ESTIMATION OF REACTIVE ENERGY LOSSES IN TRANSFORMERS 110/20 kV BASED ON ACTIVE AND REACTIVE ENERGY CONSUMPTION

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ABSTRACT

Common problem with us, is non metered data needed for calculations. Solving of this problem is often modeling of needed data. This paper offer possibility of reactive energy losses in transformers 110/20 kV estimation, based on active and reactive energy consumption. Problem is based on replacing second power of effective current in observed period, with allowed data of active and reactive energy. It starts with relation for power losses in transformer and its transformation and approximation for establishing relationship between reactive energy losses in transformers 110/20 kV, and active and reactive energy consumption. This relation was established by introducing dynamic power factor T_F. This factor is dependent of transformer load diagram. It was noticed that there is stabile results for T_F. Also was confirming that T_F is not influenced by metering errors.

RELATION FOR COUNTING REACTIVE ENERGY LOSSES

Starting counting of reactive power losses is made in goal of establishing common relation for reactive energy losses in transformer 110/20 kV, using available data:

$$Q_g = 3X_k I^2 + Q_{FE} \tag{1}$$

Where:

Q_g - transformer reactive power losses
H_k - Short circuit transformer reactance on lower tension
I - lower tension current
Q_{FE} - reactive power losses (caused by torus magnetism).

Data of lower tension are the relevant data also as transformer data related on lower tension. Replacing I, X_k and Q_{FE} in former relation, it becomes:

$$Q_{gi} = \frac{u_k}{S_n}\frac{U_n^2}{U_i^2}S_i^2 + \frac{U_i^2}{U_n^2}Q_{FEn} \tag{2}$$

Where u_k is in relative units. Index "n" is for nominal attribute, index "i" is for lower tension data in the observed (i-th) hour.
By the addition of reactive power losses we have relation for reactive energy losses in interval T.

$$W_{qg} = \frac{u_k}{S_n}\sum_{i=1}^{T}\left(\frac{U_n}{U_i}\right)^2 S_i^2 + \sum_{i=1}^{T}\left(\frac{U_i}{U_n}\right)^2 Q_{FEn} \tag{3}$$

Main problem in this formula is missing of tension and transformer power hour's data. Presence of transformer regulation (position tap changer) cause that the changing of tension is in the narrow range. So we can assume that U_i has the same value in the every hour and the same average value U_{SR}. This assumption would not have some influence on results. So we have:

$$W_{qg} = \frac{u_k}{S_n}\left(\frac{U_n}{U_{Sr}}\right)^2 \sum_{i=1}^{T} S_i^2 + T\left(\frac{U_{Sr}}{U_n}\right)^2 Q_{FEn} \tag{4}$$

INTRODUCING DYNAMIC POWER FACTOR T_F

Data for power by every hour are needed for counting reactive energy losses and by using (4). This data are often not available, so we this relation transform in other shape. In this purpose we (4) divide and multiple with T and E^2 that are the sum of second power active energy (W_P) and reactive energy (W_Q) in observed interval.

$$W_{qg} = \frac{u_k}{S_n}\left(\frac{U_n}{U_{Sr}}\right)^2 \frac{T\sum_{i=1}^{T} S_i^2}{TE^2} E^2 + T\left(\frac{U_{Sr}}{U_n}\right)^2 Q_{FEn} \tag{5}$$

Where:

$$E^2 = \left(\sum_{i=1}^{T} P_i\right)^2 + \left(\sum_{i=1}^{T} Q_i\right)^2 \tag{6}$$

Also:

$$E^2 = W_p^2 + W_Q^2 \tag{7}$$

In this relation it can be replace so the dynamic power factor T_F becomes:

$$T_F = \frac{E^2}{T\sum_{i=1}^{T} S_i^2} \tag{8}$$

This factor was introduced for eliminated power hourly data S_i from equation (4). It will be shown that T_F should be estimate without knowing power hourly data S_i, so in this purpose in eq. (8) was introduced next relation:

$$S_i = \frac{P_i}{\cos_i \varphi} \tag{9}$$

Where:
P_i - Power in 1 hour periods
$\cos_i \varphi$ - Factor in related hour

If we take that in one months cos φ of transformer station is in narrow range near medium value, we can take medium value for all hours. So we can make:

$$T_F = \frac{E^2}{T\sum_{i=1}^{T} P_i^2} \cos^2_{SR} \varphi \tag{10}$$

Average value for cosφ (cos φ_{SR}) can be solved by monthly active and reactive consumption, for that same transformers station:

