TEST Engineering & Management

July - August 2020
ISSN: 0193-4120 Page No. 5901 - 5909

Research on Adaptive Harmonic Current Detection Method Based on Neural Network

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Article Info
Volume 83
Page Number: 5901 - 5909
Publication Issue:
July - August 2020

Article History
Article Received: *25 April 2020*
Revised: *29 May 2020*
Accepted: *20 June 2020*
Publication: *28 August 2020*

Abstract

The application of a large number of non-linear loads in the power grid has caused serious harmonic pollution, which has brought serious adverse effects to the safe and efficient operation of the power grid system. However, there are many deficiencies in the current commonly used power harmonic detection methods. Based on this, this paper first studies the calculation of power grid harmonics and harmonics, and then analyses the neural network model and its adaptive adjustment principle. Finally, the adaptive harmonic current detection method based on neural network and the specific implementation strategies are given.

Keywords: *Adaptive Harmonic Current Detection, Neural Network;*

Introduction

With the rapid development of social economy, all walks of life in society demand more and more power. Therefore, higher requirements are put forward for the reliability and robustness of various power devices and equipment in the power grid. However, due to the use of a large number of power AC devices in the power grid, such as the application of various nonlinear loads, there are serious harmonic pollution in the power grid, which brings serious adverse effects and effects to the safe and efficient operation of the power grid system. Therefore, it is necessary to take certain measures to eliminate the impedance and harmonic frequency of the power grid.

The detection of harmonic current is an important measure to ensure the safe and stable operation of power system and the normal production of social electricity. At present, most of the harmonic detection methods based on instantaneous reactive power theory are used. Although it can effectively detect harmonic current to a certain extent, there are still a series of shortcomings, such as the structure is more complex, the accuracy needs to be improved and the circuit is repeatedly constructed. In addition, the harmonic current detection method on account of artificial neural network on account of parallel harmonic measurement device also has many shortcomings, such as low time efficiency and poor real-time performance, while the harmonic current detection method on account of Fourier transform also has large calculation amount, long detection time and easy impact on accuracy. The following table 1 shows some current power harmonic detection methods and their shortcomings.

Table 1. Shortcomings of current power harmonic detection methods.

Detection methods	Shortcomings
Instantaneous reactive	The structure is more complex, the accuracy needs to be

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power theory	improved and the circuit is repeatedly constructed
Artificial neural network	Low time efficiency and poor real-time performance
Fourier transformation	Large amount of calculation, long detection time and easy to affect the accuracy
P-Q method	Harmonic current detection not suitable for grid voltage distortion
Wavelet transform	It belongs to the initial stage, there are many imperfections

It can be seen from table 1 that most of the current harmonic current detection methods have many shortcomings and problems. It is urgent to find new harmonic current detection methods on account of other theories or approaches. On the other hand, with the continuous iterative development of neural network, the basic units of neurons are interconnected according to certain rules. The adaptive system has some basic characteristics of human brain neural network, such as distributed storage of information, large-scale parallel processing, self-adaptive and self-learning, etc., which bring new opportunities to the research of harmonic current detection of active power filter. At present, artificial neural network has been successfully applied to several fields as shown in Figure 1.

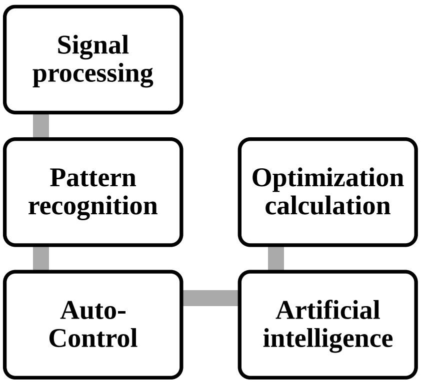

Figure 1. Application fields of artificial neural network.

The adaptive harmonic detection method on account of neural network can track the change of load current adaptively and detect the harmonic and reactive current accurately. On account of the selection of neural network samples, the selection of reference input and the update of weight, the influence of the selection of reference input on the detection results is analyzed. In addition, the feed-forward neural network is introduced into the adaptive filter to form a harmonic current detection method on account of neural network. This method can detect the harmonic current which should be compensated on account of the fundamental active current. Therefore, the adaptive harmonic current detection method on account of neural network has important practical research value.

