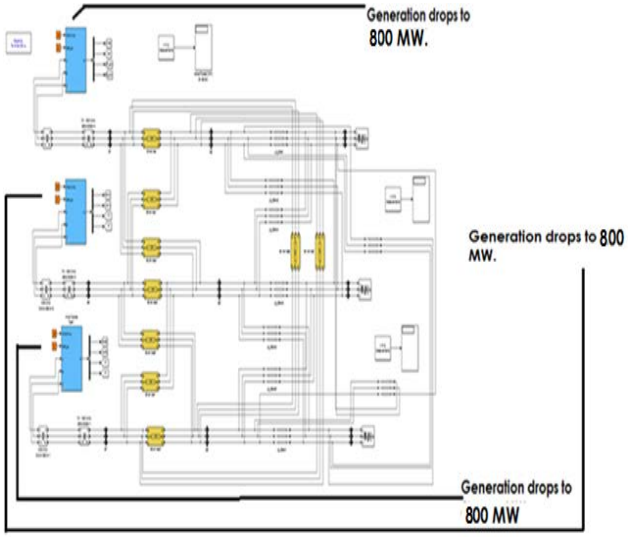

Figure.37. Optimized European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04)

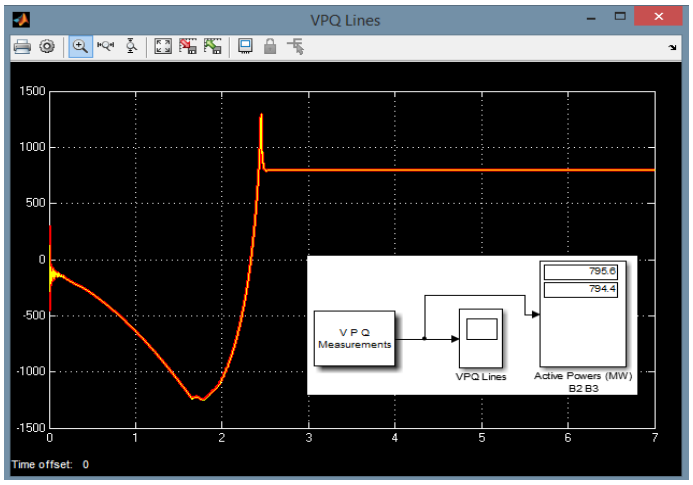

Figure.38. Optimized European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04 Output Bus B2, B3)

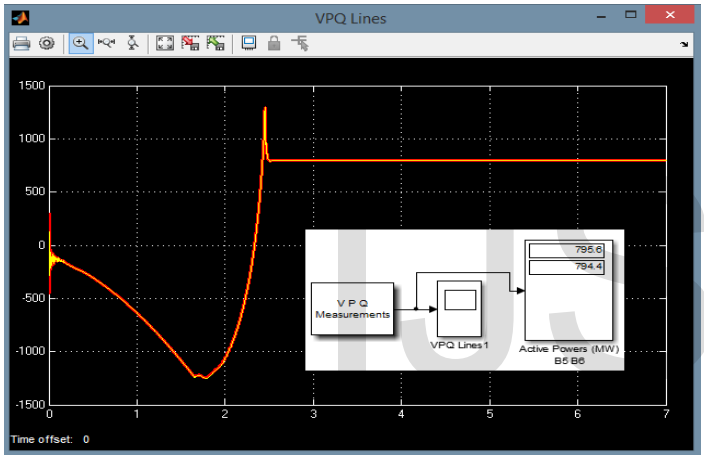

Figure.39. Optimized European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04 Output Bus B5, B6)

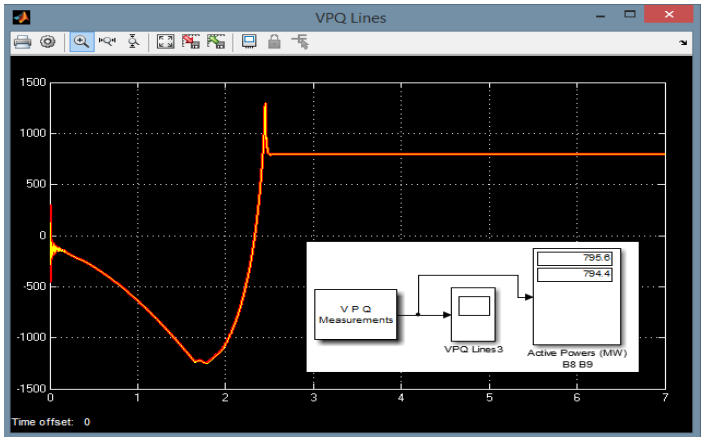

Figure.40. Optimized European Super Grid (HVAC) connecting Three European Countries with Three European Country Wind Farm generation drops to 800 MW (Case 04 Output Bus B8, B9)

4.4 European Super Grid HVAC Model

Table 2. European Super Grid HVAC Model Output

European Super Grid HVAC Models (MATLAB)				
Buses	Case 01	Case 02	Case 03	Case 04
Bus 02	951.1 MW	897 MW	841.6 MW	785.1 MW
Bus 03	945.8 MW	892.3 MW	837.6 MW	781.6 MW
Bus 05	951.1 MW	897 MW	841.6 MW	785.1 MW
Bus 06	945.8 MW	892.3 MW	837.6 MW	781.6 MW
Bus 08	951.1 MW	897 MW	841.6 MW	785.1 MW
Bus 09	945.8 MW	892.3 MW	837.6 MW	781.6 MW