$$\cos_{SR} \varphi = \frac{W_p}{\sqrt{W_p^2 + W_q^2}} \tag{11}$$

Using relations for E^2 and T_F we finally have:

$$T_F = \frac{W_p^2}{T\sum_{i=1}^{T} P_i^2} \tag{12}$$

Final relation for counting reactive energy becomes:

$$W_{qg} = \frac{u_k}{S_n}\left(\frac{U_n}{U_{Sr}}\right)^2 \frac{1}{TT_F}\left(W_p^2 + W_Q^2\right) + \left(\frac{U_{Sr}}{U_n}\right)^2 TQ_{FEn} \tag{13}$$

ANALYSIS OF TRANSFORMER STATION 110/20 kV T_F FACTOR RESULTS

Value for T_F factor is counted for TS 110/20 kV on month level, so the period T is equal to the number of hours in one month. This factor is counted for transformer stations: Temerin, Zabalj, Debeljaca, Begejci, N. Becej, Apatin, Vrbas 2, Kula, Senta, Ada.
Average T_F factor for all this transformer station and all months is 0,962, and maximum deviation from this data is for Kula in the September with range of 2,85%. In the table 1 is shown values for T_F for all month in 2002, and for all transformer stations. Last column contains average monthly values T_F but last row contains average values for transformer stations T_F. Shaded value is value that mostly steps away from total average value for T_F. In the table 2 are shown deviations in % monthly factors T_F from average values for all transformer stations, so for values from the last row in table 1. Shaded values in table 2 shows the month that T_F is mostly deviate from average value. In table 3 are shown deviations T_F in % for all transformer stations from average value in the month, so from the values from the last column in table 1. Shaded values in table 3 shown transformer station that T_F have biggest deviation from average month value.
By the results from tables 1, 2 and 3, it is obvious, with acceptable error, we can take unique value for T_F for whole year and for all TS 110/20 kV in Vojvodina region.

TABLE 1 - values for T_F

T_F	Temerin	Zabalj	Debelj.	Begejci	N. Becej	Apatin	Vrbas 2	Kula	Sid	Senta 2	Ada	Average
January	0,961	0,967	0,974	0,964	0,972	0,986	0,958	0,981	0,972	0,979	0,982	0,972
February	0,959	0,966	0,973	0,964	0,972	0,985	0,971	0,972	0,969	0,984	0,978	0,972
Mart	0,956	0,960	0,967	0,957	0,967	0,979	0,965	0,958	0,964	0,983	0,969	0,966
April	0,954	0,949	0,959	0,957	0,960	0,972	0,938	0,959	0,958	0,970	0,960	0,958
March	0,961	0,952	0,961	0,939	0,956	0,973	0,945	0,955	0,960	0,951	0,950	0,955
June	0,959	0,956	0,965	0,958	0,960	0,979	0,938	0,935	0,942	0,980	0,969	0,958
July	0,964	0,947	0,968	0,958	0,956	0,976	0,977	0,946	0,968	0,974	0,959	0,963
August	0,964	0,951	0,962	0,961	0,965	0,975	0,967	0,962	0,962	0,963	0,950	0,962
September	0,943	0,936	0,951	0,946	0,955	0,964	0,937	0,934	0,940	0,954	0,954	0,947
October	0,952	0,951	0,955	0,936	0,961	0,972	0,962	0,954	0,961	0,970	0,963	0,958
November	0,952	0,951	0,962	0,959	0,964	0,965	0,964	0,971	0,962	0,976	0,970	0,963
December	0,956	0,964	0,968	0,960	0,968	0,979	0,974	0,979	0,970	0,947	0,973	0,967
Average	0,957	0,954	0,964	0,955	0,963	0,975	0,958	0,959	0,961	0,969	0,965	

