TF Instrument Transformer Accuracy

Spring 2021 Meeting

Virtual Meeting

April 27th

TF Instrument Transformer Accuracy

Agenda:

- Start of meeting and introductions.
- Approval of Agenda
- Patent-Claims Statement
- IEEE SA Copyright Policy
- Quorum-verification.
- Approval of minutes of the fall 2020 virtual meeting
- Presentation by Hossein Nabi-Bidhendi – "Voltage Transformer errors at different burdens and power factors" and discussion on the topic
- New business: Burdens at currents different than 5A, discussion on how to address the issue
- Date and Place of next Meeting (Milwaukee, Wisconsin USA, October 17-21, 2021)
- Adjournment

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Patent statement:

"If anyone in this meeting is aware of any patent claims that are potentially essential to implementation of the document under consideration by this WG, that fact should be made known to the WG and recorded in the meeting minutes"

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6

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Quorum verification

- 30 members
- 16 needed for quorum

If you would like to apply for membership, please contact the one of the chairs:

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7

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Ivan Konta	Marek Kornowski	Deepak Kumaria	Colby Lovins	Nigel Macdonald	Arnaud Martig
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Risto Trifunoski	Kiran Vedante	Deniss Villagran	David Wallace	Mana Yazdani	Igor Ziger

8

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Fall 2020 virtual meeting minutes approval

- Fall 2020 Meeting Minutes

- Minutes were sent out on 24th April
- No objections were recieved

ABB

Voltage Transformer errors at different burdens and power factors

Hossein Nabi-Bidhendi ABB Test Manager

April 12 2021

Contents

- Actual burdens are not per standards
- VT errors vs burden at specific frequency and voltage
- Errors at 0 VA
- Pe (crad) vs Re(%) and Pe (min) vs RCF
- IEEE VT errors
- Errors at pf 1 and 0.8
- Errors at different pfs
- Examples
- Accuracy measurements using pure resistive burden
- Accuracy at corrected zero burden
- Error tables/graphs
- Conclusions

Conditions are not exactly per spec

Typical problems end-users have:

- Burden is not per IEEE
- Burden modified to mitigate the effect of ferroresonance
- Actual burden is less than 25% of rated burden when tested per IEC
- Rated voltage is not per IEEE, ie 110 and 115 V ?

- How accurate are the VTs?

VT errors vs burden at specific frequency and voltage

For small values of phase errors (less than one degree) the voltage drop of the VT can be used in a vector diagram representing the voltage error.

A change in the magnitude of the burden is proportional to the change in the length of the voltage drop.

A change in the power factor is the same as the angular displacement of the voltage drop when in % and crad.

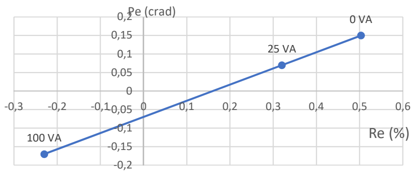
Errors per formula 17 and 18 Cl 10.1.2 IEEE C57.13:

$$\mathrm{RCF_c} = \mathrm{RCF_o} + \left(\frac{\mathrm{B_c}}{\mathrm{B_t}}\right) \times \left[\mathrm{RCF_d} \times \cos(\theta_t - \theta_c) + \gamma_d \times \sin(\theta_t - \theta_c)\right] \qquad (17)$$

$$\gamma_c = \gamma_o + \left(\frac{\mathrm{B_c}}{\mathrm{B_t}}\right) \times \left[\gamma_d \times \cos(\theta_t - \theta_c) - \mathrm{RCF_d} \times \sin(\theta_t - \theta_c)\right] \text{ [in radians]} \qquad (18)$$

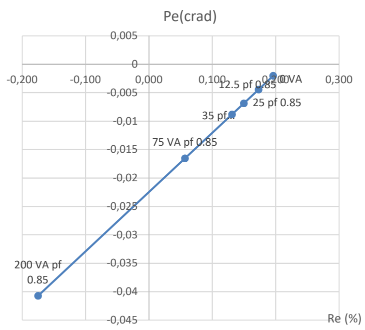
Errors at 0 VA can be calculated from 100% and 25% burden values

