Determining the Correction Factors of Overhead-Conductors in 6kV Mining System of QuangNinh, VietNam with the Consideration of Power Harmonic Impact

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Abstract

Understanding the impact of power harmonic on energy transmission play an important role not only in the operation process but also in the designing procedure of MV grid. In 6kV mining grids of Vietnamese coal mines, because of rapidly utilizing the power electronic machines, the power quality violation occurs very frequently. This lead to many disadvantages such as: the increase of power losses, voltage distortion, over-heating in transformers and conductors. Moreover, the presence of power harmonic bring the bad impact of skin effect and proximity on conductor including overhead-conductors and cables. The actual operation exhibits that the losses of transmission lines are approximately over 50% of total network losses. If there are power quality violation, this amount could be higher. Basing on investigating the fact of power harmonic violations in 6kV grid of both underground and surface mines, the paper will analyze this kind of impact. An algorithm relying on Matlab programming is used to calculate the energy losses. Results are compared with on-site measurement datas and lab-measurement to obtain series of correction factors corresponding to individual line's cross section. The outcomes of research could be applicable for power utilities to have better analysis in the designing stage of mining MV grids.

Keywords: *medium voltage grid, skin effect, correction factor, algorithm*

1. The fact of power harmonic violations and their impact on energy losses

1.1 The fact of power harmonic on 6kV grids of Vietnamese coal mines

Base on reporting figures, from 2018 up to now, there are dozens of powertronic equipment are employed in medium voltage (MV) and low voltage (LV) grids of Vietnamese coal mines. The accounting numbers shown in table 1 [1] show that:

+ Two popular kinds of powertronic devices utilized in MV grids are: inverters and soft-starter;

+ These powertronic devices are mainly equipped for ventilation system, pumping system and conveyor one.

Data in table 1 and Figure 1 exhibit that utilizing powertronic is the trend of modernized mining. These kinds of devices bring many advantages for energy saving, convenient in operation (starting big motors, reducing the voltage sag…) but they also cause unwanted power quality violations in both MV and LV grids. Implementing the site-surveying on those coal mines, some typical data is presented in figure 2, 3, 4 and 5.

The on-site surveying data in typical mines of Vietnam showed that: There are significant power quality violations in MV grids. It expresses in both current and voltage wave forms distortions (Figures 2, 3b and 4a) as well as THD value over the limits (Figure 3a, 4b). The violations exceed greatly over the limits regulated by IEEE [2, 3, 4, 29, 31].

1.2 Impact of power harmonic violations on MV system of Vietnamese coal mines

In Vietnam, because of containing heavy machines in mining procedures which utilizes inverter or AC-DC converters [1, 29, 30], the impact of power harmonics must be seriously consider in both operational of grid and equipment installation. Without this consideration, power harmonics in medium voltage mining grids could be significant and can causes of various operational and equipment problems of issues. The key impacts of bad power harmonic qualities are:

+ Increased Energy Losses and reducing the energy transmission: Power harmonics in medium voltage mining grids are causes energy losses mainly in cables, overhead conductors, transformers, and other apparatus. The increased energy losses result from the additional heating caused by harmonic currents flowing through resistive components of the system [4,5]. Hence, the conductors energy transmission efficiency will be also reduced

+ Reduced Efficiency of motors and system: Harmonics can reduce the overall power system efficiency as well as motors operation, this leads to higher energy consumption and increased operating costs for mining companies.

+ Bad perform of monitoring and measuring system: Non-linear loads injected by inverters and converters draw current in short bursts, causing to voltage waveform distortion [2]. This may influence on performance of sensitive equipment and lead to malfunctions, motors and transformer overheating, or incorrect performing of monitoring, measuring and control systems.

+ Resonance and Overvoltage: Because of having long cable feeders and distributed loads, mining grids are susceptible to resonance conditions where harmonics are significant. Resonance could lead to overvoltage phenomena, which may damage equipment and lead to unexpected downtime.

