Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

MINISTERO DELLO SVILUPPO ECONOMICO

Realizzazione e collaudo dei trasformatori speciali per gli alimentatori del controllo veloce della posizione del plasma (FPPC) di JT-60SA

P. Zito, A. Lampasi, G. Maffia, F. Starace

Report RdS/PAR2013/206

REALIZZAZIONE E COLLAUDO DEI TRASFORMATORI SPECIALI PER GLI ALIMENTATORI DEL CONTROLLO VELOCE DELLA POSIZIONE DEL PLASMA (FPPC) DI JT-60SA

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Report Ricerca di Sistema Elettrico
Accordo di Programma Ministero dello Sviluppo Economico – ENEA
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Area: Produzione di Energia Elettrica e Protezione dell’Ambiente
Progetto: Attività di fisica della Fusione complementari a ITER
Obiettivo: Metodi per verifiche di sostenibilità
Responsabile del Progetto: Aldo Pizzuto, ENEA

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Sommario

Nell'ambito del Broader Approach (che è un accordo di cooperazione internazionale tra Unione Europea Euratom e Giappone avente lo scopo di integrare il progetto ITER ed accelerare i tempi per la realizzazione dell'energia da fusione, attraverso attività di R&S relative a tecnologie avanzate per i futuri reattori dimostrativi), l'ENEA deve fornire parte delle alimentazioni elettriche del sistema magnetico di JT-60SA, per un totale di 8 alimentatori ad alta corrente (6 alimentatori per le bobine poloidali CS1, CS2, CS3, CS4, EF1 e EF6, 2 alimentatori per le bobine FPPC Fast Plasma Position Control con relativi interruttori e trasformatori).

Il documento riporta una sintesi delle prove di collaudo finale dei trasformatori per gli alimentatori FPPC. Il particolare tutti i trasformatori sono stati sottoposti a test di routine mentre uno dei trasformatori è stato sottoposto a prove di tipo:

- una prova di tipo in corto circuito sul trasformatore D/y11 degli alimentatori FPPC;
- un test di tipo termico basato sulla misura della temperatura negli avvolgimenti secondari di un trasformatore FPPC, tramite una sonda di temperatura in ciascun avvolgimento secondario, collocato nel punto più caldo superiore.

Inoltre, la distribuzione della temperatura nella resina isolante esterno su quattro lati sarà monitorata con una telecamera termografica. Queste soluzioni alternative permettono di garantire la qualità del disegno trasformatore FPPC e migliorano l'affidabilità. Prima delle prove di corto circuito, il trasformatore FPPC è stato sottoposto alle prove di accettazione di routine come specificato nella norma IEC 60076-1. Inoltre, poiché tutta la documentazione fornita è in lingua inglese, i prossimi paragrafi sono riportati in inglese.

1. Introduction

In the ENEA procurement of eight Power Supplies complete of Transformers for part of the JT-60SA PFC PSs, the First Design Report of Transformers was officially approved by ENEA, F4E and JAEA on 15th of April 2014, whereas the FPCC Converters First Design Report was approved on 07th July 2014. The transformer manufacturer chosen by Poseico-Jema was the SEA Company (Società Elettromeccanica Arzignanese) with an experience in the design and construction of special power transformers more than 50 years.
Poseico-Jema (in according to SEA) proposed, instead of evaluating electro-dynamic stress and thermal analyses of FPPC Transformers (as initially foreseen in the first design), to perform:

- a short-circuit type test on one of the four FPPC transformers;
- a thermal type test based on the temperature measurement in the secondary windings of one FPPC transformer, through a temperature probe in each secondary winding, placed in the upper hottest point. In addition, the temperature distribution in the outer resin insulating on four sides will be monitored with a thermo-graphic camera. These alternative solutions allow to assure the quality of the FPPC transformer design and improving its reliability, avoiding so possible doubts on the results of the electro-dynamic and thermal analyses, since they are very time demanding and their results can be only approximate and not really reliable. This proposal was accepted by all project partners (ENEA, F4E and JAEA). Prior to the short-circuit tests, the FPPC transformer was subjected to the acceptance routine tests as specified in IEC 60076-1.

The short-circuit type test was carried out at CESI Laboratories of Milan on 07th July 2014 in according to IEC 60076-5. A suitable value of short-circuit current was injected in the FPPC transformer (D/Y) and the currents and voltages waveform were acquired. Nine short-circuit shots were carried out, three for each phase of transformer and after each shot, the short-circuit reactance was measured. The short-circuit type test was overcome positively.
After the FPPC transformer was transferred in the SEA laboratories for final acceptance tests, held on 10th - 11th July 2014 for first two transformers, whereas 18th – 19th September 2014 last two transformers. These tests made in according to IEC 60076-1/11 as follows:
Measurement of winding resistance;
Measurement of voltage ratio and check of phase displacement;
Measurement of short-circuit impedance and load loss;
Measurement of no-load loss and current;
Dielectric tests (IEC 60076-11);
Partial discharge measurement (IEC 60076-11);
Temperature-rise test (IEC 60076-11);
Determination of sound level (IEC 60076-10);
Hot-spot temperature-rise measurements.
All tests gave positive result, moreover the hot-spot temperature-rise measurements by thermal probes and thermo-graphic camera did not highlight any critical hot spot.

