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C1-307

CIGRE 2018

Connecting South Asia with HVDC

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SUMMARY

The report explores future opportunities to connect renewables to load centers with HVDC in four nations in South Asia: India, Bangladesh, Nepal and Bhutan. Actual energy generation and prognosis up to year 2040 is summarized. Plans for future development of hydro, solar, wind and bio-mass are presented along with the need of cross-border and domestic inter-connections to evacuate power from these energy sources. Scenarios with higher utilization of renewable energy resources instead of coal fired generation are discussed. Higher utilization of renewables is needed to meet the increasing demand of energy at the same time as CO_2 emissions need to be reduced due to global warming.

Conventional point-to-point and multi-terminal HVDC schemes are concluded beneficial for evacuation of remote hydro power from north-east India, Nepal and Bhutan, due to long transmission distance and the fact that Bangladesh, whose grid is not synchronized with India's, is situated between north-east and central India. Since the most suitable route goes through Bangladesh, some part of the hydro power can be tapped there. Evacuation from Nepal and Bhutan to Bangladesh with tapping in north-east India is also possible.

The shift in government policies towards solar, wind and bio-mass power creates new challenges for grid planners. HVDC schemes for integration of solar and wind power into AC grids are expected to be dominated by the VSC technology due to the challenging characteristics of these renewables, such as the day and night variation of solar power and the frequent fluctuation of wind power. VSC has an inherent STATCOM operation mode which can compensate for these fluctuations and stabilize the system voltage. Power from solar and/or wind farms, scattered in India, can be evacuated with VSC based point-to-point or multi-terminal HVDC schemes to one or more load centers with overhead lines as well as extruded high voltage cables.

Successful integration of renewables into the grids requires co-operation of the different energy resources. Hydro power and bio-mass can compensate for the varying generation of solar and wind power. The role of HVDC here is to bring the renewables closer electrically to facilitate efficient co-operation and utilization of the energy resources.

KEYWORDS

South Asia, Cross-border, Renewable energy, HVDC, VSC, Multi-terminal

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1. OVERVIEW OF RENEWABLE ENERGY RESOURCES IN SOUTH ASIA

South Asia region comprises of eight countries of which four of them are in geographical proximity as shown in Figure 1: India, Bangladesh, Nepal and Bhutan. This report deals with the energy resource potential in these four countries, with focus on renewables, and the need of power transmissions, cross-border as well as domestic, to utilize these resources.

India, Nepal and Bhutan have a huge hydro power potential, in the range of 250 GW [1], due to the presence of the river rich Himalayan region while Bangladesh depends on natural gas to meet most of its power demands. By cross-border energy transmission of hydro power, the region will benefit not only in meeting the energy deficit but also in bringing down the CO_2 emission levels.

Figure 1: North-east part of India with neighbouring Nepal, Bhutan and Bangladesh

Besides hydro power, there is also a huge untapped potential of solar power in South Asia, mainly concentrated to the western part of India. Bulk solar power generation in the desert land of Thar and Rann of Kutch, far away from load centers, can lead to development of special desert transmission corridors for connection to the back-bone grid.

Wind power and bio-mass will also play an important role for the energy supply in South Asia, the former probably mostly in India and the latter in Bangladesh. With current installed capacity of 32 GW, India is ranked as the fourth country in the world in on-shore wind power generation. Off-shore wind farms are under planning.

2. CURRENT ENERGY SCENARIO AND FUTURE PROJECTION

Since the nations under consideration in this paper face energy deficit while their economies are growing, it is a challenge to meet the energy demand of the entire population at low costs and with minimum impact on the environment.

Table I shows the current and projected installed capacity for India, Bangladesh, Bhutan and Nepal for year 2040. Energy mix for year 2017 and future projection for year 2040 are given in Table II. Data in the tables for current installed capacity for year 2017 and its corresponding generation mix in Table II are taken from the information sources of the respective governments and their associated departments, [2], [3], [4] and [5]. The percentage of generation mix of year 2040 in Table II and corresponding installed capacity projection in MW in Table I, are taken from [6] and [7].
In the tables below and other sections of this paper, data is taken from multiple sources that include, in addition to the respective national institutions, international agencies and multilateral organizations. It should be noted that there are some differences in the forecasts.

According to the prognosis presented in Table I and II, thermal power will continue to be dominating in India despite the increase of renewables, attributed to the fact that India has large coal reserves and also import coal from neighboring countries in South East Asia. Bangladesh has high dependency on natural gas and oil owing to the country's own natural gas reserves, but it is also projected to move towards coal and solar energy.

