Integration of Hydro Power with DC Power Plant Technology

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Abstract

With the constant development of hydropower generation and significant progress of HVDC technologies, the variable speed and operation of hydropower plant with HVDC station (unit connection) became technically and commercially feasible. This resulted in a substantial improvement in system efficiency, performance and design flexibility. Further, if the hydro power plant is connected to a DC grid, thus a DC power plant with DC Power generation and DC voltage control is formed effectively and thus a DC power plant will play an important role similar to the conventional AC power plant in an AC grid system. A DC power plant can employ either HVDC Classic station or VSC HVDC station. VSC connection also provides more managed flexibility such as decoupled AC and DC voltage controls and fast electrical emergency braking too. In this review paper, the characteristics and the control principles of the hydropower plant unit connection with HVDC station are introduced. Based on this unit connect, the DC power plant concept is proposed for integration of hydropower into DC grid. The configurations of DC power plant are presented. The advantages of DC power plant and challenges for a practical system are analyzed. It concludes that the DC power plant will have a very attractive prospect for hydropower integration and DC grid application.
Keywords: DC Grid, DC Power Plant, Efficiency, HVDC, Hydropower, Unit Connection, Variable Speed

I. INTRODUCTION

Renewable energy generation is constantly growing in the past decades. Among various renewable sources, hydropower is smart in countries with abundant resources and is still the largest contributor to total renewable power generation worldwide. According to the estimation of International Energy Agency, hydro power accounted for 80% of entire renewable generation in 2011. Over 2011-2017, hydro power generation should grow on average 120 TWh per year (or + 3.1%) as capacity rises from 1070 GW to 1300 GW. China is the world's largest hydro power market and the total installation capacity will attain to 340 GW in 2017. In World and China hydropower capacity from 2010 to 2017 is shown in Figure 1[1]. At present there are 3 types of hydro power: conventional hydro with dam, pumped hydro storage and run-of-the-river. Moreover, tidal power can be also regarded as hydropower. The conventional hydro with dam is still the main method to produce hydroelectric power, by using the potential energy of water at reservoirs. Turbines positioned in water flow extract energy and convert it into mechanical energy and then electricity.

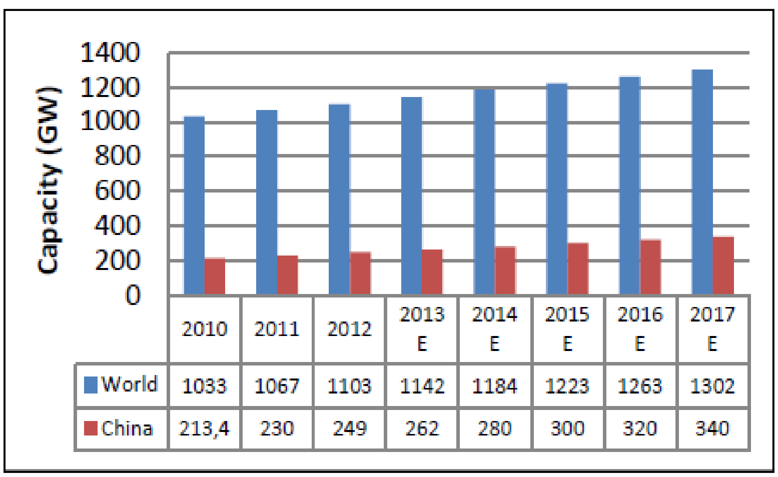

Fig. 1: World and China Hydro Power Capacity.

Hydropower has been considered as a fully commercial and mature technology for many years. However, as the majority of new hydro power plants are located at remote areas, high voltage direct current (HVDC) transmission has been preferred for large amount of energy and long distance transmission. The synchronization of hydro power plant and HVDC system brings opportunity to develop new technologies for higher efficiency and lower cost of hydro power generation system. One outstanding technology is adjustable speed operation of hydro power plant by providing an asynchronous tie between the hydro site and the main AC grid with HVDC system, which is referred to “Unit connection” in several HVDC literatures.