1. Harmonic current detection and harmonic analysis of power grid

1.1. Harmonic source

When the current guided by a load has the same linear waveform as the supply voltage, the current has no harmonic component. However, if the current guided by a load does not have the same waveform with the supply voltage, it is a nonlinear current. As shown in Figure 2 below, this current has a high harmonic component, and its spectrum depends on the type of load[1]. addition, the harmonic frequency is defined as a multiple of the fundamental frequency. The spectrum of a signal is a graph showing the amplitude of different harmonics as a function of their respective frequencies.

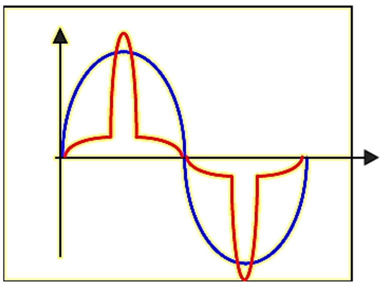

Figure 2. Nonlinear load diagram.

2.1.1. Harmonic source equipment

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The important reason for harmonic generation in power grid is the use of a large number of harmonic source equipment, especially the application of various non-linear loads, which leads to serious harmonic pollution in power grid. Typical harmonic source equipment includes variable speed drive, thyristor control equipment, fixed converter, electric arc furnace, welding machine, lighting in large buildings and saturation reactor (transformer).

2.1.2. Harmonic effect

The effects of harmonics mainly include short-term effect, long-term effect, generator interference and load interference. Among them, the short-term effect is mainly that harmonic voltage can affect the controller used in electronic system, resulting in electromagnetic instrument error, and audio control receiver (such as relay) can be disturbed by voltage harmonic distortion, vibration and noise, as well as communication and control circuit interference[2]. At the long-term effect level, the capacitor heating is caused by conductivity, dielectric hysteresis, heating caused by additional losses in machines and transformers, additional transformer losses caused by skin effect, and heating of cables and equipment.

In addition, in terms of the interference to the power equipment, for the transformer, it mainly includes the increase of active power loss, iron loss, stator loss and the reduction of efficiency caused by pulsating mechanical torque, vibration and noise. For cables, it mainly includes cable heating, pulsating mechanical torque resulting in reduced efficiency, vibration and motor heating, resonance risk caused by inductance, increase of dielectric loss in insulation and dielectric loss in insulation, etc.

2.1.3. The influence of harmonic wave on capacitor

The influence of harmonics on capacitor mainly includes that for the power grid without capacitor, the frequency impedance of the power grid is linear, only a small part of harmonic is applied on the load side, and the harmonic current is transmitted to the transformer. For the power grid with capacitors, capacitors do not produce harmonics, and capacitors can amplify the harmonics in the power grid. The specific effect of harmonics on capacitor is shown in Figure 3.

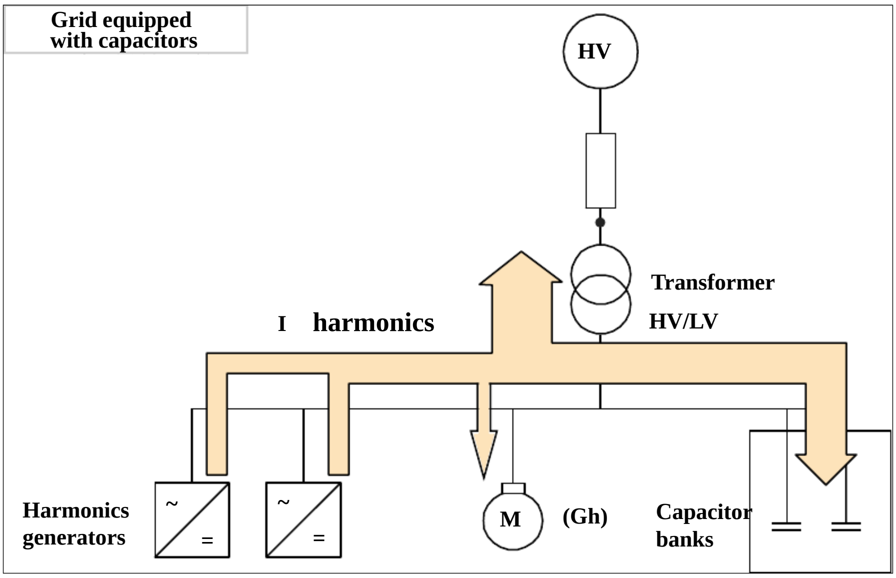

Figure 3. The specific effect of harmonics on capacitor.