2. Description of activities and results

2.1 Routine Tests

The routine tests were made in according to IEC 60076-1/11 as follows:
Measurement of winding resistance;
Measurement of voltage ratio and check of phase displacement;
Measurement of short-circuit impedance and load loss;
Measurement of no-load loss and current;
Dielectric tests (IEC 60076-11);
Partial discharge measurement (IEC 60076-11);
Temperature-rise test (IEC 60076-11);
Determination of sound level (IEC 60076-10);

Test according to specifications	I.E.C. 60076-11 - DRY-TYPE TRANSFORMERS CEI EN 60076-11 - TRASFORMATORI DI POTENZA A SECCO	Page	1
Product	TR0009690	**Testing date**	10/07/2014
Order N°	187 16/04/2014	**SEA Reference**	VEN011236
Customer	POSEICO SPA -GENOVA-		
Transformer	Dry type		
Type	TTR-C	**Serial number**	107584

Power	AN	6000	3000	3000		kVA
Power						kVA
Rated Voltage		18000	415	415		V
Tapping range		No	No	No		
Rated Current	AN	192,45	4173,62	4173,62		A
Rated Current						A
Connection		Delta	Star	Delta		
Winding in		Aluminium	Aluminium	Aluminium		
Insulation system class		F	F	F		
Winding temperature rise		100,0	100,0	100,0		K
Insulation levels		24,0-50,0-125,0	3,6-10,0-	3,6-10,0-	--	
Connection Symbol		Dy11-Dd0		Rated Frequency	77,6	Hz
Phase		Threephase		Degree of protection	IP00	
Cooling		AN		Environmental classes	E2-C2-F1	

Guaranteed ratio	**18000/415-415**	V		
Measurement summary	No-load losses (W)	No -load current (%)	Load losses (W)	Short circuit imped. (%)
Guaranteed values	9000,00	0,75	120000,00	8,00
Tolerance (%)	15,00	30,00	15,00	10,00
Measured values	8944,00	0,2467	55897,0	8,6100
Difference (%)	-0,62%	-67,10%	-53,42%	7,62%

Remark

Dielectric tests

Separate source AC withstand voltage test between primary to secondary and ground							**Result**	Positive
Highest voltage Um	24,0 kV	Test voltage	50,0 kV	f=	50 Hz	t=	60 s	
Separate source AC withstand voltage test between secondary to primary and ground								Positive
Highest voltage Um	3,6 kV	Test voltage	10,0 kV	f=	50 Hz	t=	60 s	
Induced over voltage withstand test (FIBD)								Positive
Supplied winding	0,415 kV	Test voltage	0,830 kV	f=	150 Hz	t=	62 s	

Measurement of no-load losses and current

Supplied winding 415 V f= 78 Hz

Voltage (V)					Current (A)				Power (W)				
VM uv	VM vw	VM wu	VM med	Veff med	I u	I v	I w	I med	W u	Wv	Ww	W tot	W tot corr
					See page 5								

Transformer	Dry type		Page 2
Type	TTR-C	Serial number 107584	

MEASURE ON RATIO 18000/415 V - Tap pos. 0 - Dy11

Measurement of voltage ratio and vector group

Method: Barbagelata

Tap pos.	Measured ratio			Nominal ratio	Maximum difference (%)	Remarks
	1U-1V/2UY-2VY	1V-1W/2VY-2WY	1W-1U/2WY-2UY			
/	75,234	75,311	75,322	75,125	0,262	
						Connection Symbol: Dy11
						Verified

Measurement of winding resistance

Winding under test		18000,0 V		
t (°C)	24	V	I	R
Terminals		(V)	(A)	(Ohm)
1U - 1V		4,0780	10,0000	0,40780
1U - 1W		4,0930	10,0000	0,40930
1V - 1W		4,0892	10,0000	0,40892
Average resistance		24	°C	0,40867
Average resistanc		**75**	**°C**	**0,49237**

Winding under test		415,0 V		
t (°C)	24	V	I	R
Terminals		(mV)	(A)	(mOhm)
2UY - 2VY		30,2950	100,000	0,30295
2UY - 2WY		31,6600	100,000	0,31660
2VY - 2WY		30,3050	100,000	0,30305
Average resistance		24	°C	0,30753
Average resistanc		**75**	**°C**	**0,37052**

Measurement of short-circuit impedance and load loss

Reference power **3000 kVA**

Supplied winding		18000 V		Short-circuit winding				415 V		Ambient temperatur		24 °C
Voltage (V)				Current (A)				Power (W)				Frequency (Hz)
V1	V2	V3	Vm	I1	I2	I3	Im	W1	W2	W3	W tot	f
787,55	786,01	786,08	786,55	62,324	63,732	63,923	63,326	3399,2	2937,6	3758,0	10095	59,98
Voltage at In		**1195,1 V**		**Nominal current**		**96,225 A**		**Loss at In**		**23308 W**		

Measurement of short-circuit impedance and load loss

Ambient temperature		24,00	°C	Reference temperature	75	°C
Winding resistance	MT-18000-P	0,81735	Ohm	Coefficient K	1,2048	
Winding resistance	BT-415-SY	0,30753	mOhm	Total resistive losses	23358,3	W
Winding resistance				Additional losses	3254,27	W
Winding resistive losses	MT-18000-P	11352,0	W	**Total load losses**	**26612,6**	**W**
Winding resistive losses	BT-415-SY	8035,41	W	Inductive component Xl	6,5930	(%)
Winding resistive losses			W	Resistive component Rl	0,8870	(%)
Total resistive losses		19387,4	W	**Impedance**	**6,6520**	**(%)**
Additional losses		3920,81	W	Power factor (cosfi)	0,1330	

Voltage drop (%)				**Efficiency (%)**			
Load	Cosφ= 0,8	Cosφ= 1	Cosφ= 0,6	Load	Cosφ= 0,8	Cosφ= 1	Cosφ= 0,6
100%	4,778	1,104	5,859	100%	98,489	98,788	97,996
75%	3,562	0,788	4,385	75%	98,621	98,894	98,170
50%	2,361	0,498	2,916	50%	98,615	98,889	98,162

Transformer	Dry type			Page 3
Type	TTR-C	Serial number	107584	

MEASURE ON RATIO 18000/415 V - Tap pos. 0 - Dd0

Measurement of voltage ratio and vector group — Method: Barbagelata

Tap pos.	Measured ratio 1U-1V/2UD-2VD	Measured ratio 1V-1W/2VD-2WD	Measured ratio 1W-1U/2WD-2UD	Nominal ratio	Maximum difference (%)	Remarks
/	43,464	43,462	43,462	43,373	0,205	
						Connection Symbol: Dd0
						Verified

Measurement of winding resistance

Winding under test		18000,0 V		
t (°C)	24	V	I	R
Terminals		(V)	(A)	(Ohm)
1U - 1V		4,0780	10,0000	0,40780
1U - 1W		4,0930	10,0000	0,40930
1V - 1W		4,0892	10,0000	0,40892
Average resistance		24	°C	0,40867
Average resistance		**75**	**°C**	**0,49237**

