Research on interaction characteristics of multiple converters in oilfield power grid

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Abstract. With the wide application of new energy power generation and pumping unit frequency converter driving, the phenomenon of multiple converters installed has been formed in oilfield power grid. The interaction characteristics of multiple converters are vital to the stability and safety for oilfield production. This article introduces firstly the typical topology of multiple converters based on generation and consumption in oilfield power grid. The different combination forms of converters and the influence of DC bus control performance in the DC side are researched. Then interaction characteristics are analyzed based on the peak value of transient current and voltage, and the protection setting value. In order to improve the stability and safety of the system, the layout principle of the converters is proposed. Moreover, the ultimate capacity output principle is proposed to reduce the voltage and current stress. Finally, the correctness and effectiveness of the above are demonstrated through simulation and analyses.

1. Introduction
With the impetus of low-carbon emission reduction in petrochemical enterprises, wind power, photo voltaic and other new energy power generation forms are used widely, so more and more converters are used. The interaction characteristics of multiple converters are vital considerably to the stability and safety for enterprises production process. The relative converters (include AC and DC) and their communication protocols have been presented [1]-[3]. Parallels structure general repetitive control and its error convergence rate by using exponential function properties were investigated [1]. A multiple input non-isolated DC-DC converter design that collects the output power from series-connected very small wind turbines was proposed [2]. A communication protocol converter integrated with a multi serial, multiprotocol, and multi network system was introduced[3]. There are many kinds of production loads in oilfield, especially the pumping unit [4]-[6]. In order to accurately match to the complex dynamic loads, the dynamic load changes of the beam pumping units and a serial hybrid model for the motor load torque were studied [4]. The movement law of the beam pumping unit and proper simplification of the suspension point load were analyzed [5]. The beam-pumping-unit motion law was analyzed also in petroleum exploitation [6].

Battery energy storage and its converter also are a major part for interaction characteristics in oilfield power grid. An optimal control based energy management was proposed to minimize dynamically the adjustment cost in a microgrid [7]. The operation reliability aggregate battery energy storage is was analyzed [8]. A distributed dc grid connected photovoltaic (PV) generation
configuration based on hybrid-connected three-port converters (TPCs) and its control strategy were proposed [9]. The control strategy of multi converters have been proposed for different applications. According to the application requirements of the PWM rectifier in the auxiliary converter system of electric locomotive, the working principle and working condition of the model were analyzed [10]. A novel multimodular converter was provided multiple isolated modules connected in series through low frequency transformers to operate at medium voltage levels [11]. A comprehensive comparison of conventional table-based DPC, PI-based DPC and the proposed DPC methods was conducted [12]. A new linear profit-maximizing formulation for grid-connected merchant-owned energy storage systems operating with multiple ancillary services was researched [13]. An experimental platform of advanced power electronics that can accommodate both system- and component- level studies was introduced [14].

This paper mainly has the following contents. Firstly, this paper introduces the typical topology of multiple converters based on generation and consumption in oilfield power grid. Secondly, the influence of DC bus control performance and parameters in the DC side different connection are researched. Thirdly, interaction characteristics are analyzed based on the peak value of transient current and voltage, the protection setting value. In order to improve the stability and safety of the system, the layout principle of the converters is proposed. Moreover, the ultimate capacity output principle is proposed to reduce the voltage and current stress. Finally, the correctness and effectiveness of the above are demonstrated through simulation and analyses.

2. Multiple converters topology and interaction characteristics

2.1. Topological structure of typical applications

Power generation and compensation are two important classes of converters in oilfield. Pumping units are the main load of oilfield production, and their power consumption has the characteristic of reverse power generation and low relatively load rate. With the increasing diversification of manufacturers, as well as the implementation of energy saving and emission reduction technical solutions, a hybrid distribution network structure has been basically formed. With multiple converters have used widely in oilfield exploitation, the safety and reliability are becoming the important guarantee technologies for oilfield production. Topological structure of typical applications in oilfield is shown in Fig.1.

![Fig.1. Topological structure of typical applications in oilfield](image)

2.2. Characteristics of DC bus

Generally speaking, stable voltage is obtained for AC or DC converters with voltage source type topology, and the current or power are determined by the load. So the quality of voltage transient waveform is very important. The characteristics of DC bus voltage have significant impact on the harmonic or power. DC bus as an intermediate link, the voltage fluctuation process can be expressed as (1) for multiple converters with the common bus.

\[
\Delta u(k_i) = \Delta u_{dcm}(k_i) \pm \cdots \pm \Delta u_{dcm}(k_i \pm k_m) \pm \cdots \pm \Delta u_{dcm}(k_i \pm k_n)
\]  (1)
Where, \( k_1, \Delta u_{dc1} \) are the reference time and dc voltage; \( k_1 \pm k_m, k_1 \pm k_n, \Delta u_{dc_m}, \Delta u_{dc_n} \) are relative the reference time and dc voltage. Due to the influence of different switching frequency and dc voltage counteracting each other, the bus voltage fluctuation frequency is higher, and it is difficult to unify the linear expression. Here total voltage ripple of dc bus can be assumed as follow:

\[
u_{dc,\text{ripple}} = u_{dc1,\text{ripple}} + \cdots + u_{dc_m,\text{ripple}} + \cdots + u_{dc_n,\text{ripple}}
\]  