4.5 European Super Grid Optimized HVAC Model

Table 3. European Super Grid Optimized HVAC Model Output

European Super Grid optimized HVAC Models (MATLAB)				
Buses	Case 01	Case 02	Case 03	Case 04
Bus 02	971.2 MW	913.5 MW	854.9 MW	795.6 MW
Bus 03	969.4 MW	911.8 MW	853.5 MW	794.4 MW
Bus 05	971.2 MW	913.5 MW	854.9 MW	795.6 MW
Bus 06	969.4 MW	911.8 MW	853.5 MW	794.4 MW
Bus 08	971.2 MW	913.5 MW	854.9 MW	795.6 MW
Bus 09	969.4 MW	911.8 MW	853.5 MW	794.4 MW

5 European Super Grid Optimized HVAC Model (Unified Power Flow Controller)

As, we discussed above that, one method for load flow Optimization is the interconnection of On-shore AC grid stations with one another.

There is also one more Optimization method in HVAC, which will control the load flow of a power system during unstable conditions i.e. (unstable condition means any fault occurred in the system that will affect the generation of the power systems or in other words the load flow of the power systems).

This methods includes the flexibility in the HVAC system, so in order to provide better load flow at the receiving side, and

that's why this method is called as Flexible AC Transmission System (FACTS) [27].

There is also different types of FACTS devices used for load flow Optimization i.e.

1) Series Connected FACTS Controllers.
2) Shunt Connected FACTS Controllers.
3) Series-Shunt Connected FACTS Controllers (UPFC).

The one I used in this research work is the Series-Shunt Connected FACTS Controllers (UPFC).

In this Scenario of Unified Power Flow Controller, We can Utilized Offshore Power Plant Generation instead of Offshore Wind Farms.

5.1 Performance of UPFC Connected FACTS Controller

Based on the lowest voltage magnitude, then following by underutilized line or higher power losses in the selected voltage magnitude profile, we place the shunt-series on the line with series part of compensator connected in series with the line and shunt part of compensator shunted with the line. The compensator would be placed in the middle of the line, meaning that the line impedance would have to divide by two. For this combined compensator, we would only consider of using only one FACTS controller, which is the UPFC. The performance analyzing method is actually similar to that series and shunt connected FACTS controllers [27].

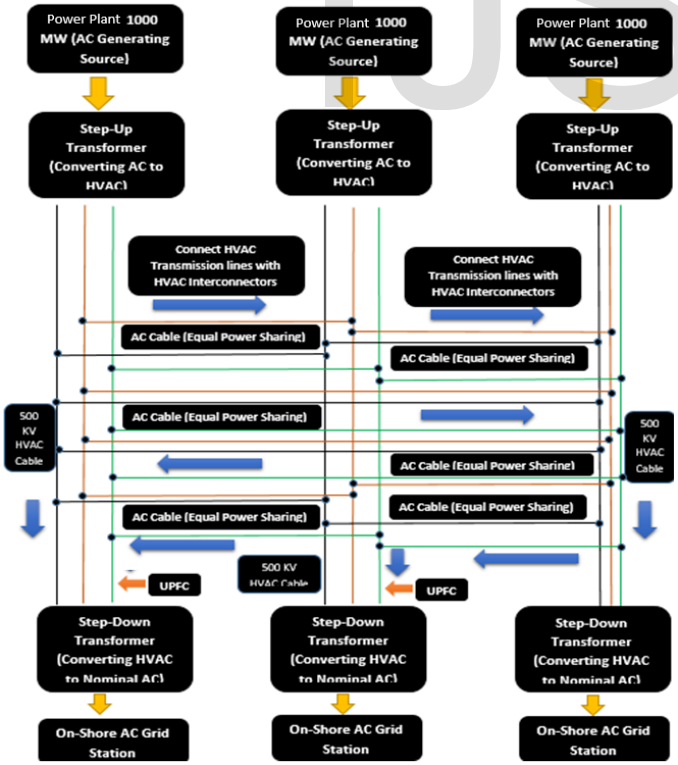

Figure.41. European Super Grid (HVAC with UPFC) connecting different European Countries

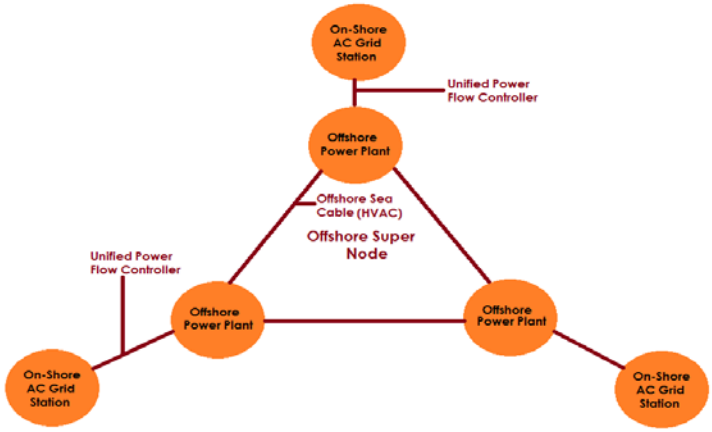

Figure.42. European Super Grid (HVAC with UPFC) connecting different European Countries

