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Transient Phenomena to Detect Out-Of-Step Error with Phasor Measurement Method in Power System

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Abstract

This paper presents a new algorithm based on simultaneous measurements by phasor measurement units in order to detect loss-of-synchronism of generator. The researchers believe that the criteria of equal energy levels and wavelet transformation are preferable to the usual methods, in the sense that in addition to the acceptable speed, their practical use in phasor control centers is also possible. Also, the two basic challenges of these methods, i.e. equalization of the network in the form of a two-machine model and estimation of the generator state in the time after the fault, have been solved. The importance of converting the power network to the two-machine equivalent network must be done adaptively and online, because the structure of the power network is not constant due to changes in the state of entry and exit of equipment. In this paper, with the help of the simultaneous information sent from the phasor measurement units installed in different points of the network, the equivalent circuit of two- machine of the power system has been calculated from the point of view of each power plant unit. Based on this and by using the developed equal levels criterion method which is introduced and developed in the paper and the wavelet transform, both in the local mode and in the wide measurement mode, there are methods to detect and predict the loss-of-synchronism is provided. In each section, the presented algorithm is tested on a standard network (preferably IEEE standard networks), for various situations of errors occurring in the system, and its results, both in terms of performance speed and accuracy, with usual industrial methods, which are impedance relays, have been compared.

Introduction

The nationwide blackout in North America on August 14, 2003, has resulted in a lot of research in the fields of system protection [1]. One of the important and unsolved issues that has been taken into consideration is the power swing and out-of-step protection for the power system [1,2]. The problem of stability of the power system is an important issue in the planning and operation of electrical power systems, and synchronous generators play an important role in this issue. An unstable system that loses its synchronism may lead to severe damage to the device, power outages, and loss of economic capital [3].

In both LOE and OOS phenomena, the generator eventually loses its synchronization with the system and must be quickly disconnected from the system [4]. The design of relays that are conventionally used in most power grids have defects; Among other things, in cases where the error can be fixed, the relays mistakenly issue the shutdown command and cause an unnecessary power outage, which lowers the reliability of the network and reduces the stability of the entire network. A general behavior of distance relays used in double-circuit transmission lines is that they are either unavailable or have reached their maximum value when the double-circuit lines are in service [5][6]. Investigations show that the general characteristics of the power system affect the accuracy of the error distance calculation. As a result, excessive fault can occur unexpectedly and affect the selection of the protection system [7]. Power swing, stable or unstable, can cause unwanted operation of relays in different points of the network, which can worsen the disturbance of the power system and cause

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large blackouts [8].

In power systems, creating a balance between energy producers and consumers is a very important issue, any disturbance in this balance in the system caused by changes in load, as well as errors and their departure, often leads to electromechanical swing (tension or disturbance). Now, the generator continues to work normally, and when a stress or disturbance is introduced to it, if the generator cannot return to its stable state, loss-of-synchronism occurs [9]. In both LOE and OOS phenomena, the generator eventually loses its synchronization with the system and must be quickly disconnected from the system. A lot of research has been done on providing methods to detect out-of-step [10]. Significant changes in load as well as faults often lead to electromechanical oscillations (stress or disturbance). Controlling the power system against loss-of-synchronism is an effective way to deal with such disturbances. In the method, the area equality criterion (EAC) and phasor measurement units are used to protect the interconnected system against loss-of-synchronism [11]. The swing of the system is modeled using the mothered regression model and then, using the phase difference, the stability value of the power system is determined using the equal area criterion. The projected energy is provided based on the step protection scheme. The dynamic model is the real time of the system and then it is used to evaluate the performance of energy systems based on the direct Lyapunov method and extract stability properties from the energy function [12]. Comparison of the proposed method with another method of step protection schemes (based on impedance relay) through illustrative examples shows that the proposed method in the condition of loss-of-synchronism is much faster than conventional methods [13]. The online method of heuristic optimization PMU control is based on modal analysis. The generator speed deviation is applied as a non-local input to the generator PSS for WADC. Based on PMU-WADC, it improves the damping of both regional and local oscillatory modes. Modal analysis in the time domain improves the performance of the network and generators [14].