Tab. 1. Numbers of powertronic devices in typical coal mines of Vietnam

Name of mines	Numbers of powertronic devices		
	2019	2020	2021
DuongHuy	42	52	56
CaoSon	26	42	42
CocSau	34	38	48
QuangHanh	40	39	51
HaLam	63	65	65
NuiBeo	34	67	67

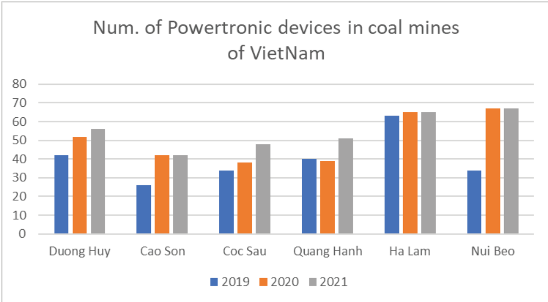
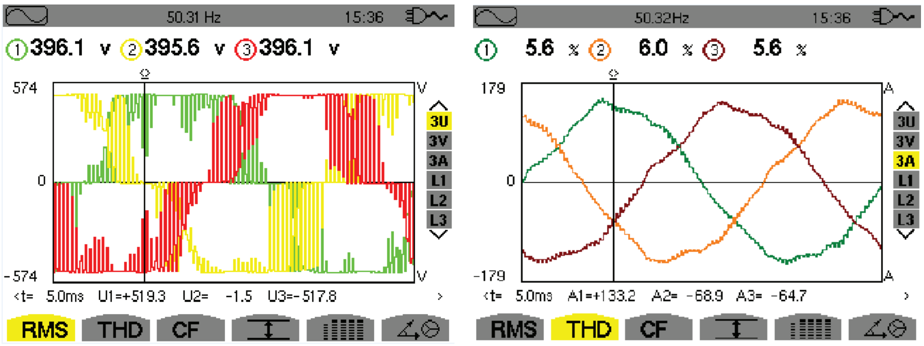
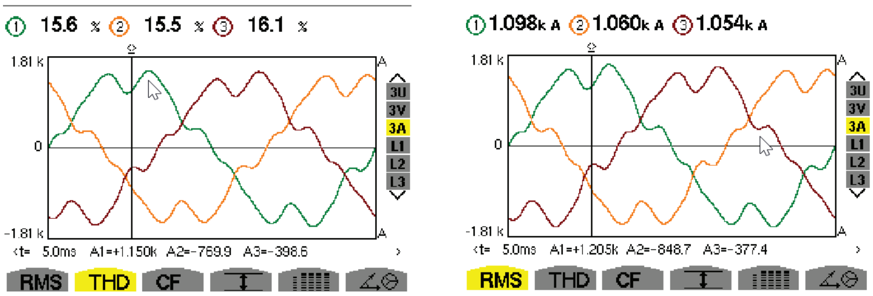


Fig. 1. Trend of utilizing powertronic devices in 3 recent years



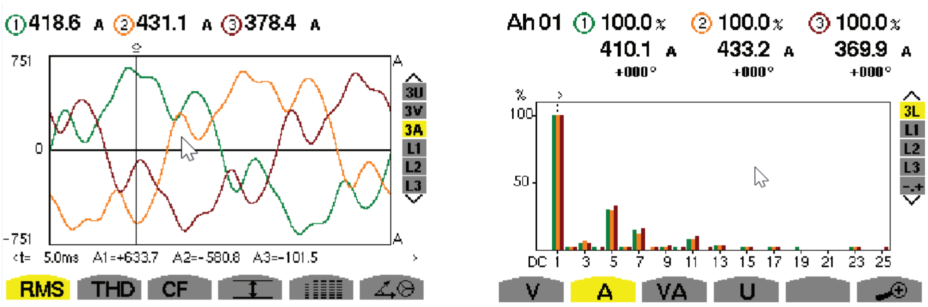
a) b)