Winding under test		415,0 V		
t (°C)	24	V	I	R
Terminals		(mV)	(A)	(mOhm)
2U - 2V		27,8100	100,000	0,27810
2U - 2W		28,9400	100,000	0,28940
2V - 2W		27,7850	100,000	0,27785
Average resistance		24	°C	0,28178
Average resistance		**75**	**°C**	**0,33949**

Measurement of short-circuit impedance and load loss — Reference power **3000 kVA**

Supplied winding		18000 V		Short-circuit winding				415 V		Ambient temperature		24 °C
Voltage (V)				Current (A)				Power (W)				Frequency (Hz)
V1	V2	V3	Vm	I1	I2	I3	Im	W1	W2	W3	W tot	f
789,69	789,74	790,11	789,85	63,077	64,241	62,838	63,385	2796,9	3280,2	3466,6	9543,7	59,98
Voltage at In		**1199,0 V**		**Nominal current**		**96,225 A**		**Loss at In**		**21995 W**		

Measurement of short-circuit impedance and load loss

Ambient temperature		24,00	°C	Reference temperature	75	°C
Winding resistance	MT-18000-P	0,81735	Ohm	Coefficient K	1,2048	
Winding resistance	BT-415-SD	0,28178	mOhm	Total resistive losses	22547,7	W
Winding resistance				Additional losses	2722,54	W
Winding resistive losses	MT-18000-P	11352,0	W	**Total load losses**	**25270,3**	**W**
Winding resistive losses	BT-415-SD	7362,60	W	Inductive component Xl	6,6210	(%)
Winding resistive losses			W	Resistive component Rl	0,8420	(%)
Total resistive losses		18714,6	W	**Impedance**	**6,6740**	**(%)**
Additional losses		3280,17	W	Power factor (cosfi)	0,1260	

Voltage drop (%)				Efficiency (%)			
Load	Cosφ= 0,8	Cosφ= 1	Cosφ= 0,6	Load	Cosφ= 0,8	Cosφ= 1	Cosφ= 0,6
100%	4,761	1,061	5,856	100%	98,543	98,831	98,067
75%	3,549	0,755	4,382	75%	98,662	98,926	98,223
50%	2,352	0,476	2,915	50%	98,642	98,911	98,197

Transformer	Dry type			Page	4
Type	TTR-C	Serial number	107584		

MEASURE ON RATIO 18000/415-415 V - Tap pos. 0 -

Measurement of winding resistance

Winding definition			MT-18000-P
Winding voltage		18000,0	V
t (°C)	V	I	R
Terminals	(V)	(A)	(Ohm)
1U - 1V	4,0780	10,0000	0,40780
1U - 1W	4,0930	10,0000	0,40930
1V - 1W	4,0892	10,0000	0,40892
Average resistance	24	°C	0,40867
Average resistanc	**75**	**°C**	**0,49237**

Winding definition				BT-415-SD
Winding voltage			415,0	V
t (°C)	24	V	I	R
Terminals		(mV)	(A)	(mOhm)
2U - 2V		27,8100	100,000	0,27810
2U - 2W		28,9400	100,000	0,28940
2V - 2W		27,7850	100,000	0,27785
Average resistance		24	°C	0,28178
Average resistanc		**75**	**°C**	**0,33949**

Winding definition				BT-415-SY
Winding voltage			415,0	V
t (°C)	24	V	I	R
Terminals		(mV)	(A)	(mOhm)
2UY - 2VY		30,2950	100,000	0,30295
2UY - 2WY		31,6600	100,000	0,31660
2VY - 2WY		30,3050	100,000	0,30305
Average resistance		24	°C	0,30753
Average resistanc		**75**	**°C**	**0,37052**

Measurement of short-circuit impedance and load loss								**Reference power**				**6000**	**kVA**
Supplied winding		18000 V		Short-circuit winding				415 V		Ambient temperatur		24	°C
Voltage (V)				Current (A)				Power (W)				Frequency (Hz)	
V1	V2	V3	Vm	I1	I2	I3	Im	W1	W2	W3	W tot	f	
605,12	604,31	604,84	604,76	96,308	98,188	97,299	97,265	3662,2	3660,6	4247,4	11570	59,978	
Voltage at In		**1196,7 V**		**Nominal current**		**192,45 A**		**Loss at In**		**45296 W**			

Measurement of short-circuit impedance and load loss						
Ambient temperature		24,00	°C	Reference temperature	75	°C
Winding resistance	MT-18000-P	0,40867	Ohm	Coefficient K	1,2048	
Winding resistance	BT-415-SD	0,28178	mOhm	Total resistive losses	45906,1	W
Winding resistance	BT-415-SY	0,30753	mOhm	Additional losses	5971,32	W
Winding resistive losses	MT-18000-P	22704,1	W	**Total load losses**	**51877,4**	**W**
Winding resistive losses	BT-415-SD	7362,60	W	Inductive component Xl	6,6050	(%)
Winding resistive losses	BT-415-SY	8035,41	W	Resistive component Rl	0,8650	(%)
Total resistive losses		38102,1	W	**Impedance**	**6,6610**	**(%)**
Additional losses		7194,36	W	Power factor (cosfi)	0,1300	

Voltage drop (%)				Efficiency (%)			
Load	Cosφ= 0,8	Cosφ= 1	Cosφ= 0,6	Load	Cosφ= 0,8	Cosφ= 1	Cosφ= 0,6
100%	4,769	1,083	5,856	100%	98,723	98,976	98,305
75%	3,555	0,771	4,382	75%	98,918	99,132	98,562
50%	2,356	0,487	2,915	50%	99,044	99,234	98,729

Test according to specifications	I.E.C. 60076-11 - DRY-TYPE TRANSFORMERS CEI EN 60076-11 - TRASFORMATORI DI POTENZA A SECCO				Page 5
Transformer	Dry type			Type	TTR-C
Power	6000 kVA	Serial number	107584	Testing date	10/07/2014