Variable speed operation of hydropower plant effects in a considerable improvement in system efficiency and performance, as well as control flexibility, hydro power plant setting and machine design [2, 3]. While the hydro power generation technology is developing, the HVDC transmission system is making major progress in recent years. The most prominent technology of HVDC today is the DC grid structure. A DC grid may be a multi-terminal dc-system (MTDC), which consists of several converter terminals linked in parallel with the dc-buses. Each terminal typically consists of forced commutated voltage source converters (VSC), as VSC is very compressed it is easy to site and has the potential to be built as a big multi-terminal system. It is also likely to use thruster based converter as a part of a VSC-HVDC grid. The voltage control in the DC grid can be realized through droop control, which is similar to the control of the frequency in an AC system. The foremost vision of a DC grid overlaying was developed in Europe during the mid-1990s [4]. Today, the required components for structuring a regional multi-terminal HVDC (MTDC) grid are available [5]. DC grid will allow the efficient integration and substitute of renewable technology, including wind, solar and hydro power. A unit connected hydropower plant to DC grid will give completely advantages of variable speed operation of turbines and brings additional profitable interests.

In this review paper, a DC power plant idea is proposed based on the hydropower unit connection and DC grid technology. Firstly, the development of hydropower unit connection is summarized and the configurations of DC power plant with both HVDC standard Station and VSC HVDC station are offered. Secondly, the advantages of employing DC power plant technology are researched; the design considerations of DC Power plant are outlined. Finally, the challenges to understand DC power plant are discussed.

II. HYDROPOWER UNIT CONNECTION AND DC POWER PLANT CONCEPT

A typical hydro power unit connection scheme with HVDC Classic is shown in Figure 2, in which a is the guide front opening and n is the turbine speed,

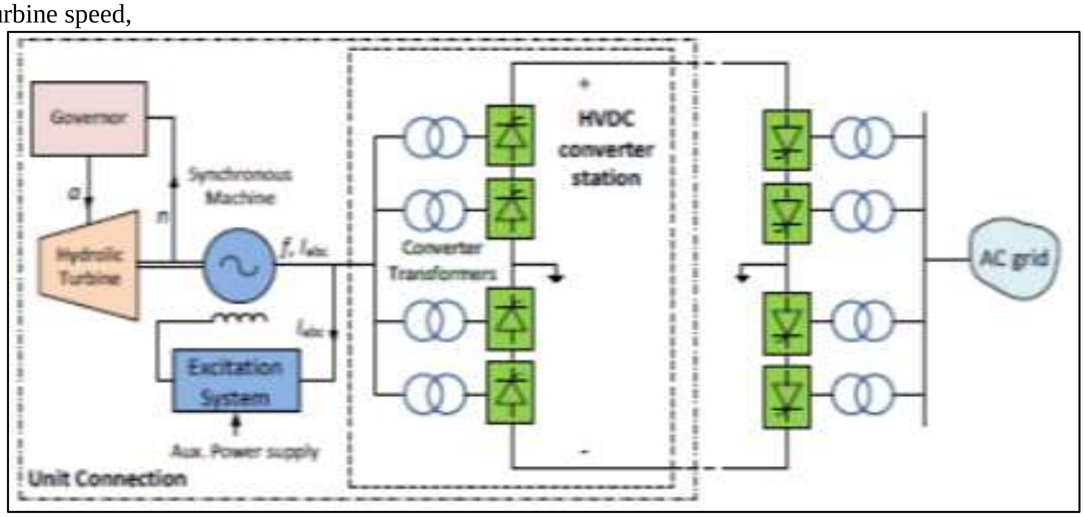

Fig. 2: Hydro Power Unit Connected with HVDC Classic

The hydro power unit connection with HVDC connection was firstly presented by Brown Boveri &Cie (BBC) in 1973[6], but the turbine was assumed to function at a fixed speed. Since 1980s, many literatures had proposed HVDC converter station for regulatory speed operation of hydro power plant [2, 3, 7-11], including variable speed pumped hydro power use [2, 3], harmonic measurement and analysis of generator [11, 12], and unit connection system design. In all these papers, the HVDC systems were thyristor converter based HVDC or HVDC Classic. The applications of VSC HVDC were not often discussed, because the capacity and voltage rating of VSC HVDC had been thought as a major restriction for transmission level application and the first commercial VSC HVDC was introduced until 1999[13]. However, in modern years, the VSC HVDC technology has been in evaluation and made considerable progress. The global trend shows VSC projects with constantly increased capacities up to 1,200 MW while the voltage rating reaches ±500kV. Due to the progress of fresh VSC topologies, the power loss of VSC converter station has reduced from about 3% to approximately 1%. All the progresses raise the VSC HVDC application from sub-transmission and distribution to transmission level.

