ANALYSIS OF A NOVEL SLIDING MODE FREQUENCY SHIFT ISLANDING DETECTION METHOD

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ABSTRACT
This paper deals with a detailed analysis of a new modified Sliding Mode Frequency Shift (new-SMFS) method which is used for detecting an islanding situation in a power system. As compared to the original Sliding Mode Frequency Shift (SMFS) detection method which uses a sinusoidal function for the phase perturbation in the reference value of inverter current, the new-SMFS method uses a non-sinusoidal function for the phase perturbation in the reference value of inverter current. This new-SMFS method is an improvement over the original SMFS method having improved detection time, better damping ability and a highly reduced Non – Detection Zone (NDZ). Even if it is an active islanding detection technique, the deterioration in power quality of the overall system is drastically reduced. The effect of various parameters in the new-SMFS method on the detection time, damping ability, NDZ and tripping action of the circuit breaker on the distributed generation (DG) side has been performed. The software used for this analysis is MATLAB – Simulink.

Key words: New Sliding Mode Frequency Shift (new-SMFS), Detection Time, Damping Ability, Non – Detection Zone, Tripping Action of Circuit Breaker on DG side, Power Quality.
1. INTRODUCTION

It is a well-known fact that Renewable Energy Systems or Distributed Generation is encouraged and given a lot of importance in modern power systems. After the restructuring of the power sector, Individual Power Producers (IPP) came into the power market scenario. These IPP’s produce electrical power mostly by using these Distributed Generation systems like Solar-PV energy, Wind energy, Tidal energy, etc [2]. Thus, to sell the power, they connect these Distributed Generation (DG) systems to the main power grid, which gave rise to the grid-tied DG systems of today. But in order to do so, they must comply with certain standards and specifications of their system parameters in accordance with the Grid code and IEEE standards [7] [8]. If any of these codes or standards is violated by the IPP, then the IPP can’t sell the power to the main grid.

But even after the DG has been tied to the grid, there are certain technical problems whose probability of occurrence in the power system increases. One of these problems is the Islanding situation [1]. In a grid-tied DG system, when the supply from the main grid is cut-off due to any reason, the DG system still continues to keep some conductors of the system powered up as shown in fig.1. This is known as islanding in a grid-tied DG power system.

Islanding situation mainly poses a threat to the safety of the maintenance personnel who provide service to the grid conductors from time to time. Other major side effects of this situation are instability in the power system, damage of customer load and equipments, reduction of quality of power being supplied to the customers as well as certain problems in reclosing operations in order to restore system supply [3] [4]. Hence, islanding in a grid-tied DG power system is a highly critical phenomenon and according to IEEE 1547 standard, such a situation must be detected and overcome in a matter of 2 seconds or less [8].

As a result, many Anti-Islanding Protection (AIP) schemes have been proposed since the discovery of this power system phenomenon. These schemes are mainly divided into 3 types: active schemes, passive schemes and remote schemes. Active schemes generally detect islanding by injecting a certain perturbation into the system parameters and recording their response to the perturbation. These schemes have the merit that their Non-Detection Zone...
(NDZ) is very small and have low Error Detection Ratio (EDR) [2] [4]. The de-merit of these schemes is that they reduce the power quality in the system because of the fact that they introduce perturbations into a system that is already stable.

Passive schemes, on the other hand, monitor the various system parameters continuously and check for abnormalities in their variation with time. The merits of these methods are that they are cheap and easy to implement and they don’t introduce any kind of perturbations into the system to detect islanding situation unlike the active schemes. The de-merit of these schemes is that they are highly sensitive with large NDZ and high values of EDR as compared to active schemes [2] [4].

Remote schemes are mainly based upon the communication between inverter on the DG side and the main power grid so as to monitor the breakers on each side. The merit of these schemes is that they have very low or almost zero NDZ and EDR. But the de-merit is that these schemes need very large investments in order to implement them and are thus, suitable only for major power stations or industries i.e. they aren’t economically viable on a smaller scale [2] [4].

In this case, an active islanding detection method i.e. the new SMFS technique has been considered for a detailed analysis regarding the detection time, the ability of the method to damp out disturbances during the instance of islanding, the extent to which power quality is affected, the Non – Detection Zone and the tripping action of the circuit breaker on the DG side. The following sections will be dealing with the description of the original SMFS method and the new – SMFS method for islanding detection followed by its simulation model with the relevant data used in the same as well as the simulation results.