MEASUREMENT OF NO-LOAD LOSSES AND CURRENT

Winding definition BT-415-SY Voltage 415 V

Tapping range /

R.M.S. Voltage			Mean Voltage			Current			Power		
U			U'			I			P		
(V)			(V)			(A)			(W)		
Vuv	Vvw	Vwu	Vuv	Vvw	Vwu	Iu	Iv	Iw	Wuo	Wvo	Wwo
353,49	354,05	352,41	352,10	352,77	351,18	17,739	13,108	13,803	2974,2	2425,5	1886,3
337,27	337,77	336,24	335,96	336,55	335,10	16,838	12,517	13,058	2702,5	2219,0	1724,0
323,00	323,51	322,03	321,77	322,32	320,97	16,130	12,039	12,480	2480,2	2047,3	1586,7
306,23	306,72	305,32	305,08	305,58	304,33	15,339	11,492	11,843	2235,4	1854,8	1433,2
288,85	289,29	287,97	287,79	288,21	287,04	14,550	10,933	11,214	1998,6	1665,3	1283,2

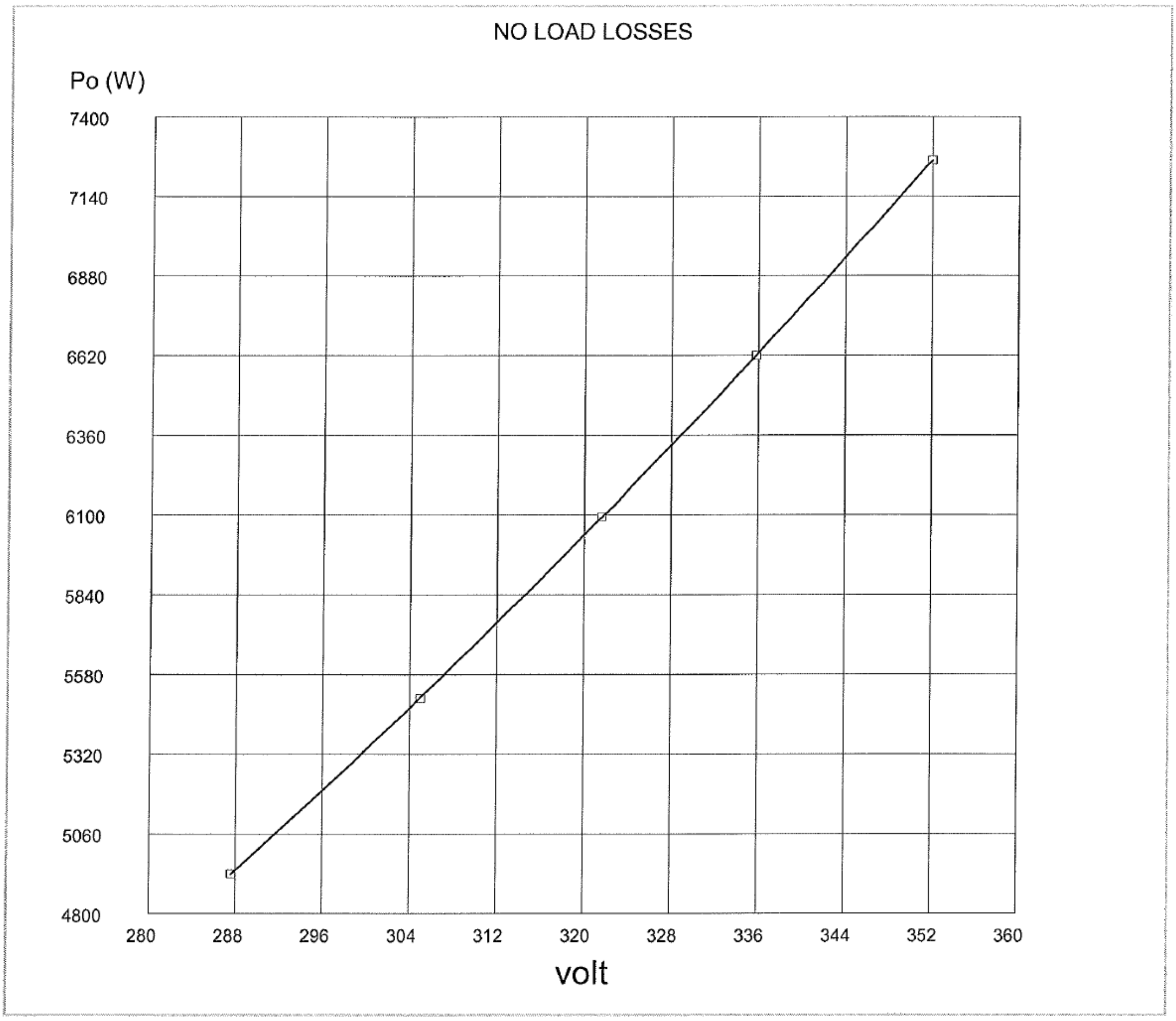
Frequency	Average Voltage				Current	Measured Losses	Correction Factor	Corrected Losses
f	U		U'		I	Pm	$K=(1+\frac{U'-U}{U'})$	Po=(Pm x K)
	Vrms	Vrms*√3	Vrm	Vrm*√3				
(Hz)	(V)				(A)	(W)		(W)
60,000	353,32		352,02		14,883	7286,0	0,9963	7259,2
60,000	337,09		335,87		14,138	6645,5	0,9964	6621,4
60,000	322,85		321,69		13,550	6114,2	0,9964	6092,2
60,000	306,09		305,00		12,891	5523,4	0,9964	5503,7
60,000	288,70		287,68		12,232	4947,1	0,9965	4929,6

Test Circuit Arrangement

Voltage Range	VT Ratio	Current Range	CT Ratio
(V)		(A)	
520	700/700	5	50/5
520	700/700	5	50/5
520	700/700	5	50/5
520	700/700	5	50/5
520	700/700	5	50/5

Test according to specifications	I.E.C. 60076-11 - DRY-TYPE TRANSFORMERS CEI EN 60076-11 - TRASFORMATORI DI POTENZA A SECCO				Page 6
Transformer	Dry type			Type	TTR-C
Power	6000 kVA	Serial number	107584	Testing date	10/07/2014