It is natural way to expand the unit connection concept from HVDC classic to VSC HVDC. The VSC converter station can authorize current in both the directions and decoupled control of active power and reactive power, which will make best use of the advantages of HVDC unit connection. Thus a hydro power unit connection scheme with HVDC Classic is proposed in Figure 3.

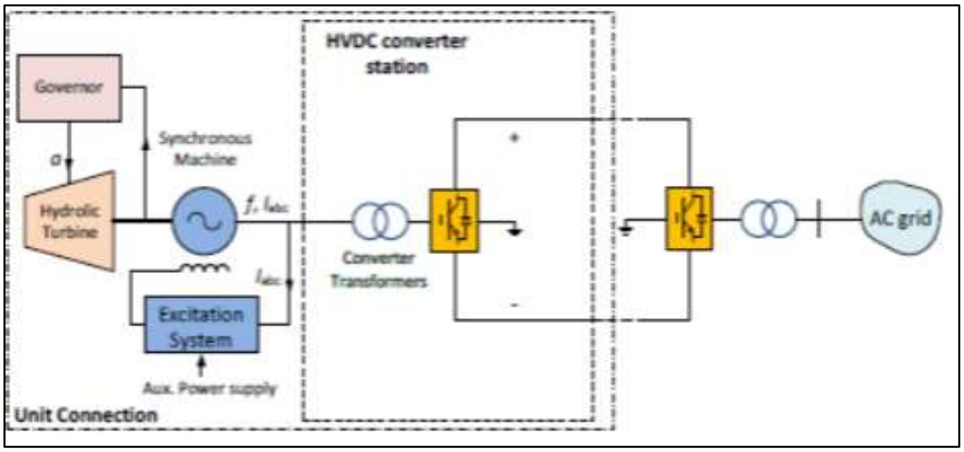

Fig. 3: Hydro Power Unit Connected with VSC HVDC

Additionally, it can be foreseen that DC grid would be formed in the future, which consists of a number of terminals connected in parallel with DC buses. Therefore it's possible to connect several HVDC based (either HVDC Classic or VSC HVDC) hydropower units into one DC grid. This is mainly advantageous when several hydro power plant are cascaded situated at one river. For this case, the hydropower unit connection becomes a DC Power plant, which DC voltage and power can be adjusted according to the orders from dispatch center of the DC grid. The major differentiation between the DC power plant and unit connection is that the control of DC voltage should be considered to fulfill a drooping control feature for DC grid power flow control, with the input of both, the power order and the hydraulic head. The HVDC converter controls, the excitation system and the turbine governor will be integrated into a DC power plant controller. Thus such a similar DC power plant is illustrated in Figure 4. The DC power plant technology would have a very eye-catching prospect in the countries which have fine potential hydro power resources such as China, India, Brazil and Norway. In China, the productivities and the energy resources are distributed reversely. The majority of the large hydropower bases to be constructed are far away from the load centers. As matter of fact that the amount of single hydropower of the upstream of the rivers is comparatively small and far away from the back bone AC grid, MTDC/ DC grid connected with several DC power plants can be engaged to transfer power cost efficiently.