Using synchronism measurement data, transmission networks and protection systems can be controlled. Regional monitoring, protection and control (WAMPAC) systems are a combination of three levels of protection functions. The first layer of protection is the impedance relay, the second layer of protection is the central system with wide functions of area protection (WAP) and the final layer is the power level of the control system. Centralized protection can use new methods based on synchronism data [15]. Another one of these new methods based on flux is presented to prevent the synchronous generator from going loss-of-synchronism. By measuring the angular velocity and acceleration of the magnetic flux in the generator, at the relay location, it is used to detect loss-of-synchronism. The condition of loss-of-synchronism at the point where the pole of angular acceleration changes from negative to positive and the angular velocity is greater than the basic angular velocity [16]. The basic idea is that the resulting magnetic flux will rotate at synchronous speed, in other words, this magnetic flux will be constant. Therefore, the proposed method can be directly applied to the network. In addition, the proposed method does not require any online studies [16] [7]. By using the information obtained from the phasor measurement units in a wide area, the loss-of-synchronism time is divided into several parts. Through a series of proofs, it is found that the absolute value of the phase angle of the bus voltage in a section is always smaller than 110°, while the phase angle of the slack bus voltage varies from -180° to 180°. Now, by using changes in phase angle and voltage, it is possible to divide the loss-of-synchronism time into several parts without any complicated mathematical operations. The digital simulation results of the proposed design are efficient [17]. Another one of these methods to detect loss-of-synchronism is to use a relay to detect and clean between power swing and a fault. Fast and reliable detection of symmetrical errors during power swing is one of the important issues. In this method, by using the wavelet, we can detect any power swing and any errors in a power network. The total number of levels of the binary voltage/current waveform and the selection of specific levels for such detection are carefully considered and this block of logic based on the wavelet transform is developed. The output of this block is compared with the normal output of the distance relay and causes optimal performance during the fault [18].

An important issue in power systems is the use of transmission lines with maximum load. Now, in case of an error that cannot be fixed, the generator must be disconnected from the network within a short period of time. Establishing a balance between the energy producer and consumer is a very important issue, any disturbance in this balance in the system caused by changes in the load, as well as errors and their departure, often leads to electromechanical fluctuations (tension or disturbance). The generator continues to work normally and when a stress or disturbance is introduced to it, if the generator cannot return to its stable state, loss-of-synchronism occurs. Various methods have been proposed to detect loss-of-synchronism, such as relays to detect loss-of-synchronism and status monitoring systems, these two methods have weakness in detecting various errors (unstable power swing and stable power swing and internal errors) as well as weakness in detecting the location of the errors that occurred is one of the problems of these methods. In the previous two methods, when a stable power swing or an internal error occurs, the relay has malfunctioned, it identifies it as an unstable power swing, and the trip command Gives. While stable power swing is not harmful to the grid and generators.

In this paper, various methods have been proposed to detect loss-of-synchronism, such as loss-of-synchronism detection relays and status monitoring systems. In these two methods, the weakness of the system in detecting different errors (unstable power swing and stable power swing and internal errors) and also the weakness in detecting the location of the errors are among the problems of these methods. The paper tries to investigate power swing with a sample network including a power network, a transmission line, and a generator. Collect data from sample network measurements with the PMU running in the program. The method can be used to detect loss-of-synchronism conditions using the area criterion with different types of errors in different places and different models of transmission lines. It should also be mentioned that MATLAB and PSAT software were used for simulations and modeling of power grid components.

RESEARCH METHOD

Flowchart of the proposed model

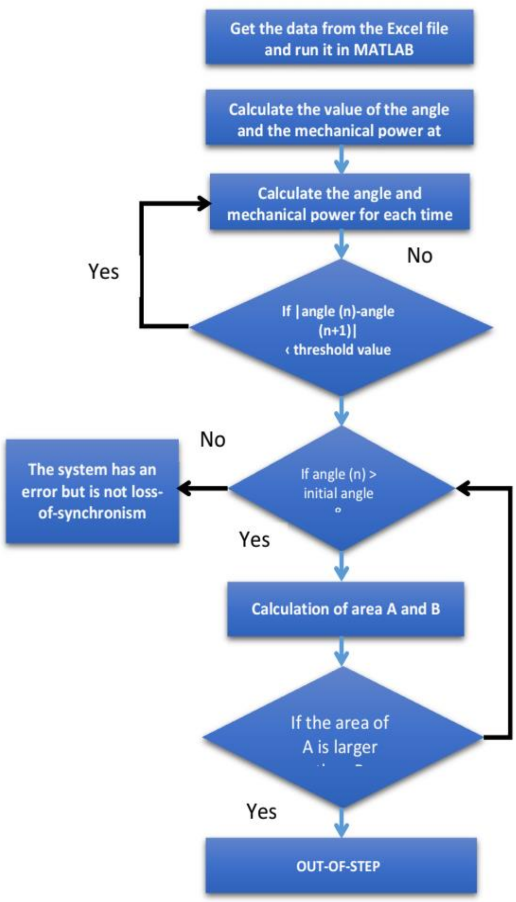
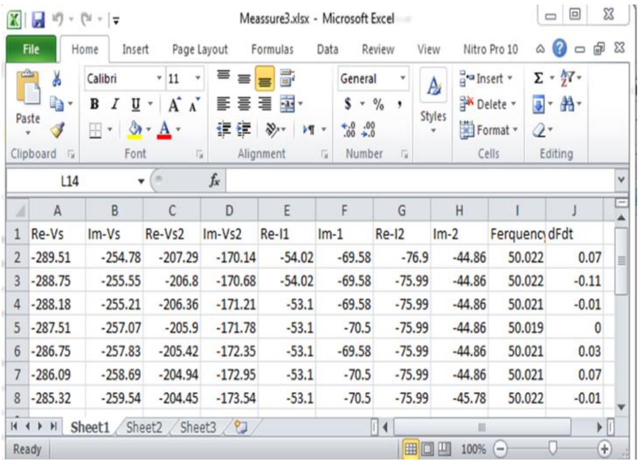