Table I: Installed Capacity 2017 and 2040

Installed capacity (MW)	Bangladesh	Bhutan	India	Nepal
2017	12551	1488	330860	960
2040	67800	14800	1204000	19151*

* Water and Energy Commission Secretariat, Electricity Demand Forecast Report (2015-2040), Government of Nepal

Table II: Generation Mix in percentage for 2017 and 2040

Percentage Mix	Coal	Oil + Gas	Hydro	Solar	Wind	Biomass	Nuclear
Bangladesh 2017	2	30+66	2				
2040	67	24.5	0.6	7	0.1		0.9
Bhutan 2017			100				
2040		0.1	99.9				
India 2017	58.5	8	14	5	10	2.5	2
2040	37	6	6	30	15.5	3.5	2
Nepal 2017		5.5	94	0.2			
2040		0.6	99.2	0.2			

For Bangladesh, the plan is to generate about 7500 MW from coal fired power by year 2040, to compensate for a decreasing generation based on oil and gas. The country is however seeing a shift towards small scale solar generation where, as a result of government initiatives, around 12% of the population has access to off-grid solar power along with targets to install 50 solar mini-grid by year 2018 [8]. India, in contrary, is planning for more large scale exploration of solar power. With a current installed capacity of about 16 GW of solar power, there are plans to reach 100 GW by year 2022 [9].

According to "International Renewable Energy Agency" (Irena), wind power could constitute 14% of India's renewable energy in use by year 2030 indicating that renewables will meet about one-fourth of the country's power need. As per the same study, an increased capacity of renewables will help bringing down the demand for fossil fuel based sources, mainly coal, 17-23% by year 2030 [10].

In addition to on-shore installations for wind energy, there are plans to harness off-shore wind energy with an estimated potential of about 106 GW along the western coastline of India and about 60 GW along the eastern coast line of Tamil Nadu [11].

3. PLANNED HYDRO POWER GENERATION AND TRANSMISSION

Most of the combined hydro power potential in India, Nepal and Bhutan is located within or in the vicinity of the north east part of India. This hydro power potential is consequently far away from the load centers of both India and Bangladesh. The hydro power generation needs to be evacuated by long distance HVAC or HVDC transmission. An overview of existing and planned power transmissions for evacuation of this hydro power is presented below [12].

3.1 Bhutan-India

The bulk hydro power generated in Bhutan is transmitted to India after meeting its internal demand. Today there is a power transfer capability of 2500 MW with one HVDC link under execution and another HVDC link planned for future power evacuation, as detailed in Table III.

Table III: Bhutan-India Interconnections

Status	Generation	Power	Transmission
Current	Chukha	336MW	220 kV AC (1 single circuit and 1 double circuit)
	Tala	1020MW	400 kV AC (2 double circuit)
Under Execution (Generation)	Punatsangchu-I Punatsangchu-II Mangdechhu	1200 MW 1020 MW 720 MW	
Current			Bishwanath Chariyali–Agra ±800kV, 6000 MW HVDC multi-terminal link
Planned	Sunkosh River Kuri-Gongri, Chamkarchhu, Amochhu	4000 MW 1800MW 672 MW 620MW	Bhutan-Bangladesh-India ±800kV, 7000 MW HVDC multi-terminal link 400 kV AC (double circuit)

3.2 Nepal-India

Despite the plentitude of hydro power potential in Nepal, about 200 MW is imported from India to meet its own demand. There are however several hydro power projects under construction and planning that will not only meet Nepal's own demand but also enable export to India, as per Table IV.

Table IV: Nepal-India Interconnections

Status	Generation	Power	Transmission
Planned	Arun-III Upper Karnali Upper Marsyangdi Taamakoshi	900 MW 900 MW 600MW 880MW	400 kV AC (double circuit quad lines)

3.3 India-Bangladesh

Bangladesh is depending on natural gas and oil to meet its energy demands, but thanks to its geographical location with the proximity to India, Bhutan and Nepal, Bangladesh can benefit from cross-border trade by importing the hydro power from its neighboring countries. Since the power grid of Bangladesh is not synchronized with India, as is the case with Nepal and Bhutan whose grids are synchronized with India, cross-border inter-connection by HVDC is the only possibility. Table V summarizes actual and planned inter-connections.

