No-load Voltage Waveform Analysis of Large Tubular Hydro-generator under Damper Bar Broken Down Failure

Z. GUANGHOU [1, 2], Z. ZHITING[3], H. LI[2], F. ZHENNAN [3*], L. JIANFU [1]

[1] Chongqing University

[2]Dongfang Electrical Machinery Company Limited

[3]Xihua University

China

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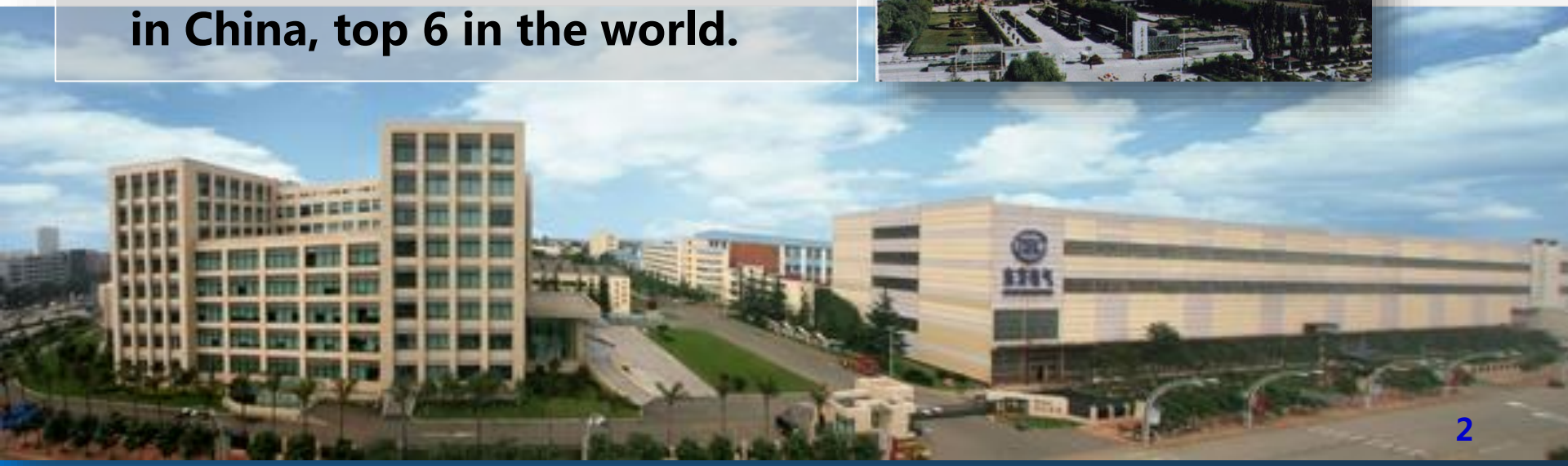
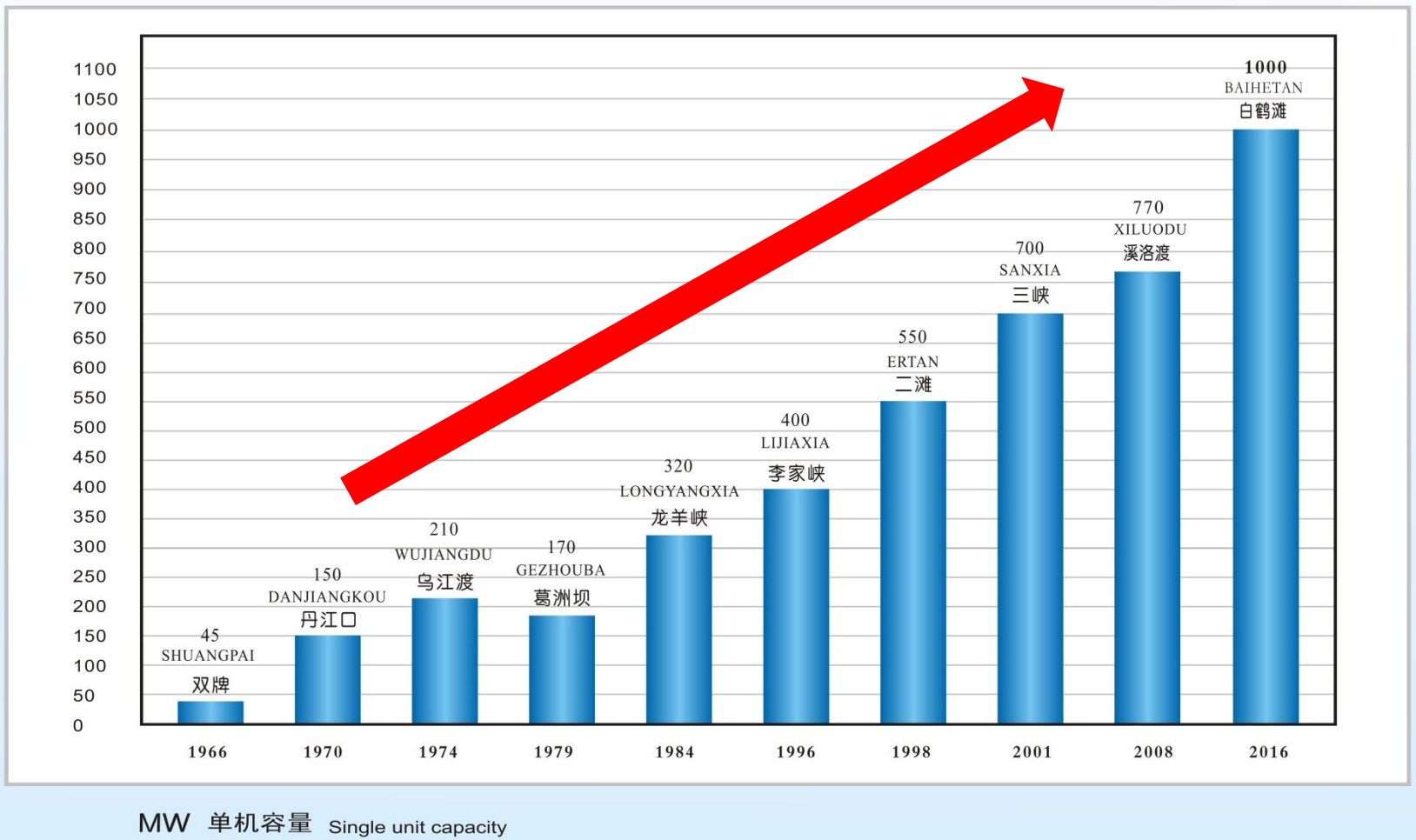
Preface

