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An Overview of Out-Of-Step Protection in Power Systems

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Abstract: Power system is subjected to an extensive variety of little or bigger disturbance to the system during the operation. The power system that designed as one of the main requirement is to survive from the larger type of disturbances like faults. The power swing in certain system is the variation in three phase power flow in the power system. This paper mainly discussed the power swing and distance relay and the effect of the power swing on the distance relay and demonstrate about the basic power system stability and power swing phenomena. Moreover, out of step protection and detection applications are revised as well. At the end, the paper also demonstrated the past study of out of step application of TNB 275 KV network.

Keywords: Out-of-Step Blocking (OSB), Out-of-Step Trip (OST), Out-of-Step (OOS), Power swing

1. Introduction

Power systems are persistently vulnerable to numerous disturbances either in small or large type during steady state operation [1]. Therefore, design engineers and planners are working firmly to initiate most reliable power system structure which is capable to deal with most of the contingencies. However, one of the most unpredictable power system instability situation is the angular instability or known as out-of-step (OOS). Whenever insufficient transmission line capacities or any faults occurred in the systems will originate the generation and load demands is not equilibrium. Hence, the generation side of the power system will begin to work asynchronously with the other parts of the system. The power system generation is unable to tolerate the prolonged time of OOS due to a negative effect of the system materials. Consecration of OOS protection must respond to asynchronous operation acting on power network separation to determine the place with the objective to preserve the generation load equilibrium with each of the system. All sorts of OOS power protection can be categorized as follows [11]:

- Protection of local type, that usually operated locally and gives obtainable measurement of OOS detection.
- The measurement of the whole system based on OOS protection which applies to measurements of numerous places in the power system.

2. Background study

2.1 Power Swing

Power swing refers to the oscillation in active and reactive power flows on a transmission line following by large disturbances to power system transmission lines which consequently cause wrong process to the distance relay if not blocked, Moreover, it may generate undesired tripping on the power system transmission line circuit breaker. Therefore, if that undesired tripping did not isolate with the generator, then it may cause some damages to the machine [2].

The authors in [3] defined the power swing as the variation in three phase power flow in the power system which occurs when the rotor angels of the generator advancing each other because it response to the changing of the load factors such as the change in direction and the magnitude of the load, line switching, faults and system disturbances that happened to the power system and the loss in generation.

The power swing has a negative impact on the power system such as protective relays malfunction which cause an electrical equipment damage. Power system operates on a frequency of 50Hz or 60Hz during steady state conditions [4]. The entire synchronism of nominal frequency and voltage at the sending and receiving ends causing entirely equilibrium of active and reactive power between generated and consumed active and reactive powers [2].

The sudden adjustments of electrical power are resulted by the power system faults, line switching, generator interruption, and the loss or implementation of large groups of load [5]. These losing will appear in unpredicted results alteration towards the electrical power

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according to some factors such as the loss of synchronism between voltage phase angles and between frequencies.

2.2 Distance Relay

The distance relay is utilizing the Mho circle concept. Mho circle is used for the first and second zone as a backup protection system for power swing and fault from the relay [6]. Mho distance function is illustrated in Fig. 1.

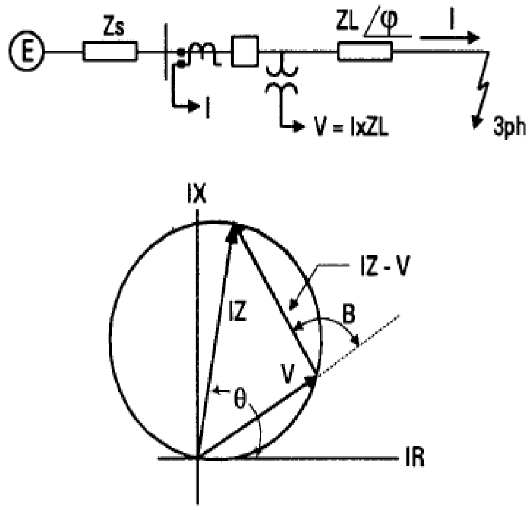

Fig. 1 Simple Mho function [6]

In addition, the impedance vectors will be functioned on by the current, *I*. The Mho circle function utilizes the measured voltage and current at the transfer to figure out whether the apparent impedance plots within the Mho circle characteristic or not. In order to make that determination a comparing the angle between the polarizing *V*. Where $V = IZf$ and operating quantity $IZ - V$. Moreover, if $\theta > 90°$, then the fault impedance, Z_f falls outside of the Mho characteristic and for that no output will be produced. However, if $\theta \leq 90°$, then fault impedance, Z_f plots within the characteristic and Mho function will produce an output [7].