Fig. 1: Flowchart of the proposed

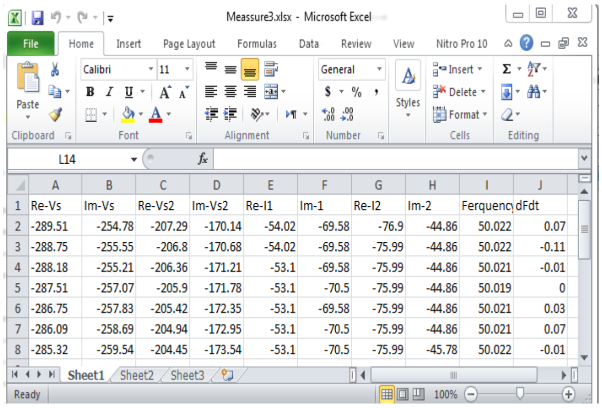
In the desired network, by carrying out the load spreading operation, the values required to detect loss-of-synchronism are measured and the values are saved in an Excel file.



	A	B	C	D	E	F	G	H	I	J
1	Re-Vs	Im-Vs	Re-Vs2	Im-Vs2	Re-I1	Im-1	Re-I2	Im-2	Ferquency	dFdt
2	-289.51	-254.78	-207.29	-170.14	-54.02	-69.58	-76.9	-44.86	50.022	0.07
3	-288.75	-255.55	-206.8	-170.68	-54.02	-69.58	-75.99	-44.86	50.022	-0.11
4	-288.18	-255.21	-206.36	-171.21	-53.1	-69.58	-75.99	-44.86	50.021	-0.01
5	-287.51	-257.07	-205.9	-171.78	-53.1	-70.5	-75.99	-44.86	50.019	0
6	-286.75	-257.83	-205.42	-172.35	-53.1	-69.58	-75.99	-44.86	50.021	0.03
7	-286.09	-258.69	-204.94	-172.95	-53.1	-70.5	-75.99	-44.86	50.021	0.07
8	-285.32	-259.54	-204.45	-173.54	-53.1	-70.5	-75.99	-45.78	50.022	-0.01

Fig. 2: Excel sheet with measured data

The measured data is saved in one page of Excel and the maximum time required to save the measured data in this page is 10 minutes. In this network time steps are, _t = 0.02s.



	A	B	C	D	E	F	G	H	I	J
1	Re-Vs	Im-Vs	Re-Vs2	Im-Vs2	Re-I1	Im-1	Re-I2	Im-2	Ferquency	dFdt
2	-289.51	-254.78	-207.29	-170.14	-54.02	-69.58	-76.9	-44.86	50.022	0.07
3	-288.75	-255.55	-206.8	-170.68	-54.02	-69.58	-75.99	-44.86	50.022	-0.11
4	-288.18	-255.21	-206.36	-171.21	-53.1	-69.58	-75.99	-44.86	50.021	-0.01
5	-287.51	-257.07	-205.9	-171.78	-53.1	-70.5	-75.99	-44.86	50.019	0
6	-286.75	-257.83	-205.42	-172.35	-53.1	-69.58	-75.99	-44.86	50.021	0.03
7	-286.09	-258.69	-204.94	-172.95	-53.1	-70.5	-75.99	-44.86	50.021	0.07
8	-285.32	-259.54	-204.45	-173.54	-53.1	-70.5	-75.99	-45.78	50.022	-0.01

Fig. 3: The values in the line n=1 are assumed to be stable in a system.

