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TESTING OF COMPONENTS USED IN ELECTRICAL POWER DISTRIBUTION SYSTEM

DP/DRK/86/003

DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA

Technical report: Assistance in Short Circuit Generator Design and Manufacture *

Prepared for the Government of the Democratic People's Republic of Korea
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of P. Stuchl
Expert in Short-Circuit Synchronous Generators

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United Nations Industrial Development Organization
Vienna

* This document has not been edited.

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CONTENTS

ABSTRACT

The mission has been undertaken under the post 11-03 of the project DP/DRK/86/003, Testing of Components Used in Electrical Power Distribution System as a follow-up to a preparatory assistance phase which led to the concerned project being approved in May 1988.

The objective of the mission was to assess the possibility of, and requirements for, the production/reconstruction of a Short Circuit Generator by local industry with the view of assisting the Government of the DRK in the creation of a central testing laboratory to accelerate the country's expertise and experience in short-circuit testing of switchgear and other system components. The duration of the mission was 1 month, starting October 1988.

As a result, a Short Circuit Generator Design Manual was elaborated with related instructions and technical information for the parameter design and manufacture. According to this Manual, the Short Circuit Generator shall be designed in the Turbogenerator Design Department of the Institute of Dae-An Heavy Machine Design upon completion of a fellowship training programme which is supposed to be arranged with SKODA, Pilsen.

INTRODUCTION AND RECOMMENDATIONS

A. Introduction

The Government of DPRK accords high priority to quality of switchgear and other equipment delivered by national industry in order to improve electrical power distribution system.

At this time, no national facilities exist to produce such testing. The Institute of Machine Industry has prepared a concept of a Short Circuit Laboratory with an option of using nationally produced power supplying machines.

The UNDP project document "Testing of Components used in Electrical Power Distribution System" also takes into account the fact that the heavy equipment of the laboratory such as the Short Circuit Generator can be provided by the Government from local industry adjusting it to the purpose for which it is used. The above-mentioned project document assumed that an existing and redeveloped/reconstructed synchronous generator of 50MW capacity can be applied.

B. Recommendations

1. The existing 50MW turbogenerator designed and manufactured for power station operation is, in its present stage, not suitable for the Short Circuit Laboratory because of its inadequate parameters related to short-circuit testing and its possible application to the purpose of SCL would require quite substantive constructional changes.

2. The generator used in Short Circuit Laboratory should be designed for the special work of the Short Circuit Generator which is in the nature of a repeated intermittent load and enable the Short Circuit generator to generate alternating currents of high intensities. The design of the Short Circuit Generator should fulfil the requirements mentioned in Annex III.

3. The Leading Project Engineer of the Short Circuit Laboratory is recommended to provide the Short Circuit Generator with such excitation system that makes it possible to change the excitation voltage immediately.

4. The manufacturer of the Short Circuit Generator the Dae-An Heavy Machine Complex is recommended to send engineers who are responsible for the design and production of the Short Circuit Generator to SKODA, Pilsen for fellowship training. The Turbogenerator Design Department of the Institute of Dae-An Heavy Machine Design should prepare the design documentation of the Short Circuit Generator after the completion of this training.

5. The manufacturer of the Short Circuit Generator the Dae-An heavy Machine Complex is recommended to prepare also, an alternative solution in case that the redesign and reconstruction of the 50MW turbogenerator does not guarantee short circuit currents according to project requirements.

6. The Czechoslovak Foreign Trade Corporation Polytechna is recommended to arrange the fellowship training at SKODA, Pilsen which should include training in disciplines according to Annex VI.

I. OBJECTIVE OF THE ACTIVITY AND DUTIES

A. Objective

The objective of the mission was to provide consultancy on short circuit generator design and assess the possibility of and requirements for producing/reconstructing the special generator of 50MW capacity for a Short Circuit Laboratory by local industry.

B. Duties

According to the Job Description, the duties of the author were as follows:

1. Consultancy on generator design and foundations of a short circuit generator and motor.
2. Supervision of stator assembly, testing of windings and final assembly of the machine.
3. Assistance in running tests and performing vibration measurements.
4. Commissioning of the machine and auxiliary equipment.
5. Training of maintenance staff.
6. Submit a detailed report after completion of each split mission. This report must describe findings of the mission and provide conclusions/recommendations for immediate as well as long-term actions.

