Effect of Power Quality on the Performance of Explosion-Proof Transformers in Mining in Vietnam

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Abstract

When meeting customer demand, utility companies must consider power quality. Currently, the industrial power network in general and the underground mine power network in particular have long feeder lines, supplying power to many nonlinear loads and power electronic converters, which reduces power quality. Poor power quality can damage sensitive equipment and lead to costly repairs, leading to lost time, data corruption, and lower productivity. In this paper, a fuzzy system is developed to determine the power quality of the power network for different operating conditions and study its influence on the performance of the explosion-proof transformer in the underground mine power network in Vietnam. The simulations and calculations were performed on Matlab-Simulink software for a three-phase, 630-kVA, 6/1.2 kV explosion-proof transformer in power networks with variable power quality. A fuzzy system is developed with four measurable inputs, including frequency deviation, voltage unbalance factor, total harmonic distortion of supply voltage, total harmonic distortion of current, and an output variable, power quality. The simulation results show that the explosion-proof transformer's performance decreases when the power quality degrades, and the proposed fuzzy system can accurately diagnose this.

Keywords: *power quality, performance, explosion-proof transformer, fuzzy system*

1. Introduction

Irrational use of electricity and improper operation of electrical equipment also partly adversely affect the environment and increase global warming [1]. Power quality is a term used to describe efficient electrical energy [2]. This means that if the device is working properly thanks to the power it receives, the power quality is good. Electrical equipment can malfunction, fail prematurely, or shut down suddenly when disturbances occur. Poor power quality leads to losses and increased costs. Outages can be costly, but damaged property can be even more costly, including potential losses due to downtime in the production process. Property damage due to power quality issues that increase heat will almost certainly shorten the life of the equipment. Common power quality problems are divided into: voltage unbalance and harmonic distortion; variable frequency. Each power quality issue will normally be evaluated individually without any focus [3, 4].

Research on power quality in power systems has attracted considerable attention from utility companies, consumers, and researchers alike [5–7]. Many power quality assessments, classifications, and diagnostics of power systems are carried out through the expert system [8], using fuzzy logic and adaptive techniques [9].

The 6kV power grid in open pit mining has typical characteristics: long service life, long feeder lines, use of large capacity equipment, many branches, many power electronics [10]. These problems degrade the overall power quality, leading to increased power loss of electrical equipment. including transformers.

Research on the effect of harmonics on transformer performance in underground mines has shown that the current flowing through the transformer is not sinusoidal, causing overload for the transformer even when operating properly with design specifications [11]. Voltage unbalance causes the peak efficiency working point to shift and transformer efficiency to decrease under all load cases [3]. Experiments show that not only the magnitude of the harmonic content in the supply voltage but also the phase angle has a significant effect on the saturation of the transformer [12]. Experimental results have shown that additional core losses due to non-sinusoidal voltage excitation can increase up to 20.8% [13]. The open circuit test using the sinusoidal source demonstrates that the core loss increases with both frequency and voltage; for frequencies below 1 kHz, the effect of increased voltage was seen to be higher [14].

However, studies of power quality in the underground mine power network currently have few research papers. In addition, evaluating the overall effect of power quality on explosion-proof transformers has not been studied. The explosion-proof transformer is one of the most important electrical components in the underground power distribution network. Proper operation and preventive maintenance of transformers will ensure continuous and reliable power supply to end-user customers without outages or interruptions.

The power quality of Vietnam's distribution power system is regulated in Circular No 39/2015/TT-BCT of the Vietnam Ministry of Industry and Trade [15]. For mine power system, a 6 kV grid, the article uses regulations for medium voltage grids. Table 1 presents the power quality of Vietnam's distribution power system for the medium voltage grid.

The novelty of the paper compared to previous studies is that it focuses on building a fuzzy system for the deter-

Tab. 1. Power quality of Vietnam's distribution power system

Voltage lever	Voltage unbalance	Voltage total harmonic distortion, THDu	Current total harmonic distortion, THDi	Frequency
01 kV to 35 kV	± 05%;	5%	8%	50 Hz ± 0.2 Hz

Tab. 2. Parameters of three-phase explosion-proof transformer

Rated power, kVA	No-load voltage (V)		Rated current, A		Short circuit voltage, $V_{sc\%}$	No-load current, I_{NL}%	Losses, W	
	V_{NL1}	V_{NL2}	I_{1n}	I_{2n}			No-load P_{NL}	Short circuit P_{sc}
630	6000	1200	60.6	304.3	3.5	3	2800	4700

Tab. 3. Simulation parameters of three-phase transformer

Resistance (Ω)		Inductance (L)		Magnetization resistance, R_m (Ω)
R_{HV}	R_{LV}	L_{HV}	L_{LV}	
0.2133	0.0085322	0.0031125	0.0001245	12857

mination of power quality and studying its influence on the performance of the explosion-proof transformer in the underground mine power network in Vietnam. The second part presents the construction of a fuzzy system for the determination of power quality. The third part builds a simulation model for a three-phase explosion-proof transformer. Section 4 is the result of research and discussion. Finally, the conclusion.