The algorithm described in this thesis receives the data set not in 20 milliseconds, but in 10 minutes. In fact, the algorithm should receive continuous values from PMUs continuously. The stable power angle is the angle at which the system and the generator continue to work in normal mode and there is no disturbance or fluctuation in the angle of the generators. Mechanical power is the input power to the system. Now with these definitions, the second part of the algorithm is as follows. The first line at t = 0 is assumed to give constant values. Steady angle and mechanical power input are calculated.

It is assumed that the first line is measured by measuring the data in the Excel sheet when the system is in steady state. The algorithm uses these values as reference values for some IF statements to determine changes in the network. In the step, the active angle and power must be calculated in each time step.

The algorithm creates a vector for current, voltage and complex impedance. From these vectors, new vectors with phase angle and power are calculated for all time steps.

The next step is the IF announcement algorithm to change the angle. In this section, an IF statement compares values with each other or with a threshold value, the result can be either yes or no. In this part of the IF statement, the difference between the two values next to each other compared to the phase angle, if the values are greater than the value specified by the algorithm, the warning of the start of the power swing will be announced.

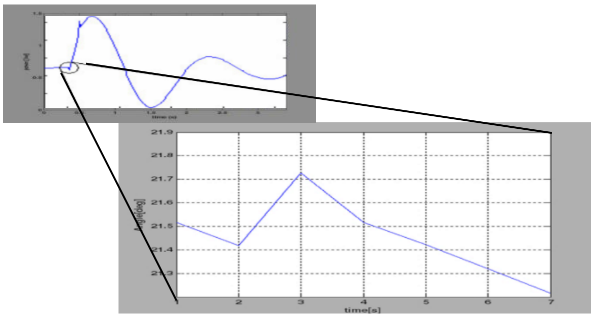


Fig. 4: Phase angle calculated for each time step

A difference greater than 0.1 degrees will alert the algorithm. The threshold value is taken from the study of phase angle change graphs.

IF ANNOUNCEMENT TO CHANGE THE ANGLE AND AMOUNT OF OUTPUT POWER

The IF statement is the most important part of the algorithm. If the angle has changed too much and the power output has dropped below the mechanical + input energy level, the system will certainly experience a power swing. If the IF statement occurs, the command is yes and the comparison is made, the algorithm begins to calculate the area of A and the area of B, and if the IF statement receives No, the algorithm tells the user that there is a disturbance, but the system still maintains its synchronization.

System has had a failure but will not losesynchronism

Warning message when the system has fluctuated.

CALCULATION OF AREA A AND AREA B

If the answer is yes in the IF statement in No. 5, this part of the algorithm will be warned. Area A is calculated by calculating the Riemann integral. This integration is made by calculating the areas of the bars and adding them. A bar in x direction is the angle change between two time steps and in y direction is the difference between mechanical input and power output. Fig. 5 shows a summary of bars. Area A is increasing and area B is decreasing.

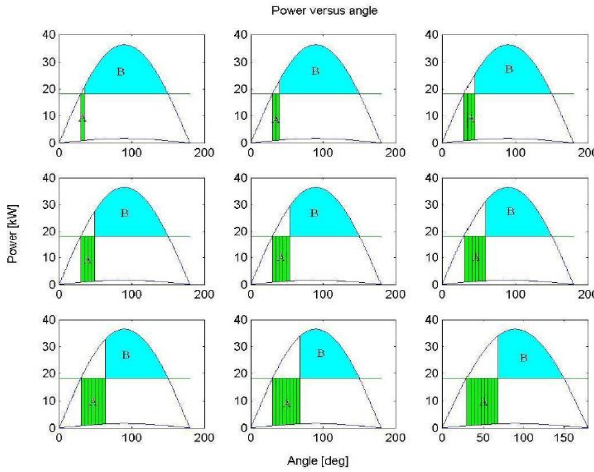


Fig. 5: Riemann integral for equal area criterion

IF TO COMPARE AREA A AND B

This IF statement, although the area of A is smaller than the area of B, if it receives the command NO, the algorithm continues, but if the angle is too large, and the area of A is larger than the area of B, the IF statement receives YES and the algorithm it stops. Algorithm sends warning about loss-of-synchronism conditions. In fact, the islanding of different parts of the network should start from this point.