2.3 Power Swing Effect on Distance Relay

When impedance due to power swing matches with the operating of the distance relay gives false tripping as depicted in Fig. 2. Power swing can affect the distance relays during their operation. In addition, the effect is able to cause unwanted tripping of the power system transmission line as well as to the different power system protection equipment. Consequently, failing the power system and may be allowed to damage and causing a blackout at the main portion of the power system.

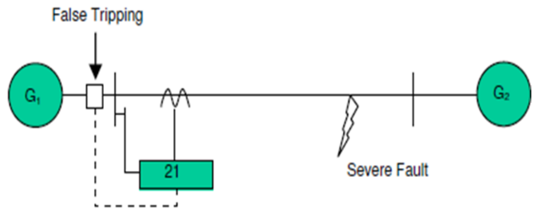

Fig.2 Wrong operation of distance relay due to power swing

Throughout the stability condition of the power swing, during stable condition the relay must not trip and therefore permit the power system to yield to the stable operating condition. Throughout the stable operation condition the distance relay must stop temporarily from operating in order to prevent the system separation from happening at randomly or other pre-selected locations. However, in the modern distance relays a new function called Power Swing Block (PSB) which is used to avoid the undesirable distance relay operation during the period of the power swings [8]. Moreover, the use of the PSB is simply to distinguish between the power swings faults, block distance even other distance relay elements from operating [9]. Moreover, the detected fault during the power swing must be removed.

Severe disturbances are able to yield a great separation of the system and a large fluctuating in voltage and current and large swing in the power flow, therefore which will cause losing synchronism. The effect of losing synchronism between two areas can cause damaging to the equipment of the power system. In order to avoid damaging the power system equipment, the power system areas must be disconnected from each other rapidly. However, the method of the system separation may not usually attain the wanted load generation stable. However, whether or not the separated area is in excess of local generation an amount of load shedding is required in order to prevent any disconnection or total blackout for the power system. Controlling tripping is a must for the power system elements because through an OOS uncontrolled tripping of circuit breakers could cause damaging to the equipment and causing a shutdown to bugger portions in the power system. Therefore by controlling the tripping that will prevent the equipment's of the power system from damaging and preventing widespread power outages. Also, the disturbance effects will be reduced. The main function of the Out-of-Step Trip (OST) is to achieve systematic separation. The OST function that it is used to differentiate the power swing condition either is stable or unstable.

Moreover, maintaining system stability and preventing power outages by initiation system area separation of the predetermined network locations and at the appropriate voltage source phase-angle difference between systems, in order to maintain power system stability and service continuity. During the normal operation condition state in power system, the nominal frequency must be operated near to the range of 50 Hz or 60 Hz.

In addition, the system can also be operated through slight deviations, less than 0.02 Hz for the larger systems and for smaller systems it reaches to the 0.05 Hz. Therefore, the load and also the power generation can be considered as balanced [5]. The power angle curve which shows the connection between the angle between the two ends and the power transmitted is illustrated in Fig. 3. $P_{\max}$ is the maximum power, E_S is the sending end voltage, E_R is the receiving end voltage and Z_T is the total impedance. In addition, curve shows that when the angle, δ from 0° to 90° increases the power transmitted, then decreases after 90°.

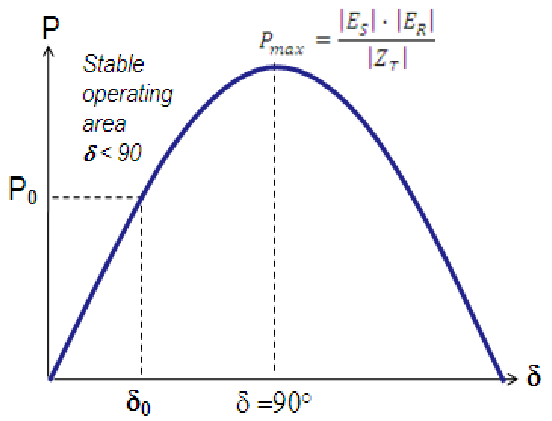

Fig. 3 The power angle curve

The power transmitted in power system will immediately reduce when there is a fault occurs. The output during the fault is provided in Figure 4. Moreover, the electrical machine output will cause the reduction of P_F . On the other hand, the input power, P_0 is corresponding to the generator mechanical torque which are not able to decrease instantly. After a fault, the power output is reduced to P_F, the generator rotor, δ therefore starts to accelerate, and δ starts to increase. At the time that the fault is cleared when the angle difference reaches δ_C , there is decelerating torque acting on the rotor because the electric power output, P_C at the angle δ_C is larger than the mechanical power input, P_0. Therefore, the impedance will cause accelerating in the rotor of that machine and the angle, δ also increases.