Fig. 2. Voltage (a) and current (b) waveforms of 6kV conveyor system of NuiBeo coalmines



a) b)

Fig. 3. THD of current (a) and RMS current (b) waveforms of 6kV pumping system of QuangHanh coalmines



a) b)

Fig. 4. RMS of current (a) and THD current (b) waveforms of 6kV Ventilation system of HaLam coalmines

Tab. 2. Annual cost function of QuangYen MV grid

Type of conductor	Annual optimal cost function $Z = f(U^2)$, (10^6 VND)			
	6kV	10kV	22kV	35kV
AC35	172.552,65	92.443,62	52.462,87	43.562,17
AC50	168.668,84	73.556,47	50.353,93	40.253,63
AC70	147.446,83	65.912,15	49.070,23	39.075,13
AC95	139.741,99	52.190,12	44.464,50	36.213,50
AC120	139.960,928	48.221,648	43.767,75	34.261,35

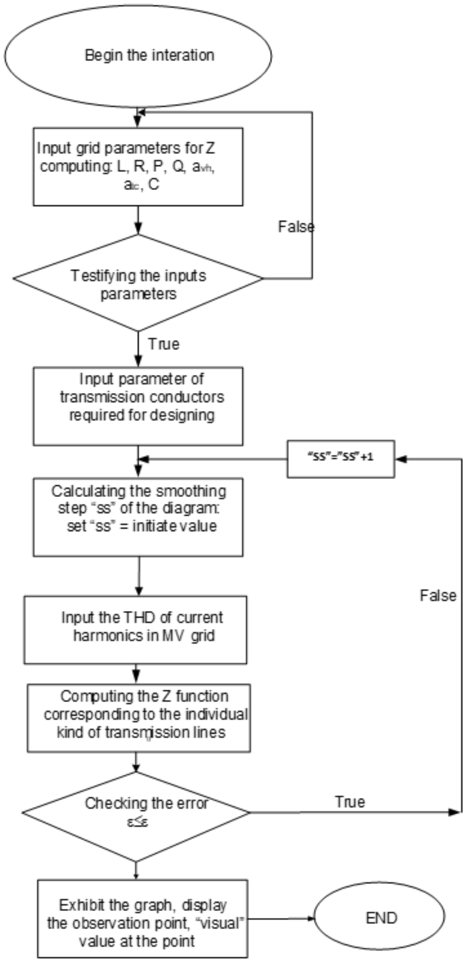


Fig. 5. Mathematic diagram presented the calculation for optimal value of Cost function Z with consideration of current power harmonic impact

+ Transformer Overheating: Most of Vietnamese coal mines contain 35/6kV transformer substation with 2 parallel operational transformers. These ones are exposed to harmonic currents, particularly if their loads are 6kV non-linear ones. "Harmonic currents cause additional eddy current and hysteresis losses in transformer cores" [2], leading to overheating and insulation failure.

Nuisance Tripping: The presence of harmonics can cause discriminative tripping of digital protective devices [29] Wrong tripping of circuit breakers could lead to bad disrupting the mining operations and economical loss because of producing interruption.

As can be seen in above analysis, there are many great impacts of bad power quality on both energy transmission and system operation. Next part of the paper will deeply analyze the influence of current power harmonic on lowering the electrical energy transmission in 6kV conductors of Vietnamese mining grids.

2. Theory basis of power harmonic consideration on designing stage of 6kV mining grid

2.1 Mathematic equations of Zcost function on estimating the economic benefit of mining grids

During power planning or grid designing, various economic indicators might be employed to assess the economic impact through Cost Benefit Analysis (CBA). The primary purposes of CBA are twofold: firstly, to ascertain the viability of an investment or decision by determining if its benefits outweigh the costs and to what extent; secondly, to establish a foundation for comparing projects by evaluating the total expected costs and benefits of each option. In the realm of mining electrical grid construction, some researches in [18, 21, 22, 23, 24] list the following indicators:

+ NPV-Net Present Value (NPV)-the difference between the discounted social benefits and cost;

+ IRR-Economic Internal Rate of Return (IRR)-the sick-out rate that produces a zero value for NPV;

+ B/C ratio-ratio between discount economic benefits and costs;

+ Zcost functions-express the cost containing in operation (a year) of grid including operating cost and maintenance cost.