OUT –OF-STEP, system will lose synchronism

Warning message when loss-of-synchronism occurs

SIMULATION RESULTS

THE STUDIED NETWORK

The network for sampling by PMU must be modeled and the required parameters to detect loss-of-synchronism must be measured. For this purpose, two 9-bus and 14-bus networks have been used. Using load distribution and optimal load distribution, the required values are measured and after this step, the data is entered into MATLAB software for diagnosis. Now we model a network and sample the required outputs. The parameters of the simulated three-machine system are as follows:

Basic power = 628 megavolts
Nominal power of generator 1 = 545 megavolt ampere
Nominal power of generator 2 = 625 megavolt ampere
Nominal power of generator 3 = 60 megavolt ampere
Bus voltage = 24 kV
Z1=0.035+ j0.35Ω, Z2=0.00474+ j0.472Ω,
Z3=0.0177+ j0.288 Ω, Z4=0.0580+ j0.580Ω,
Z5=0.0185+ j0.185 Ω, Z6=0.0186+ j0.186Ω,
Z7=j0.0875Ω

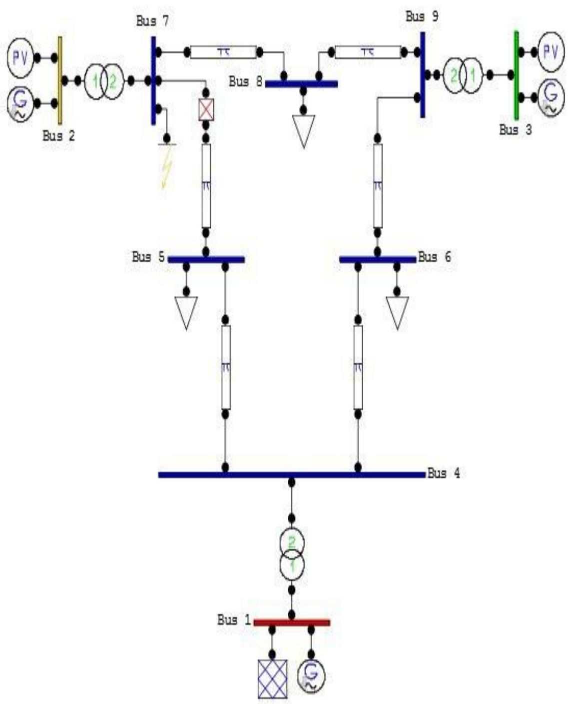


Fig. 6:The studied network of 9 IEEE bus

The above network is a 9-bus IEEE network that has three generators and a number of loads. This network has been selected as a sample network to measure the required information and is fed through a local network on bus 1. The value of impedance and output power of each of the generators, base power and bus voltage are given above.

Now, we model the IEEE 14-bus network. The parameters of the simulated five-machine system are as follows:

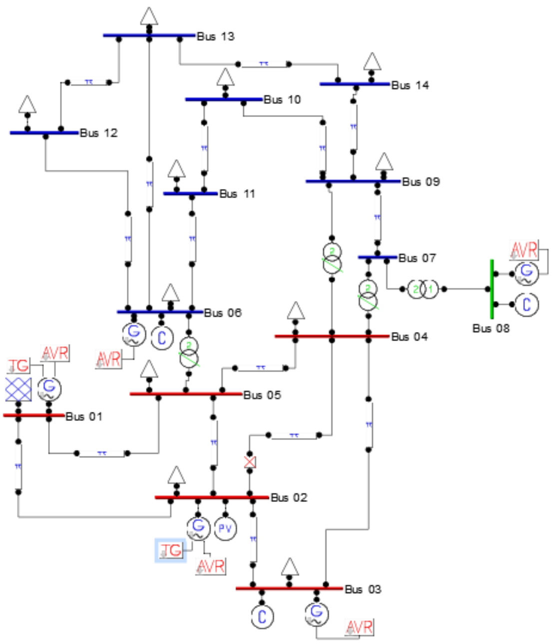


Fig. 7: The studied network of 14 IEEE bus

The three-phase fault on bus 1 is applied to the first simulation case. P-t curves for all three generators are shown in Fig. 8. From the P-t curve related to generator 2, region A1 is equal to s=0.0568pu. After 0.2882 seconds, the total area becomes zero and the swing is recognized as a stable swing.

Table (1) shows simulation scenarios in stable mode and Table (2) shows simulation scenarios in loss-of-synchronism mode.

Table 1: simulation scenarios in steady mode

pre-fault load, pu	1.55	1.25
Error duration, seconds	0.12	0.28

Nominal power of generator 5 = 550 MW
Basic power = 628 megavolts
Nominal power of generator 1 = 545 megavolt ampere
Nominal power of generator 2 = 625 megavolt ampere
Bus voltage = 24 kV
Bus voltage = 63 kV
Bus voltage = 11 kV
Nominal power of generator 3 = 60 megavolt amps
Nominal power of generator 4 = 68 megavolt ampere

The pre-fault load is set to 1.2 pu. A three-phase fault is applied to bus 1 and is fixed after 0.25 seconds. The P-t curve for this case is shown in Fig. 9. From the P-t curve related to generator 2, it is found that area 4 is equal to s-pu0.1632 and after 0.16642 seconds, the total area becomes zero, and therefore this case is recognized as a stable swing.