5.2 European Super Grid HVAC Model using Offshore Power Plants

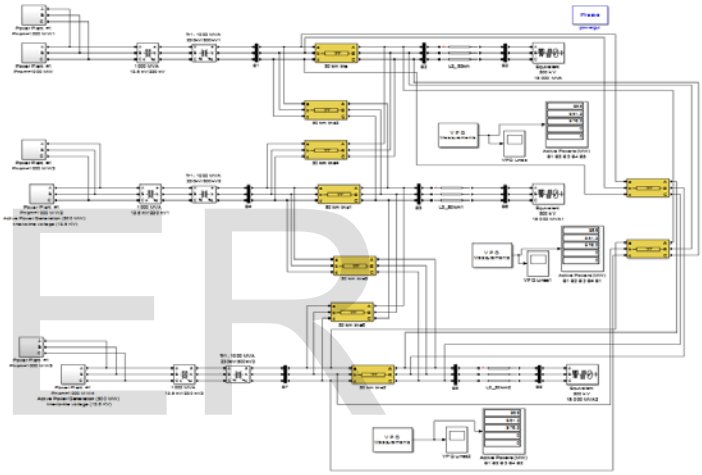

Figure.43. European Super Grid (HVAC with Offshore Power Plant) connecting different European Countries

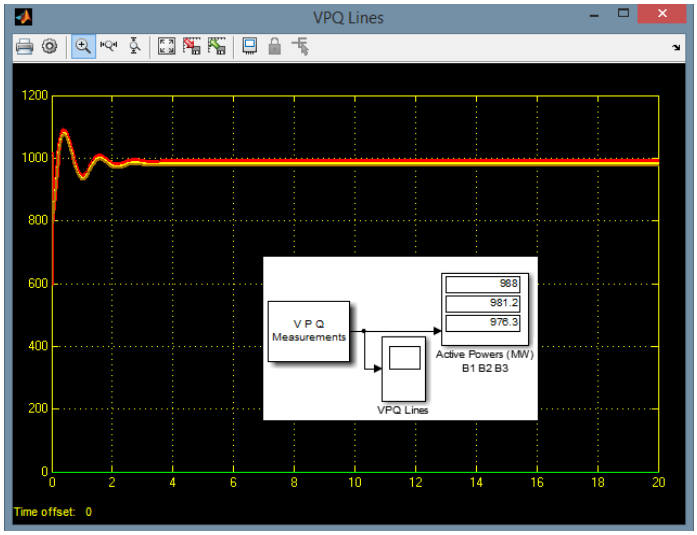

Figure.44. European Super Grid (HVAC with Offshore Power Plant) connecting different European Countries (Output Bus B1, B2, B3)

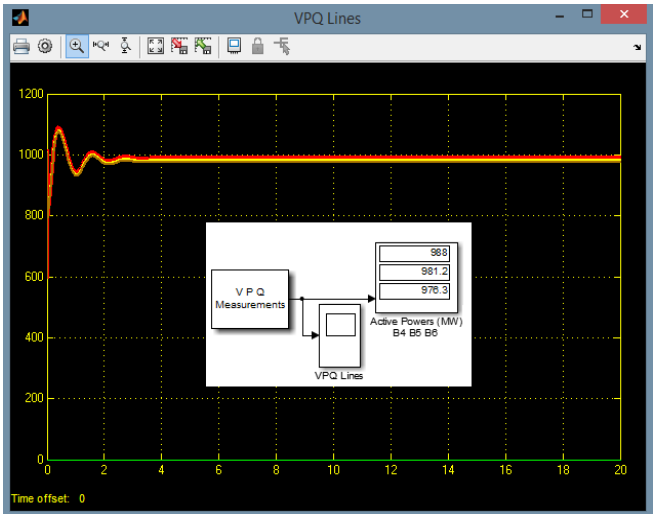

Figure.45. European Super Grid (HVAC with Offshore Power Plant) connecting different European Countries (Output Bus B4, B5, B6)

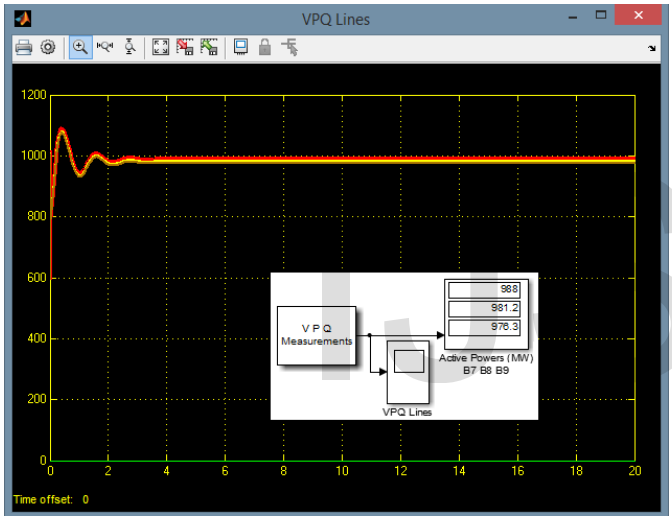

Figure.46. European Super Grid (HVAC with Offshore Power Plant) connecting different European Countries (Output Bus B7, B8, B9)

5.3 European Super Grid HVAC Model with Unified Power flow Controller using Offshore Power Plants

Now, lets us considered the fact, that the load Requirement at Bus B3 and Bus B6 is increased up to 1100 MW.