MEASUREMENT OF NO-LOAD LOSSES AND CURRENT



Winding definition: BT-415-SY

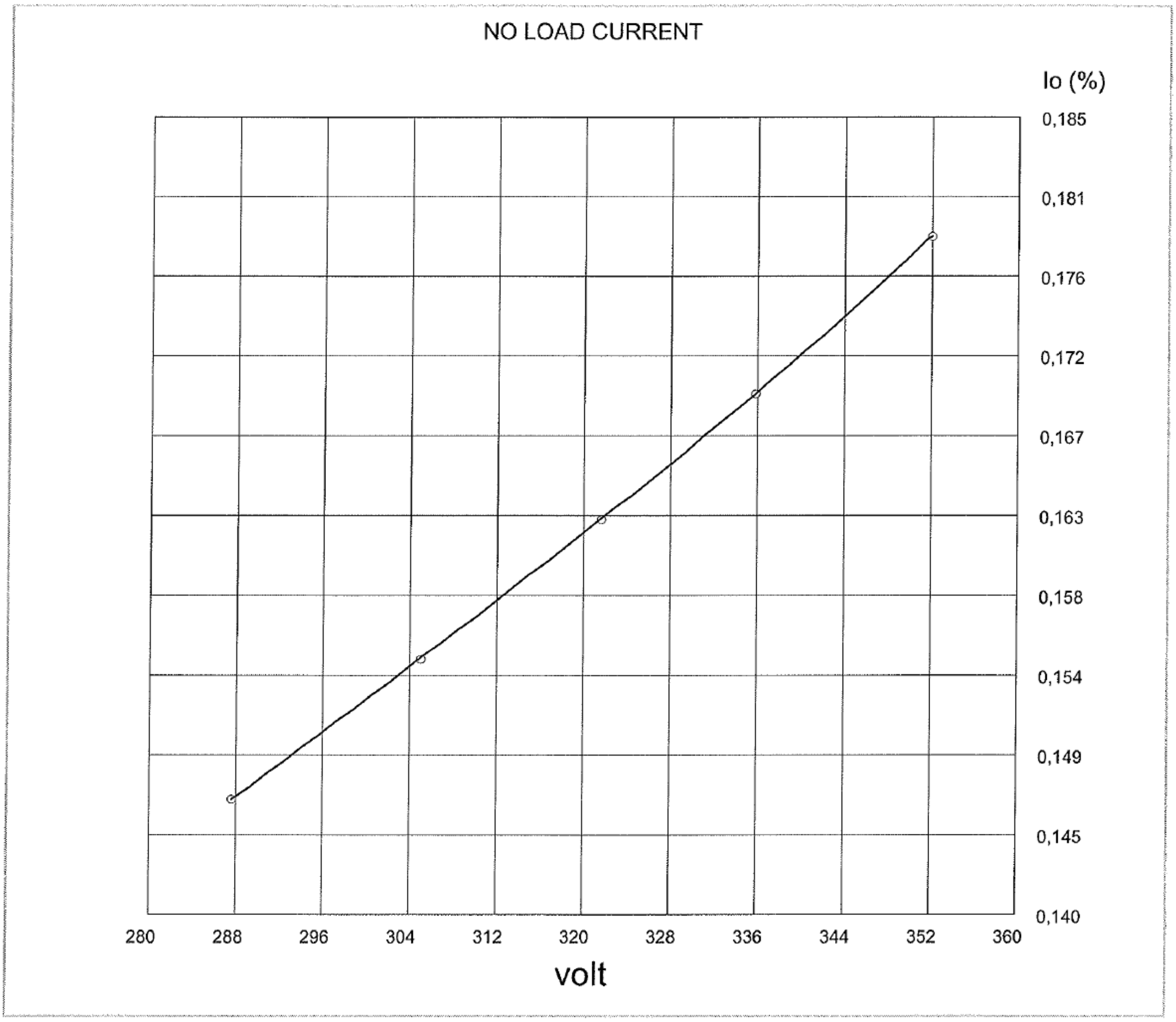
Voltage: 415 V

Extrapolated value from the curve

	V	Po
	(V)	(W)
Vn	415,00	10202,8
1.1Vn	456,50	12694,5

Test according to specifications	I.E.C. 60076-11 - DRY-TYPE TRANSFORMERS CEI EN 60076-11 - TRASFORMATORI DI POTENZA A SECCO				Page 7
Transformer	Dry type			**Type**	TTR-C
Power	6000 kVA	**Serial number**	107584	**Testing date**	10/07/2014

MEASUREMENT OF NO-LOAD LOSSES AND CURRENT



Winding definition: BT-415-SY

Voltage: 415 V

Extrapolation value from the curve

	V	Io	Io
	(V)	(A)	(%)
Vn	415,00	20,594	0,2467
1.1Vn	456,50	30,629	0,3669

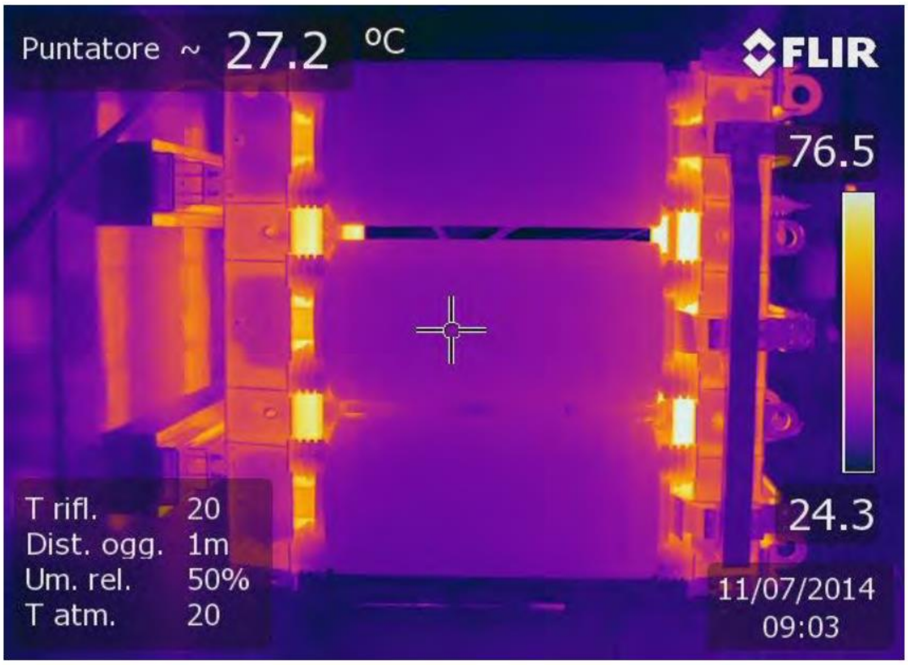
2.2 Type Tests

The type tests consists in:

- a short-circuit type test on one of the four FPPC transformers;
- a thermal type test based on the temperature measurement in the secondary windings of one FPPC transformer .