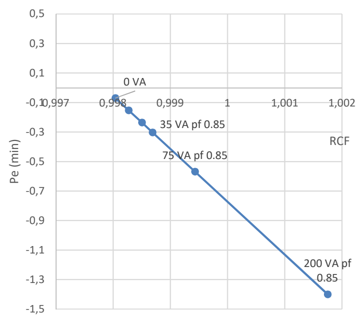
Burden (VA)	pf	RCF	Pe	Re
25	1	0.9968	2.4	0.32
100	1	1.0023	-5.85	-0.23



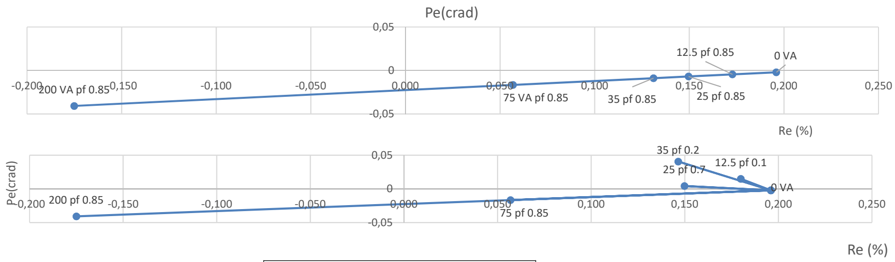
Burden	RCF	Re	Pe(min)	Pe (crad)
0	0.994967	0.503333	5.15	0.14984

Pe (crad) vs Re(%) and Pe (min) vs RCF, VT 7200/120 V



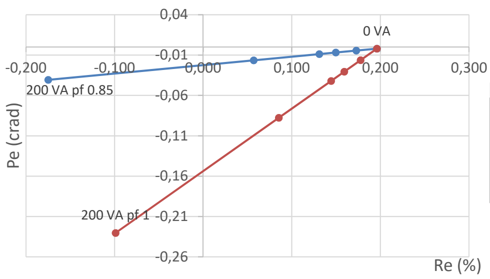


IEEE VT errors



Burden coefficient		
	ΔPe (min)/12.5 VA	ΔRe (%)/12.5 VA
pf 0.85	-0.08313	0.00023
pf 0.7	0.10922	0.00023
pf 0.6	0.21270	0.00022
pf 0.2	0.52289	0.00018
pf 0.1	0.58158	0.00016

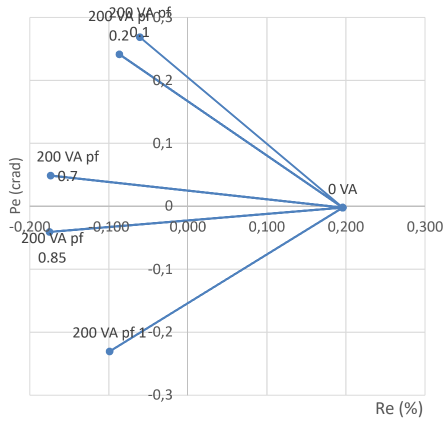
Errors at pf 1 and pf 0.8



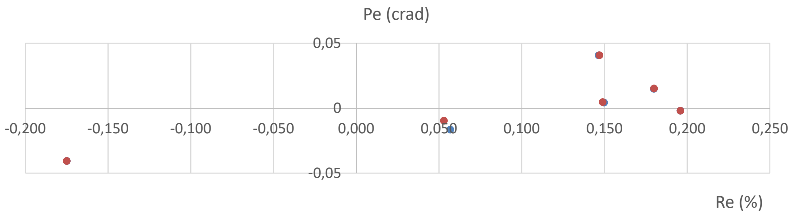
	pf 0.8			pf 1		
VA	Re(%)	Pe(crad)	Pe (min)	Re(%)	Pe(crad)	Pe (min)
0	0.196	-0.002	-0.070	0.196	-0.002	-0.070
12.5	0.173	-0.004	-0.153	0.178	-0.016	-0.561
25	0.150	-0.007	-0.236	0.159	-0.031	-1.052
35	0.131	-0.009	-0.303	0.144	-0.042	-1.444
75	0.057	-0.017	-0.569	0.085	-0.088	-3.014
200	-0.175	-0.041	-1.400	-0.099	-0.230	-7.920