Table V: India-Bangladesh Interconnections

Status	Transmission
Under Operation	500 MW HVDC back-to-back station and 230 kV switching station at Bheramara, Bangladesh
Current	500 MW HVDC back-to-back station at Bheramara, Bangladesh
Under Execution	500 MW HVDC back-to-back station
Planned	±800kV, 7000 MW HVDC multi-terminal Bhutan-Bangladesh-India link with one 1000MW inverter terminal at Bangladesh

4. ROLE OF HVDC IN HYDRO POWER TRANSMISSION

Load centers in India are distributed across the country: cluster of industries in the north including leather processing, brass artifacts, garments and sports equipment; high concentration of pharmaceuticals in the central part; heavy machinery industry and manufacturing in the northern, western and central part of the country; major business and commercial centers in the west; and software and service industry dominating in the south.

As already proved by the North-East Agra HVDC link, multi-terminal HVDC is the natural solution for evacuation of the distributed hydro generation within the north-east part of India, Nepal and Bhutan to the remote load centers thousands of kilometers away in India and Bangladesh. Multi-terminal HVDC is also the only solution that offers routing part of the generated bulk power through Bangladesh. Owing to the narrow chicken-neck corridor between north-east India and Bangladesh, the hydro power from north-east India is preferably transmitted through Bangladesh. On the other hand, hydro power from Nepal and Bhutan to Bangladesh must cross Indian territory. Power can be tapped in Bangladesh in the former case, while power can be tapped in India in the latter case. Since the power grid of Bangladesh is not synchronized with either India, Nepal or Bhutan, HVDC is the only option for routing power to Bangladesh, either by over-head line or by back-to-back scheme. An example of such a power transmission is the proposed multi-terminal HVDC scheme of 7000 MW and ±800kV with one rectifier station pooling power from India (Kameng basin and Tawang basin of Arunachal Pradesh) and Bhutan; and two inverter stations, one each in Bangladesh and India. 1000 MW of 7000 MW would be tapped in Bangladesh [13].

Evacuation of hydro power with HVDC has historically been achieved by both two-terminal systems and multi-terminal systems. The Quebec-New England HVDC scheme with three terminals have two receiving stations, one at Montreal in Canada, and one at Boston in USA, while the sending stations is located the hydro power scheme at Radisson in northern Quebec. The North-East Agra HVDC scheme on the other hand, has two sending station, one at Biswanath Chariali for pooling the hydropower generated in the state of Arunachal Pradesh; and the other in Alipurduar in Assam for pooling hydropower generated in Bhutan, while the receiving station is located at Agra.

The benefit with multi-terminal HVDC schemes is the higher flexibility compared to two-terminal systems that resembles a back-bone HVAC system. The DC line can be utilized in a more efficient way by adding more terminals. The costs for the converter stations and overhead lines will be much less for a multi-terminal scheme consisting of three stations compared to two two-terminal schemes consisting of totally four converter stations and two HVDC lines.

The technology development with more reliable inter-station telecommunication by optical fibers and more powerful control and protection systems, makes multi-terminal HVDC schemes less complex to implement. Operational experiences from the Quebec-New England and North-East Agra HVDC three-terminal HVDC schemes are also very satisfactory.

For time being, conventional HVDC based on thyristor valves, is the preferred HVDC solution for large scale evacuation of hydro power. However, hybrid configurations with rectifier station of conventional design combined with two or more inverter stations of VSC design could be the optimal solution in case of weak AC networks at the receiving ends.

5. SHIFT OF GOVERNMENT POLICIES TOWARDS SOLAR AND WIND POWER

India has vast coal reserves in the central and east part of the country and the power generation is dominated by thermal power which today is the cheapest and most reliable form of energy. With the focus on environment and reduction of CO_2 emissions, there is an increasing interest in other renewables than hydro power, such as solar, wind and bio-mass power, which will be less remote in terms of distances from the load centers than the hydro power generation. The government of India has the target to install 175 GW of renewable energy by year 2022 that includes 100 GW of solar power and 60 GW of wind power. Of the 100 GW solar power, 40 GW will be generated with solar farms and the remaining with distributed roof top solar panels [9].

According to the “Institute for Energy Economics & Financial Analysis” (IEEFA), coal fired power in India will be replaced by solar and wind power to a larger extent which will account for 27% of generation capacity by year 2027 [14].

With its large population and among the lowest per capita electricity consumption in the region, Bangladesh has a plan to have 10% of total power produced from renewable generation by year 2020. This plan is largely driven by the “Infrastructure Development Company Limited” (IDCOL), a state-owned institution in Bangladesh that started the solar home system (SHS) program in year 2003 to provide off-grid solar power in rural areas [15].