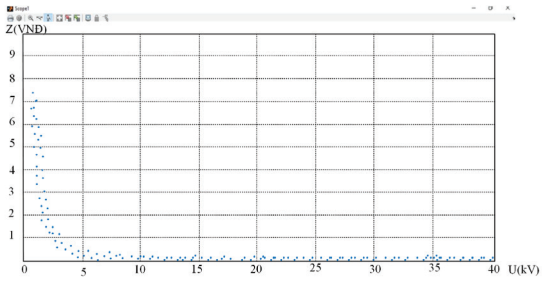


Fig. 6. Results of Zcost corresponding to AC35 conductor

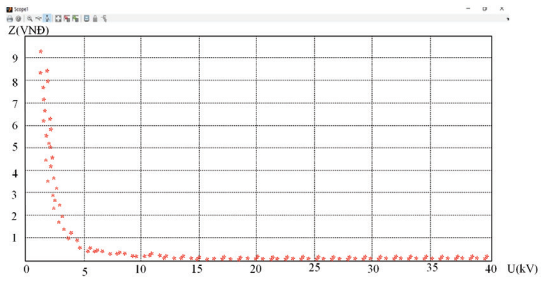


Fig. 7. Results of Zcost corresponding to AC50 conductor

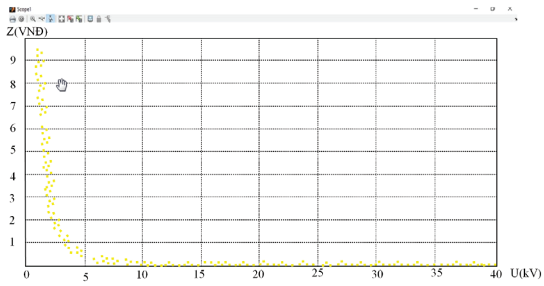


Fig. 8. Results of Zcost corresponding to AC70 conductor

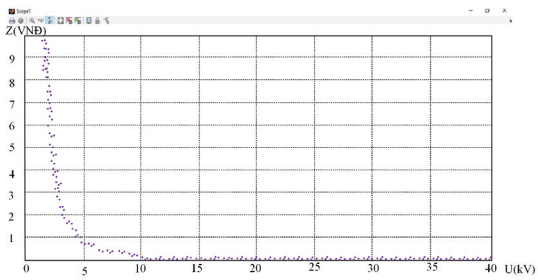


Fig. 9. Results of Zcost corresponding to AC95 conductor

During the designing stage of MV grids, three prior indicators (NPV, IRR and B/C) are not utilized. Instead, the Zcost function is employed, as it takes into account not only the initial construction investment but also the ongoing operational costs borne by operators and users. The Zcost function is typically represented by equation (1) [18, 22]:

$$Z = (a_{vh} + a_{tc})K + Y_{\Delta A} \quad (1)$$

Whereas: a_{vh} – the operation factor
a_{tc} – standard recovery factor
K – annual cost
ΔA – power losses when power is transmitted for long distance.

Detaily, Z can also be expressed by equation (2):

$$Z = (a_{vh} + a_{tc})C_{dd}m_0\ell + C\frac{(P^2+Q^2)}{U^2}\tau\frac{\delta}{s}\ell \quad (2)$$

However, as mentioned before, to get the impact of

$$Z = (a_{vh} + a_{tc})K + Y_{\Delta A}{\cdot}H \quad (3)$$

In equation (3) H-is indicator reflect the impact of current power harmonic (Harmonic impact indicator). This indicator will raise the value of Z because the power losses is increased. The problem is how to identify this indicator corresponding to different cross sections of conductors as well as various value of THD.