Now, In order to achieve the load flow requirement of 1100 MW at the receiving side i.e. Bus B3 and Bus B6, we insert a FACTS device i.e. UPFC across these Buses in order to enhance the Load flow, and so in order to meet over load flow re-quirements.

Unified Power Flow Controller is actually the combination of series and shunt convertors and can provide better voltage and power stability, and allow the electrical power to be transmitted to a larger distance with fewer losses as compared to simple AC transmission lines.

The Unified Power flow Controller can be used in two modes.

1) Power Flow Control Mode.

2) Manual Voltage Injection Mode.

The one I used in this research work is the power flow control mode of UPFC in order to enhance the load flow requirement at the receiving side.

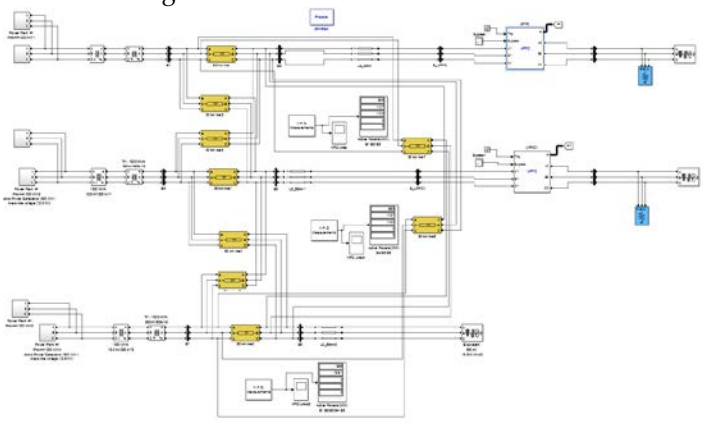

Figure.47. European Super Grid (HVAC with Offshore Power Plant and UPFC) connecting different European Countries

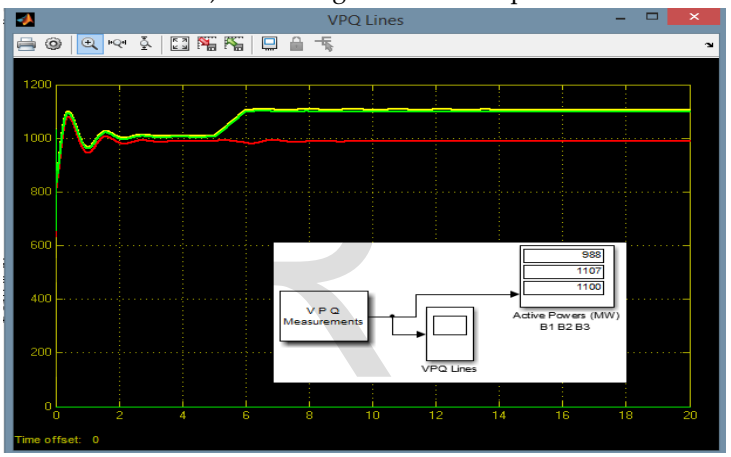

Figure.48. European Super Grid (HVAC with Offshore Power Plant and UPFC) connecting different European Countries (Output Bus B1, B2, B3)

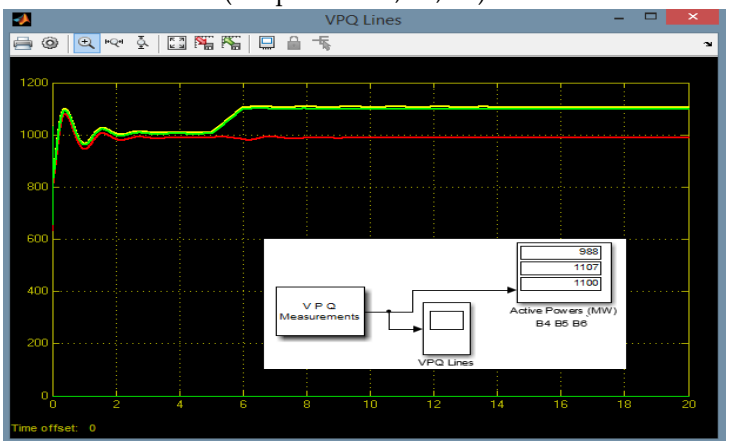

Figure.49. European Super Grid (HVAC with Offshore Power Plant) connecting different European Countries (Output Bus B4, B5, B6)

Now, as you see from the above figure that we can insert the

FACTS device i.e. UPFC in between these buses i.e. (Bus B3 and Bus B_UPFC) and (Bus B6 and Bus B_UPFC1) in order to increase the load flow demand at the receiving side i.e. from 976.3 MW (without UPFC at Bus B3 and B6) to 1100 MW (with UPFC at Bus B3 and B6), also with the utilization of this Unified Power Flow Controller (UPFC) at Bus B3 and Bus B6, the Correspondence power at Bus B2 and Bus B5 can also increase from 981.2 MW to 1107 MW.

The Output of the above Simulink Model is shown below, which will clearly give us the picture of how can we increased the load demand at the receiving side by utilization of Unified Power Flow controller in power flow control mode.