5.1 Solar power development

Large solar farms of photo voltaic (PV) design have a wide variation of the generation profile. Since power is produced only during day light hours, the solar farms will be idle at night. Furthermore there is also a daily as well as seasonal variation of power output due to the variation of solar radiation. Since storage of power of a large solar farm is economically not feasible, solar power needs support from other energy sources such as hydro power.

Plugging in and out large solar farms will definitely have an impact on the AC grid. Solar panels generate DC current which is converted to AC current by inverters. These inverters operate mostly at unity power factor but inject harmonics into the AC grids which may cause resonance or other adverse phenomena. Consequently measures are to be taken to mitigate these negative effects.

Installed capacity in India of PV solar power at the end of September 2017 was 16.2 GW, witnessing a growth of 84% within the last four quarters. This can result in shift of the generation pattern in long turn that may reduce the share in thermal power and a significant increase of renewables. The largest solar power tender launched in India to date has a capacity of 2 GW.

The Ministry of New and Renewable Energy (MNRE) plans to set up about 50 solar farms with capacity of 500 MW each. This creates need of a reliable transmission corridor that maintains the grid stability under the wide range of generation from peak to zero power.

Bulk PV generation is planned in the desert areas in the western part of India based on the potential generation capacity of about 230 GW from available wasteland. About 200 GW is estimated from the Thar desert and 30 GW from the Rann of Kutch [16]. Evacuation of this power will lead to the need of a desert transmission corridor to remote load centers.

One of the largest solar farm in the world is planned in Pavagada in Karnataka, in south west India, with a capacity of at 2 GW. It is expected to reduce CO_2 emissions by 20 million tons annually and save about 3.6 million tons of natural gas annually, which is currently the main source of Pavagada’s electricity supply [17].

5.2 Wind power development

Wind power is the least predictable of the renewables due to the inaccuracy of weather forecast. Furthermore its power output is varying due to variation of wind speeds. Consequently wind power always needs immediate back-up and support from other energy sources such as hydro power.

India has set a target for 60 GW of wind energy by March 2022. The current installed capacity is about 32.5 GW amounting to 55% of the total renewable installed generation capacity. The government has plans to auction 4-5 GW every year. During year 2016 and 2017, India added 5400 MW wind power which is a record in added installation. The bulk of this wind power was added in the states of Andhra Pradesh (2190 MW), Gujarat (1275 MW) and Karnataka (882 MW), followed by six other states in west, central and south of India [9].

According to the “International Energy Agency” (IEA), Indian wind power market could reach about 155 GW by year 2030. European Union co-financed the FOWIND project (Facilitating Offshore Wind in India) where India’s first off-shore wind research platform was installed, which may be followed by a first commercial off-shore wind farm tender year 2019 under the “Offshore Wind Policy” of MNRE [11]. Planned solar and wind generations and the major load centers are shown in Figure 2.

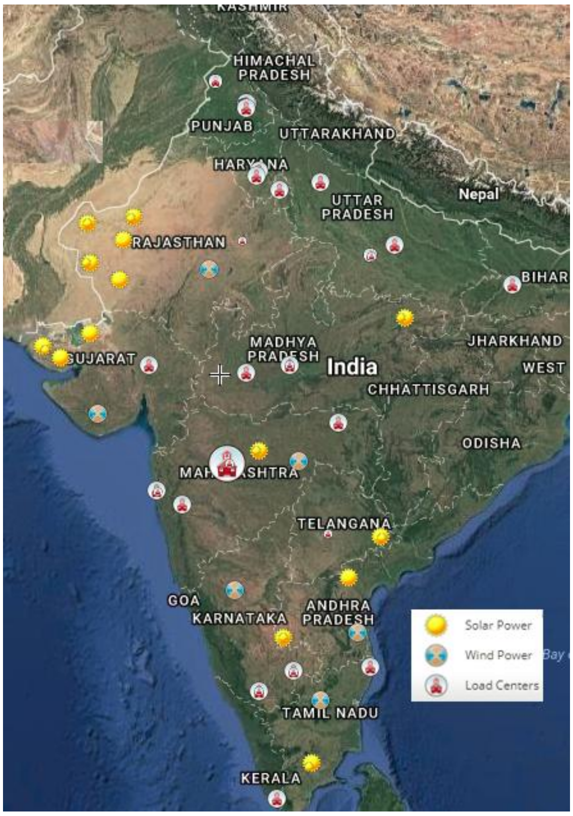

Figure 2: Map of India indicating solar and wind generation and load centers

6. ROLE OF HVDC IN SOLAR AND WIND POWER TRANSMISSION

One of the challenges the solar and wind power developers will face is the need of transmission corridors for evacuation of the generated power. There will also be a concern for the grid operators and the regulatory authorities to ensure the quality and reliability of power to the last level of connectivity from generation centers to remote domestic end user.