2.2 Propose Algorithm and Matlab application to find optimal value of Zcost function corresponding to conductor's cross sections

As mentioned in many previous research, there are series of method to optimize the power flow with consideration of

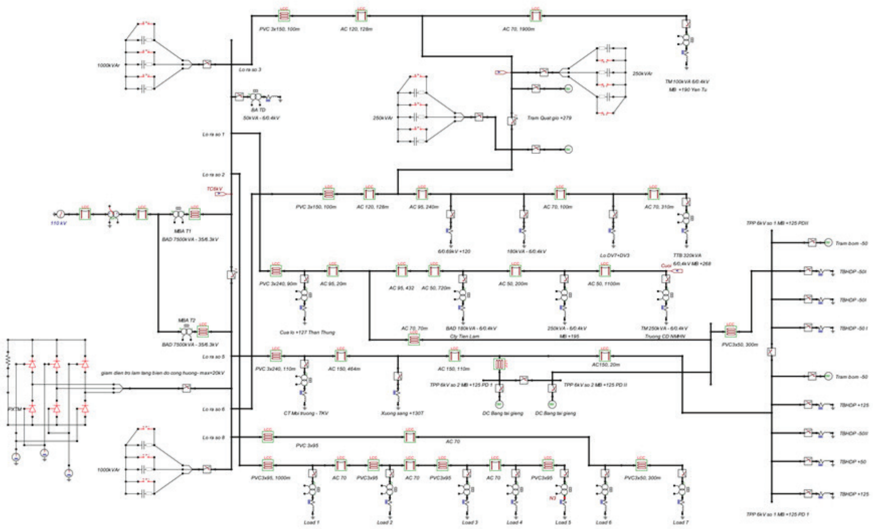


Fig. 10. Simulation in ATP with 7 harmonic sources (in red circles)

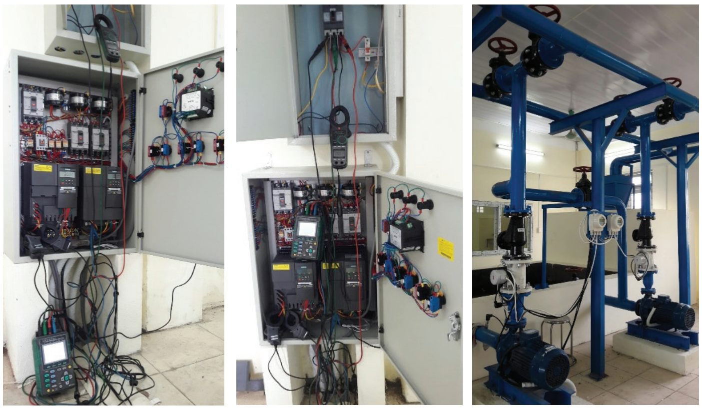


Fig. 11a. Lab-test setup for power losses measurement with pumping system

parameters affecting to energy transmission [6-10]. All of these researches rely on computer-aid program. In this section, the paper will propose an Algorithm which is the basis of computing optimal value of Z-cost function in which all impact of skin effect and current harmonic are taken into account.

In MV energy transmission, when currents flow through one or more nearby conductors, the distribution within the first conductor becomes constrained to smaller regions. This phenomenon, known as the proximity effect, can lead to current crowding, which in turn significantly increases the AC resistance of adjacent conductors. Because of the consideration to this effect, the total losses in a conductor will be result of two kinds of effects: skin and proximity [11-17] one which is expressed as equation (3) [20]:

$$P_{total} = P_{skin} + P_{Prox} \quad (4)$$

Where

$P_{skin} = I^2_{rms} \times R_{AC} \times \mathbf{H}$

$P_{prox} = (cR + d)(\frac{\mu_0 \mu_r I}{2\pi r})^2 (if R \geq \delta)$

$P_{prox} = aR^b (\frac{\mu_0 \mu_r I}{2\pi r})^2 (if R < \delta)$

a, b, c, d are constants in accordance with kinds of materials (copper and aluminum)