Phase error is worse at pf 1 but ratio error is better

VT errors at different power factors



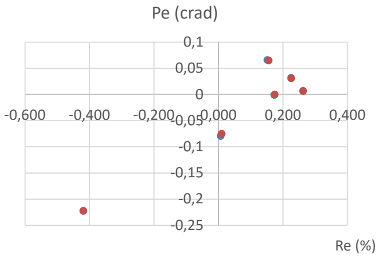
Example 1- 60 Hz VT 7200/120 V NMI vs NMI



Measurements at 0 and Z were used to calculate errors at all VAs and compared with the measured values. Measurements were done in an NMI lab.

			Measured		Calculated				
VA	pf	B	Re(%)	Pe(crad)	Re(%)	Pe(crad)	ΔR_e (%)	ΔP_e (crad)	ΔP_e (min)
0	1	O	0.196	-0.00204	0.196	-0.00204			
12.5	0.1	W	0.18	0.01513	0.180	0.01488	0.000	-0.0002	-0.01
25	0.7	X	0.149	0.00466	0.150	0.00432	0.001	-0.0003	-0.01
35	0.2	M	0.147	0.04073	0.147	0.04055	0.000	-0.0002	-0.01
75	0.85	Y	0.053	-0.00960	0.057	-0.01654	0.004	-0.0069	-0.24
200	0.85	Z	-0.175	-0.04073	-0.175	-0.04072			

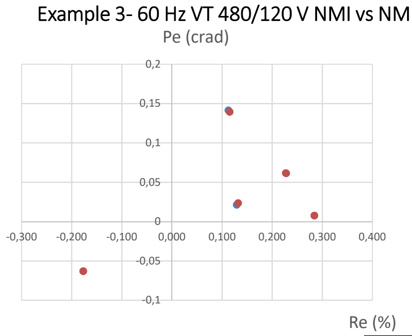
Example 2- 60 Hz VT 4800/120 V NMI vs NMI



Measurements at 0 and Z were used to calculate errors at all VAs and compared with the measured values. Measurements were done in an NMI lab.

			Measured		Calculated				
VA	pf	B	Re(%)	Pe(crad)	Re(%)	Pe(crad)	ΔR_e (%)	ΔP_e (crad)	ΔP_e (min)
0	1	O	0.263	0.00669	0.263	0.00669			
12.5	0.1	W	0.226	0.03084	0.226	0.03177	0.000	0.00093	0.03
25	0.7	X	0.175	0.00000	0.173	-0.00082	-0.002	-0.00082	-0.03
35	0.2	M	0.156	0.06488	0.152	0.06600	-0.004	0.00112	0.04
75	0.85	Y	0.01	-0.07507	0.007	-0.07927	-0.003	-0.00420	-0.14
200	0.85	Z	-0.419	-0.22258	-0.419	-0.22253			

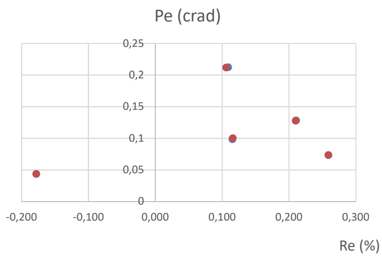
Example 3- 60 Hz VT 480/120 V NMI vs NMI



Measurements at 0 and Y were used to calculate errors at all VAs and compared with the measured values. Measurements were done in an NMI lab.