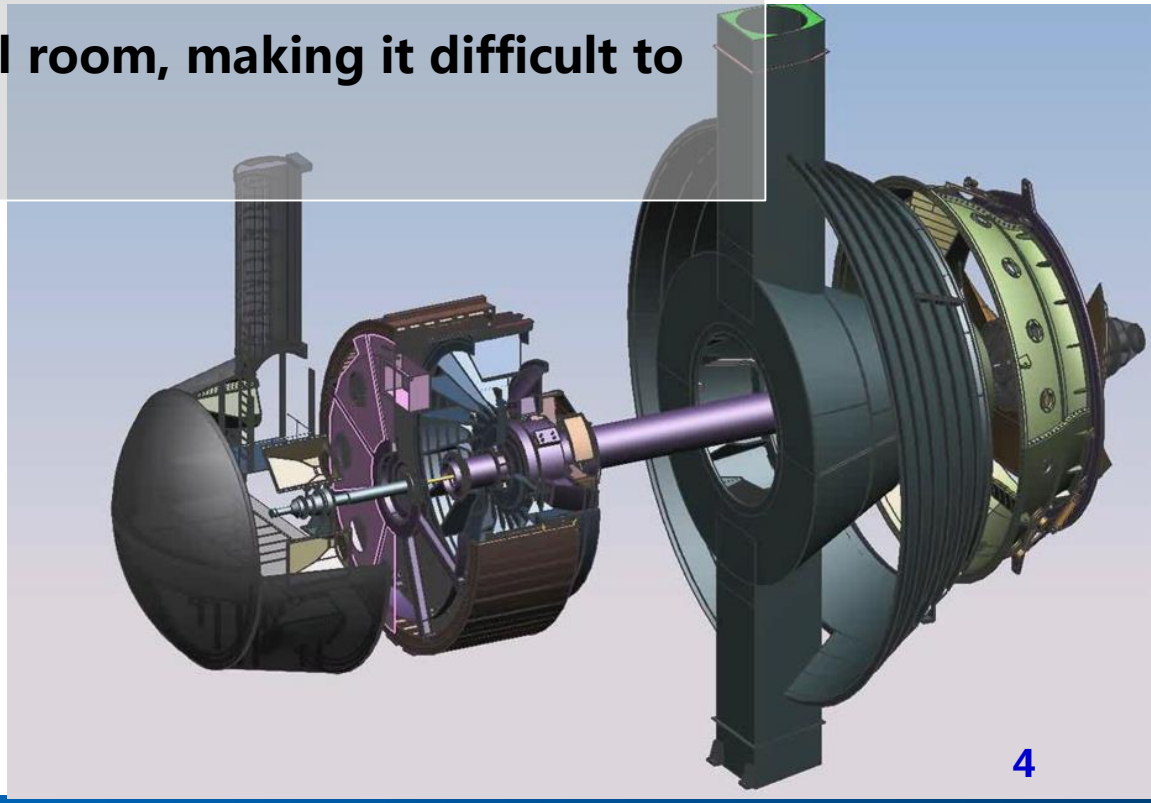
- A fully state-owned company
- A core enterprise of Dongfang Electrical Corporation (DEC)
- One of the top 3 manufacturers of power generating equipment in China, top 6 in the world.