II. DESCRIPTION OF ACTIVITY

A. Visits to industry

An initial meeting establishing the programme of visits and subsequent activities, was held with Mr. Ko Ju Chol, senior official, Fifth Department of the Ministry of Foreign Trade. From the Ministry of Machine Industry, Dr. Kim Jong Ho, the Head of the laboratory in the Institute of Machine Industry was present. The latter has been appointed a partner to the author, responsible for design and production of the Short Circuit Generator, explaining problems and organizing visits to factories.

Two large-scale factories of electrical equipment have been selected for appropriate visits. Some of their products were relevant to the author's activity. During the visits to both of these factories, chief engineers and other staff presented actual products and outlined some development problems.

The Dae-An Heavy Machine Complex

This heavy machine complex has been established in 1980, machinery and electrical production has more than 40 years of tradition in this place. Production programme of this multiplex combine comprises transformers, hydrogenerators, turbogenerators, motors, steam and hydro turbines, boilers, gears and other machinery products.

The Dae-An Heavy Machine Complex is a unique manufacturer of hydrogenerators, turbogenerators and large motors in the country. Especially production of hydrogenerators achieved high parameters, i.e. rated output 125MVA at voltage of 16kV and speed 163.6 rpm.

The turbogenerator production development is quite impressive. Since 1980 the Dae-An heavy Machine Complex manufactured 4 types of turbogenerators from 6MW up to 60MW.

The production programme of the Dae-An Complex in the branch of synchronous machines is enclosed as Annex IV. The newly equipped production hall enables the production of high-capacity hydrogenerators, turbogenerators and motors.

The author's attention was paid to the turbogenerator production and testing. The piece of information concerning the production of 125 MVA turbogenerator offered to the BSO in Vienna was not accurate enough. This 125MVA synchronous machine is a hydrogenerator.

The Complex has manufactured the first 50MW turbogenerator in 1982. Design parameters are attached as Annex II. This turbogenerator was not delivered to any power station. At the present time this 50MW turbogenerator is still at the Complex.

The new type of 60MW turbogenerator is being manufactured at the present time. This hydrogen-cooled turbogenerator is designed for the voltage of 11 kV, the class of insulation is F. The design of the turbogenerator is similar to the USSR Elektrosila factory design.

The Institute of Dae-An Heavy Machine Design employs roughly 600 engineers and technicians. The Turbogenerator Design Department of this Institute employs 25 designers (15 engineers and 10 technicians). They provided technical information related to Short Circuit Generators from journals and reviews which were published in the USSR and Japan.

The Dae-An Heavy Machine Complex is equipped with centrifugal tunnel. This tunnel delivered by Schenck firm was installed in 1984. The centrifugal tunnel enables the company to balance rotors up to weight 32 tons at speed of 4,320 rpm.

The present conditions of the turbogenerator testing plant do not allow for 50MW turbogenerator tests, such as measurement of no-load characteristic, measurement of short circuit characteristic and sudden short circuits at reduced voltages. Therefore the 60MW turbogenerators will be tested directly at the power station.

The Technical Development Department of Dae-An Heavy Machine Complex is now preparing a turbogenerator testing plant which enables them to perform the above-mentioned measuremnts in future.

The visit to the synchronous generator factory of the Complex and the interview with the engineers responsible for design and production of Short Circuit Generator proved that the decision to produce the Short Circuit Generator in the Dae-An Heavy Machine Complex is right.

However, there are also indications* that the related 50MW turbogenerator seems to be unsuitable for the Short Circuit Laboratory purpose and any rebuilding/rewinding of this turbogenerator would be impractical.

The 5th June Electric Factory in Kyongsong

The production programme of this electric factory is described in the technical report DP/IO/SER.A/974 prepared by an expert in power system equipment engineering under this project in February 1988. The author of this report wishes to complete the given information only.

The factory produces 800 types of insulators. One year production amounts to 3,000 tons. Part of the production is exported.

The type, denomination and some parameters of the oil circuit breakers are described in Annex V.

Research and development of products is made locally. The Technical Department employs roughly 500 engineers and technicians. The High Voltage Laboratory is equipped with alternating voltage source of 1,000kV. This source can generate pulse voltage of 1,800kV also.

The current testing of the resistors for circuit breakers is executed by the pulse current source of 15 kA. This source consists of the condensers battery. The capacity of each condenser is 3 mikroF at voltage of 50 kV.

The equipment of the laboratories is in full operation. The creation of Short Circuit Laboratory allows a complete testing of products in future.