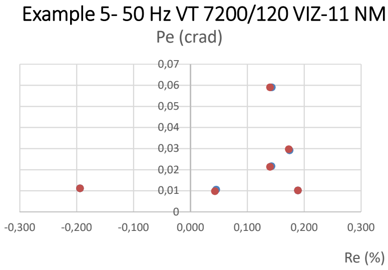
			Measured		Calculated				
VA	pf	B	Re(%)	Pe(crad)	Re(%)	Pe(crad)	ΔR_e (%)	ΔP_e (crad)	ΔP_e (min)
0	1	O	0.284	0.00756	0.284	0.00756			
12.5	0.1	W	0.227	0.06168	0.228	0.06133	0.001	-0.00036	-0.01
25	0.7	X	0.132	0.02357	0.129	0.02130	-0.003	-0.00227	-0.08
35	0.2	M	0.115	0.13937	0.112	0.14145	-0.003	0.00208	0.07
75	0.85	Y	-0.177	-0.06314	-0.177	-0.06312			

Example 4- 50 Hz VT 480/120 V NMI vs NMI



			Measured		Calculated				
VA	pf	B	Re(%)	Pe(crad)	Re(%)	Pe(crad)	ΔR_e (%)	ΔP_e (crad)	ΔP_e (min)
0	1	O	0.259	0.07332	0.259	0.07330			
12.5	0.1	W	0.21	0.12779	0.211	0.12806	0.001	0.00027	0.01
25	0.7	X	0.116	0.10020	0.115	0.09841	-0.001	-0.00179	-0.06
35	0.2	M	0.106	0.21193	0.109	0.21217	0.003	0.00024	0.01
75	0.85	Y	-0.178	0.04364	-0.178	0.04363			

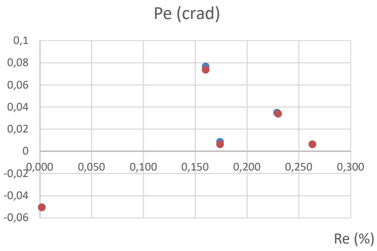
Example 5- 50 Hz VT 7200/120 VIZ-11 NMI vs NMI



Measurements at 0 and Z were used to calculate errors at all VAs and compared with the measured values. Measurements were done in an NMI lab.

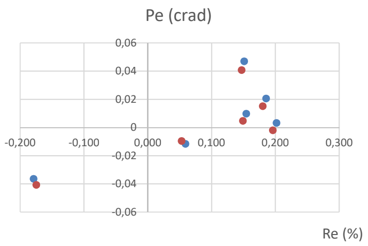
			Measured		Calculated			
VA	pf	B	Re(%)	Pe(crad)	Pe(crad)	ΔR_e (%)	ΔP_e (crad)	ΔP_e (min)
0	1	O	0.189	0.01013	0.01012			
12.5	0.1	W	0.173	0.02968	0.02915	0.001	-0.00053	-0.02
25	0.7	X	0.14	0.02130	0.02166	0.003	0.00036	0.01
35	0.2	M	0.14	0.05900	0.05901	0.003	0.00001	0.00
75	0.85	Y	0.043	0.00978	0.01052	0.002	0.00074	0.03
200	0.85	Z	-0.194	0.01117	0.01117			

Example 6- 50 Hz VT 4800/120, NMI vs NMI



			Measured		Calculated				
VA	pf	B	RCF	Pe (min)	RCF	Pe(min)	ΔR_e (%)	ΔP_e (crad)	ΔP_e (min)
0	1	O	0.99737	0.216	0.99737	0.22			
12.5	0.1	W	0.9977	1.164	0.99771	1.20	-0.001	0.0011	0.0395
25	0.7	X	0.99826	0.216	0.99826	0.30	0.000	0.0023	0.0795
35	0.2	M	0.9984	2.532	0.998399	2.64	0.000	0.0030	0.1040
75	0.85	Y	0.99998	-1.74	0.99998	-1.74			