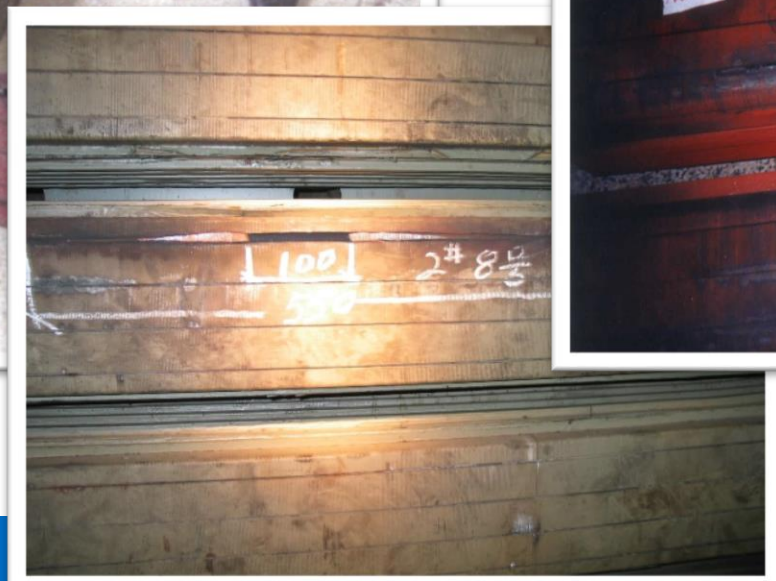
Preface

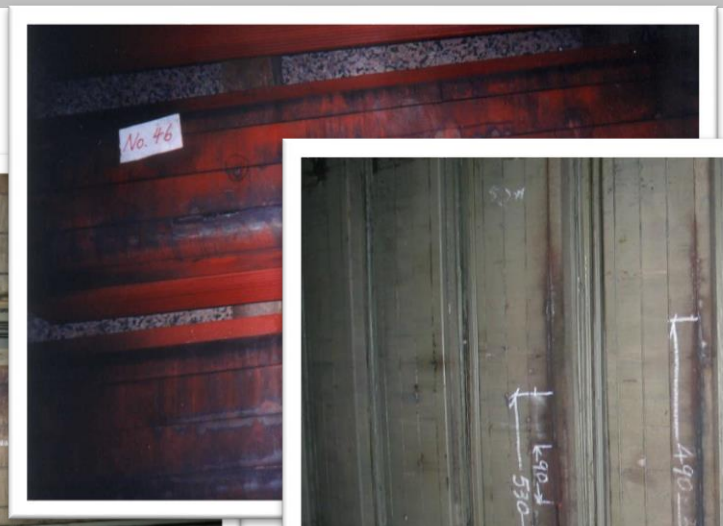
- Bulb Type Hydro Generator unit
- Making use of low water head flow and tide energy,
- Developed profoundly in china in recent years
- Low rotation speed, small room, making it difficult to design and maintain.