Table 2: Simulation scenarios in loss-of-synchronism mode

pre-fault load, pu	1.55	1.25
Error duration, seconds	0.15	0.35

Performance of the presented method in OOS conditions

A three-phase short circuit error was applied at the moment of one second and in the middle of the L7-8 line in order to create OOS conditions on the G2 generator, and this error was fixed after 400 milliseconds with the operation of the switches at both ends of the transmission line. Fig. 8 shows the performance of the proposed method compared to the impedance method. As can be seen, in this case, the second area of the impedance relay operates with a high delay. This is while the proposed method can detect OOS with a delay of 1.833 seconds and 0.377 seconds faster than the impedance method.

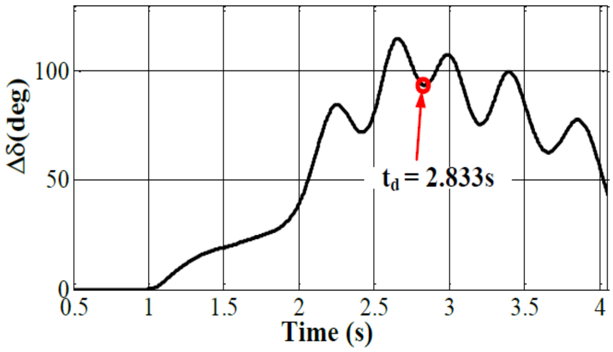


Fig. 8: Performance of the proposed method compared to impedance OOS method for OOS conditions [18]

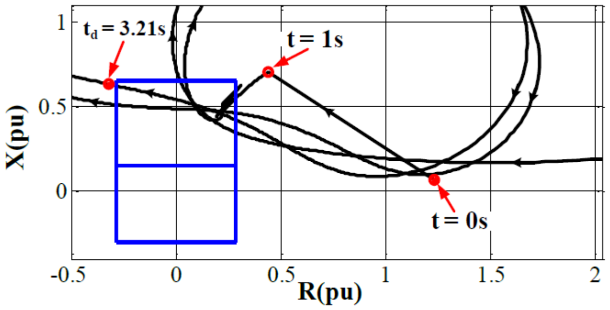


Fig. 9: Performance of the proposed method compared to impedance OOS method for OOS conditions [18]

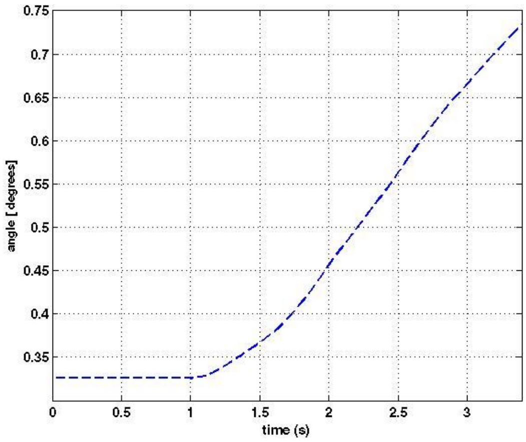


Fig. 10: The increasing speed of the rotor angle in terms of time for stable mode

As you can see in Fig. 11, the angle increases at a linear rate. In this form, the system is in a normal state and after a period of about one and a half seconds, the system has undergone stable swing and the angle has increased. Since the system has become stable in another area, it will return to the normal state and the new stable area. Fig 11 shows the angle related to the generator bus, which continued to work in normal mode and after one second experienced unstable power swing, and as expected, the system angle increased as you can see in Fig. 12 found and reaches an angle of 90 degrees.

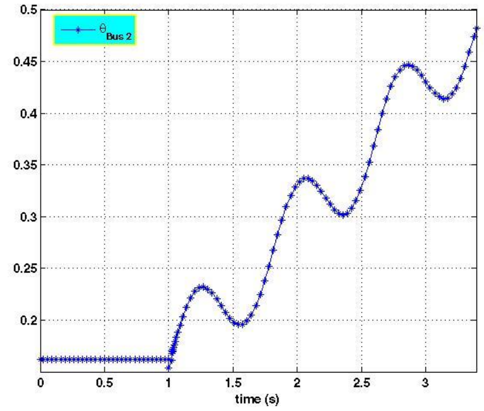


Fig. 11: Angle changes in the generator bass over time

Fig. 12 shows an unstable power swing that occurred at a 90-degree angle. Also, the results and the diagram seen in Fig. 13 are similar to the previous condition, but with the difference that this time the error occurs at an angle of 180 degrees and has completely caused out-of-step.