2. THE SMFS DETECTION METHOD
This is an active islanding detection method which introduces periodic phase perturbations in the reference current of the DG inverter as given by equation (1) and monitors the system’s response to the same.

\[ i_{ref} = i_{p_k} \sin(2\pi ft + \theta_{SMFS}) \]  

(1)

The phase perturbation \( \theta_{SMFS} \) is expressed in this method as a sinusoidal function of the deviation in frequency of the voltage signal at the PCC which is given as:-

\[ \theta_{SMFS} = \theta_{MAX} \sin\left(\frac{\pi}{2} \frac{f-f_{nom}}{f_{max}-f_{nom}}\right) \]  

(2)

where, \( f_{nom} \) = nominal value of system frequency = 50 Hz
\( f_{max} \) = frequency corresponding to maximum phase shift \( \theta_{MAX} \)

The angle by which the current leads the voltage for the RLC parallel load connected at the PCC is given as:-

\[ \theta_{RLC-LOAD} = \tan^{-1}\left(Q_f \left(\frac{f}{f_0} - \frac{f_0}{f}\right)\right) \]  

(3)

where, \( Q_f \) and \( f_0 \) are the \( Q \) – factor and the resonant frequency of the parallel RLC load respectively.

The phase angle versus frequency plot of both equations (2) and (3) are shown in figure 2:-

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From figure 2, it is seen that with increase in $\theta_{\text{MAX}}$ the amplitude of phase perturbation increases. Also the load line intersects the curve at three different points which indicate stable operation of the system during an islanding situation. Hence, for a given $Q$ – factor of load, the value of $\theta_{\text{MAX}}$ must be chosen in such a way that the stable operating points must lie as far outside the nominal frequency tolerance range. For a given $Q$ – factor of the load, if $\theta_{\text{MAX}}$ is increased then the stable operation points will lie even further away from the frequency tolerance region. Also it is seen from figure 3 that the slope of the load line increases with the value of $Q$ – factor. This means that for a given value of $\theta_{\text{MAX}}$, the stable operating points will shift much closer to the frequency tolerance region. Hence, it leads to the conclusion that this islanding detection method will fail to detect an island in the power system for higher values of $Q$ – factor of the load. Another observation can be made from figure 2 which is a stable operating point at the nominal frequency itself. So if during islanding, the frequency deviation is very small, then the phase perturbation introduced in the inverter’s reference current as given by (2) may have a very small value that will reduce the detection speed and hence increase the detection time thus, allowing an island to persist for a longer period of time in the system.

Figure 2 Plot of $\theta_{\text{SMFS}}$ and $\theta_{\text{LOAD}}$ for different values of $\theta_{\text{MAX}}$ at a given $Q$-factor of the load in SMFS method

Figure 3 Plot of $\theta_{\text{LOAD}}$ for different values of Q-factor of the RLC load
The Non-Detection Zone for the SMFS method is found out from the load parameter space of $Q$ – factor versus resonant frequency of the load given by equation (4):

$$f_0 = \frac{f_{isl}}{2Q_f} \left[ \sqrt{(\tan \theta_{SMFS}(f_{isl}) + 4Q_f^2) - \tan \theta_{SMFS}(f_{isl})} \right]$$  

(4)

where, $\theta_{SMFS}(f_{isl}) =$ value of phase perturbation to be introduced in the inverter’s reference current at the corresponding islanding frequency $f_{isl}$.

and

$$f_{isl} = \begin{cases} 50.2 & \text{if } f > f_{nom} \\ 49.8 & \text{if } f < f_{nom} \end{cases} = \text{islanding frequency}.$$  

The plot of Non-Detection Zone for SMFS method is shown in figure 4:

Figure 4 NDZ of SMFS method for various values of $\theta_{MAX}$

From figure 4, it is observed that the NDZ reduces with increase in $\theta_{MAX}$ and the $Q$ – factor of load at which the NDZ starts varies linearly with respect to change in $\theta_{MAX}$. So in order to make the NDZ start from a higher $Q$ – factor of load, a large value of $\theta_{MAX}$ is required. Hence, in order to eliminate the NDZ, a very large value of phase perturbation is needed which is practically not desirable because it may lead to deterioration of power quality in an already stable system. Thus, to counteract the disadvantages of SMFS method a new
SMFS method has been proposed for islanding detection which will be discussed in the following section.