1.2. Harmonic impedance characteristics

As a kind of pollution and interference in the power grid, harmonics will bring many adverse effects and effects to the normal operation of the whole power grid[3]. Therefore, it is necessary to conduct in-depth research on the generation, transmission, measurement, harm and suppression of harmonics in the whole power grid. Let a function of

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period t be used to represent the actual distorted current or voltage:

$$f(t) = f(t + kT), k = 0, 1, 2, \cdots \tag{1}$$

Expressed by Fourier series:

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \sin(n\omega_1 + \varphi_n) \tag{2}$$

AC-DC electric traction load is a single-phase rectifier load, which mainly contains odd harmonics:

$$i(t) = \sqrt{2} \sum_{n>1} I_n \sin(n\omega_1 t + \phi_n) \tag{3}$$

The current used by electrical equipment with nonlinear characteristics is non sinusoidal, and its harmonic component distorts the sinusoidal voltage of the system. The quantity of harmonic current depends on the characteristics and working conditions of harmonic source equipment itself, and has nothing to do with the parameters of power grid, so it can be regarded as constant current source.

The non-sinusoidal voltage acts on the linear network, and the non-sinusoidal voltage can be regarded as the harmonic voltage source with low internal resistance[4]. In power system, this kind of harmonic source mainly describes the effect of converter device in inverter state on AC system. The sinusoidal voltage acts on the nonlinear system, which is manifested as harmonic current source with low internal resistance or directly regarded as harmonic current source. Electrical equipment with nonlinear characteristics is the main harmonic source. The amount of harmonic current depends on the characteristics of harmonic source equipment and its working conditions, and has nothing to do with grid parameters, so it can be regarded as constant current source.

1.3. Nonlinear electromagnetic coupling device

The electrical equipment with nonlinear characteristics has nonlinear volt ampere characteristics, so that the current waveform will be distorted even under the action of sinusoidal voltage. When the magnetic circuit is seriously saturated, the current waveform distortion is intensified, which makes the system voltage waveform distortion. The harmonic generated by the normal operation of the saturable reactor usually has no great influence on the AC power grid system because of the better filtering device.

1.4. Converter unit

The converter is divided into symmetrical converter and asymmetric converter. The symmetrical converter is divided into three-phase fully controlled bridge, three-phase semi controlled bridge and three-phase non controlled bridge. The specific characteristics of these three types of converter are shown in Table 2 below:

Table 2. The specific characteristics of converter unit types.

Types	Characteristics
Three phase uncontrolled bridge	Rectifier, natural commutation, voltage is not adjustable
Semi controlled bridge	Rectifying, changing the control angle of three thyristors, adjustable voltage
Fully controlled bridge	Rectifier, inverter, voltage adjustable

1.5 Influence of harmonic current on power system

When the power grid is connected with multiple harmonic sources, the sum of the harmonic current

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components will be less than the arithmetic sum due to the different phases of the same harmonic current components of each harmonic source[5]. Characteristic harmonic is the harmonic generated by the normal operation of the specified power grid device, which is usually caused by voltage imbalance, phase or trigger asymmetry and other abnormal conditions in the converter device with three or more phases. No matter which type of harmonic will have adverse effects on the power grid and users, and these effects and effects are different, so it needs to be studied separately.

2.5.1. Effect of harmonic current on generator in power system

The effect of harmonic current on power system generator is mainly reflected in the vibration torque and alternating electromagnetic torque acting on the rotor, stator, rotor shaft and stator frame of the generator. Secondly, the harmonic current also increases the additional power loss of stator winding and stator core, and causes additional heating of rotor excitation winding, which leads to additional power loss. In addition, the harmonic current will cause the damper winding to overheat or even damage.