(2)

Where, \( u_{dc,\text{ripple}}, u_{dc1,\text{ripple}}, u_{dc_m,\text{ripple}}, u_{dc_n,\text{ripple}} \) are peak value of voltage ripple of corresponding converter on the same common bus. In order to ensure the normal operation of equipment, \( u_{dc,\text{ripple}} \) can be treated as the lower limit of dc protection voltage threshold of the converter.

3. Research contents and principles

3.1. Three aspects considered for interaction characteristics

Although the functions of devices are different in Fig.1, they all have similar external characteristics. The peak value of transient current and voltage, and the protection setting value of converters are different separately. The setting of these parameters can ensure the safety of the converter under harsh working conditions and improve the performance index of operation. According to above-mentioned analysis, multiple converters can optimize the above parameters without changing the original control strategy and function, which makes it possible to optimize the operation in a specific scenario. For instance, the protection setting value of the converter can be optimized to give full play to the reserved capacity potential of the converter, and then contribute to the improvement of the whole system.

3.2. System layout principle of the converters

Typical layout of one scene in oilfield is shown Fig.2. In practically, the application of converter should meet the requirements of energy saving, easy maintenance, and so on. At the same time, the centralized control of different converters should be satisfied, and the communication lines should be considered. Therefore, the following principles are put forward for reference.

1. AC/DC converter1 and AC/DC converter2 in Fig.2 as node converters should be time-sharing multiplexing function, so that the capacity can be used fully, and the energy loss of the converter can be reduced under light load.

2. According to the load distribution, the same type of frequency converter shall be arranged as close as possible, so as to facilitate unified setting in terms of starting time and speed characteristics, and reduce the over-voltage and over-current pressure of distribution network brought by frequency converter.

4. Ultimate capacity output principle
4.1. Premise or assumption
For a class of power electronic equipment, in order to explore the potential ultimate capacity output ability, that hypothesizes are observed as follows:
1. The electrical installations or products involved have the same or similar characteristics operating states and protection setting values;
2. The ultimate capacity output values must be within the scope of safety;
3. Multiple devices follow the same control protocol that ensures the consistency of adjustment.

4.2. Implementation method and process
In Fig.3, the implementation method and process are illustrated based on three kinds of equipment under hypothetical situation Here D₁, D₂, D₃ are three frequency converters, S₁, S₂, and S₃ are three stages of operation, n₁, n₂, n₃, n₄, n₅, n₆, n₇, n₈, and n₉ are nine fixed values. Take D₁ for example, n₉ is the maximum value of a variable under state S₃. It is assumed here that it is the peak of the voltage at a detailed level. ① is allowable value or adjustable value under stage S₂-S₃; ② is allowable value or adjustable value under stage S₁-S₂. The voltage and current maximum values of the common bus line under continuous state, the values upper limit as follow:

\[
\begin{align*}
I_{\text{max}} & \leq i(t_1) + i(t_2) + i(t_3) \\
U_{\text{max}} & \leq u(t_1) + u(t_2) + u(t_3)
\end{align*}
\]  

(3)

Based on the above situation, it can be considered when wind power or photo voltaic power are sufficient, the charging capacity of the energy storage converter can be improved, so as to reduce the line loss of energy flow.

Fig.3. System layout of one scene in oilfield

5. Simulation Result and Analysis
With the change of load, the change of common DC bus voltage is frequent. In Fig.4, the corresponding curve changes of DC bus voltage and \(u_{\text{dc}}-u_{\text{eq}}\) under load variation can be seen from 0.3s to 0.5s, the ripple of DC bus voltage is increased up to about 12V. Return to original state at 0.6s the ripple of DC bus voltage up to original size also.

Fig.4. Curves of \(u_{\text{dc}}\) and \(u_{\text{dc}}-u_{\text{eq}}\) under load variation

With the above simulation conditions unchanged, the DC bus voltage changes as follows after adding energy storage DC converter. The DC voltage reduction setting value as 240V after adding
DC/DC converter circuit, the curves of $u_{dc}$ and $u_{dc1}$ (actual value of DC/DC) can be seen in Fig. 5. The change of waveform is mainly caused by the change of DC side load impedance.

6. Conclusions
The typical topology of multiple converters based on generation and consumption in oilfield power grid has been researched, and the related characters and optimization method also have been involved. The main conclusions of the paper are as follows: the peak value of transient current and voltage, and the protection setting value that can be used to response the interaction characteristics between multiple converters. The parameters of multiple converters can be optimized without changing the original control strategy and function, which makes it possible to optimize the operation in a specific scenario. The key technologies focus on the definition of application scale, and how to centralize control and management in the future.

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