The assumed location of the Short Circuit Laboratory is nearby the High Voltage Laboratory. The siding is situated between these laboratory places.

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* See Mr. Cesul's/Mr. Podgorski's letter dated 20 May 1988.

B. Lecture

During the stay in the 5th June Electrical Factory in Pyongyang, a lecture was given for the technical staff. The title was: "Short Circuit Generator operation in the Testing Laboratory for Electrical Apparatus".

The objective of the lecture was to explain the function of revolving electric machines, such as Short Circuit Generator, driving inductive motor, pilot generator and excitor in the laboratory.

III. SHORT CIRCUIT GENERATOR DESIGN MANUAL

A. Data Information of the 50MW turbogenerator

Data information was handed over to the author by the general designer of the synchronous generator of the Institute of Dae-An Heavy Machine Design. The design drawings were also at the disposal of the author. The data were completed with further characteristics. All above-mentioned data are attached in Annex II.

According to this data information it will be possible to increase the no-load stator voltage because:

- the no-load characteristic is not saturated at rated voltage
- the stator winding is parallel connected and this connection can be changed into serial connection
- the air gap can be reduced
- the field winding can be overloaded during the short time operation
- the Dae-An Heavy Machine Complex manufactured hydrogenerator stator windings for the voltage up to 16kV.

B. General summary of the Short Circuit Generator

Short Circuit Generator is a synchronous machine of which a part of the kinetic energy of the rotor, and the magnetic field excited by direct current, are utilised for a repeated short time generation of alternating current of high intensities. Considered as an output is, in this case, the three-fold product of the root-mean-square phase voltage prior to the short circuit and the alternating components of the current after the short circuit at the terminals of the machine.

The time characteristic of the current is given by the equation

$$N(t) = Uo \left[\frac{1}{x_d} + \left(\frac{1}{x'_d} - \frac{1}{x_d} \right) e^{-\frac{t}{T'd}} + \left(\frac{1}{x''_d} - \frac{1}{x'_d} \right) e^{-\frac{t}{T''d}} \right]$$

which describes the time decrement of the alternating component of the current.

The electromagnetic design of the Short Circuit Generator should be performed from the economic point of view and in such a way that the highest value of short circuit current at rated voltage and present generator dimensions can be reached. According to the above-mentioned equation the short circuit current value is an inverse proportion to reactances x''_d and x'_d. The values of reactances x''_d and x'_d depend on electromagnetic leakage reactances of the stator winding, damper and field winding.

Therefore short circuit generators are usually designed, contrary to turbogenerators i.e. with single layer winding and shallow slots of the stator and rotor.

C. Fixation of Short Circuit Generator Parameters

According to the Project Document the testing circuits of the Short Circuit Laboratory should be provided with short circuit current up to 40kA at voltage to 10kV.

Following parameter corresponds to these requirements:

- rated stator no-load voltage of 12kV
- testing current (by the end of 3rd period) of 40 kA
- rated short circuit current (limited by reactance x''_d only) of 50kA

- subtransient direct-axis reactance at rated voltage	X''_d	=	0,138 Ohm
- duration of testing current	t_T	=	50 ms
- number of tests in series	n	=	3
- time between single tests	t_B	=	180 s
- duration of unexcited running between series	t_U	+	1,800 s
- class of insulation	F		
- nominal torque at 3-phase short circuit	M_{k3}	=	2,205 kNm (60 Hz)
- nominal torque at 2-phase short circuit	M_{k2}	=	3,308 kNm (120 Hz)
- max. torque at crash short circuit	M_{max}	=	4,152 kNm (120 Hz)

D. Discussion about 50MW turbogenerator reconstruction

The 50MW turbogenerator will be redesigned for the special work of the Short Circuit Generator whose parameters were mentioned in paragraph III.C. This redesigning will be ensured by the Turbogenerator Design Department of the Institute of Dae-An Heavy Machine Design after the fellowship training of the engineers responsible for design and production of the Short Circuit Generator.

The first step of redesigning will be made with the aim to achieve no-load stator voltage of 12kV. This voltage value should be achieved at single layer stator winding. The number of stator slots will depend on the magnetic flux provided by the rotor and ratio of stator slots number to rotor slots number.

The stator slots number of 42 or 30 should enable the designers to place the stator winding outlets on the opposite sides of the stator which is suitable for the manual switchboard design.