2.5.2. Effect of harmonic current on induction motor

The bad effect of harmonic current on induction motor is mainly reflected in harmonic power loss, which reduces the fundamental reactance and harmonic reactance, thus increasing the harmonic power loss. Secondly, the magnetic saturation of the core teeth caused by the increase of harmonic current will also reduce the excitation impedance and the negative sequence impedance of the fundamental wave. In addition, the copper loss and additional heat caused by excitation current and negative sequence current will increase. Not only that, harmonic current will also lead to the inaccuracy of electric metering instrument in power system, and lead to the increase of its error.

2.5.3. Effect of harmonic current on power system transformer

The harmonic current will cause the magnetic hysteresis of the transformer core in the circuit, which will lead to the increase of noise, and the additional iron loss and copper loss, which will increase the total power loss of the transformer and reduce the capacity utilization rate[6]. Secondly, harmonic current will lead to the increase of power loss of power grid and overheat of lines and equipment, which will easily cause misoperation of relay protection and automatic devices. In addition, the harmonic current will also bring magnetic field interference, and cause the electronic instrument and system abnormal, reduce the stability and reliability of the system.

1.5. Calculation of harmonics

The non-sinusoidal phase voltage and line current are assumed to be defined as follows:

$$u_a(t) = \sqrt{2}\sum_{h\neq 1}^{\infty} U_a(h)\sin(h\omega_1 t + \alpha_{a,h}) \tag{4}$$

$$i_a(t) = \sqrt{2}\sum_{h\neq 1}^{\infty} I_a(h)\sin(h\omega_1 t + \beta_{a,h}) \tag{5}$$

The root mean square value of phase voltage and line current is related to harmonic component, thus distinguishing fundamental frequency from total harmonic:

$$U_a^2 = U_a^2(1) + \sum_{h\neq 1}^{\infty} U_{a1}^2(h) = U_a^2(1) + U_{aH}^2$$
$$I_a^2 = I_a^2(1) + \sum_{h\neq 1}^{\infty} I_{a1}^2(h) = I_a^2(1) + I_{aH}^2 \tag{6}$$

Total harmonic distortion rate of voltage and current:

$$THD_{eU} = \frac{U_{eH}}{U_{e1}} \qquad THD_{eI} = \frac{I_{eH}}{I_{e1}} \tag{7}$$

Effective harmonic apparent power is related to harmonic distortion power and effective harmonic active power:

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$$S_{eH}^2 = P_{H,3\phi}^2 + D_{eH}^2$$

(8)

Among them, S_{eH}^2 is the effective harmonic apparent power, $P_{H,3\phi}^2$ is the effective harmonic active power, and D_{eH}^2 S is the harmonic distortion power.

1.6. Harmonic impedance and characteristics of power system

The harmonic impedance of power system refers to the rule that the harmonic impedance of the specified node in the system model changes with the frequency. Resonance is divided into series resonance and parallel resonance. The harmonic impedance characteristic is to study the impedance characteristics when resonance occurs in the system, find out the law, and identify which kind of resonance occurs. For parallel mode of resonance, its structure is shown in Figure 4.

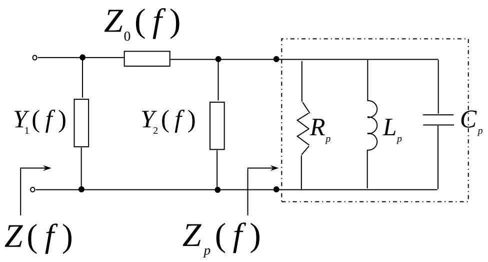

Figure 4. Parallel mode of resonance.

$$\left|Z_p(f)\right| = \sqrt{R_p^2(f) + X_p^2(f)}$$

(9)

The impedance of parallel resonance has the characteristics of maximum impedance modulus, pure resistance and reactance changing from inductive to capacitive. Moreover, the impedance angle changes from positive to negative, and the impedance angle derivative reaches the minimum value when the impedance angle crosses zero. Series resonance has the characteristics of impedance angle changing from negative to positive, maximum value of impedance angle derivative and minimum value of impedance modulus at impedance angle crossing zero, which is pure resistance and reactance changes from capacitive to inductive.