2. A fuzzy system for determination of power quality

The article builds fuzzy systems on the MATLAB fuzzy logic toolbox; it includes membership functions and fuzzy rules. Where the membership functions of frequency deviation (b) voltage unbalance, (c) voltage total harmonic distortion (THDu), and (d) current total harmonic distortion (THDi) are determined by 2 states: Low and high, corresponding to the values shown in Table 1, The measurement of the output variable power quality is expressed as membership functions such as very good, good, fair,poor, and very poor. The configuration of membership functions is shown in Figure 1. The power quality detection system in fuzzy logic uses the Mamdani fuzzy system. Fuzzy rules are shown in Figure 2.

In addition, a voltage unbalance factor is defined as the ratio of the negative-sequence voltage component (Vneg) to the positive-sequence voltage component (Vpos). This definition is consistent with IEC standard 61000-4-30 [3]:

$$K_V = \frac{V_{neg}}{V_{pos}}.100 \tag{1}$$

where, Vneg is the negative-sequence voltage component; Vpos is the positive-sequence voltage component; KV is voltage unbalance factor, %.

3. Simulation model for a three-phase explosion-proof transformer

The three-phase explosion-proof transformer with power of 630-kVA and voltage 6/1.2 kV is the type used quite commonly in the underground mine power network. Parameters of it are presented in Table 2 [11]. This is the main research object of the paper.

"Three-Phase Transformer (Two Windings)" model on MATLAB/Simulink software is used as a model of three-phase explosion-proof transformer. From the manufacturer's parameters, the paper builds simulation parameters for three-phase explosion-proof transformer based on linear transformer combined with saturation characteristic. The simulation parameters of single-phase transformer are given in Table 3. Transformers using Y/Y connection use neutral isolated from earth.

The performance of a transformer is calculated as follows:

$$eff = \frac{P_2}{P_2 + P_l + P_{nl}}100 \tag{2}$$

where, P_2 is the 3-phase low-voltage output power of a transformer (W), P_l is the load loss of a transformer (W), P_{nl} is the no-load loss of a transformer (W).

The no-load loss of a transformer is independent of the load and is caused by the induced voltage in the core. In the proposed model no-load loss of a transformer is the iron losses modeled by Magnetization resistance R_m and it is calculated by the following formula:

$$P_{nl} = P_{Fe} = R_m \sum_{i=1}^{3} I_{i,core}{}^2 \tag{3}$$

where R_m is the magnetization resistance, Ω; $I_{i,\ core}$ is the true RMS value of core loss current of the ith phase of the transformer (A).

The load loss in the proposed model is the copper loss, which is proportional to the square of the true root mean square (RMS) value of the load current and is calculated according to the following formula:

$$P_l = R_{HV}.\sum_{i=1}^{3} I_{i,HV}{}^2 + R_{LV}.\sum_{i=1}^{3} I_{i,LV}{}^2 \tag{4}$$

where RHV is the high voltage phase resistor; R_{LV} is the low voltage phase resistance; $I_{i,\ HV}$ is the true RMS value of high voltage load current of the ith phase of the transformer; $I_{i,LV}$ is the true RMS value of low voltage load current of the ith phase of the transformer.

The simulation model on Matlab-Simulink is shown in Figure 3. In this part, the source block "Thee Phase Programmable Voltage Source" is used, the forms of power quality change used through this source block include: creating harmonics, creating phase voltage difference or changing the frequency of the power supply. In addition, the power calculation stages are performed according to the formulas present-