5.4 European Super Grid HVAC Models Vs Optimized HVAC Model (UPFC)

Table.4 European Super Grid HVAC Model VS Optimized European Super Grid HVAC Model with UPFC

European Super Grid HVAC Models		Optimized European Super Grid HVAC Models with UPFC
Bus 02	981.2 MW	1107 MW
Bus 03	976.3 MW	1100 MW
Bus 05	981.2 MW	1107 MW
Bus 06	976.3 MW	1100 MW

6 European Super Grid HVDC Model

As there is the rate of changing of growth of electricity demand for the European countries is increasing day by day, which will conclude the fact that European Electrical Energy system Required a Fundamental upgrade of the present intra-connecting transmission system to inter-connecting transmission system which will connects the different European countries to same electrical bulk power generation system i.e. the concept of building a new overlay grid (Super grid). And also, as we previously discuss, that in order to transmit the Electrical power to a larger distance with a minimum losses than Ultra-High voltage DC is the most effective solution for it. Therefore such a super grid can be established by keeping in mind the HVDC (VSC) Technology and the mesh interconnecting system for the transmission of the Electrical power to different European countries [31].Also in the future HVDC (LCC) should also be used in super grid technology because of its low cost, low loses and greater capability of power transmission to a larger distance.

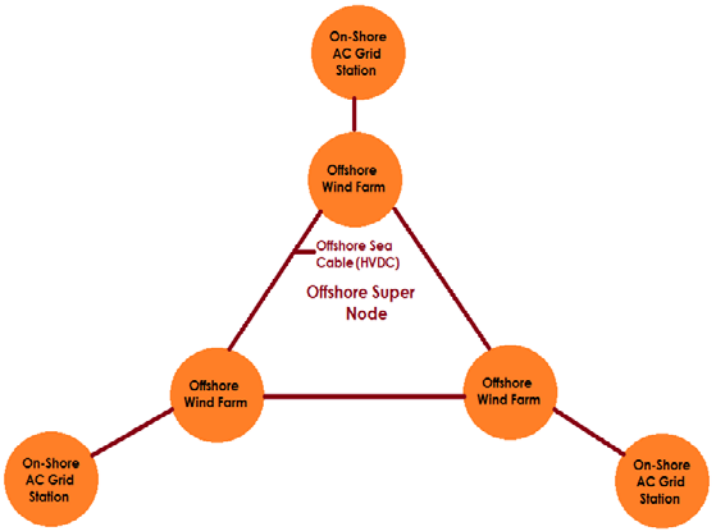

Figure.50. European Super Grid (HVDC) connecting Offshore Wind Farms to On-Shore AC Grid Station [43]

Below shows the Block diagramed model of HVDC Technology for implementing a European Super Grid.

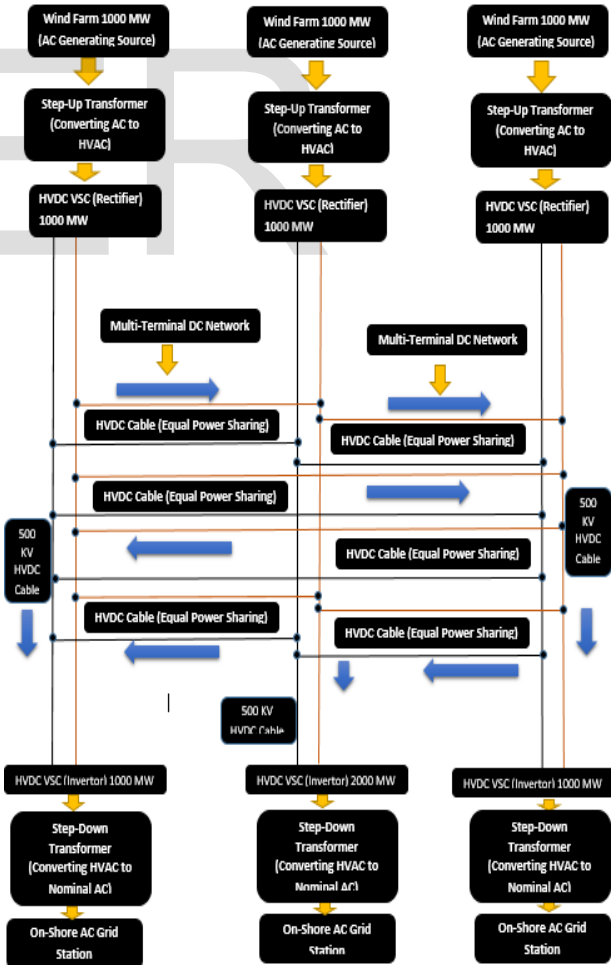

Figure.51. European Super Grid (HVDC) connecting different European Countries

6.1 European Super Grid HVDC Model

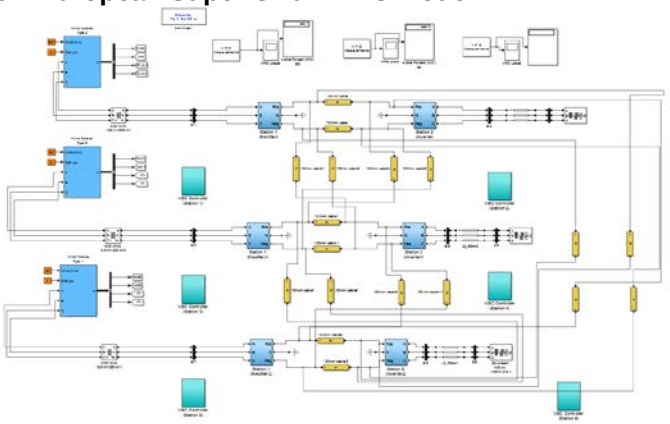

Figure.52. European Super Grid (HVDC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km)