2. Neural network model

2.1. The architecture of neural network

The neural network structure has an input layer and a competition layer, as shown in Figure 5. The input layer of the neural network is responsible for receiving the external information and transmitting the input mode to the competition layer. The competition layer is responsible for the analysis and comparison of the mode, finding out the rules to correctly classify.

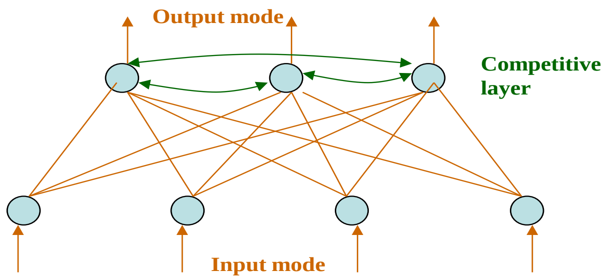

Figure 5. The architecture of neural network.

The connection between the neurons in the competition layer is the weight to simulate the mutual inhibition of the neurons in the biological neural network layer, which conforms to a certain distance distribution relationship. This weight does not need to be adjusted in the training process. In the competition layer composed of self-organizing neural network, each neuron competes for the response to the input pattern, and the neuron becomes the winner of the competition. The neuron represents the recognition of the input pattern, reflecting the mechanism of the lateral inhibition competition of the biological nerve cells.

2.2. Vector normalization

Different vectors have different length and direction. The purpose of vector normalization is to change the vector into a unit vector with direction invariant length of 1. When unit vectors are compared, only the angles between vectors are compared[7].

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$$\hat{X} = \frac{X}{\|X\|} = [\frac{x_1}{\sqrt{\sum_{j}^{n} x_j^2}} \frac{x_2}{\sqrt{\sum_{j}^{n} x_j^2}} \cdots \frac{x_n}{\sqrt{\sum_{j}^{n} x_j^2}}]^T$$

(10)

The input mode vectors in the neural network and the inner star WV $\hat{W}_j(j = 1, 2, \cdots m)$ corresponding to each neuron in the competition layer are normalized, as shown in figure 6 below.

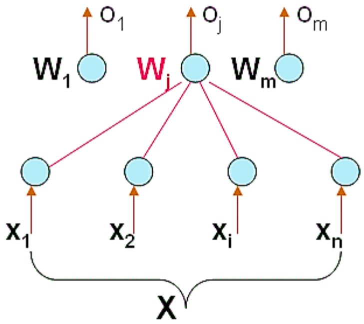

Figure 6. Vector normalization.

2.3. Network output and weight adjustment

In the neural network competition learning algorithm, the output of winning neuron is 1, and the rest is zero. Only winning neurons have the right to adjust their Weight Vector (WV), and the adjusted WV is:

$$\begin{cases} W_*(t+1) = \hat{W}_*(t) + \Delta W_* = \hat{W}_*(t) + \alpha(\hat{X} - \hat{W}_{j*}) \\ W_j(t+1) = \hat{W}_j(t) \end{cases}$$

(11)

After adjusting the normalized WV, the new vector needs to be normalized again and continue training until the learning rate decreases to zero[8].

2.4. Self-organizing feature neural network

The self-organizing feature neural network has the input layer of the retina which simulates the perception of external input information, and the output layer of the cerebral cortex which simulates the response. The topological structure of the self-organizing feature neural network includes one-dimensional linear array and two-dimensional planar array, as shown in Figure 7. The one-dimensional linear array can map any dimensional input mode into one-dimensional discrete figure in the output layer[9]. Two dimensional planar arrays can map any dimensional input pattern into two-dimensional discrete graphics in the output layer.