TABLE 2 - deviations monthly factors T_F from year average value for TS

Deviation %	Temerin	Zabalj	Debelj.	Begejci	N. Becej	Apatin	Vrbas 2	Kula	Sid	Senta 2	Ada
January	0,447	1,326	1,043	0,941	0,933	1,151	0,042	2,336	1,189	1,017	1,765
February	0,278	1,220	0,904	0,979	0,896	0,946	1,384	1,389	0,861	1,503	1,370
Mart	0,050	0,627	0,288	0,188	0,430	0,346	0,688	0,116	0,327	1,390	0,422
April	0,303	0,493	0,495	0,187	0,308	0,353	2,122	0,035	0,299	0,096	0,527
March	0,391	0,271	0,311	1,708	0,675	0,275	1,367	0,433	0,090	1,852	1,529
June	0,256	0,229	0,104	0,302	0,302	0,364	2,094	2,436	1,907	1,092	0,408
July	0,719	0,785	0,479	0,359	0,695	0,121	1,996	1,334	0,723	0,500	0,556
August	0,738	0,356	0,140	0,643	0,166	0,008	0,904	0,308	0,193	0,639	1,502
September	1,414	1,911	1,283	0,890	0,836	1,201	2,141	2,556	2,124	1,542	1,111
October	0,495	0,362	0,888	1,991	0,206	0,377	0,402	0,482	0,081	0,048	0,185
November	0,524	0,290	0,182	0,422	0,084	1,098	0,603	1,255	0,111	0,693	0,587
December	0,043	1,066	0,480	0,568	0,512	0,384	1,705	2,103	0,935	2,306	0,857
max. %	1,414	1,911	1,283	1,991	0,933	1,201	2,141	2,556	2,124	2,306	1,765

TABLE 3 - deviation T_F by TS from monthly values

Deviation %	Temerin	Zabalj	Debelj.	Begejci	N. Becej	Apatin	Vrbas 2	Kula	Sid	Senta 2	Ada	max. %
January	1,165	0,576	0,150	0,883	0,045	1,448	1,442	0,907	0,043	0,696	0,954	1,448
February	1,290	0,640	0,055	0,803	0,041	1,284	0,079	0,014	0,325	1,221	0,604	1,290
Mart	0,973	0,579	0,091	0,941	0,144	1,337	0,119	0,829	0,209	1,766	0,311	1,766
April	0,395	0,860	0,142	0,110	0,244	1,476	2,092	0,084	0,001	1,312	0,197	2,092
March	0,619	0,322	0,648	1,687	0,192	1,879	1,022	0,003	0,530	0,344	0,496	1,879
June	0,101	0,204	0,682	0,058	0,186	2,142	2,125	2,381	1,673	2,255	1,075	2,381
July	0,063	1,705	0,556	0,499	0,705	1,387	1,456	1,770	0,460	1,150	0,393	1,770
August	0,194	1,169	0,049	0,106	0,268	1,371	0,483	0,022	0,045	0,116	1,230	1,371
September	0,381	1,159	0,483	0,057	0,849	1,760	0,994	1,327	0,710	0,790	0,745	1,760
October	0,604	0,748	0,271	2,300	0,327	1,433	0,415	0,382	0,363	1,244	0,523	2,300
November	1,183	1,225	0,116	0,448	0,062	0,142	0,059	0,796	0,162	1,333	0,740	1,333
December	1,116	0,297	0,130	0,715	0,074	1,222	0,737	1,220	0,244	2,092	0,593	2,092

CALCULATION T_F USING LINEAR APPROXIMATION OF DIAGRAM ACTIVE POWER

Active load duration curve could be approximated by the relation:

$$P = at + b \tag{14}$$

Where are “a” and “b” the coefficients of linear equation.
If we take that 1 hour is sufficiently small interval for one month period, sum of power in relation (12) for T_F become integral. Then, instead of power we have approximation of power and we have:

$$\sum_{i=1}^{T} P_i^2 \approx \int_0^T P^2 dt = \frac{a^2 T^3}{3} + abT^2 + b^2 T \tag{15}$$

In the similar way we can have:

$$W_P^2 = \left(\int_0^T P dt \right)^2 = \frac{a^2 T^4}{4} + abT^3 + b^2 T^2 \tag{16}$$

Relation (15) should divide with T, and (16) with T^2, and after that, (15) should reduce with (16). So we have:

$$\frac{\int_0^T P^2 dt}{T} - \frac{W_P^2}{T^2} = \frac{a^2 T^2}{12} \tag{17}$$

From this relation could be gain coefficient “a”. That value for “a” provide that we could find T_F throw attributes of linearized load duration curve, and that is equal with value from relation (12). (For transformer station that are assumed here, values for “a” gain in this way and by sum of second power method from descendant power diagram, are very near.)
Relation (12) become:

$$T_F = \frac{W_p^2}{T \sum_{i=1}^{T} P_i^2} \approx \frac{W_p^2}{T \int_0^T P^2 dt} \tag{18}$$