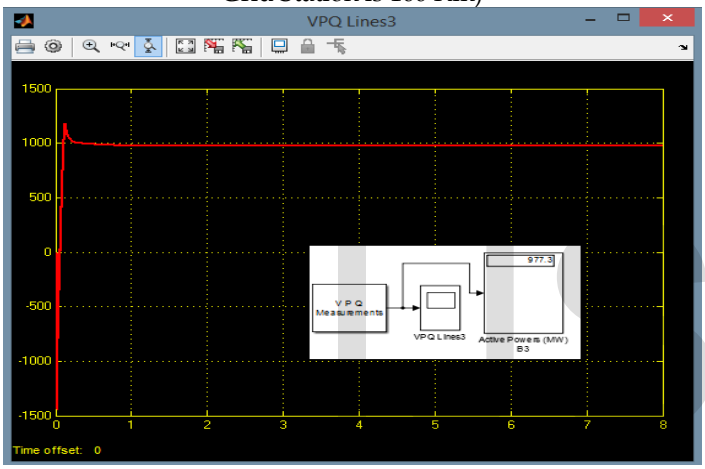

Figure.53. European Super Grid (HVDC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km) (Output Bus B3)

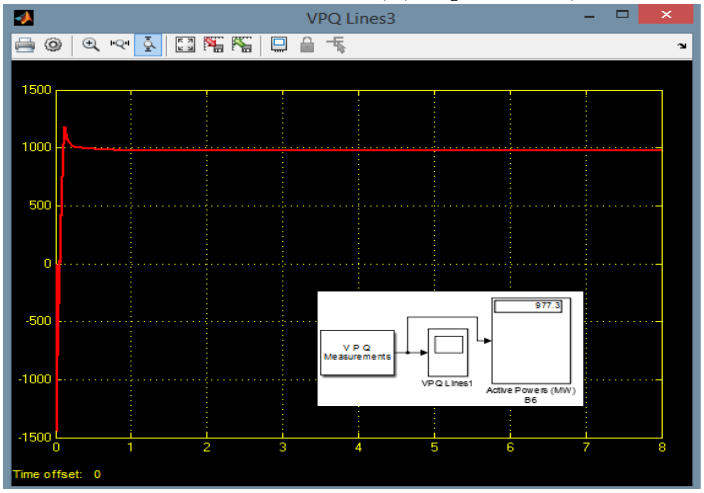

Figure.54. European Super Grid (HVDC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km) (Output Bus B6)

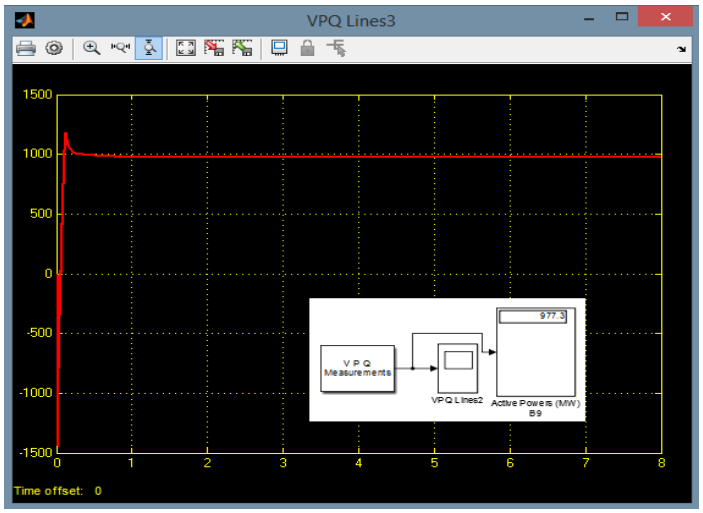

Figure.55. European Super Grid (HVDC) connecting Three European Countries with each country generating 1000 MW (Output Bus B9)

6.2 European Super Grid HVAC Models (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km)

The Same HVDC Model i.e. (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km) can now be modeled in MATLAB as HVAC Model in order to show the fact, that in order to transmit power to a larger distance, than HVDC is more favorable as compared to HVAC.

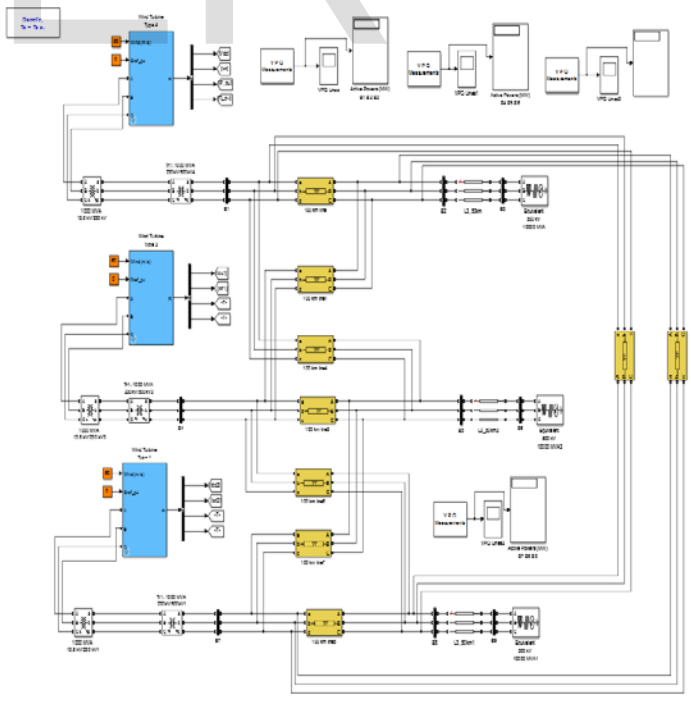

Figure.56. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km)