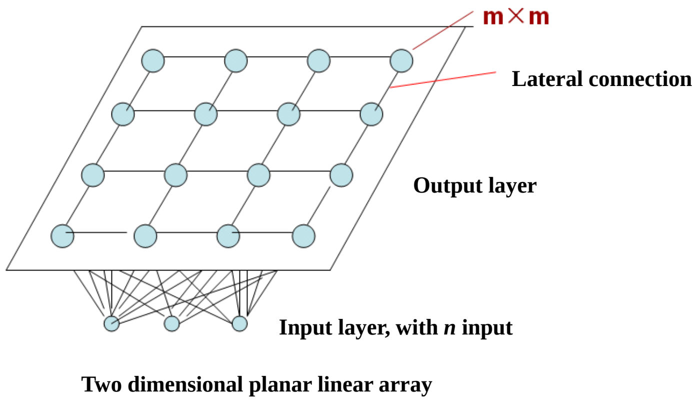

Figure 7. Two dimensional planar linear arrays.

3. Adaptive harmonic current detection method on account of Neural Network

3.1. Adaptive harmonic a detection on account of neural network

In signal processing, the signal source is separated from the noise on account of the adaptive noise cancellation method. The principle is shown in Figure 8 below. The detection system has two input variables: original input and reference input. The signal source is not related to noise, and the signal source is not related to the reference input. The output of the adaptive filter is adjusted automatically to approach the noise interference of the main road under the minimum mean square error. In addition, the output of the system is used as an error signal to adjust the parameters of the adaptive filter.

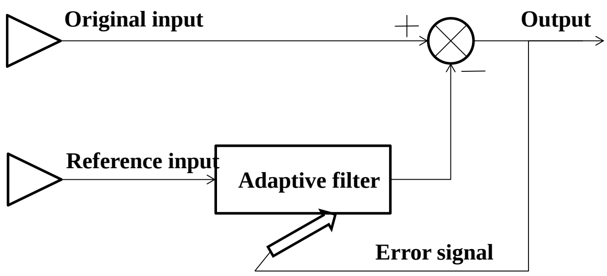

Figure 8. Principle of adaptive harmonic and reactive current detection.

Taking the load current as the original input and replacing the adaptive filter with neurons, the adaptive harmonic and reactive current detection

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circuit on account of ANN is constructed on account of the orthogonal characteristic of sine function. It has been verified by practice that if the load current only contains fundamental and harmonic components, the detection results of harmonic current will be very accurate as long as there are fundamental harmonics in the replacement of interference noise, and the more harmonic times contained in the substitute interference noise, the more accurate the training results will be. However, in order to reduce the complexity of neural network, the selection of harmonic number needs to be on account of the actual accuracy requirements and real-time requirements of power system.

3.2. Realization of adaptive harmonic detection on account of neural network

The adaptive linear unit neural network on account of single input is used as its input. The sine and cosine signals of fundamental wave are obtained from the grid voltage signal through the phase-locked circuit, and then the harmonic sine and cosine signals are obtained by frequency doubling, and then the fundamental and harmonic sine and cosine signals are taken as the reference input of the neural network.

Due to the mapping and adaptive learning ability of a single neuron, a neural network can be constructed on account of the neuron model to realize the adaptive harmonic detection. The sine and cosine signals of each harmonic in the reference input can effectively obtain the fundamental active current component, which lays the foundation for accurate detection of distorted current. When the harmonic and reactive current is compensated, the difference between the load current and the weight of the neural network is the sum of the harmonics in the load current.

4. Conclusion

In summary, the adaptive harmonic detection method on account of neural network can track the change of load current adaptively and detect the harmonic and reactive current accurately. On account of the selection of neural network samples, the selection of reference input and the update of weight, the influence of the selection of reference input on the detection results are analyzed. Besides, on account of the adaptive noise cancellation technology, the feedforward neural network is introduced into the adaptive filter to form a harmonic current detection method on account of neural network.

In this paper, through the analysis of power grid harmonics and harmonics, the harmonic effects and the effects of harmonics on various devices and equipment in the power grid are studied. Secondly, through the analysis of neural network model, it points out the structure of neural network, the adaptive adjustment of neural network model and the principle of self-organizing feature neural network. In addition, the adaptive harmonic current detection method on account of neural network is studied, and the adaptive harmonic and reactive current detection method on account of neural network and the specific implementation strategy of adaptive harmonic detection on account of neural network are given.

Acknowledgments

This work was supported by the Key Project of the Natural Science Fundation of the AnHui Higher Education Institutions of China (Grant No.KJ2018A0780).

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