The second step of redesigning will be made with the aim to achieve short circuit current according to the paragraph III.C simultaneously reinforcing the structure against the dynamic forces caused by this short circuit current.

Principles of this reconstruction are attached in Annex III.

E. Manufacturing process of the Short Circuit Generator

Short Circuit Generator must withstand without damage high dynamic forces and torque. Some of them are defined in paragraph III.C of this report. The other calculations of forces will be performed during the designing documentation process.

Manufacturing process must be prepared in such a way that the machine withstands all mechanical and electrical stress. Therefore, the engineers responsible for production of SCG were informed by the author about the methods of stator and rotor winding reinforcing which are used by SCG producer SKODA, Pilsen.

The engineers were also informed about the manufacturing process which is used for this purpose. The main principle of this process is to separate manufacture bars and coil ends. The bars are mounted into slots and properly stiffened. The coil ends are mounted into non-magnetic steel bell. The coil ends are compound filled in the bell. Therefore, the coil ends create reinforced designing whole which is mounted into the stator. The coil ends are connected with bars by flexible connections. This manufacturing process allows to limit the bend stress of the stator winding.

F. Excitation system

The magnitude of time decrement of current alternating component and magnitude of recovery voltage of Short Circuit Generator depend on the SCG parameters and magnitude of ceiling excitation voltage. An excitation system which allows to change the excitation voltage immediately can improve the quality of SCG because such excitation system can limit the time decrement of alternating component of short circuit current.

The above-mentioned excitation system consists of direct current excitors, serial resistor which will be overbridged by a contactor during the duration of ceiling excitation voltage, de-excitation resistor and field circuit breaker. The components of the excitation system can be overloaded considerably because the operation of the excitation system is only a short time operation. The excitation system will be loaded by the current which is induced by short circuit into the rotor winding.

G. Driving Motor of Short Circuit Generator

The driving motor enables the SCG to accelerate the rotor from rest or from reduced speed after a short circuit. The starting time of the set from rest to the full speed can last several minutes. The driving motor output must be higher than the mechanical and ventilation losses i.e. the respective no-load losses of SCG.

For the decrease of ventilation losses of the SCG it is suitable to use a forced draught ventilation of the SCG.

According to the operation sequence the driving motor will be disconnected from the power network before a short circuit occurs.

To reduce the stress of the driving motor shaft from short circuit moments and torques the coupling with the SCG should be made with a special slip clutch designed for such purpose. The clutch limits the torque transmitted during a short circuit to an acceptable magnitude.

Driving motor should be a slipring inductive motor type to enable the control of speed by the starting device.

H. Accessories of Short Circuit Generator

Short Circuit Generator will be equipped with the following accessories:

- excitation system described in paragraph III.F
- driving motor described in paragraph III.G
- ventilator driven by inductive motor for the forced open ventilation system of SCG
- oil lubrication system for needs of SCG and driving motor bearings
- 3-phase Pilot Generator on the SCG shaft
- manual switchboard of the SCG stator winding outlets
- special slip clutch for coupling of SCG shaft with driving motor shaft
- protection of the Short Circuit Generator

Annex I

Senior counterpart staff

Pak Gi Gun	Director-General Foreign Collaboration Ministry of Machine Industry
Han Tae Hyok	Director-General Fifth Department Ministry of Foreign Trade
Ko Ju Chol	Senior Officer Fifth Department Ministry of Foreign Trade
Dr. KimJongHo	Chief of the Electr.Machinery Modernization The Machinery Engineering Institute
Tong Ke Guk	Chief Engineer Dae-An Heavy Machine Complex
Li Tae Gyun	Vice Chief of Technical Development Dae-An Heavy Machine Complex
Kim Jong Gi	General Designer of Synchronous Generator Dae-An Heavy Machine Complex
Ho Do Gil	Chief Designer of Turbogenerators Dae-An Heavy Machine Complex
Dak Yong Chol	Chief Engineer 5th June Electrical Factory
Li Chi Bae	Director High Voltage Laboratory 5th June Electrical Factory
Pak Sang Won	Chil of Section for Control of Products 5th June Electrical Factory
Kim Du Il	Senior Technical Officer, Technical Department 5th June Electrical Factory

Annex II
(Page 1)

Parameter Schedule of the 50MW Turbogenerator

Turbogenerator was manufactured by Dae-An Heavy Machine Complex in 1982.