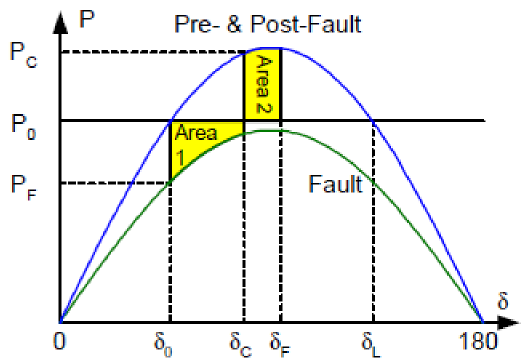

Fig.4 Fast fault clearance and a stable swing

In the power system the transferring of electrical power will be initially at the angle, δ_0 known the fault reduce the power transmission so, when the fault occur consequently the output power will be reduced until P_F at the time the angle will increase and therefore the rotor will be increased. But after a while the fault will be cleared at that time the electrical power is larger than the mechanical power and the rotor of the machine will be decelerated to eventually the fault will be cleared when the angel at δ_C. However, because of inertia the machine rotor angle will keep increasing until δ_F. At that time, the acceleration energy that gained in area 1 will be equal to the decelerating energy lost at area 2.

The transient unstable system is illustrated in Fig. 5 with sufficient damping when the angle, δ_C is smaller than the angle, δ_F . However, the difference between angles eventually will return to δ_0 or the original stable position. Area 2 will be equal to area 1 when the fault are cleared quickly and before the angle reaches to δ_L Although some oscillation will occur but the system will recover back and will be settle at δ_0 which consider the initial conditions of the system and at that moment it can be called as stable system. However, if the area 2 is smaller than area 1 and at that time angle reaches to the limiting angle which explaining about unstable system during transient which at that moment the mechanical power input is larger than the electrical output power and as a result the rotor of the machine will be accelerated again and also angle will be increasing. During unstable conditions the generator rotor speed is rotated with different speeds of other equivalent generator in the system. This condition is considered an unstable power swing or an OOS condition [10, 11].

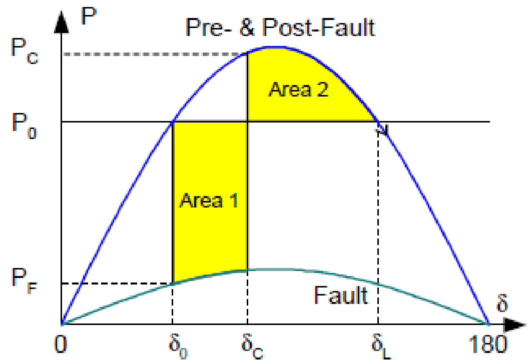

Fig. 5 A transient unstable system

3. Overview of Power Swing and Relay Misoperation

The necessity of suitable supply is to retain the synchronous machines running in corresponding and with sufficient ability to come across the demand of the load [12]. OOS environments in a power system are generated through to try to transference a given volume of power from side to side impedance of unnecessary, otherwise by poor level of voltage. Those situations are always created by fault situations, manual or automatics circuit switching and also machine loss excitation [13]. The operation associated with protective relays is difficulty of power systems transient stability and their important part of clearance faults as fast as able to suitable to continue stable [14].

Generator tripping, power system faults or removal of the load are effecting the rapid variations in electromagnetic power. So the system transient stability respects powerfully effect the schemes on which out-of-step protection relays are required to function to have dependable operations [15, 16]. Generator manages and prime movers could not regulate the mechanical power rapidly sufficient, therefore equilibrium among electromagnetic among mechanical results alternations in power flow and machine rotor angle. Dependent on the activities of the power system control and serious interferences, the system might achieve creating operational balance point undergoing what is mentioned by means of a stable power swing. Simple interference can cause the rotor angle of the generator in to great expedition, huge power swing flow, can cause huge variation of current and voltage and also synchronization of loss [8].