Connection of large scale solar and wind power generation to AC grids will require not only support from other energy resource but also voltage regulators at the grid connections to compensate for the wide range of the daily voltage variation to ensure grid stability. VSC based HVDC transmissions simplify the integration of the highly variable PV generation into the AC grids, without additional compensation devices, due to its inherent STATCOM capability. Losses are in the same range as HVAC.

VSC is also beneficial with respect to power evacuation from electrically isolated islands of solar and wind farms, or combinations of these, since it is not dependent on a live AC grid to function but can energize a black network and allow start-up of isolated solar and wind farms. VSC converter stations at solar farms can hibernate at sunset and re-start at sunrise in order to evacuate solar power during day light hours. In the same way VSC converter stations for wind power evacuation can hibernate at wind standstill and re-start when the wind returns.

Another advantage with HVDC for this application is that it will also serve the purpose as a firewall against transfer of harmonics or other disturbances to the AC grids. The receiving converter station equipped with state-of-the-art cascade connected multi-level VSC valve will generate a nearly perfect sinusoidal voltage with minimum operational losses without any need of harmonic filtering. Consequently the footprint of the station will be very small, which might be of importance since such power transmissions often will be routed to densely populated load centers where land use may be an issue.

As for large scale evacuation of hydro power with conventional HVDC, multi-terminal VSC based HVDC schemes are also possible for evacuation of solar and wind power. The same set-up can be used with two sending stations and one receiving station at a load center; or one sending station and two receiving stations. Due to the fact the several areas rich in solar and wind power within India are situated between load centers, contrary to the hydro power, multi-terminal HVDC schemes linking two load centers with in-feed of renewables in between, are also possible. This would resemble plans for similar schemes in the Northern Sea and the Baltic in Europe with off-shore wind power in-feed in the mid and power supply to two or more countries or regions.

Overhead lines in deserts have a harsh environment with risk of salt contamination of insulators. For evacuation of bulk power from desert areas, underground cables may be the best option. VSC based HVDC is suitable for on-land cable transmission and due to the development of high voltage extruded cables it is possible to transmit large amounts of power over long distances. Underground cables are also preferred in densely populated areas, which may be the case for most of the load centers, and could be the only acceptable alternative due to environmental issues.

The cost aspects of all items discussed above are to be evaluated in order to find the most feasible transmission alternative, i.e. HVDC or HVAC. Comparison of costs and capitalized losses of the transmission system itself should include additional costs for STATCOM and harmonic filters if needed in combination with HVAC. Costs for larger right-of-way for HVAC such as land acquisition should be taken into account as well. Furthermore, the precise dispatch of power to and between different load centers with multi-terminal HVDC schemes facilitates trading of power and optimal use of energy resources and can reduce overall transmission costs.

7. CO-OPERATION OF RENEWABLES USING HVDC

Renewable generation, predominantly hydro power followed by wind and solar power, has different generation profile and operating characteristics compared to non-renewable generation. Thermal generation and other non-renewable generation operate at pre-set power output levels providing system operators with reliable and predictable firm power. Hydro power on the other hand, with significant water storage, can be considered as firm power. Wind and solar generation are characterized by high variability and the inherent risk of not accurate forecasting, in particular for wind power. For reliable and stable grid operation, there must be available power at all times meeting the demand, flexibility to handle variations in both generation and demand, as well as possibility to readily switch between different sources of generation at different times during the day.

Hydro power stations can be set into and taken out of operation fast and the power output can be controlled within a certain range. Thus hydro power provides stability to the power systems by efficient balancing of power consumption and generation. This feature is not only useful at peak hour consumption when the power demand increases rapidly but also for support and back-up of solar and wind power connections to grids.