Rated active output	50	MW
Rated apparent output	62,5	MVA
Power factor cos fi	0,8	
Frequency	60	Hz
Number of revolutions per minute	3 600	rpm
Rated voltage	6 600	V
Rated current	5 475	A
Class of insulation		B
Moment of inertia $\frac{GD^2}{4}$	1 525	kgm^2

Reactances (at nominal voltage)

Nominal reactance	x_n = 100 %	X_n = 0,696 Ohm
Synchronous reactance	x_d = 179 %	X_d = 1,247 Ohm
Transient direct-axis reactance	x'_d = 20,9%	X'_d = 0,146 Ohm
Subtransient direct-axis reactance	X''_d = 14,7%	X''_d = 0,1026 Ohm
Zero sequence reactance	x_o = 7,3%	X_o = 0,0543 Ohm
Negative sequence reactance	x_2 = 18 %	X_2 = 0,1253 Ohm

Time constants

Transient direct-axis time constant	T'_d = 0,64	s
Subtransient direct-axis time constant	T''_d = 0,03	s
Positive sequence time constant	T_2 = 0,39	s
Transient direct-axis no-load time constant	T'_{do} = 5,45	s

Annex II
(Page 2)

Stator winding connection	2Y
Number of phases	3
Number of layers	2
Number of slots	42
Winding pitch	17 (1-18)

Cooling system — enclosed type with hydrogen circulation and its colling in a water cooler

Bearings — located in the bearing shields

Excitation

No-load excitation voltage	36 V
No-load excitation current	726 A
Nominal excitation voltage	125 V
Nominal excitation current	1 300 A

No-load characteristic

Excitation current A	343	726	1 140	1 626
Stator voltage V	3 300	6 600	7 336	8 773

Short circuit characteristic

Nominal current 5 475 A	I_{1k}	I_{2k}	I_{3k}
Excitation current A	423	724	1 131

Rated torque M = 133 kNm (=)

Max. torque at crasch short circuit M_{max} = 1 610 kNm (120 Hz)

Annex III
(Page 1)

Short Circuit Generator design requirements

Short Circuit Generator should withstand without damage high dynamic stress of the structural parts caused by sudden short circuits which are to be considered as normal operational conditions.

In view of the short time load of the Short Circuit Generator and of the relatively small air gap the field winding in the rotor should occupy smaller cross section than of conventional turbogenerator. The cross section of the rotor iron increased at the expense of the copper permits the magnetic flux to be increased without over-saturating the magnetic circuit.

The rotor slots should be designed with the aim of making their magnetic conductivity minimal which correspondens to a small number of shallows and wide slots.

The rotor should be provided by massive copper strips placed in the rotor slots above the winding on the entire length of rotor body. These copper strips, together with the slot wedges, form a damper winding.

At the location of the seats of the end bells the copper strips should be short circuited together with forged brass rings pressed into an internal recess of the end bells.

In the poles a row of moonshaped depressions is cut which afford an equalization of the moments of resistance in the traverse and longitudinal axis and contribute to a reduction of the vibration. The depression should be bridged by bronze wedges fitted in shallow slots.

The rotor body should be mounted in pedestals with plain bearings of which the one on the coupling side is a combined radial and thurst bearing. The pedestals should be provided with flanges for force-feed lubrication serving to raise the rotor and to form an oil film before the start and for trouble-free coasting of the machine. The pedestals as well as the flanges of the oil pipe are insulated from the base parts.

The stator winding should be designed into wide and shallow slots. These slots should be filled with the conductor with a minimum of necessary insulating materials and, as far as the mechanical stress permits, also with a low wedge. This concept is best satisfied by a sigle-layer winding.

Very good sine shape of the voltage curve is demanded from a Short Circuit Generator and therefore the winding pitch should be shortened, particulary with a view to the 5th and 7th harmonic component.

The coil ends of stator winding should be perfect stiffened against the action of the dynamic forces produced during the operation of the Short Circuit Generator.

The ventilation system of a generator serves the purpose of cooling the machine during the interval between short circuits at least sufficiently to enable another short circuit, or a series of short circuits, to follow.

The Short Circuit Generator should have a forced open ventilation system with an air inlet and outlet.