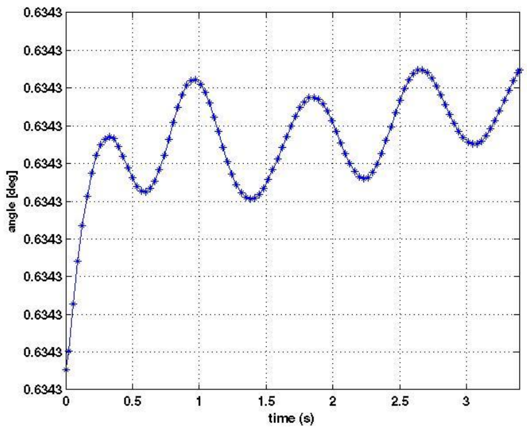


Fig. 12: Rotor angle increase speed in terms of time for unstable mode

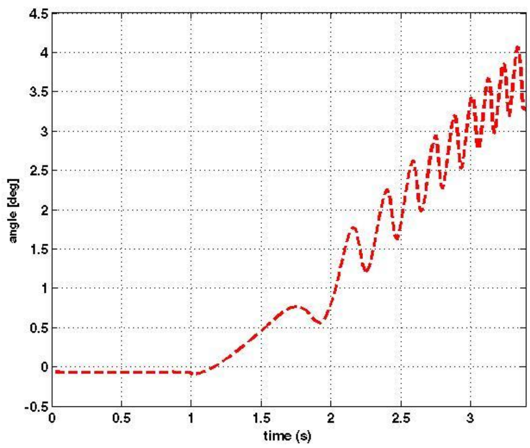


Fig. 13: 180° out-of-step

As you can see, Fig. 14 is related to out-of-step and it shows that in this case the angle dropped at the first moment and because the swing or disturbance introduced to the system was too much it caused it to go out-of-step. In this mode, the generator is out of circuit.

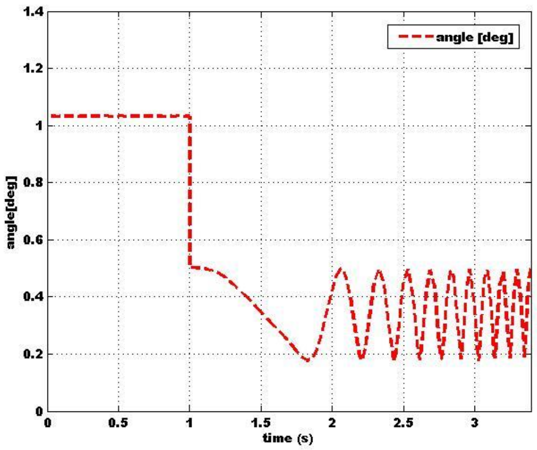


Fig. 14: The moment of out-of-step

Fig. 15 shows the changes in the voltage of bus number two, which has experienced a transient disturbance after the instability of the system, which is one of the power quality problems.

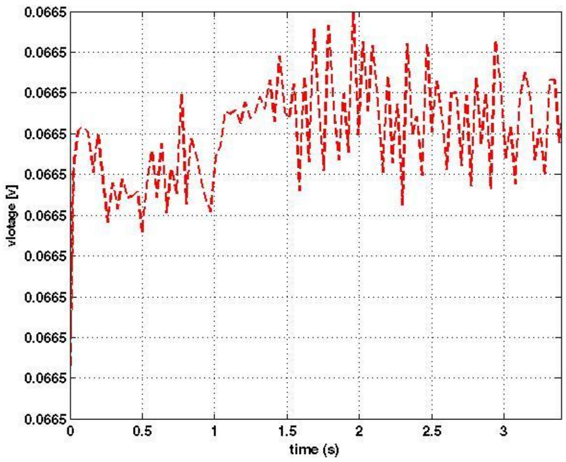


Fig. 15: voltage changes after out-of-step error

Fig. 16 shows the changes in active power after the occurrence of the out-of-step error 4.11. As expected, the generator has an oscillatory behavior after the fault occurs.