R – conductor radius;

δ – the skin depth: $\delta = \sqrt{\frac{2}{\sigma \omega \mu_0 \mu_r}}$

H – harmonic impact indicator

To determine H indicator, two quantities must be identified: The value of Zcost and power losses. For building the relation of Z-cost function and its depend variable, an algorithm is proposed and shown in figure 5. It is very easy to be seen that, in equation (3) Z is a function of many variants including rated voltage (U), conductor cross-section (S)… In designing process of an MV grid, it should be economically optimal if S is selected correspondingly to U [20, 21]. Utilizing the mathematic diagram in figure 5, programming in Matlab, results (figure 6 to 9) showing theoretical computing of Z is expressed for finding the optimal values of Z-cost. Some of typical outcomes applied for QuangYen MV grids [19, 22] are presented in table 2.

3. Calculating the H indicator and its impact on Z-cost computing

To identify H indicator, a simulation will be implemented in ATP (figure 10) with various power harmonic source (in red circles). By "switching in" or "switching out" the circuit breakers in skeleton networks, the impact harmonic current will be isolated. The simulation results are compared and verified with lab measurement performed in figure 11a, and 11b.

Ngày	Thời gian	V1 THD	V2 THD	V3 THD	V1 CF	V2 CF	V3 CF	Pst1	Pst2	Pst3	A1 THD	A2 THD	A3 THD
		%	%	%							%	%	%
07/08/2021	8:04:35 AM	2.4	2.3	2.7	1.49	1.49	1.49	0	0	0	43.2	43.6	31.3
07/08/2021	8:04:51 AM	2.5	2.3	2.8	1.49	1.49	1.49	0	0	0	43.4	44.3	32.7
07/08/2021	8:05:07 AM	2.3	2.1	2.8	1.48	1.49	1.49	0	0	0	37.7	39	31.1
07/08/2021	8:05:23 AM	2.3	2.2	2.7	1.48	1.49	1.49	0	0	0	34.6	35.5	28.5
07/08/2021	8:05:39 AM	2.2	2	2.6	1.49	1.49	1.49	0.3	0.4	0.3	34.9	35.6	26.4
07/08/2021	8:05:55 AM	2.2	1.9	2.5	1.49	1.49	1.49	0.3	0.4	0.3	35.3	35.1	27.1
07/08/2021	8:06:11 AM	2.5	2.1	2.3	1.49	1.49	1.49	0.3	0.4	0.3	37.6	36.7	27
07/08/2021	8:06:27 AM	2.4	2.3	2.5	1.49	1.49	1.49	0.3	0.4	0.3	39.4	38.4	27.9
07/08/2021	8:06:43 AM	2.4	2.1	2.6	1.49	1.49	1.49	0.3	0.3	0.3	33.9	33.8	26.8
07/08/2021	8:06:59 AM	2.3	2.1	2.5	1.49	1.49	1.49	0.3	0.3	0.3	34.8	34.7	27.9
07/08/2021	8:07:15 AM	2.4	2	2.5	1.49	1.49	1.49	0.3	0.3	0.3	39.3	39.1	29.1
07/08/2021	8:07:31 AM	2.3	2.3	2.5	1.49	1.49	1.49	0.3	0.3	0.3	38.2	41.9	29.4
07/08/2021	8:07:47 AM	2.4	2.4	2.6	1.49	1.49	1.49	0.3	0.3	0.3	33.6	35.3	27.1
07/08/2021	8:08:03 AM	2.3	2.3	2.6	1.49	1.49	1.49	0.3	0.3	0.3	40.2	42	31
07/08/2021	8:08:19 AM	2.2	2.1	2.4	1.49	1.49	1.49	0.3	0.3	0.3	40.4	41	31.1
07/08/2021	8:08:35 AM	2.3	2	2.2	1.49	1.49	1.49	0.5	0.6	0.5	32.8	32.9	24.1
07/08/2021	8:08:51 AM	2.2	2	2.3	1.48	1.49	1.49	0.5	0.6	0.5	40.6	40.3	29
07/08/2021	8:09:07 AM	2.4	2.4	2.4	1.49	1.49	1.49	0.5	0.6	0.5	35.8	35.4	25.8
07/08/2021	8:09:23 AM	2.3	2.4	2.6	1.49	1.49	1.49	0.5	0.6	0.5	33.3	34.9	27.4
07/08/2021	8:09:39 AM	2.6	2.5	2.6	1.49	1.48	1.49	0.4	0.4	0.4	40	40.5	29.3
07/08/2021	8:09:55 AM	2.7	3	2.8	1.5	1.49	1.49	0.4	0.4	0.4	39.8	37.9	30.1