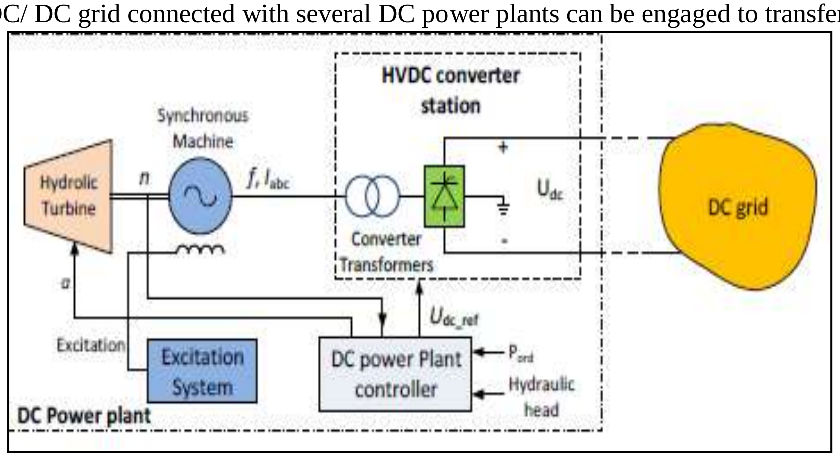

Fig. 4(a): DC power plant with HVDC Classic station.

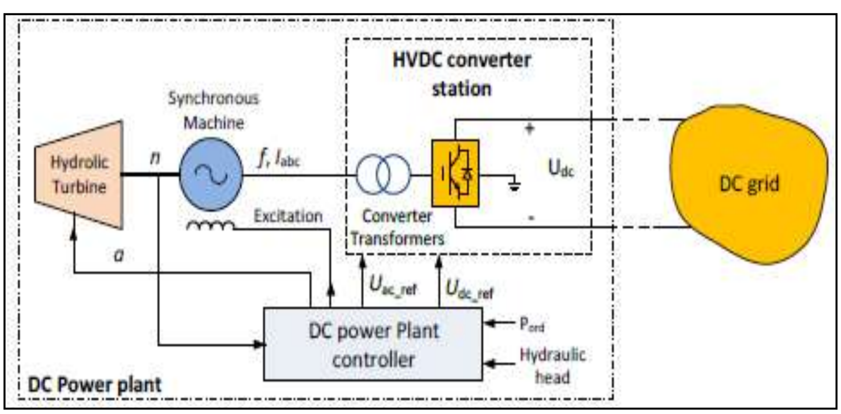

Fig. 4(b): DC power plant with VSC HVDC station

III. Advantages of DC Power Plant

The main advantages of DC power plant come from variable speed operation of hydro turbines, and unit connection. Moreover, the application of DC power plants brings commercial benefits for both generation companies and transmission system operators.

IV. Benefits from Variable Speed Operation of Hydro Turbines

Today, all the synchronous generators used in usual hydropower plants are considered to match the rated frequency of integrated AC grid, i.e. 50Hz or 60Hz. The turbines are also planned to run at the speed specified by frequency of AC grid, under rated hydraulic head and the guide vane opening. This means that the control and design of hydropower plant are severely constrained. Any deviation of hydraulic head will effect in reduce of efficiency.

This operation characteristic can be explained by the so called the hill chart curves shown in Figure 5[8], in which AA' defines the fixed speed operation range for a normalized flow change. The efficiency of the turbine system decreases from 89% to 88% when unit flow changes from about 0.72 to 0.68. In contrast, with variable speed operation, higher efficiency can be obtained: Adjusting the operating speed to move from point Pf to Pa increases the power output by 1% in the case in Figure 5. Finally, the adjustable speed of turbine permits a highest efficiency tracking for a given power command.

In addition to the significant energy savings, a number of other vital benefits will be realized if the speed of the turbine can be adjusted [2], such as:

- Longer life time of turbine thanks to reduced vibration, noise and cavitations problems;
- New flexibility in site selection and sizing of hydro units;