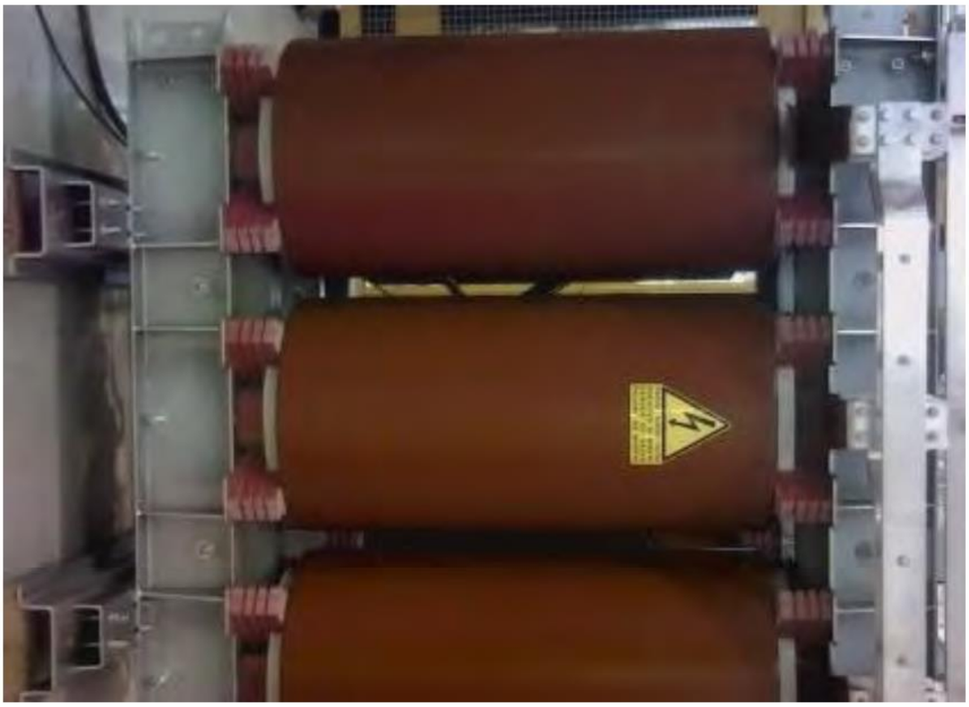
Test according to specifications	IEC 60076-11 - DRY-TYPE TRANSFORMERS CEI EN 60076-11 - TRASFORMATORI DI POTENZA A SECCO				Page
Transformer	Dry type			Type	TTR-C
Power	6000 KVA	Serial number	107584	Testing date	10/07/2014

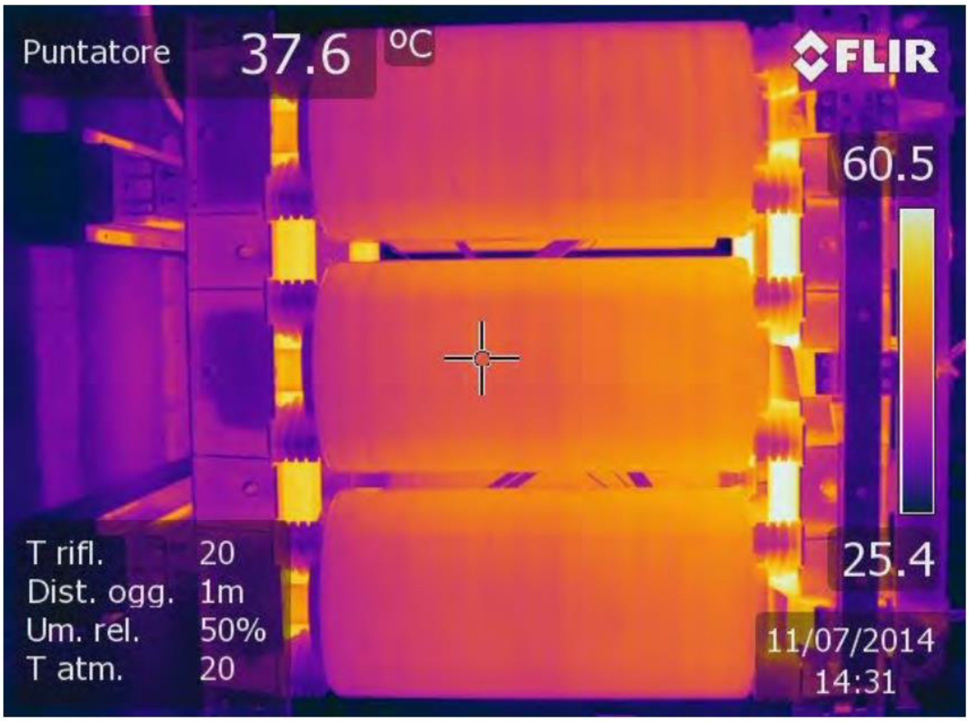
THERMOGRAPHIC ANALISYS - CORE



Test according to specifications	IEC 60076-11 - DRY-TYPE TRANSFORMERS CEI EN 60076-11 - TRASFORMATORI DI POTENZA A SECCO				Page
Transformer	Dry type			**Type**	TTR-C
Power	6000 KVA	**Serial number**	107584	**Testing date**	10/07/2014

THERMOGRAPHIC ANALISYS - WINDINGS





Verification of dynamic ability to withstand short-circuit

Requested values

Tests were performed with a short-circuit primary current of 1559 A.