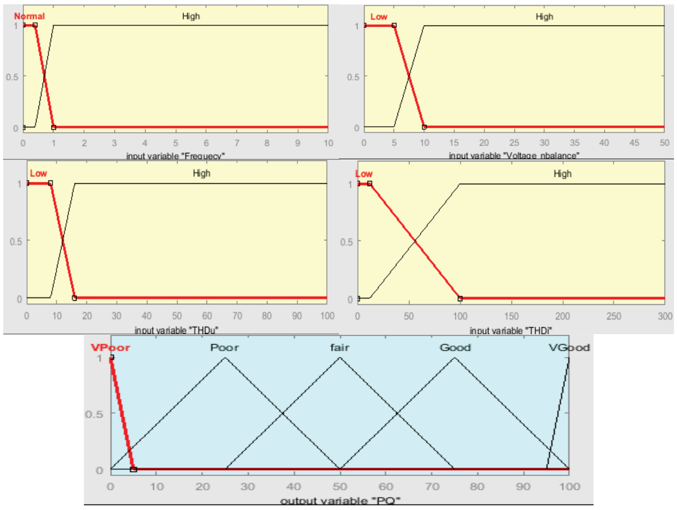

Fig. 1. The fuzzy membership functions used for (a) frequency deviation (b) voltage unbalance, (c) voltage THD, (d) current THD, and (e) power quality

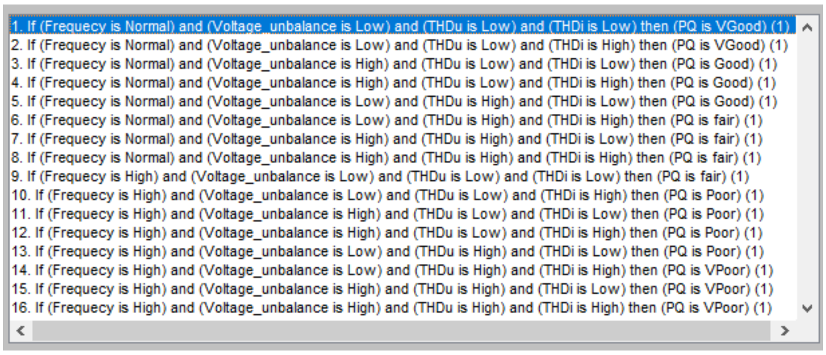
1. If (Frequecy is Normal) and (Voltage_unbalance is Low) and (THDu is Low) and (THDi is Low) then (PQ is VGood) (1)
2. If (Frequecy is Normal) and (Voltage_unbalance is Low) and (THDu is Low) and (THDi is High) then (PQ is VGood) (1)
3. If (Frequecy is Normal) and (Voltage_unbalance is High) and (THDu is Low) and (THDi is Low) then (PQ is Good) (1)
4. If (Frequecy is Normal) and (Voltage_unbalance is High) and (THDu is Low) and (THDi is High) then (PQ is Good) (1)
5. If (Frequecy is Normal) and (Voltage_unbalance is Low) and (THDu is High) and (THDi is Low) then (PQ is Good) (1)
6. If (Frequecy is Normal) and (Voltage_unbalance is Low) and (THDu is High) and (THDi is High) then (PQ is fair) (1)
7. If (Frequecy is Normal) and (Voltage_unbalance is High) and (THDu is High) and (THDi is Low) then (PQ is fair) (1)
8. If (Frequecy is Normal) and (Voltage_unbalance is High) and (THDu is High) and (THDi is High) then (PQ is fair) (1)
9. If (Frequecy is High) and (Voltage_unbalance is Low) and (THDu is Low) and (THDi is Low) then (PQ is fair) (1)
10. If (Frequecy is High) and (Voltage_unbalance is Low) and (THDu is Low) and (THDi is High) then (PQ is Poor) (1)
11. If (Frequecy is High) and (Voltage_unbalance is High) and (THDu is Low) and (THDi is Low) then (PQ is Poor) (1)
12. If (Frequecy is High) and (Voltage_unbalance is High) and (THDu is Low) and (THDi is High) then (PQ is Poor) (1)
13. If (Frequecy is High) and (Voltage_unbalance is Low) and (THDu is High) and (THDi is Low) then (PQ is Poor) (1)
14. If (Frequecy is High) and (Voltage_unbalance is Low) and (THDu is High) and (THDi is High) then (PQ is VPoor) (1)
15. If (Frequecy is High) and (Voltage_unbalance is High) and (THDu is High) and (THDi is Low) then (PQ is VPoor) (1)
16. If (Frequecy is High) and (Voltage_unbalance is High) and (THDu is High) and (THDi is High) then (PQ is VPoor) (1)