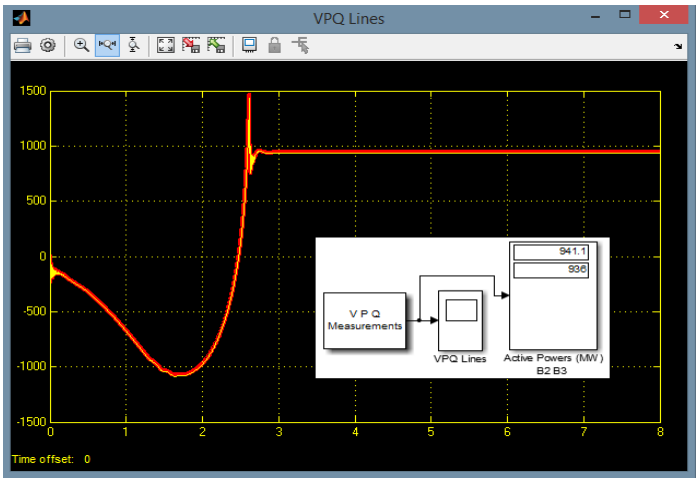

Figure.57. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km) (Output Bus B2, B3)

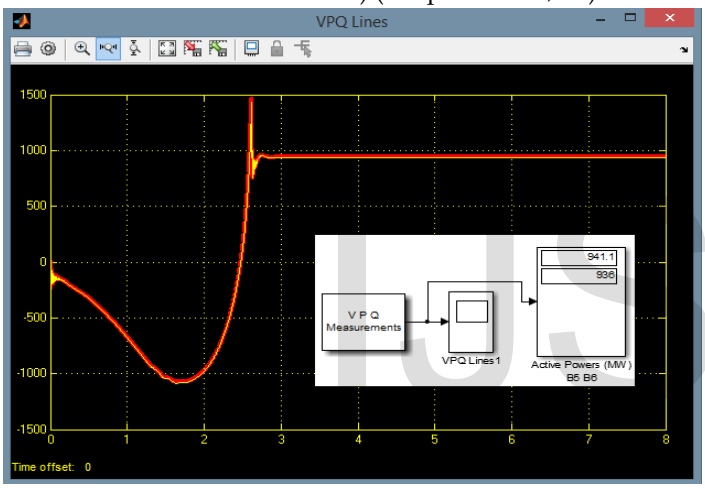

Figure.58. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km) (Output Bus B5, B6)

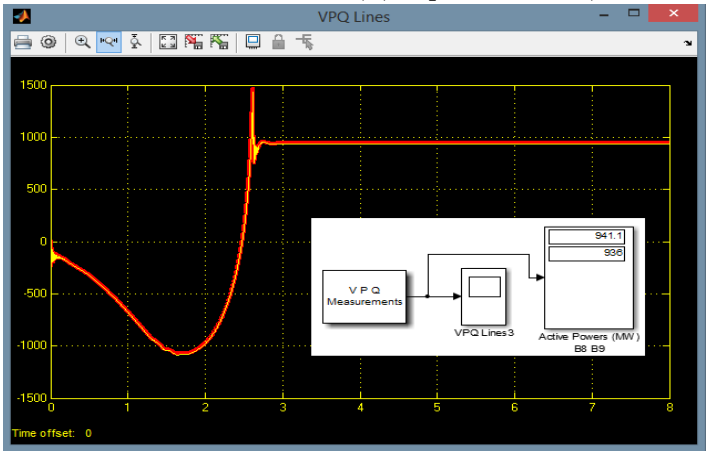

Figure.59. European Super Grid (HVAC) connecting Three European Countries with each country generating 1000 MW (Distance between Offshore Wind Farm and On-Shore AC Grid Station is 100 Km) (Output Bus B8, B9)

6.3 European Super Grid HVAC Models VS HVDC Model

Table.5 European Super Grid HVAC Model VS European Super Grid HVDC Model

European Super Grid HVAC Models		European Super Grid HVDC Models
Bus 03	936 MW	977.3 MW
Bus 06	936 MW	977.3 MW
Bus 09	936 MW	977.3 MW

7 Future Advancements in European Super Grid

My Focus in this Research work is to utilized HVAC Technology and HVDC (VSC) Technology in order to analyze the load flow study of future European Super Grid.

There is also some more advancements that should be consider in order to complete the full structure of European Super Grid in 2050.

These Advancements includes certain factors, Such as,

1) The Utilization of HVDC (LCC) in order to transmit a large amount of power to larger distances [28].
2) The Inter-Connection of On-Shore AC Grid stations with one another in order to provide more secure and Sustainable Supply of Electrical Energy to the Receiving Side (Referred Section 4.2.5).
3) Besides Wind power Generation, European super Grid also Utilizes Biomass, Solar, and Hydro generation.