Tap-changer position	U_r	Z_{SC}	X/R	k x √2	Short-circuit current (*) r.m.s. value	peak value
-	kV	%	-	-	A	A
-	18,00	5,6	6,386	2,291	67619	154931

(*) Values of short-circuit current of the low-voltage winding (star-connected).

Test arrangements and test procedures

The transformer was tested connecting a three-phase supply to the high-voltage winding (primary winding).

The low-voltage winding was short-circuited before the application of the voltage to the other winding of the transformer (pre -set short-circuit).

During each test were recorded the line-to-line supply voltages, the phase currents of the low -voltage winding and the fault current, if any, between the mass (insulated) of the transformer and earth.

Nine tests were performed (three tests on each limb):

- three tests with the maximum peak current on the middle limb),
- three tests with the maximum peak current on one of the outer limbs),
- three tests with the maximum peak current on one of the other outer limbs).

Short-circuit tests with three-phase current

Test circuit: M0022
Test frequency: 50 Hz
Reference number of the oscillograms: B4016757

Conditions of the transformer before the tests: as supplied by the Client

Transformer prearranged on the voltage ratio: 18,0 kV / 0,415 kV

Date: July 7, 2014

Test	Oscillogram	Tap-changer position	No-load supply voltage	Test current peak value	Test current r.m.s. value	Test current average value	Duration
No.	No./sheets	-	kV	A	A	A	s
1	2/1	-	-	92000	40320 40790 40570	40560	0,11
2	3/1	-	-	162200	67180 68950 67290	67810	0,5
3	5/1	-	-	162400	67310 68900 67310	67840	0,5
4	6/1	-	-	159800	67380 68900 67460	67910	0,5
5	7/1	-	-	152900	67330 68950 67460	67920	0,5
6	8/1	-	-	158100	67530 69280 67610	68140	0,5
7	9/1	-	-	159300	67810 69430 67940	68400	0,5
8	10/1	-	-	158000	67960 69580 68220	68590	0,5
9	11/1	-	-	156100	68040 69630 68400	68690	0,5
10	13/1	-	-	159000	68320 69930 68750	69000	0,5

Conditions of the transformer after the tests: see notes

- Externally did not show any damage.
- After the tests, two seals were applied on the transformer (see photos no.3 and no.4)

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Measurement of short-circuit inductance

The measurement of short-circuit inductance was performed before the short-circuit tests and after every series of three tests by means of a Schering bridge (Maxwell diagram) which allows a reproducibility of at least ± 0,2%.

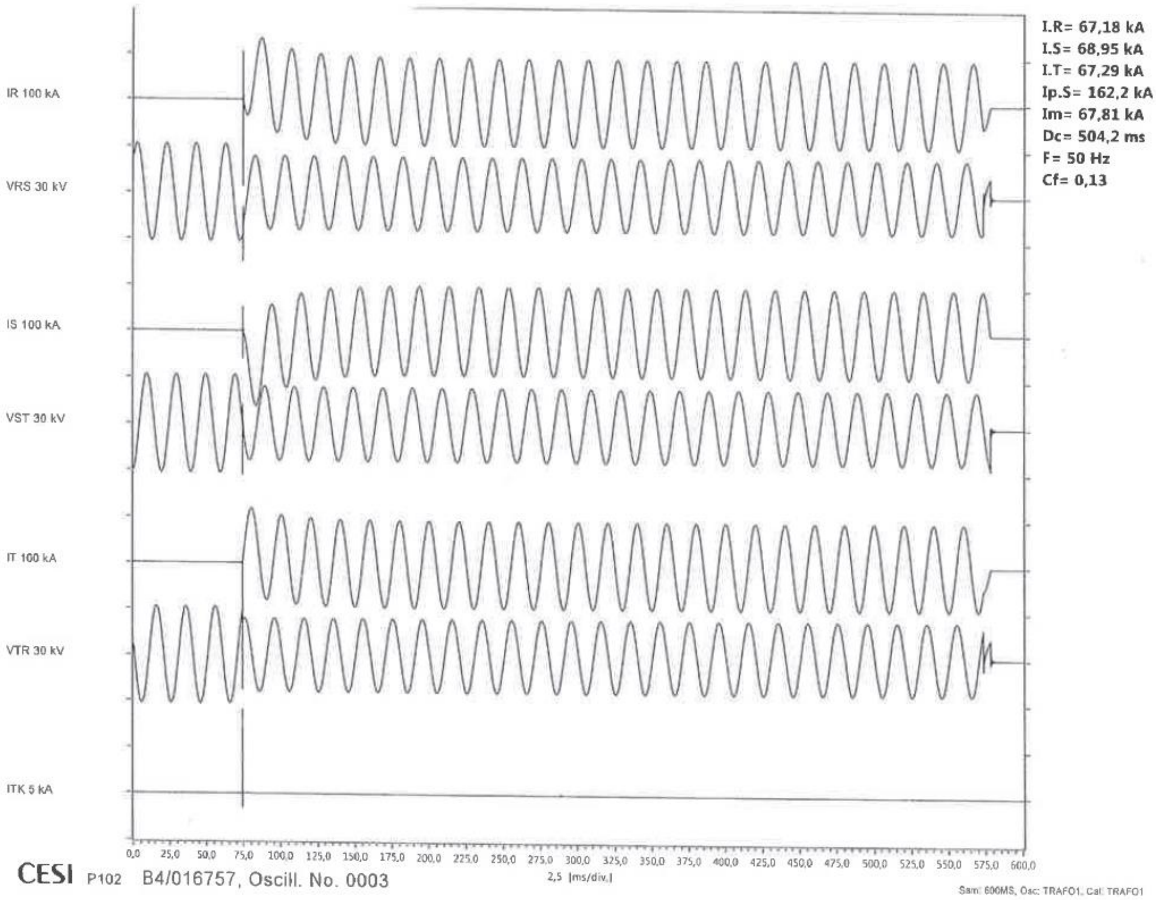
For all measurements the transformer was set-up in the following conditions:

- the terminals of the low-voltage winding were short-circuited,
- the measurement points were applied to the terminals of the high-voltage winding, delta-connected.