3. THE NEW SMFS DETECTION METHOD

The proposed modification in the original SMFS method is the use of a non – sinusoidal function to introduce phase perturbation in the reference current of the DG inverter. The governing equation of this method is given as:

\[ \theta_{\text{new-SMFS}} = x(f - f_{\text{nom}}) + \psi(f - f_{\text{nom}})\theta_0 \]  

(5)

where, \( x \) = accelerating gain factor, \( \theta_0 \) = additional phase shift, \( f_{\text{nom}} \) = nominal system frequency = 50 Hz

and

\[ \psi(f - f_{\text{nom}}) = \begin{cases} +1 & \text{if } f > f_{\text{nom}} \\ -1 & \text{if } f < f_{\text{nom}} \end{cases} \]  

(6)

The plots of equation (5) are shown in figures 6 and 7 for different values of accelerating gain and additional phase shift. From figure 6, it is observed that as compared to the original SMFS method, there are no stable operating points in the frequency tolerance region during islanding and with increase in value of accelerating gain ‘\( x \)’ the slope of the family of curves increases. So if the Q – factor of the load increases i.e. if the slope of load line increases, then with an appropriate value of ‘\( x \)’ the stable operating points can be eliminated for an islanding situation. From figure 7, it is seen that with change in the additional phase shift ‘\( \theta_0 \)’, the slope of the curve doesn’t change but the upper and lower bounds of the curves are simply offset from their original position. But in this case, with increase in slope of the load line, the stable operating points in the frequency tolerance zone can’t be avoided. So changing the value of \( \theta_0 \) only, may not be sufficient to avoid these operating points. Hence, it is concluded that changing the value of ‘\( x \)’ is a necessary condition for avoiding the stable operating points. From figures 6 and 7, it can also be seen that with change in ‘\( x \)’, the change in phase perturbation is relatively less as compared to that with change in ‘\( \theta_0 \)’.

![Figure 6](http://www.iaeme.com/IJEET/index.asp)

Figure 6 Plot of \( \theta_{\text{new-SMFS}} \) and \( \theta_{\text{LOAD}} \) for different values of ‘\( x \)’ at a given Q-factor of the load in new SMFS method.
Figure 7 Plot of $\theta_{\text{new-SMFS}}$ and $\theta_{\text{LOAD}}$ for different values of ‘$\theta_0$’ at a given Q-factor of the load in new SMFS method.

The NDZ of this method is also plotted as per equation (4) and the effects of both ‘x’ and ‘$\theta_0$’ are shown in figures 8 and 9. It has been plotted in the load parameter space of Q–factor of load versus the load’s resonant frequency. From figures 8 and 9, it is seen that the NDZ has been substantially reduced as compared to that of the original SMFS method and the Q–factor of load at which the NDZ starts is much higher than that of the original SMFS method.

Figure 8 NDZ of the new SMFS method for various values of accelerating gain ‘x’

Figure 9 NDZ of the new SMFS method for various values of additional phase shift ‘$\theta_0$’
From figures 10 and 11, it is seen that as compared to the original SMFS method, the variation of Q – factor of load with respect to change in accelerating gain and the additional phase shift is non – linear in nature and hence, it can be concluded that for eliminating the NDZ from this method, small values of accelerating gain and the additional phase shift are required. Also the change in ‘x’ and the change in ‘θ₀’ are having the same effect on the Q – factor of load at which the NDZ starts.

**Figure 10** Variation of Q – factor of load at which the NDZ starts with respect to change in ‘x’

**Figure 11** Variation of Q – factor of load at which the NDZ starts with respect to change in ‘θ₀’

**4. SIMULATION MODEL AND DATA**

The model that has been developed in MATLAB – Simulink for the analysis of the new SMFS islanding detection method has been shown in figure 12. In this model, a single phase equivalent of the three phase power system is shown. This model consists of a DG source that is connected to the main power grid via an L – type LC filter circuit. The step function is given as an external input to the grid side circuit breaker so that it will open at t = 0.5 seconds in order to intentionally create an islanding situation. An RLC parallel load is connected in the system at the Point of Common Coupling (PCC). The conversion block simply extracts the frequency at the PCC using a Phase – Locked Loop (PLL) from the voltage signal. The threshold block simply sets the threshold values of frequency and voltage at the PCC for the islanding detection technique. The detection block is modelled as per the governing equation of the new – SMFS detection method given by (5). PWM wave generator acts as a current controller which provides PWM gate pulses to the single phase H – bridge inverter which
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converts DC output of the DG system to AC output. The PWM generator compares the measured current and the reference current and will provide the gate pulse only when the measured current is greater than or equal to the reference current of the inverter. The inverter uses IGBT switches and the DG system is represented in the model as a simple DC voltage source. The values of different parameters in the simulation model that has been chosen to perform the analysis are as mentioned in table 1.