Accuracy measurements using pure resistive burden, NMI vs ABB



Burden	RCF	Pe	Burden (VA)	pf
O	0.997983	0.11	1.1	1
205.81	1.0011	-8.18	205.81	1

Red bullets are the NMI values

			NMI		ABB				
VA	pf	B	Re (%)	Pe(crad)	Re (%)	Pe(crad)	ΔRe (%)	ΔPe (crad)	ΔPe (min)
0	1	O	0.196	-0.0020	0.202	0.0032	0.006	0.0052	0.18
12.5	0.1	W	0.180	0.0151	0.185	0.0206	0.005	0.0054	0.19
25	0.7	X	0.149	0.0047	0.154	0.0097	0.005	0.0051	0.17
35	0.2	M	0.147	0.0407	0.151	0.0469	0.004	0.0062	0.21
75	0.85	Y	0.053	-0.0096	0.059	-0.0117	0.006	-0.0021	-0.07
200	0.85	Z	-0.175	-0.0407	-0.179	-0.0364	-0.004	0.0043	0.15

Accuracy measurement using pure resistive burden 0VA corrected

Burden	RCF	Pe	Burden (VA)	pf
O	0.997966	0.15	0	1
205.81	1.0011	-8.18	205.81	1

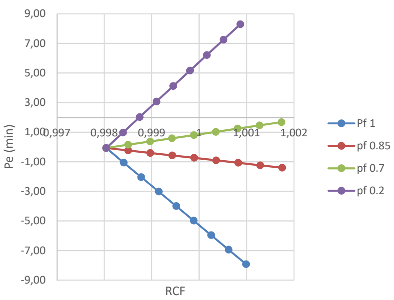
			NMI		ABB				
VA	pf	B	Re (%)	Pe(crad)	Re (%)	Pe(crad)	ΔR_e (%)	ΔPe (crad)	ΔP_e (min)
0	1	O	0.196	-0.00204	0.2034	0.004363	0.007	0.0064	0.22
12.5	0.1	W	0.18	0.015129	0.18685	0.021832	0.007	0.006703	0.23
25	0.7	X	0.149	0.004655	0.15573	0.010949	0.007	0.006293	0.22
35	0.2	M	0.147	0.040733	0.15237	0.048346	0.005	0.007613	0.26
75	0.85	Y	0.053	-0.0096	0.05981	-0.01053	0.007	-0.00092	-0.03
200	0.85	Z	-0.175	-0.04073	-0.1795	-0.03534	-0.005	0.005392	0.19

7200/120 VT errors; the effect of 1.1 VA as O VA

			O VA=1.1 VA		O VA=0 VA				
VA	pf	B	Re (%)	Pe(crad)	Re (%)	Pe(crad)	ΔRe (%)	ΔPe (crad)	ΔPe (min)
0	1	O	0.2017	0.0032	0.2034	0.004363	0.0017	0.00116	0.040
12.5	0.1	W	0.1852	0.020573	0.1869	0.021832	0.0016	0.00126	0.043
25	0.7	X	0.1543	0.009737	0.1557	0.010949	0.0015	0.00121	0.042
35	0.2	M	0.1509	0.046939	0.1524	0.048346	0.0014	0.00141	0.048
75	0.85	Y	0.0589	-0.01166	0.0598	-0.01053	0.0010	0.00113	0.039
200	0.85	Z	-0.1792	-0.03641	-0.1795	-0.03534	-0.0003	0.00107	0.037

Errors tables/graphs can be provided based on two measurements

VA	pf	RCF	Pe(min)	VA	pf	RCF	Pe(min)
0	1	0.99804	-0.07	0	0.7	0.99804	-0.07
25	1	0.998409	-1.05	25	0.7	0.998502	0.15
50	1	0.998777	-2.03	50	0.7	0.998964	0.37
75	1	0.999146	-3.01	75	0.7	0.999426	0.59
100	1	0.999515	-3.99	100	0.7	0.999888	0.80
125	1	0.999884	-4.98	125	0.7	1.00035	1.02
150	1	1.000252	-5.96	150	0.7	1.000811	1.24
175	1	1.000621	-6.94	175	0.7	1.001273	1.46
200	1	1.00099	-7.92	200	0.7	1.001735	1.68
VA	pf	RCF	Pe(min)	VA	pf	RCF	Pe(min)
0	1	0.99804	-0.07	0	0.2	0.99804	-0.07
25	0.85	0.998504	-0.24	25	0.2	0.998393	0.98
50	0.85	0.998968	-0.40	50	0.2	0.998747	2.02
75	0.85	0.999431	-0.57	75	0.2	0.9991	3.07
100	0.85	0.999895	-0.74	100	0.2	0.999454	4.11
125	0.85	1.000359	-0.90	125	0.2	0.999807	5.16
150	0.85	1.000823	-1.07	150	0.2	1.00016	6.20
175	0.85	1.001286	-1.23	175	0.2	1.000514	7.25
200	0.85	1.00175	-1.40	200	0.2	1.000867	8.30