Fig. 11b. Lab-test results extract from KEW meter

Tab. 3. Results of power losses bias (kWh) which influence Zcost function between theoretical calculation (by ATP simulation) and lab-measurement

Feeder No	S (mm²)	ATP calculation without harmonic impact	ATP calculation with harmonic impact	On-site measurement	H indicator	THD (%)
No1	AC95	3761	5288	5336	1.418	7
No2	AC70	1744,2	2687,7	2793,8	1,602	11
No3	AC120	2720,3	4089,65	4123,5	1.416	8
No5	AC150	2822,6	3994,67	4069,2	1.341	6
No6	AC120	1422,6	1934,67	1953,23	1.373	7
No8	AC70	622,6	812,6	823,7	1.433	5

Tab. 4. Series of H indicators corresponding to alternative values of THD and conductor's cross section (utilized in 6kV mining grid of VietNam)

THD (%) \ S (mm2)	AC35	AC50	AC70	AC95	AC120
3	1,342	1,296	1,273	1,266	1,22
4	1,513	1,439	1,406	1,341	1,297
5	1,548	1,476	**1,433**	1,358	1,313
6	1,576	1,492	1,460	1,402	1,346
7	1,612	1,523	1,489	**1,418**	**1,373**
8	1,638	1,562	1,526	1,456	**1,416**
9	1,66	1,583	1,545	1,481	1,426
10	1,701	1,611	1,577	1,515	1,458
11	1,715	1,629	**1,620**	1,538	1,497

Corresponding to 6 feeders of 6kV mining grids, the difference between power losses outcomes with and without harmonic impact are presented in table 3.

Figures in table 3 shows that:

+ With current harmonic consideration, the power losses in feeders must multiple with H indicators which are normally 30% greater than 1.

+ Simulations results and on-site measurements/lab tests are mostly the same for determining H indicators, Therefore, for multiple H indicators determination, simulation in ATP is suitable and does not diminish the accuracy of the computing procedure.

Implementing hundred simulations, series of H indicator corresponding to various AC cross-sections and THD are summarized in table 4

In the table, results shown in "bold" are deducted from table 3, others are computed from simulation in ATP corresponding to 6kV rated voltage.

4. Conclusion

Base on the lab test and ATP simulation, utilizing the proposed algorithm a series of H indicators are determined. Through values in table 4, the impact of current harmonic violations is strongly impressed. Depending on the THD, the power losses could be expanded from over 22% to nearly 75%. Though over the procedure some following conclusions are pointed out:

+ The proposed method with algorithm presented in figure 5 are suitable for estimating the Z-cost values of any kinds of conductors;

+ Corresponding to altenative cross-section of steel-cored aluminum conductors, the correction (H) factors vary from 1.22 to 1.71. It means that if the skin effect with harmonic consideration is much greater than other studies [25-28]. Particularly, if the THD is violate the limit required by IEEE (5%), over 50% power losses must be taken into account of power losses computing. Hence, all of grid designing stages must modified correspondingly.

+ In the initiative designing stage of MV mining grids, using the optimal Zcost function with above recommendation H factors is a good point that allow project manager having a better technical and economical parameter.

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