7.1 Utilization of HVDC (LCC) in Future European Super Grid

As we discussed in this Research work that HVDC (VSC) is the Optimum solution for interconnection of offshore wind farms with one another.

But, in future, the Utilization of HVDC (LCC) should also considered in order to fully implement the European Super Grid in 2050.

The importance of HVDC (LCC) is lies in the transfer of bulk power to a larger distances with smaller losses.

Below Table explains that why it is necessary to used HVDC (LCC) Technology in Future European Super Grid.

Table.6 HVDC (VSC) VS HVDC (LCC)

Technology	Maximum installed	Maximum Currently installed/Planned	Maximum Achievable rating in Near 2020
HVDC (VSC)	0.5GW; +-200 KV	1GW; +-320 KV 0.7 GW; 500 KV	2GW; +-500KV
HVDC (LCC)	7.2GW; +-800KV	7.2GW; +-800KV	7.2GW; +-800KV

So, the above table shows that, with the utilization of HVDC (LCC), we can transfer a bulk power i.e. 7.2 GW with the help of +-800Kv transmission line, which cannot be possible with the utilization of HVDC (VSC) [28].

7.2 Inter-Connection of On-shore AC Grid station with one-another

One more advancements that occurred in future European Super Grid is the interconnection of Onshore AC Grid Stations with one another.

This can be done with the help of two Technologies that is currently available to us.

1) HVAC (If the distance between different On shore AC Grid station of different European countries is less than the break-even distance of combined HVAC and HVDC).
2) HVDC (LCC) (If the distance between different on shore AC Grid station of different European countries is greater than the break-even distance of combined HVAC and HVDC). This technology is used when we interconnecting European countries that are far away from one another.

7.3 Utilization of Hydro, Biomass and Solar Generation

As European Super Grid is a Global phenomenon that interconnects various European countries with one another. So in order to provide equal power sharing between each country ,and also to provide a secure and sustainable electrical energy at the receiving side of each European country, This type of Grid is designed with the utilization of different renewable energy resources i.e. Wind, Biomass, Solar and Hydro.

The integration of all these Renewable energy resources in European Super Grid will provide a strong interconnection, i.e. in case of not availability of one form of renewable energy, the electrical power can still be provided with the Utilization of another form of renewable energy [29].

Figure.60. European super Grid (Interconnection of Wind, Solar, Biomass and Hydro Power Generation) [36]

8 Problems Assessments in European Super Grid

The main Problem that lies in the future European Super Grid is DC Circuit Breakers, As European Super Grid is actually based on High Power Generation and Transmission Scenario.

So, therefore the Utilization of DC Circuit breakers is necessary in order to interrupt the high power current during fault conditions.

But high power current interruption DC Circuit breakers are not implemented so far, Recently Alstom Company announces the implementation of DC circuit Breakers in order to provide a secure supply, and secure interconnection between offshore wind farms with one another in future European super Grid [30].

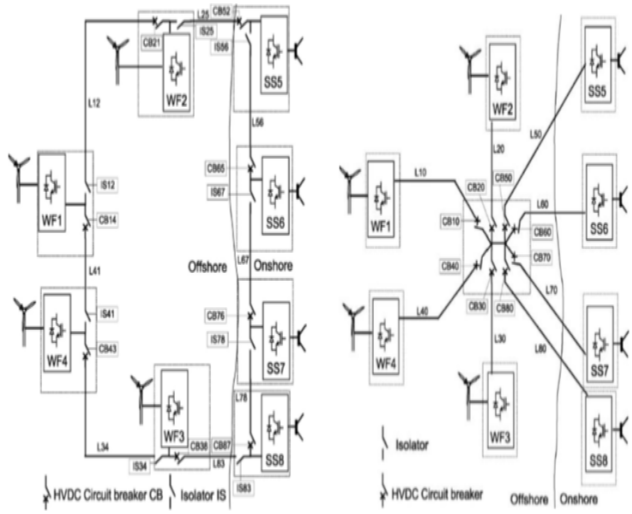

Figure.61. DC Circuit Breakers utilization in Ring Topology and Star Topology [37]

9 Conclusion

This Research work describes the fact, that in order to transmit the Electrical power to a larger distance with a minimum losses than Ultra-High voltage DC is the most effective solution for it. At the start of this Research work, I describes different facts which will lead us to the conclusion than instead of using Ultra-High Voltage AC we can used Ultra-High Voltage DC as an effective solution for bulk power transmission especially of Renewable energy (Referred section 6.1). Than after this, I proposed different solutions and describes different configuration using Ultra High Voltage DC and Ultra Voltage AC, in order to provide an Optimum Results for different Situations (Referred Section [4-5-6]). In this research work, I also highlighted the idea of Flexible AC Transmission System (FACTS) by utilizing one of its technology, i.e. UPFC (Unified Power Flow Controller) in order to provide an optimal setting for the case of an efficient power system Reliability, So that the bulk generation power can be transmitted securely and sustainably to a larger distance with minimal losses (Referred Section 5.1). Than at the end, I concluded the discussion by providing an overall picture of the European Super Grid Technology which will be completely implemented in a Practical way in 2050 and which will used these above technologies in order to provide a secure and sustainable Electrical Energy to different European Countries.

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