Swing power must be reviewed for harmless process in large power systems. Protecting control activities have to be occupied to moderately severe swing power. Moreover, alternative control movements, for instance OOS protection, should be occupied to prevent the spread of simple limit load outage and interferences. Predictable OOS protection arrangement is created generally on measuring the impedance of the positive sequence at the location of the relay [3, 17, 18].

As soon as a fault happens, the measured impedance changes directly from the impedance of the load position to the place which presents the impedance plane of the faults. For the duration of a system swing, the measured impedance transfers gradually the degree of impedance variation and the impedance is determined by the slip frequency of an equivalent two-source system. System interferences affect swing power otherwise alternations in the system. So different devices control is fixed in the system to be able to correctly damp the fluctuations. The system can bring back to both the original and an additional balance working point. Such fluctuations are named stable power swings. Else, if some of the generators might considerate slippery poles from this time can it fail synchronism. Therefore, those situations are called as Out of Step conditions and caused swing power is named as unbalanced swing power [19].

An OOS relay must discriminate among a condition fault of normal operating, stable and unstable power swing. Then it can cause in tripping cascade which the opportunity may cause in blackout power system. Similarly, when an out-of step situations are distinguished, more time will be vital to select the best appropriate islanding scheme ensuing in the lowest load of loss. If result could not take as a correct example at that time the voltage passes through the terminal of the circuit breaker be able to go above valued system voltage, and might be as large as double the system rated voltage [20]. Therefore, precision and speed relaying are the two significant principles to be achieved by relay using for out of step in detecting situation.

3.1 Power Swing Phenomena

During the state of steady situation of power system, the produced and used up power to sustain similar. Once the system exposed to huge interruption, the electrical power at the generator bus varies through the mechanical power input to the generators rests unchanged producing the fluctuations in the rotor angle of the machine and caused power swings [21, 22].

When the condition power swing is stable therefore variations are decreased. On the other hand, unstable swings result is progressive which split the angle among two zones power systems, creating huge power swing, great oscillations of currents and voltage, then ultimately results synchronization of loss in the middle of that zones called OOS state [23]. Distinguishing amongst faults and power swings may perhaps come to be hard once these great alternations of voltage and current happen for the duration of a power swing [24].

Conventional impedance designs method recommends same situations as underneath system faults. For that reason, the impedance path might come into the impedance areas of relays distance [25].

3.2 Relay Miss-Operation

Together unstable and stable swing power can result in harms protection distance. For stable swings, relay should be blocked to avoid trips of incorrect, whereas in the situation of unstable, relay have to function to discrete unsynchronized zones then should stop more outages [26]. Trip control of an electrical canter can be needed for the period of unstable swings. In such situation, the control center might appreciate in several relays to split the power system into isolated stable subsystems. The OOS detection logic at the electrical center discriminates among swing power stable wherever the system improves an unstable OOS situation where the grid wants to be separated. The study of in depth on the influences of mutually unstable and stable swing power on relay distance process [25, 26]. According to Fig. 6, at the time the transmission line does not realize any faults, it can have understood the impedance by relay distance set up on Bus 1.

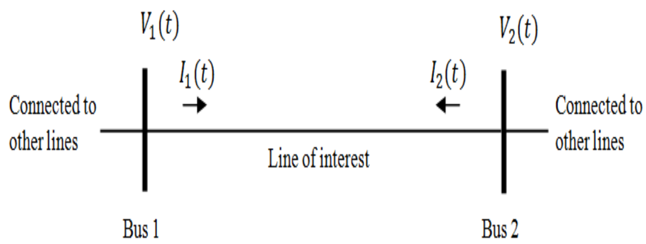

Fig. 6 Transmission line with two-end measurements

The measured impedance, Z_{mean} in equation (1) by the relay is influenced by the magnitude ratio and the angle alteration of the voltages at the two ends. For the duration of power swings, by reason of fluctuation of the bus voltages and line currents, the measured impedance realized by the relay might go in the area locations results in relay miss-operation.

$$Z_{mean} = \frac{V_1}{I_1} = \frac{V_1}{\frac{V_1 - V_2}{Z_L}} = Z_L \left[\frac{1}{1 - \frac{V_2}{V_1}} < \varnothing_{21} \right] \quad (1)$$

Where:

I_1 is the current at Bus 1

I_2 is the current at Bus 2

V_1 is the voltage at Bus 1

V_2 is the voltage at Bus 2

Z_{mean} is the measured impedance

Z_L is the line impedance between Bus 1 and Bus 2

ϕ_{21} is the difference of voltage angle between Bus 1 and Bus 2

The diagram of measured impedance trajectories in the R-X plane with consideration of angle variances and magnitude of the voltage as given in Figure 7, in the condition of $1 < 180°$ [27]. To sense swings and checked undesirable trips, conventional distance relays fitted out with swing power blocking (SPB) module. The SPB module functions depend upon the rate-of conversion of the locus of the apparent impedance for the period of stability of the system. For a stable swing, this rate-of-conversion is small while for an instable swing, it is rapid. As showed in Fig. 7, by way of describing external regions or blinders, dependent on the sort characteristics of relay that are set up, individual be able to measure the time interval which is essential to the apparent impedance locus to pass the two characteristics. If the time goes above a definite rate, so at that point the swing power blocking function is started.

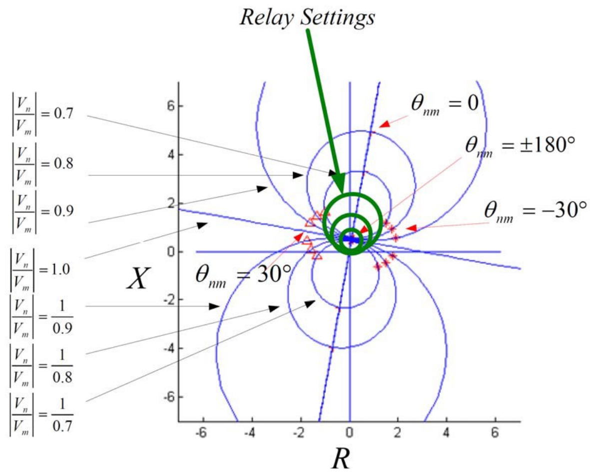

Fig. 7 Measured impedance trajectory in the R-X plane

3.3 Out-of-Step Protection Functions

Some ways that diminishing the feast of a cascading outage produced means of synchronization of losses is the use of OOS relays system protection which identify OOS situations which proceeds suitable movements that discrete the cause of the system zones, decreasing the load losses, then continue extreme service continuousness [28]. Out of step detection has mainly associated two functions. The first one is OOS tripping function protection which differentiates between unstable as well as stable, also it starts sectionalizing of the network or islanding for the period synchronization of losses. Other function is named OOS blocking function protection, it distinguishes among unstable power swing or stable and faults. However, the out step blocking purpose has to block element relay work likely for the period of unstable power swing and also stable power. Move over the out-of-step blocking role must agree elements relay for the function of the period of fault currents which make development for the duration of OOS situation [12, 29].

3.4 Out-of-Step Tripping and Blocking Function

Out-of-step tripping method is planned for the power system for a purpose of safeguard for the duration of unstable situations, separating higher power system zones and unstable generations both of them through the establishment of islanding system. Therefore, sustaining equilibrium in the interior, every island means of equalizing the generation supply with the load area [30]. achieving that balance that we mention above out-of step system tripping have be functional the selected network place, normally close at an electrical network canter, and network parting must take place at such points to reserve a near equilibrium among load and generation. In that reason, out-of–step tripping systems have to be accompanied with OOS blocking utilities to avoid unwanted system relay operation, however stopping apparatus hurt and blackout the most important of the power system portion, and realize a system separation control. Besides that, out-of-step blocking should be applied in additional position of the network avoiding separation of the system. Wherever the generation of the load could not be done at equilibrium, the important feature of out-of-step tripping is to equivocate tripping a line as soon as the angle between systems is closed to 180 degrees. Tripping for the period of this condition carry out great pressures on the circuit breaker this condition cause limitation and breaker harm [31].

4. TNB 275kV Network and an Out-of-Step Application

4.1 Description of the Network

The authors in [32] have demonstrated Tenaga National Bernhard (TNB) eastern corridor. The schematic diagrams that showed in Fig. 8. The figure shows four groups of generator. Two blocks of thermal generators where the first generator is consist of. Moreover, the second generator consists of 3 blocks while the third generators represent a 1 block of generator. In addition, Generator 4 is representing a group of 4 units of hydro generators. In this network, generators 1, 2 and 4 are available at 275 kV network. While, generator number 3 is connected to132 kV network. The measurements of the active and reactive power generations are taken from a remote terminal unit (RTU) at high voltage side of each generator. In order to measure the positive sequence voltages and angles PMU 1 installed at Bus 1 while PMU 2 installed at Bus 2. Remote terminal unit RMU 3 will be installed soon to specify whether the out-of-step is causing by 6-line trip or 4-line trip.

