ICIEA 2022

16 - 19 Dec 22

Chengdu, China

ICIEA22-000350
Economic Analysis and Research of Electronic Traction Transformer used in Flexible Traction Power Supply System

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INTRODUCTION

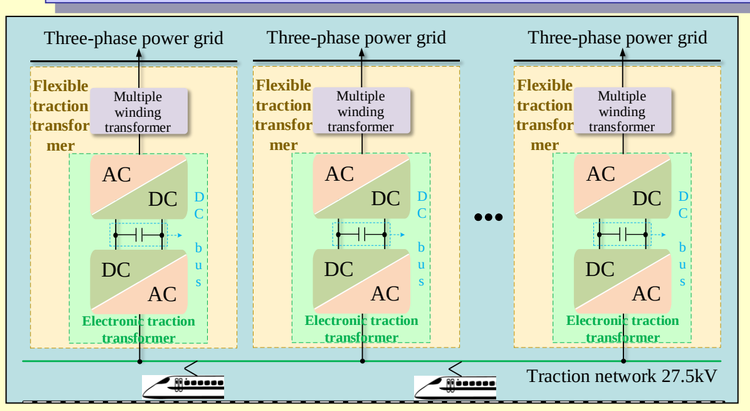

Fig. 1. Structure of studied system

Flexible traction power supply system by using the level - single-phase three-phase converter converts three-phase grid side of 110 kV voltage single-phase ac traction net 27.5 kV, and its system structure is shown in fig. 1. An appropriate and comprehensive economic analysis method is explored.

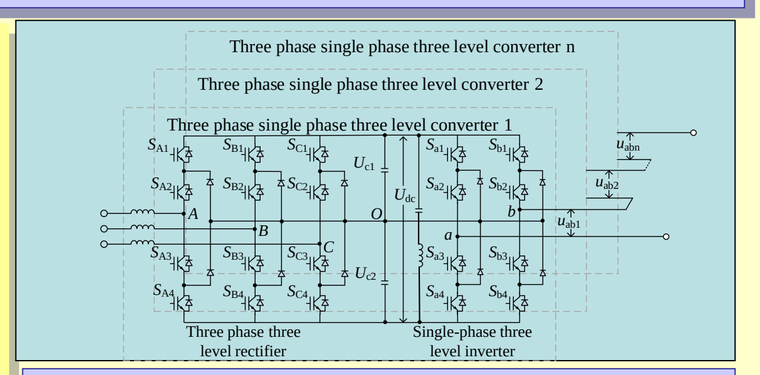

Fig. 2. Topology of electronic traction transformer

ELECTRONIC TRACTION TRANSFORMER AND ITS SIMULATION

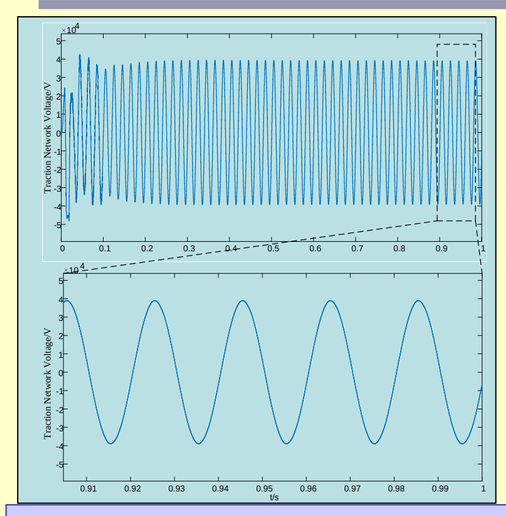

Fig. 3. Output voltage waveform of the traction network side（3300）

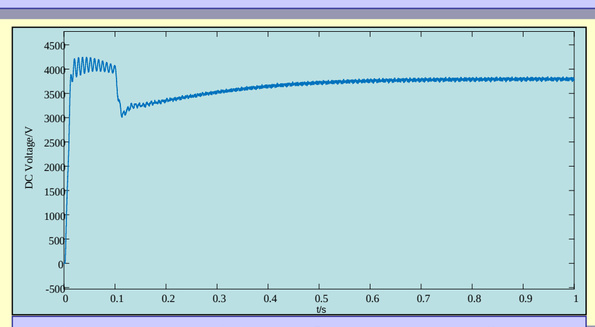

Fig. 4. Dc side voltage waveform（3300）

The current mainstream IGBTs with 1700V, 3300V and 4500V voltages were selected to design the device parameters of the three schemes, and Matlab/Simulink software was used to build the simulation model of electronic traction transformer. Taking the 3300V scheme as an example, the load is connected at 0.15s, Its effective value is 27.5kV, which meets the design requirements. Its DC side can be stabilized at the design value of 3800V.