Conclusions

- A combination of measurements (only two) and calculation are used to calculate the accuracy values for different burdens.
- The measurements and calculation are per standards but hardly employed in industries.
- Using this method will:
- simplify testing and test equipment
- reduce calibration time
- reduce test time
- require less training
- improve the uncertainty of measurement
- produce results for non-standard burdens whenever needed
- Support end-users to determine the exact errors of the VTs based on the actual burden

TF Instrument Transformer Accuracy

New business - Burdens at currents different than 5A, discussion on how to address the issue

- In C57.13-2016 Table 10 a note states that for secondary ratings other than 5A the burden impedance stays the same and the VA will change.
- This statement is not consistent with C57.13-2008 or the approach taken by IEC.

IEEE C57.13-2016

Table 10 —Standard metering burdens for current transformers with 5 A secondary windings[a]

Burdens	Burden designation[b]	Resistance (Ω)	Inductance (mH)	Impedance (Ω)[c]	Total Power (VA at 5 A)	Total Power (VA at 1 A)	Power factor
Electronic burdens	E0.04	0.04	0	0.04	1.0	0.04	1.0
	E0.2	0.2	0	0.2	5.0	0.2	
Metering burdens	B-0.1	0.09	0.116	0.1	2.5	0.1	0.9
	B-0.2	0.18	0.232	0.2	5.0	0.2	
	B-0.5	0.45	0.580	0.5	12.5	0.5	
	B-0.9	0.81	1.040	0.9	22.5	0.9	
	B-1.8	1.62	2.080	1.8	45.0	1.8	

[a] If a current transformer secondary winding is rated at other than 5 A, the impedance, the power factor, and the burden designation remain the same while the VA at rated current shall be adjusted by $[5/(\text{ampere rating})]^2$.
[b] These standard burden designations have no significance at frequencies other than 60 Hz.
[c] The impedance tolerance is +5% and –0%.

IEEE C57.13-2008

Table 9—Standard burdens for current transformers with 5 A secondary windings[a]

Burdens	Burden designation[b]	Resistance (Ω)	Inductance (mH)	Impedance (Ω)[c]	Total Power (VA at 5 A)	Power factor
Metering burdens	B-0.1	0.09	0.116	0.1	2.5	0.9
	B-0.2	0.18	0.232	0.2	5.0	0.9
	B-0.5	0.45	0.580	0.5	12.5	0.9
	B-0.9	0.81	1.040	0.9	22.5	0.9
	B-1.8	1.62	2.080	1.8	45.0	0.9
Relaying burdens	B-1.0	0.50	2.300	1.0	25.0	0.5
	B-2.0	1.00	4.600	2.0	50.0	0.5
	B-4.0	2.00	9.200	4.0	100.0	0.5
	B-8.0	4.00	18.400	8.0	200.0	0.5

[a]If a current transformer secondary winding is rated at other than 5 A, ohmic burdens for specification and rating shall be derived by multiplying the resistance and inductance of the table by $[5/(\text{ampere rating})]^2$, with the VA at rated current, the power factor, and the burden designation remaining the same.
[b]These standard burden designations have no significance at frequencies other than 60 Hz.
[c]The impedance tolerance is +5% and −0%.

TF Instrument Transformer Accuracy

Proposal – To set up a dedicated meeting (call) between meetings to address this issue and conclude why this change was made and if possible determine the approach to be taken in the future

- If you would like to be a part of the dedicated discussion please add your preferred email in the session chat
- Or contact one of the chairs:

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