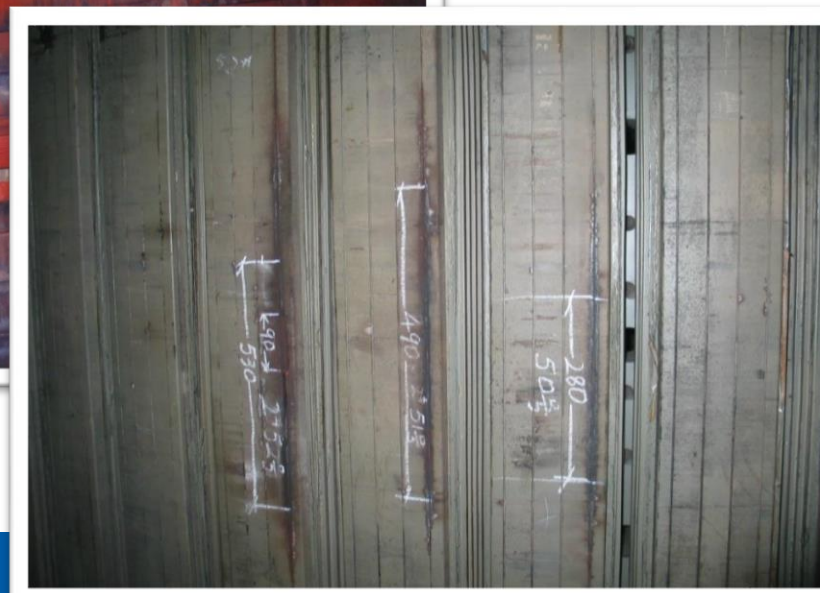


Preface

- The no-load voltage waveform harmonics have important influence on the security of power grid and power supply quality
- Damper bar design scheme has great influence on the generator no-load voltage waveform quality
- Damper bar broken down failures in China







Object

- **How to detect broken bar failure in time to minimize loss?**
  - **Most studies were done for IM (induction machines);**
  - **The possibility of detecting bar failure by voltage waveform surveillance on synchronous machine?**

Object

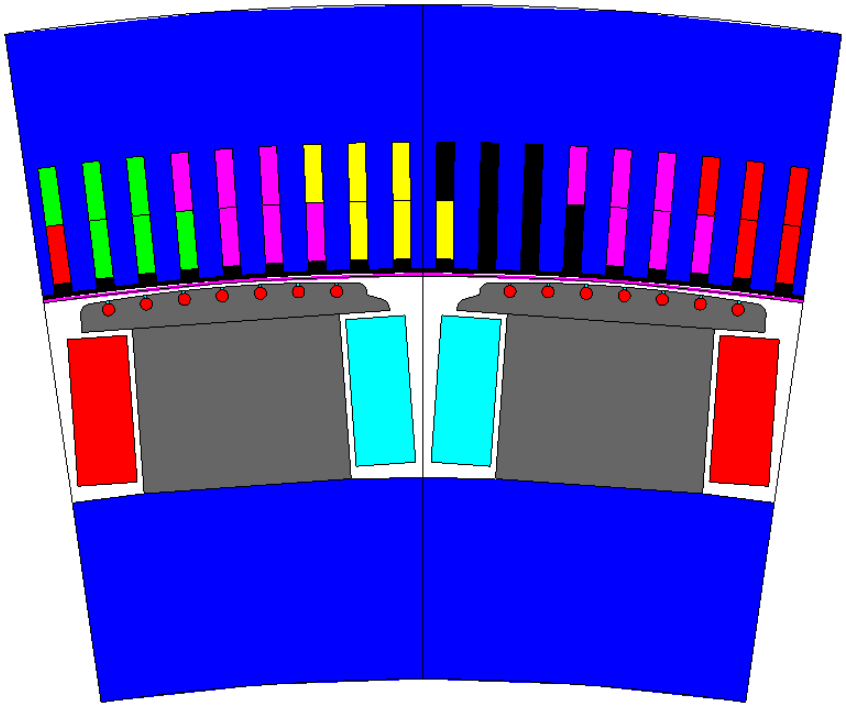
- **To ensure the OC voltage wave shape quality and provide reference for detecting damper bar broken down failure:**

1) **Verify the accuracy and rationality of the analysis by a site test.**
2) **Study different structure design schemes and broken down situations' influence on OC voltage wave shape quality and harmonics**

➢ Design schemes comparison:

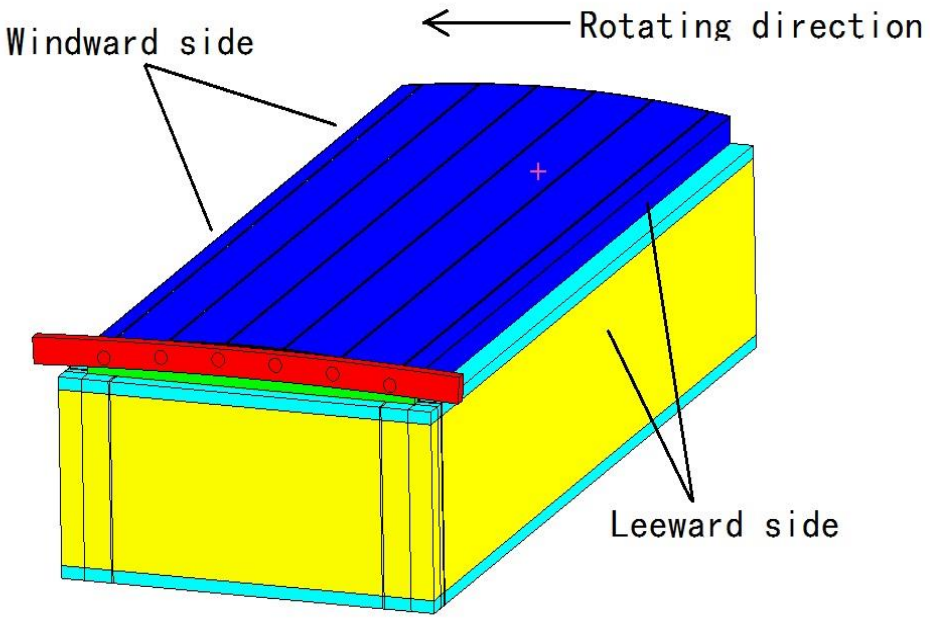
	Rotor pole and damper bar shift pitch	Stator slots skew pitch
1	0	0
2	$t_1/4$	0
3	0	$t_1/2$
4	0	t_1

t_1 is the stator tooth pitch



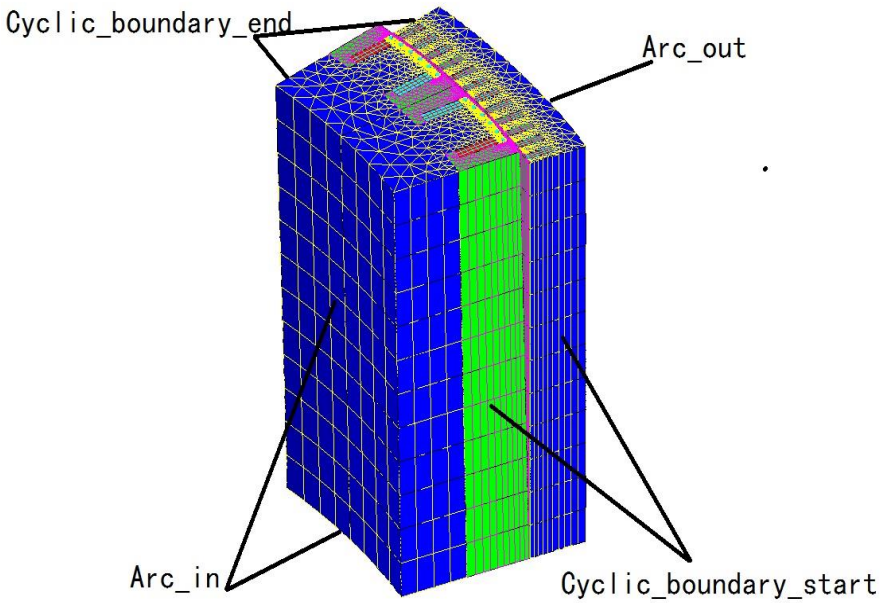
Example of pole/ damper bar shifted

➢ Numerical Models:



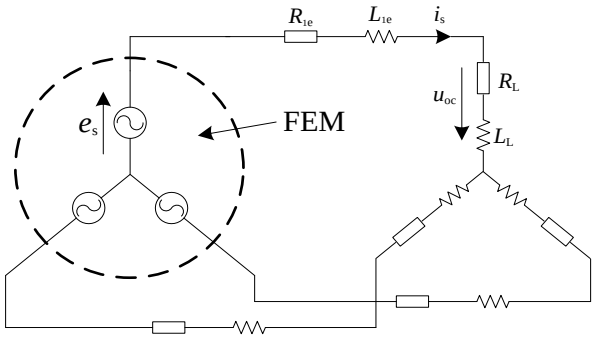
➢ Numerical Models:

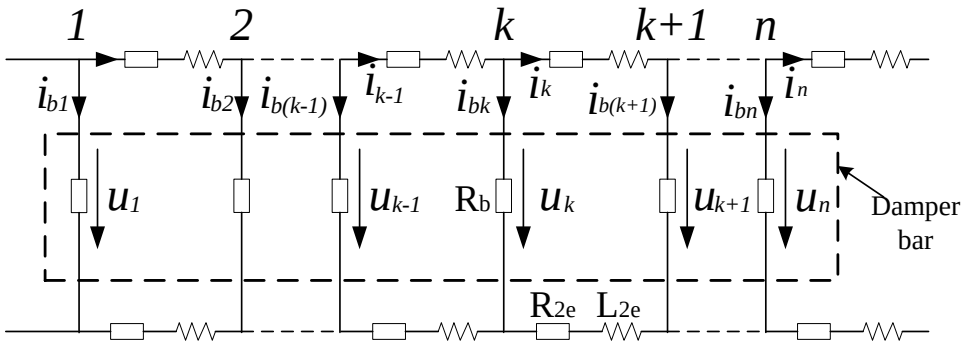
Parameter	Value
Rated power P_N (MW)	34
Rated voltage U_N (kV)	10.5
Rated current I_N (A)	1968
Rated Power factor cosφ_N	0.95
Number of magnetic poles 2p	44
Number of damper bars per pole N_b	6
Number of slots per pole per phase q	2



Stator slot skewed

FE Coupling:

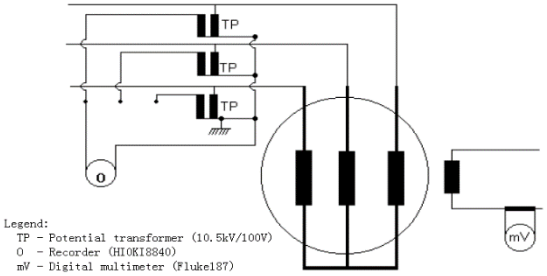


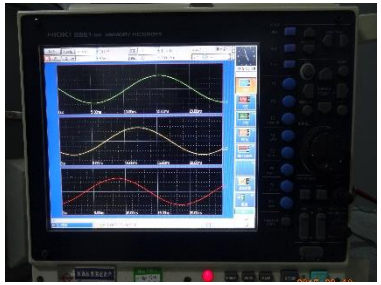


FE Coupling circuit of the stator winding and damper bar winding

Test & Verification

➢ Test on site:





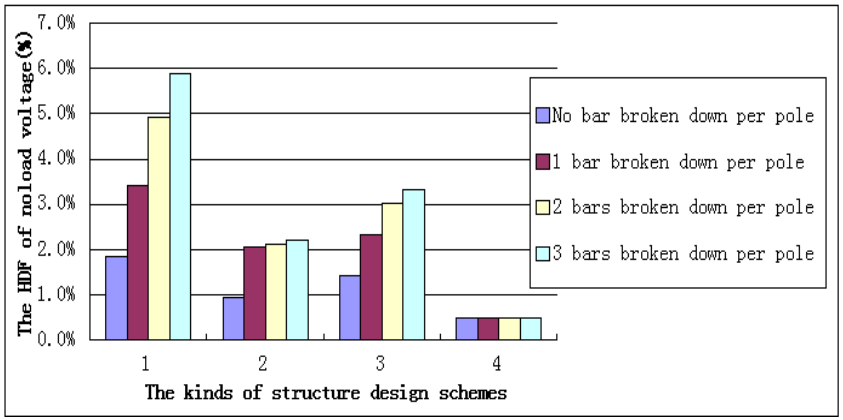
	Harmonics of the no-load voltage (%)					Voltage quality	
	1	11	13	23	25	HDF(%)	THF (%)
Calculated	100	1.512	0.799	0.044	0.150	1.843	1.172
Measured	100	1.550	0.816	0.039	0.161	1.850	1.186

OC voltage wave shape quality calculation vs measurement

The accuracy and rationality of the calculation model of this paper are successfully verified.