Fig. 2. Fuzzy logic rules for determination of power quality

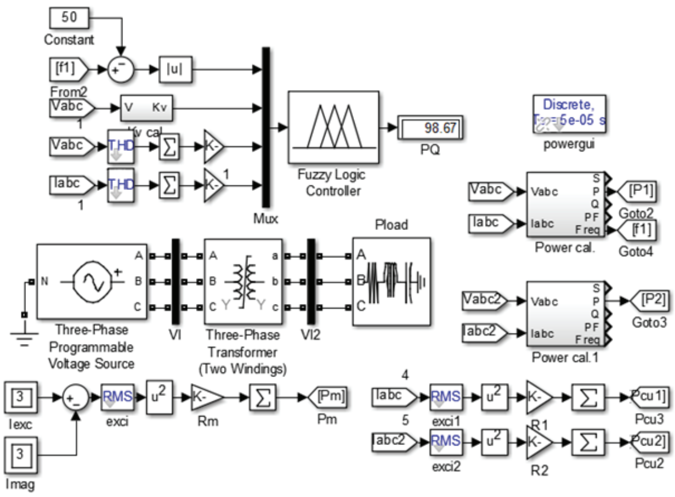

Fig. 3. Simulation model for a three-phase explosion-proof transformer

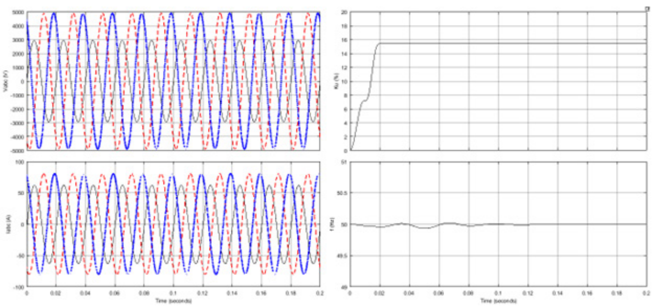

Fig. 4. The case of good power quality

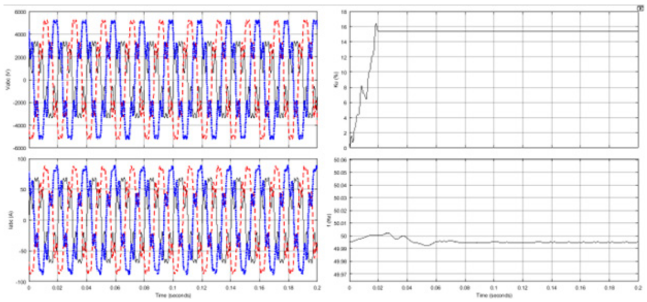

Fig. 5. The case of fair power quality

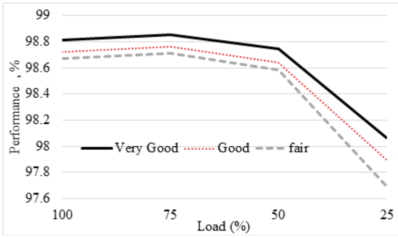

Fig. 6. Dependence of transformer performance on load in case of power quality

ed above. Calculation of voltage and current total harmonic distortion is done through tools available at Matlab-simulik software.

4. Research results and discussion

With the characteristics of the underground mine power grid, the study conducts simulation tests with three typical cases of voltage quality: power quality is very good; power quality is good; and power quality is fair. The case power quality is very good, corresponding to the values within the allowable range in Table 1.

The case of good power quality corresponds to the case of a source with a voltage unbalance factor of 15.38%. Voltage, current, phase difference, and frequency waveforms are shown in Figure 4. Obviously, phase A of the source is given 0.6 times smaller, and the remaining phases are rated.

The case of fair power quality corresponds to voltage unbalance factor of 15.38% and voltage total harmonic distortion THDu of 34.6%, current total harmonic distortion THDi of 31.2%, and constant grid frequency. The voltage, current, phase difference and frequency waveforms are shown in Figure 5.

Figure 6 depicts the dependence of transformer performance on load in case of power quality. Obviously, when the voltage quality is "very good", the performance of the explosion-proof transformer is highest. As power quality deteriorates, the performance of explosion-proof transformer gradually decreases. This result is similar to the results presented experimentally in the study [5]. In any case, transformer performance is maximized with a load of about 75% of the manufactured power, then the performance will decrease as the load decreases. It is also clear from the diagram that when the load is less than 50% of the capacity of the transformer, the bad voltage quality will reduce the performance significantly.

5. Conclusions

This paper focuses on building a method to determine power quality through fuzzy systems and building a model to evaluate the performance of explosion-proof transformers in underground mine power grids in Vietnam under different power quality conditions. The results show that the fuzzy system clearly identifies the power quality parameters with four measurable inputs, including frequency offset, voltage unbalance factor, voltage total harmonic distortion, and current total harmonic distortion. Simulation results show that explosion-proof transformer performance decreases when power quality degrades, and the proposed fuzzy system can accurately diagnose this. When the load is less than 50% of the transformer power, the poor power quality will reduce the performance significantly. The results clarify the importance of power quality to the consuming equipment, thereby requiring solutions to improve the power quality of the power system, especially the underground mine power grid system.

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