Annex IV

List of the Synchronous generators

produced by Dae-An Heavy Machine Complex

Type of machine	Unit output	Voltage V	Nominal speed rpm	Year of delivery
Hydrogenerator	125 MVA	16 500	163,6	1986
Hydrogenerator	50 MVA	11 000	600	1975
Hydrogenerator	50 MVA	11 000	400	1987
Hydrogenerator	50 MVA	11 000	150	1982
Hydrogenerator	6 MVA	6 600	450	1969
Hydrogenerator	6 MVA	6 600	600	1974
Hydrogenerator	15 MVA	11 000	360	1981
Covered Hydrogenerator	3 MVA	3 300	120	1982
Covered Hydrogenerator	5 MVA	3 300	94	1983
Turbogenerator	50 MW	6 500	3 600	1982
Turbogenerator	60 MW	11 000	3 600	in prod.
Turbogenerator	6 MW	6 600	3 600	1985
Turbogenerator	12 MW	6 600	3 600	1980
Motor	10 MW	6 600	3 600	1973

Annex V

List of the Oil circuit breakers

produced by 5th June Electric Factory in Kyongsong

Oil circuit breaker	Nominal voltage	Nominal current	Breaking current
Type	kV	A	kA
soucha 10 - 630	10	630	20
soucha 10 -1 000	10	1 000	20
soucha 10 -2 000	10	2 000	20
soucha 10 -3 000	10	3 000	20
soucha 10 -4 000	10	4 000	60
soucha 10 -5 000	10	5 000	60
soucha 60 - 630	60	630	20
soucha 60 -1 000	60	1 000	20
soucha 110 -1 000	110	1 000	20
soucha 220 -1 000	220	1 000	20