Calculation Result

➢ The no-load voltage waveform quality:

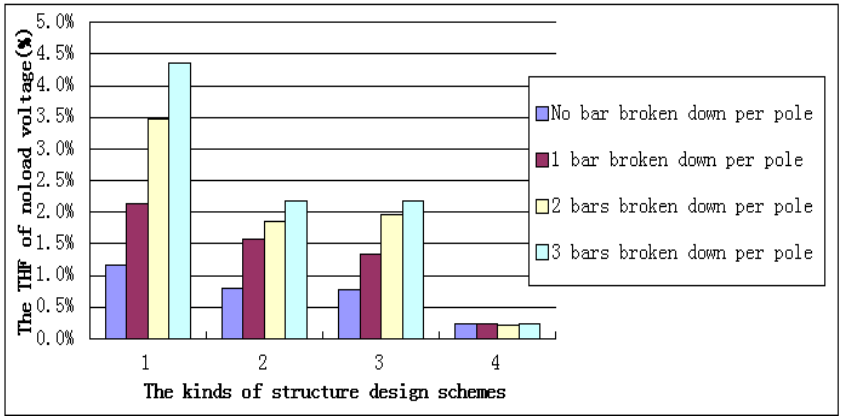


HDF (Harmonic Distortion Factor)

$$HDF = \frac{\sqrt{U_2^2 + U_3^2 + \cdots\cdots + U_n^2}}{U_1} \times 100\%$$

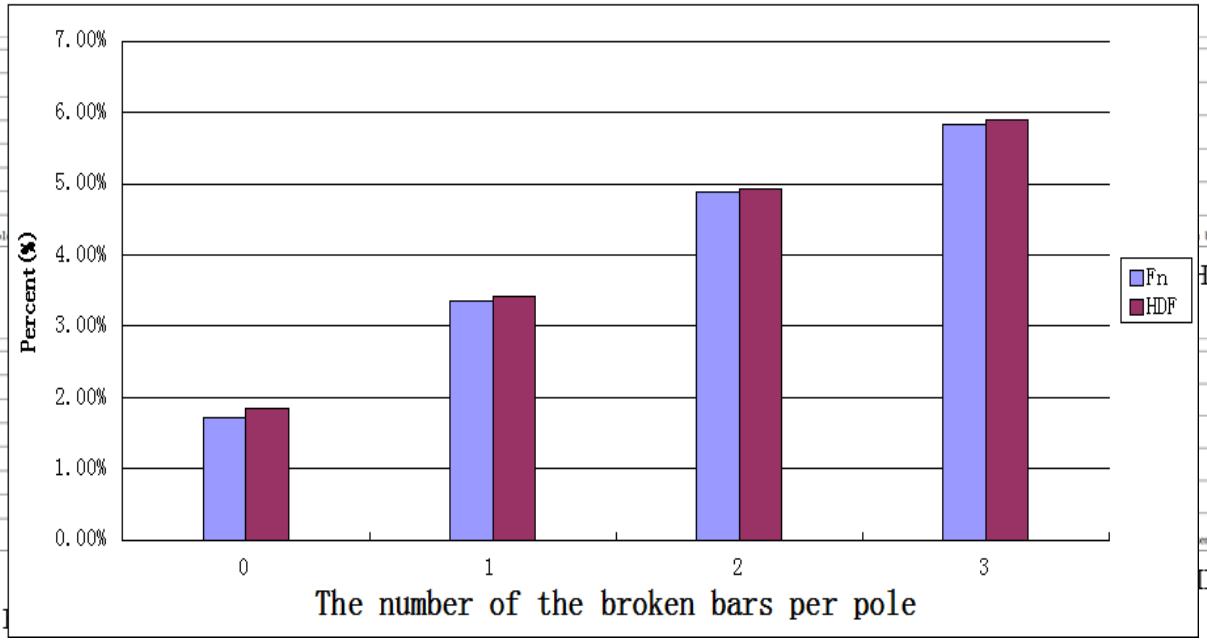
(Telephone Harmonic Factor) THF

$$THF = \frac{\sqrt{U_1^2\lambda_1^2 + U_2^2\lambda_2^2 + ... + U_n^2\lambda_n^2}}{U} \times 100\%$$



Calculation Result

The Harmonic analysis:



(a)F_n and HDF

(a)F_n and HDF

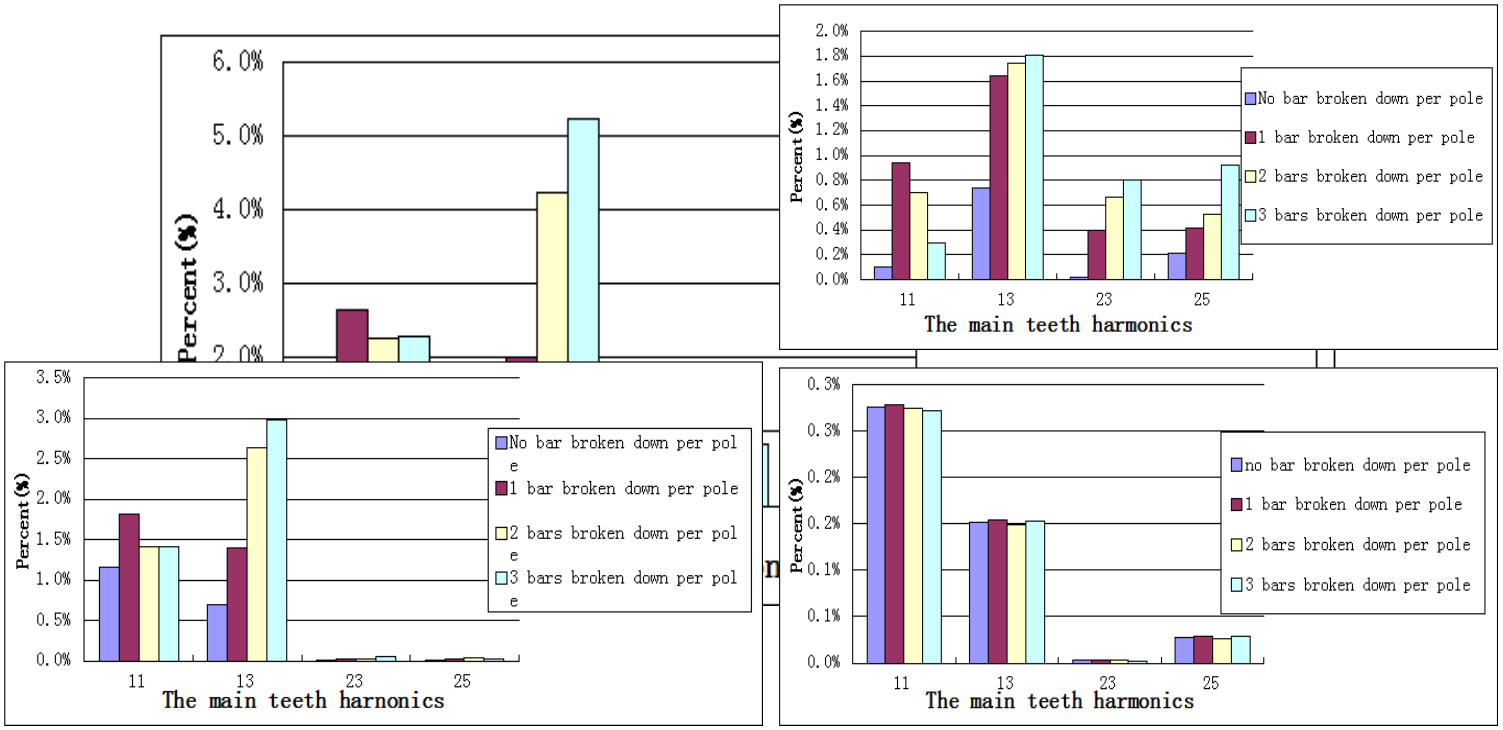
$$F_n = \frac{\sqrt{U_{11}^2 + U_{13}^2 + U_{23}^2 + U_{25}^2}}{U_1} \times 100\%$$

$$T_n = \frac{\sqrt{U_{11}^2\lambda_{11}^2 + U_{13}^2\lambda_{13}^2 + U_{23}^2\lambda_{23}^2 + U_{25}^2\lambda_{25}^2}}{U} \times 100\%$$

The 1st (11th and 13th) and 2nd (23rd and 25th)order tooth harmonics have decisive influences on the no-load voltage waveform.

Calculation Result

The Harmonic analysis:



Scheme 1, 2 and 3: more broken bars, worse wave shape;

Scheme 4: no influence

Conclusion

➢ Conclusion :

TWO ways to get better wave form (esp. for q = 2):

I. **pole shoe and damper winding shifted 0.25t_1**

- tooth harmonics reduced effectively, acceptable wave shape
- damper failures can be detected by HDF/THF;

II. **stator slots skewed t_1**

- Best wave shape.
- increased difficulties of manufacturing, may cause other problems.
- damper bar fails can not be detected easily

Thanks for your attention !