AVERAGE MTTF OF ELECTRONIC TRACTION TRANSFORMER

$$R_{Rec}(t) = e^{\sum_{i=1}^{12}\lambda_{IGBTi}t - 6\lambda_{D1}t}$$

$$R_{Dc}(t) = e^{-2\lambda_C t}$$

$$R_{LC}(t) = e^{-\lambda_C t - \lambda_L t}$$

$$R_L(t) = e^{-3\lambda_L t}$$

$$R_{Inv}(t) = e^{\sum_{i=1}^{8}\lambda_{IGBTi}t - 4\lambda_{D2}t}$$

$$R_S(t) = e^{\sum_{i=1}^{20}\lambda_{IGBTi} - 6\lambda_{D1} - 4\lambda_{D2} - 4\lambda_L - 3\lambda_C}$$

$$R(k,n) = \sum_{i=k}^{n} C_n^i e^{-i\lambda t}(1-e^{-\lambda t})^{n-i}$$

The reliability of the system

$$T_{MTTF} = \int_0^\infty R(t)dt = \int_0^\infty \sum_{i=9}^{n} C_n^i e^{-i\lambda_{mk}t}(1-e^{-\lambda_{mk}t})^{n-i}$$

The MTTF of the system

When the number of system modules changes from n-1 to N, the contribution to improving system reliability changes according to the following law: With the increase of N value, the contribution of the Nth module to the overall system reliability decreases successively. Under the premise of ensuring reliable operation, the reliability and economic cost of multi-objective optimization.

SYSTEM ECONOMIC ANALYSIS

$$L_{IC} = C_{ET} + C_{MT} + C_{CE} + C_{in} + C_{RP}$$

The initial investment cost

$$C_{ET} = N(\sum_{i=1}^{N_{Sre}} C_{igbtre} + \sum_{i=1}^{N_{Sin}} C_{igbtin} + \sum_{i=1}^{N_{Dre}} C_{vdre} + \sum_{i=1}^{N_{Din}} C_{vdin} + \sum_{i=1}^{N_{cap}} C_{cap} + \sum_{i=1}^{N_l} C_l + \sum_{i=1}^{N_{Sre}+N_{Sin}} C_{db} + C_{aps}) + C_{others}$$

$$C_{CE} = N(r_{bm}S_{bm} + m\Delta C)$$

$$C_{in} = (C_{ET} + C_{MT})\square a_{in}$$

$$C_{RP} = k_{bre}\square C_{bre} + k_{ds}\square C_{ds}$$

$$CE = MTTF / L_{IC}$$

Reliability - Cost effectiveness

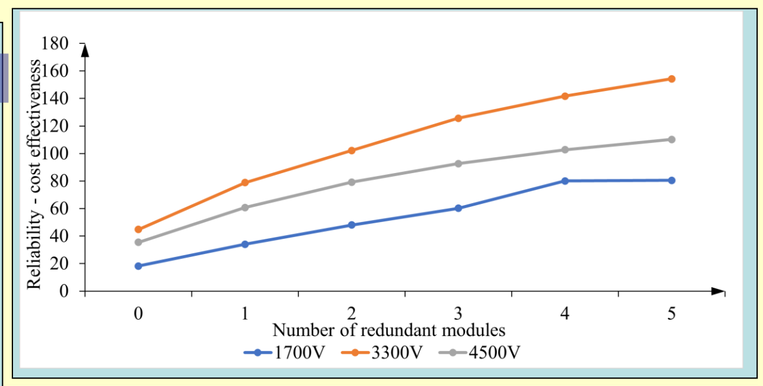

Fig.4. Reliability – Cost effectiveness

This article recommended 15 modules cascade structure design, its average trouble-free working time was about 4.3 times the 11 modules without redundancy, reliability benefit is 3.2 times than 11 modules for redundancy.

Summary

In this paper, the parameters of the system and the number of expansion modules are designed and verified by simulation under the scheme of 1700V, 3300V and 4500V pressure-resistant IGBT for three-level three-phase to single-phase cascaded converter, and its reliability - cost - benefit analysis is carried out. The results show that the electronic traction transformer with 3300V IGBT has the best reliability and cost-benefit. Combined with the research results, this paper proposes to adopt the electronic traction transformer scheme with 3300V voltage class 15 module cascade. Its average fault-free working time is about 4.3 times of that without redundancy, and its reliability benefit ratio is 3.2 times of that without redundancy.