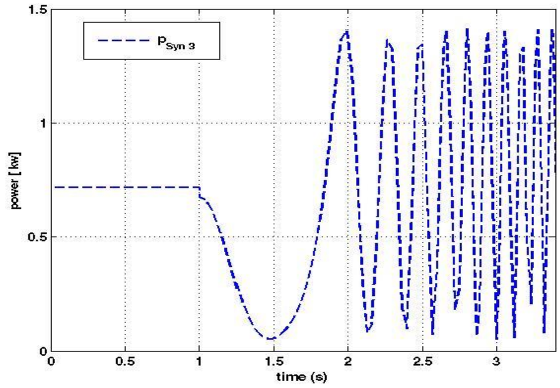


Fig. 16: Active power changes after an out-of-step error occurs

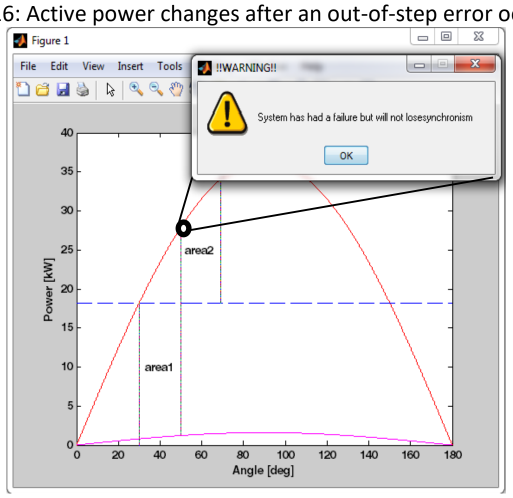


Fig. 17: The previous step of going to loss-of-synchronism mode

Now, when all the data is taken from this network, it is determined directly by the MATLAB software and by using the proposed algorithm, what state the system is in, and according to the available data, the algorithm can be implemented, in this case, if the system is in the state of going loss-of-synchronism, we have:

A simulated error has been tested before going to the loss-of-synchronism mode and by the algorithm the message: "The system has an error, but the loss-of-synchronism has not yet occurred."

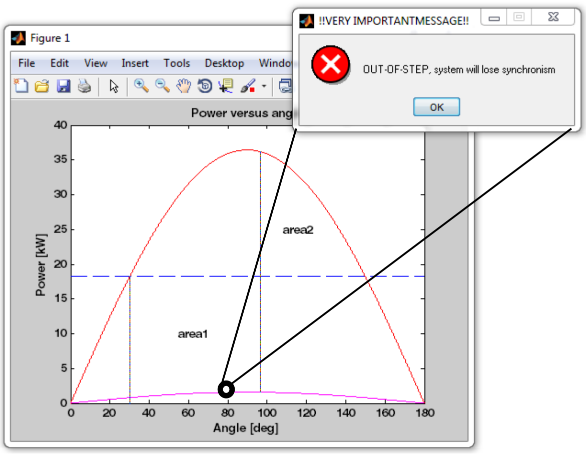


Fig. 18: Error after time fixed critical error

In this case, the algorithm returns the message: " loss-of-synchronism, the system has lost its synchronization" when the angle is 80.7 degrees, in this area one is larger than area two, so loss-of-synchronism has occurred. Algorithm's answer in both cases it is true and for this reason it can be said that the algorithm works correctly.

CONCLUSION

This paper presents a new algorithm based on simultaneous measurement by phasor measurement units in order to detect loss-of-synchronism of generator. The importance of converting the power network to the equivalent network of two-machine must be done in an adaptive and online manner, because the structure of the power network is not constant due to changes in the state of entry and exit of equipment. In this research, with the help of the simultaneous information sent from the phasor measurement units installed in different points of the network, the equivalent circuit of two-machine of the power system has been calculated from the point of view of each of the power plant units. Based on this and using the developed equal levels criterion method which is introduced and developed in this paper and the wavelet transform, both in the local mode and in the wide measurement mode, methods are presented in order to detect and predict loss-of-synchronism. Is. In each section, the presented algorithm is tested on a standard network (preferably IEEE standard networks), for various situations of errors in the system, and its results, both in terms of performance speed and accuracy, with methods the usual industry that is impedance relays was compared. This algorithm is able to discriminate well between stable swing and loss-of-synchronism based on voltage and current information at the relay location. The analysis showed that the proposed algorithm does not need any parameters of the system or off-line studies. Simulation studies using the proposed algorithm on a configuration of three-machine connected to an infinite bus showed that the presented algorithm can be well applied to a multi-machine system without the need to reduce the dimensions of the system.

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Author Contributions

Each author role in the research participation must be mentioned clearly.
Example:

M. Arghan interpreted the results and wrote the manuscript.

Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.