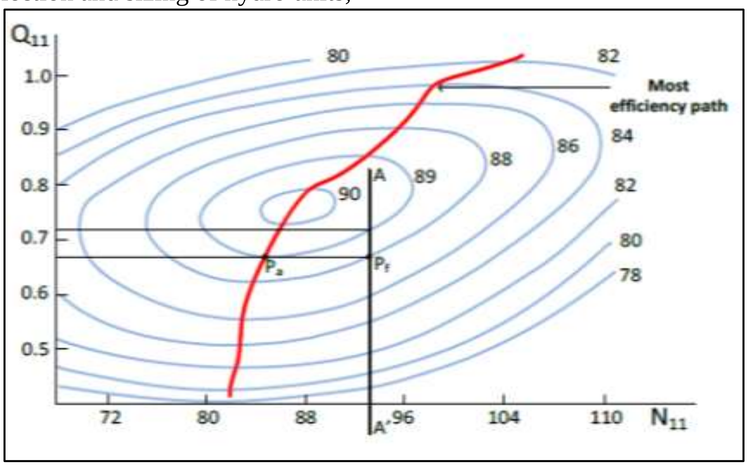

Fig. 5: Hill chart curves of a normalized hydro turbine

- Rapid response during load changes and emergency braking function;
- Relaxation of parameter requirements on machine design.

A. *Benefits from Unit Connection*

Large power plants are usually installed far away from load centers. In this situation, HVDC transmission is preferred. Conventionally, an AC transmission system, which connects the large power plant, local AC grid and HVDC converter station, is constructed. Considering the high investment of new AC line and the limited capacity of local AC grid, power conversion located at power plant side could be a convictive choice. Besides the new AC line, generator transformer can also be saved as only one voltage transmission step is desirable with the direct connection of generator and HVDC converter station.

Further, the AC filters, reactive power compensation devices on-load tap changers and most of the AC switch gears and busbars at the HVDC converter station can be removed. The capital cost and maintenance cost of converter station will be reduced to a great extent. Elimination of AC filter also avoids the danger of low order harmonic resonances [7].

V. Challenges and Design Considerations of DC Power Plant

Attracted by the major technical and commercial advantages of variable speed operation of hydropower stations, many researchers and institutes had studied the design issue of unit connection with HVDC Classic[8, 10, 17], whereas few study performed for unit connection with VSC HVDC, much less DC power plant. Anyhow, the plant optimizing design, control & protection, modeling and calculation are more complex than a conventional hydropower plant with a self-governed HVDC converter station.

VI. EXCITATION SYSTEM

The conventional excitation systems for hydropower generators are planned to operate at constant frequency. The performance of excitation systems and the stability of the whole system under variable speed need to be re-evaluated. In addition, due to the variable frequency of the AC system inside the plant, the auxiliary power supply for excitation system needs special design consideration. This disadvantage may not be a serious problem as a small capacity static frequency converter can be installed to provide auxiliary power to the whole plant.

VII. DC POWER PLANT WITH VSC HVDC STATION

Operating characteristics of unit connection with HVDC Classic and even diode valve based converter were studied [8, 10, 17]. For HVDC Classic connection, the AC voltage amplitude of generators will decline during low frequency operation to avoid flux saturation. This will result in decreased rectifier DC voltage and may limit the power transmission capacity. This issue can be resolved by using VSC HVDC station connection. VSC employs insulated gate bipolar transistors (IGBTs), which brings major advantages such as small size of converter station, independent reactive power control capability and islanding power supply. With VSC converter station connection, the DC voltage output of DC power plant is directly controlled by converter itself with faster speed. The AC voltage and DC voltage control are decoupled to a great extent. Besides, the electrical emergency braking of generators is easy to be implemented as the VSC station can realized power flow reverse quickly.

As the VSC converter has independent AC voltage/reactive power control capability, the coordination control between VSC and generator excitation system is needed, which may bring simplicity to the whole control system.

VIII. CONCLUSION

The DC power plant has considerable profits due to its variable speed operation, unit connection and additional commercial interests. It would have a very smart prospect in the countries with good potential hydro power resources, where most of the large hydropower bases to be constructed are far from the load centers. The HVDC Classic based unit connection technology had been well developed in the past decades. Based on the existing studies, DC power plant is more complex than a conventional hydropower plant with a self-governed HVDC converter station, while there is no big technical barrier for a practical system. With the VSC HVDC connection, additional advantages can be obtained such as decoupled AC and DC voltage control and fast electrical emergency braking. Although the authors are positive on the DC power plant technology, intensive studies and refinement design are needed to realize commercial application.

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