From (17) should be derived integral of power on second power, and take into (18). In this way we have relation that after linear approximation we have factor T_F.

$$T_F = \frac{W_p^2}{\frac{a^2 T^4}{12} + W_p^2} \tag{19}$$

Picture 1 shows dependence deviations T_F from linear approximation load duratio curve “a” to the monthly active energy consumption with values: 6000, 10 000 and 16 000 MWh. By the shape of diagram some could find that more flat diagrams offer biggest approximations, so dependence T_F from “a” is smaller with less flat diagrams. In addition, with biggest consumption, we have more opportunities with choose of approximation.
Biggest deviations T_F from adopted value could be expected if the steep slope of load duration curve extremely enlarges, or if the consumption of energy becomes smaller. It is possible that transformer station doesn’t have big consumption with big difference between max and min power, but it is a rear case. More often case is change of connection and shape of 20 kV network. When we have changes of these parameters during month, we can have immense reduction of power and energy that cause augmentation of steep of load duration curve, so T_F will be changed from usual. The third possibilities is that transformer station had period of out of working. Than T_F should be recounted the number of working hours, so the period for counting is period of working.
It should be mentioned that in the all of three former case is not needed deviation of T_F from unique value for year, but it should be take care about if there have critical cases.

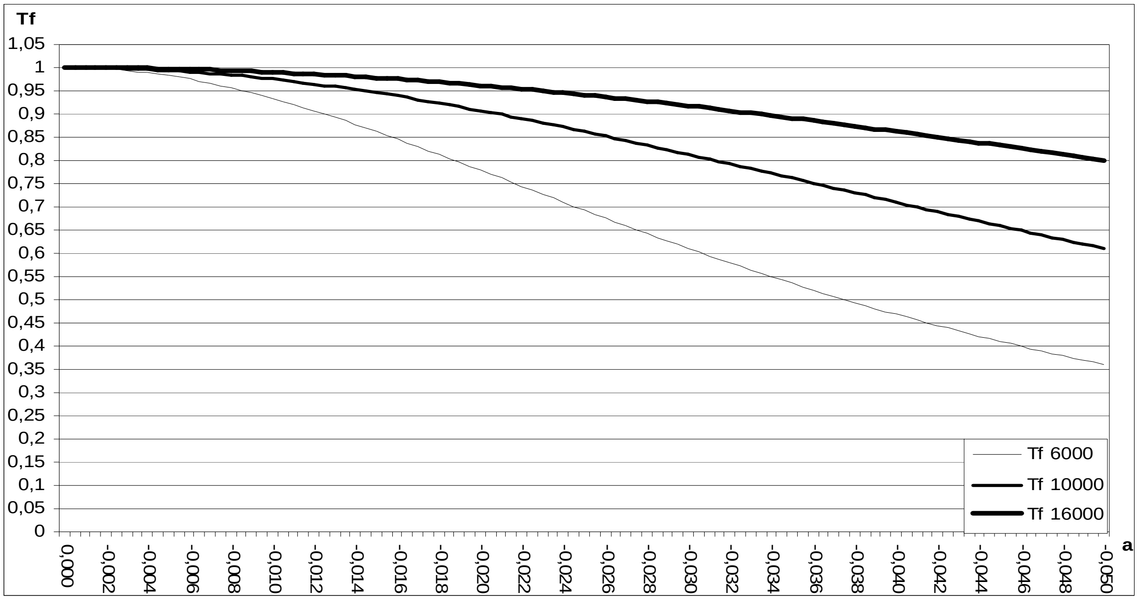

FIG. 1 - dependence T_F from linear approximation power diagram coefficient for three values (6 000, 10 000, 16 000 MWh)

CONCLUSION

In this paper is submit model for counting reactive energy losses in transformer 110/20 kV, using active and reactive energy throw transformer 110/20 kV, and manufacturers data. Model allowed correction of results depending on knowledge about tension on transformer secondary.
Attempted to simplified relation it was introduced dynamic power factor T_F, and there was counted values of this parameter; that was base for proposed value for all TS 110/20 kV. In this way is eliminates need for knowing more precise active and reactive energy diagram of transformer .
If is known active energy diagram, we can calculate T_F by using relation (12), but we can calculate reactive energy losses by (13).
Dependence, dynamic power factor T_F to the power diagram shape was analyzed and analytical relation between was created. When we can assume history of consumption, then it could be created power diagram of transformer, and also T_F by relation (19), so reactive energy losses to.