Date: July 7, 2014

tap-changer position	measurement effected		short-circuit inductance [mH] measured at the terminals			variation [%] from the initial measurement			short-circuit inductance [mH] calculated for single limb			variation [%] from the initial value		
			U-V	U-W	V-W	U-V	U-W	V-W	U	V	W	U	V	W
-	before the tests		40,270	40,346	38,919	-	-	-	61,037	57,082	61,276	-	-	-
-	after the test no.	4	40,380	40,498	39,007	0,27	0,38	0,23	61,189	57,176	61,561	0,25	0,17	0,46
-	after the test no.	7	40,410	40,495	39,018	0,35	0,37	0,25	61,262	57,191	61,530	0,37	0,19	0,41
-	after the test no.	10	40,405	40,448	39,032	0,34	0,25	0,29	61,269	57,246	61,405	0,38	0,29	0,21

Maximum variation of short-circuit inductance stated by Standard: 4 %


I.R= 67,18 kA
I.S= 68,95 kA
I.T= 67,29 kA
Ip.S= 162,2 kA
Im= 67,81 kA
Dc= 504,2 ms
F= 50 Hz
Cf= 0,13
IR 100 kA
VRS 30 kV
IS 100 kA
VST 30 kV
IT 100 kA
VTR 30 kV
ITK 5 kA
0,0 25,0 50,0 75,0 100,0 125,0 150,0 175,0 200,0 225,0 250,0 275,0 300,0 325,0 350,0 375,0 400,0 425,0 450,0 475,0 500,0 525,0 550,0 575,0 600,0
2,5 [ms/div.]
CESI P102 B4/016757, Oscill. No. 0003
Sam: 600MS, Osc: TRAFO1, Cat: TRAFO1

Conclusion

All tests gave positive result, moreover the hot-spot temperature-rise measurements by thermal probes and thermo-graphic camera did not highlight any critical hot spot.

Abbreviations and acronyms

Acronym	Term	Definition
AC	Alternating Current	–
AI	Analog Input	
AoC	Agreement of Collaboration	Framework between F4E and VC-DI to reinsure its commitments towards JAEA under the Procurement Arrangements
BA	Broader Approach	Agreement between Japan Government and the European Atomic Energy Community for the joint implementation of the activities in the field of fusion energy research
CB, CBU	Crowbar (Unit)	Electrical circuit used to prevent an overvoltage of a power supply
CC-R	Crowbar Control Rack	Fires, controls and protects the crowbar thyristors, measuring current, DC voltage and status monitoring, apart from communicating with the MC-R.
CPU	Central Processing Unit	
CS	Central Solenoid	Nb_3Sn conductor consisting of 4 independent modules
–	Customer	VC-DI responsible for handling financially and legally the Procurement of its in-kind contributions: for this Procurement, the Customer is ENEA
DC	Direct Current	–
DDP	Detailed Design Phase	In this phase, the IS shall detail the technical solutions selected to comply with the requirements
DSP	Digital Signal Processor	
EU	Europe	
EM	Electromagnetic	
EMC	Electromagnetic Compatibility	Correct operation of different objects in the same electromagnetic environment
ENEA	ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
F4E	Fusion for Energy	European joint undertaking for ITER and the Development of Fusion Energy: integral part of the JT-60SA Project EU Home Team ensuring the coordination of implementation of the PA and its interfaces with other PAs in BA activities

FPPC FPPC(u,l) FPPC(1,2)	Fast Plasma Position Control	Coils used to control the plasma position (classified as upper/lower or 1/2)
HV	High Voltage	
HVCB	High Voltage Circuit Breaker	
IAs	Implementing Agencies	F4E and JAEA
IDC	Identification Code	Code used for identification and traceability of JT-60SA components
IPC	Inter-Process Communication	
IS	Industrial Supplier	The company selected by ENEA to provide the supplies, services or works described in these Technical Specifications, according to a Procurement Contract
JT-60SA	JT-60SA	JT-60 Super Advanced tokamak, the construction and exploitation of which shall be conducted under the Satellite Tokamak Programme and the Japanese national programme
LV	Low Voltage	–
MC-R	Main Control Rack	MC-R is in charge of the regulation and firing of thyristor rectifiers and at the same time communicating all data/signals to with JT-60SA supervising system PS-SC. It shares data with both RC-R and CC-R.
PF, PFC	Poloidal Field (Coil)	In a tokamak, the poloidal field travels in circles orthogonal to the toroidal field
PID	Plant Integration Document	Document defining the technical basis of the JT-60SA Project [ANX1]
PA	Procurement Arrangement	Framework between F4E and JAEA for the main governing, financial and collaborative requirements for the supply of a procurement package
PS	Power Supply	–
PS SC	Power Supply Supervising Computer	Computer provided by JAEA that communicates with SCSDAS, GPS and SIS and includes an IPS
RCM	Remote Control Mode	Remote Control Mode of the operations
RC-R	Rectifier Control Rack	Measures rectifier input and output currents, over temperature and monitors fuse melting status so as to communicate all this data to MC-R through optic fiber links.
RM	Reflective Memory	Real-time Local Area Network in which each computer always has an up-to-date local copy of the shared memory set
SCADA	Supervisory Control And Data Acquisition	
SCB	Static Circuit Breaker	Switch system based on static devices that supports the BPS to satisfy the SNU time specifications

SCMPS	Superconducting Magnet Power Supply	Power systems, electrical and electronic devices to feed the coils of JT-60SA
SCR	Silicon Controlled Rectifier	
SCSDAS	Supervisory Control System and Data Acquisition System	JT-60SA system
STP	Satellite Tokamak Programme	One of the three projects in the BA activities with the purpose to develop JT-60SA
TCS	Transformer for Central Solenoid	
TF, TFC	Toroidal Field (Coil)	In a tokamak, the toroidal field travels around the torus in circles
TFPPC	Transformer for Fast Plasma Position Control	
–	Tokamak	Device using a magnetic field to confine a plasma in the shape of a torus
TS	Technical Specifications	The present document
UPS	Uninterruptible Power Supply	APS provided by JAEA
VC-DI	Voluntary Contributor Designated Institution	Institution appointed by the Government of the countries (Voluntary Contributors) that give voluntary contributions to Euratom for the implementation of the BA activities