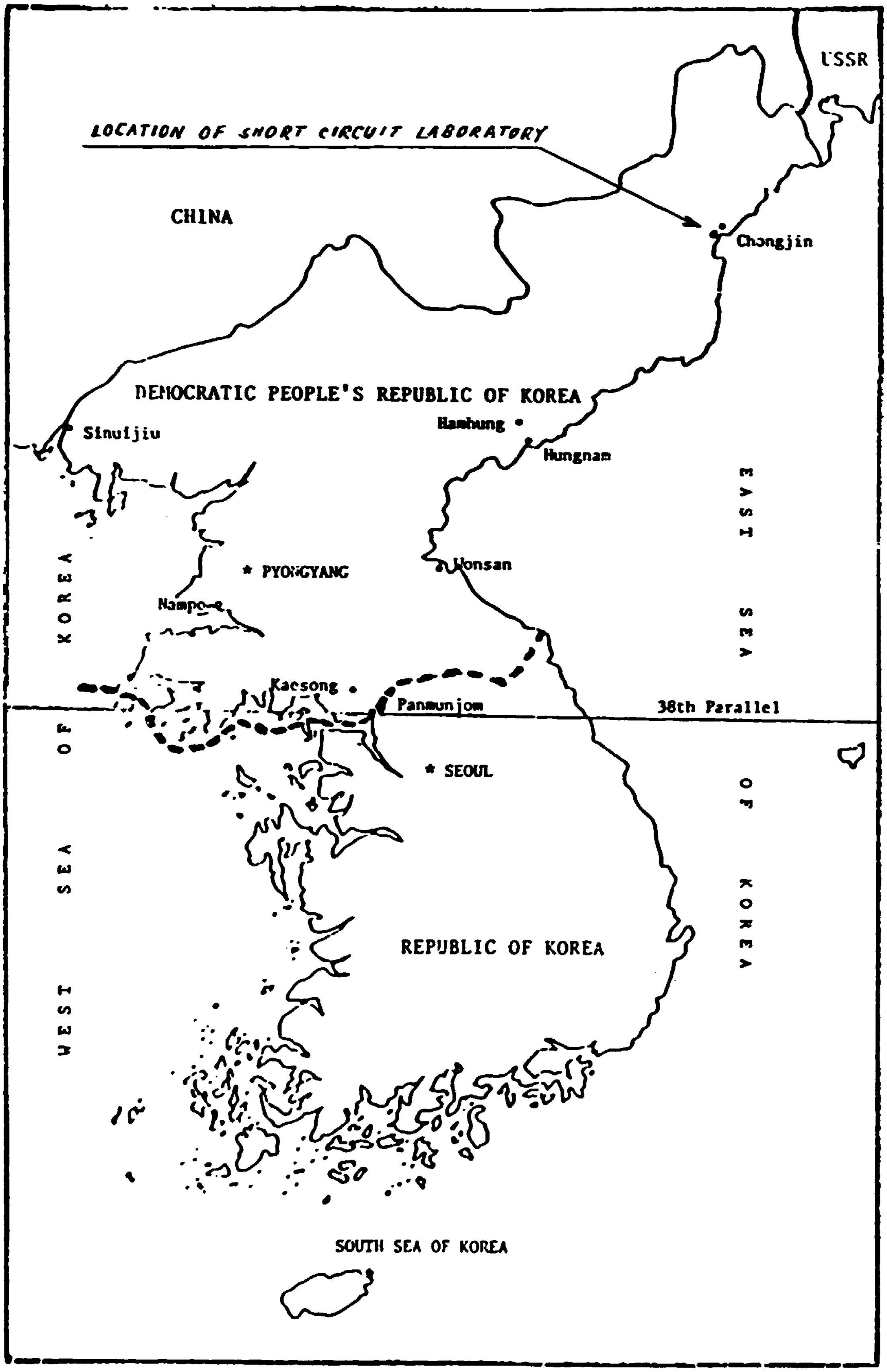
Annex VI

Fellowship training programme

1. Electromagnetic design of Short Circuit Generator and calculation of its parameters
2. Thermal and cooling calculation of SCG
3. Calculations of mechanical running of SCG, calculation of mechanical stress
4. Design of Short Circuit Generator rotor
5. Design of Short Circuit Generator stator
6. Stator winding design and calculation of electromagnetical forces which affect on winding
7. Design and calculation of Short Circuit Generator foundation
8. Excitation system of SCG
9. Dependance of Short circuit current courses on the excitation system parameters
10. Calculations of Driving motor torsial stress
11. Design and calculation of slip clutch
12. Calculation and design of Pilot Generator
13. Manufacturing process of Short Circuit Generator stator
14. Manufacturing process of stator winding
15. Manufacturing process of Short Circuit Generator rotor
16. Testing programme during the SCG manufacturing process
17. Testing of the machine in manufacturer's factory

Annex VII

MAP OF KOREA



Annex VIII

Supplementary Considerations

The author came back from the mission to the DPRK on 15/11/88. At that time Skoda, Pilzen had already responded negatively to the fellowship training of three Korean engineers. Discussions between the author and the General Designer of big rotating electrical machines did not, however, change the decision at that time.

UNIDO repeated its request for fellowship training in December 1988. Subsequently, the SKODA designers performed some calculations for the Short Circuit Generator of the Short Circuit Laboratory in DPRK along with the following conditions:

- utilization of 50 MW turbogenerator rotor
- considerable increase of magnetic flux
- reconstruction of the stator

As a result of these calculations there are two theoretical options of such Short Circuit Generator which can fulfil the parameters:

- rated voltage 12,000 V
- rated output 1,000 MVAr

1. Short Circuit Generator provided by double-layer stator winding. This winding is situated in 30 stator slots.
2. Short Circuit Generator provided by single-layer stator winding. This winding is situated in 60 stator slots.

According to SKODA's Electrical Engineering Works, the Generator as to option number 1 is only a theoretical one because SKODA is building Short Circuit Generators with single-layer winding. This manufacturer does not know the reinforcing method of double-layer winding ends of Short Circuit Generators and cannot design such a machine.

The generator design according to option number 2 uses stator winding bars which are very slender. The width of such bars is two times less than under option number 1. The binding rigidity of these slender bars is therefore eight times less. Such bars are not suitable for Short Circuit Generators.

The use of 50 MW turbogenerator rotor is not without problems. The rotor of SCG must have the damper winding (see Annex III, page 1). The speed of the SCG changes considerably during the operation and therefore the second critical speed of SCG must be higher than the rated speed.

According to the SKODA specialist calculations and opinion, the reconstruction of the 50 MW turbogenerator for such big Short Circuit Generator parameters is not possible.

The requirements of the Short Circuit Laboratory can be fulfilled with some reserve by the Short Circuit Generator made by SKODA. The respective design documentation could be bought by the Korean Government. The dimensions of this SCG are considerably larger than the 50 MW turbogenerator dimensions. Technical parameters and dimensions of the SKODA SCG are known to the Korean specialists.

Finally, it is understood that after reconsideratiog the matter, fellowship training could basically be arranged with SKODA, Pilzen if the Korean engineers are still interested in SCG training there. However, following the findings that the reconstruction of a 50 MW turbogenerator is practically not possible, the study visit would be concentrated on calculations and the design of the SKODA Short Circuit Generator of 2,500 MVAr. The duration of the training programme in SKODA, Pilzen would cover 1 month.