HVDC transmissions simplifies the integration of these varying renewables to the grid. Hydro power from remote generating stations is effectively transmitted to load centers by conventional HVDC. Such HVDC schemes can be used for frequency control of the connected grid in the receiving end provided there is sufficient water storage capacity of the hydro power at the sending end. VSC based HVDC systems help maintaining the proper voltage profile at in-feed of fluctuating and varying wind and solar power, without need of any additional reactive power compensation devices. The STATCOM operation mode is the key to maintain grid stability. Consequently the role of HVDC in this context is to connect scattered hydro, solar and wind power generation plants to load centers or regions with significant demand of power, making such a co-operation of energy sources and integration of renewables possible.

A fourth renewable that could to some extant replace the role of coal fired power as firm power and that could be installed at the load centers themselves, would be bio-mass power. When compared to solar and wind power, bio-mass has the potential to provide pre-determined constant power output depending on its capacity, along with this feature inherent in hydro and coal fired power plants. However, the long-term goal should be to replace coal fired power entirely by sustainable renewables to reduce CO_2 emission and the global warming.

Another possibility would be to integrate bio-mass power in large-scale islands of solar and wind power farms and by that utilize the inter-connecting transmission lines better. At no wind or sun, bio-mass generation could be started for full utilization of the transmission system. Like coal and hydro power, in contrary to wind and solar power, bio-mass can be stored till utilization for generation is most suitable.

Denmark is a successful example of cross-border integration of renewables with HVDC [18]. Denmark leads the world ranking in installation of wind power. About 40% of the total electricity consumption is covered by wind energy generation. In the World Economic Forum's Global Energy Architecture Performance Index (EAPI) for 2017, Denmark ranks number four [19].

Denmark has two separate grids that are linked with HVDC and the country is also linked to the neighboring countries Sweden, Norway and Germany with both HVAC and HVDC links, as shown in Table VI. A new inter-connection to Germany with a combination of AC cables and HVDC back-to-back is under construction. The purpose is evacuation of wind power from the Baltic to both countries. Also under construction is a VSC based HVDC link to the Netherlands for back-up support to wind power.

Table VI: Integration of Danish Network with HVDC and HVAC

Danish Grid	Country	Name of Link	Type of Transmission
West Denmark	Norway	Skagerrak	HVDC+ HVDC VSC
East Denmark	Germany	Kontek	HVDC
West Denmark	Sweden	Konti–Skan	HVDC
West Denmark	East Denmark	Great Belt Power Link	HVDC
West Denmark	Netherlands	Cobra (2020)	HVDC VSC
East Denmark	Germany	Krigers Flak (2018)	HVDC VSC back-to-back
East Denmark	Sweden	Öresund Cables	HVAC 400 kV
West Denmark	Germany	Jutland-Germany	HVAC 220 kV

8. CONCLUSION

Harnessing South Asia's plentitude of hydro, solar, wind and bio-mass renewable energy resources is essential for meeting the increasing demand of energy in the region in the most environmental friendly way and in turn reduce the dependence on fossil-fuels including coal, oil and gas helping to bring down the CO_2 emissions.

Large-scale two or multi-terminal HVDC transmissions will play an important role in the evacuation of these renewables. Conventional HVDC schemes, point-to-point as well as multi-terminal schemes already play an important role of evacuating hydro power and it is expected to continue so. Conventional HVDC may still be more feasible for bulk power transmission with over-headlines between electrically strong points in the grids, but the fast development of VSC may change this. Hybrid solutions are possible for power injection to weak grids.

HVDC schemes for evacuation of solar and wind power are expected to be dominated by the VSC technology due to the characteristics of these renewables, such as fluctuating power output. A VSC based HVDC converter station has an inherent STATCOM operation mode which can compensate for these fluctuations and stabilize the system voltage. An HVDC link also serves as fire wall avoiding disturbances from solar and wind farms to be transferred to the grid. Consequently VSC based HVDC will facilitate the integration of solar, wind and bio-mass into the grids. Multi-terminal schemes for evacuation of renewable to more than one load center is possible. These kind of schemes can also be designed for the purpose of inter-connections between load centers.

Due to important features of HVDC, such as the controllability and the ability to inter-connect unsynchronized grids, HVDC is often found the most optimal transmission solution. HVDC connections to load centers will make co-operation of renewables more efficient since HVDC links will reduce the electrical distance between them. Hydro power can then compensate for the varying power output from solar and wind power. Bio-mass based power close to load centers can replace coal fired power to some extent and also help balancing the generation pattern of solar and wind power.

Denmark is a successful example of cross-border inter-connection using HVDC technology for integration of renewables in the grid.

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