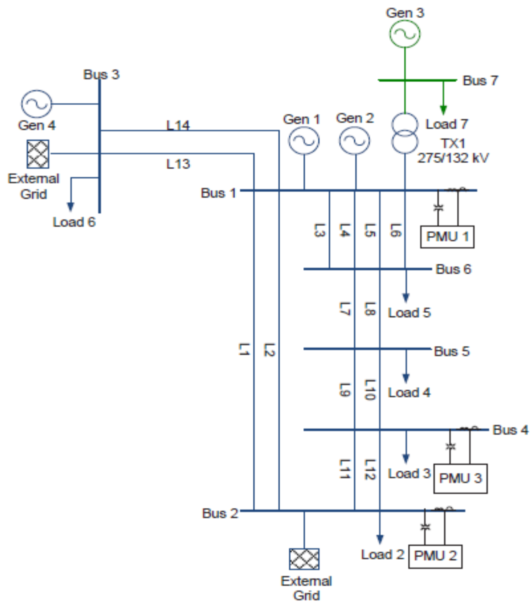

Fig. 8 TNB network under investigation

The majority of the generate power in the normal condition will be exported to the central and southern corridors. However, the power that goes to the north corridors is less comparing to that goes to the central and southern corridors. When 13 degrees is the angle difference between Bus 1 and Bus 2. If any fault happened in the system, the machine angle difference will change as well as the speed and the acceleration of the machine. The transmission lines are tripped and in that condition the system will be not stable and the different angle will be beyond 180 degrees.

4.2 System Dynamic Behaviour and Detection

Fig. 9 shows angle differences between Bus 1 and Bus 2 for unstable operation conditions. At the beginning of the angle difference is 13 degrees when the system working under the normal condition. However, the angle difference will increase to 180 degrees after 2.5 seconds.

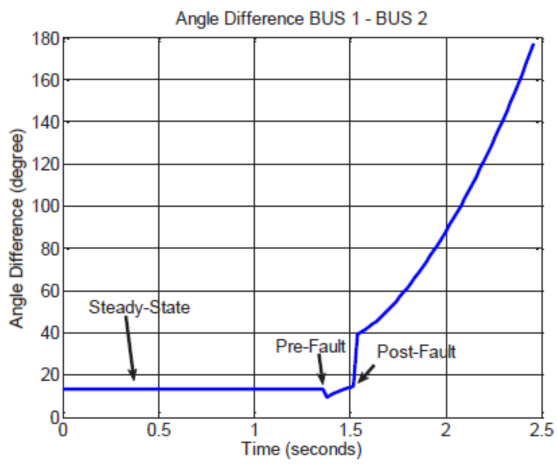

Fig. 9 During unstable condition the angle difference between Bus 1 and Bus 2

In Fig. 10, the trajectories of slip frequency are shown also the acceleration on the slip frequency. The acceleration plane and the operating point of the system in the direction of the unstable region after post-fault and tripping of the transmission lines after 2.5 seconds.

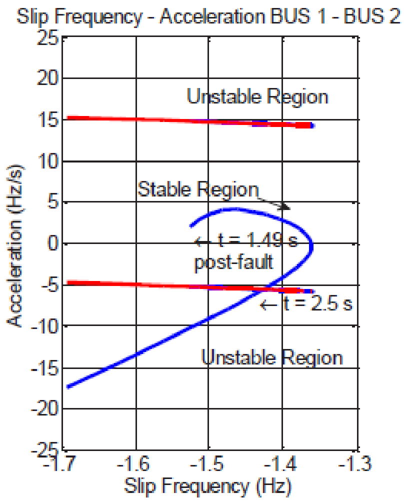

Fig. 10 During stable condition the angle difference between Bus 1 and Bus 2

5. Conclusion

OOS relaying systems is to prevent unwanted tripping of transmission lines, reduces the magnitude of the interferences therefore it protects devices from being broken. The main purpose is to provide sufficient decision to ensure personal safety, safe grounding and then service reinstallation is able to be conducted. Besides that, OST in power systems must be used in an appropriate network positions to separate the network from the duration of an OOS condition and then generated system islands. Whenever the power generation is balanced, then the load demand will always in synchronism condition. OST systems must be complementary with OSB of the systems in order to block elements of the relay susceptible. The main purpose is to ensure the system is either in stable or unstable of power swings.

This paper has been well explained regarding the power swing and relay miss-operation throughout the power system. Moreover, the application of OOS has been elaborated as well especially in TNB 275 kV.

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