<table>
<thead>
<tr>
<th>SIMULATION PARAMETERS</th>
<th>VALUE OF PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Voltage Source</td>
<td>350 V</td>
</tr>
<tr>
<td>AC Power Grid</td>
<td>220 V</td>
</tr>
<tr>
<td>Filter ‘L’ and ‘C’</td>
<td>L = 3 mH and C = 4.7 μF</td>
</tr>
<tr>
<td>RLC Parallel Load</td>
<td>R = 40 Ω, L = 20.54 mH and C = 493 μF</td>
</tr>
<tr>
<td>Step Delay Block</td>
<td>Initial value = 1, final value = 0 and t = 0.5 seconds</td>
</tr>
<tr>
<td>Frequency Threshold</td>
<td>50±0.2 Hz</td>
</tr>
<tr>
<td>Voltage Threshold</td>
<td>220±20 V</td>
</tr>
<tr>
<td>SMFS Method</td>
<td>( f_{nom} = 50 \text{ Hz}, f_m = 53 \text{ Hz}, \theta_m = 11^\circ )</td>
</tr>
<tr>
<td>New – SMFS Method</td>
<td>( f_{nom} = 50 \text{ Hz}, \theta_0 = 0.5^\circ , x = 11.5 )</td>
</tr>
</tbody>
</table>

Table 1 Simulation Data

![Simulation Model for analysis of the new SMFS islanding detection method](image)

5. SIMULATION RESULTS

The simulation has been done from \( t = 0 \) to \( t = 1 \) second and the islanding situation is created by disconnecting the grid at \( t = 0.5 \) seconds. First the results of original SMFS method will be discussed followed by the new – SMFS method for island detection.
5.1. Original SMFS Islanding Detection Method
The results of the original SMFS islanding detection method have been shown in figures 13(a) to 13(d).

![Graph 13(a)](image1)

![Graph 13(b)](image2)

![Graph 13(c)](image3)
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Figure 13 Waveforms of original SMFS islanding detection method that shows (a). Voltage at PCC (b). Current at PCC (c). Reference current of the DG side inverter (d). Trip signal given to breaker on the DG side.

From figure 13.(a), it is seen that after islanding occurs in the system, over-voltage peaks are observed at the PCC and these peaks persist for sometime in the system due to re-closing operation of the circuit breaker on the DG side as noted from figure 13.(d). The time taken for detection in voltage waveform is 0.3 seconds and that in current waveform is 0.15 seconds as seen from figure 13.(b). Figure 13.(c) shows the reference current waveform of the DG side inverter from which it can be observed that the phase perturbation before and after islanding is almost same i.e. the change in phase after islanding is nearly inconspicuous because the phase perturbation introduced in the reference current as given by equation (2) is very small thus, resulting in more detection time and low detection speed. Thus, to overcome this disadvantage, the new SMFS method has been proposed for islanding detection which will be discussed in the next section.

5.2. New – SMFS Islanding Detection Method

The results of the new – SMFS islanding detection method has been shown in figures 14.(a) to 14.(d) and these results have been obtained for accelerating gain ‘x’ = 11.5 and additional phase shift ‘θ₀’ = 0.5 degrees. From figures 14.(a) and 14.(b), it is seen that as compared to the original SMFS method, the detection time has improved drastically to 0.15 seconds for the voltage at PCC and 0.05 seconds for the current at PCC. The disturbance in voltage and current waves damped out much faster after islanding as compared to the original SMFS method due to the consideration of a non – sinusoidal phase perturbation in the reference current waveform of the DG inverter given by equation (5), thereby improving the dynamic stability. Thus, due to ‘x’ and ‘θ₀’, in the governing equation, the improvement in detection time has been obtained. Also in this case, from figure 14.(d), it is seen that there is no re-closing operation of the circuit breaker on the DG side due to which additional disturbances are not injected to the load connected at PCC. This re-closing problem is avoided by choosing a suitable value of ‘x’. The disturbance in current at PCC is detected in just 1 cycle as compared to nearly 4.5 cycles in the original SMFS method. From figure 14.(c), it is seen that the phase perturbation after islanding in the reference current waveform is much more conspicuous as opposed to the same in case of original SMFS method which is again due to the non – sinusoidal governing equation as represented by (5). The effect of ‘x’ and ‘θ₀’ on the detection time and trip signal issued to the DG side circuit breaker is discussed in the next section.
Figure 14 Waveforms of new SMFS islanding detection method that shows (a). Voltage at PCC (b). Current at PCC (c). Reference current of the DG side inverter (d). Trip signal given to breaker on the DG side.
6. EFFECT OF ‘X’ AND ‘Θ₀’ ON PERFORMANCE PARAMETERS OF NEW–SMFS METHOD

In this section, the effect of accelerating gain ‘x’ and additional phase shift ‘Θ₀’ on performance parameters of the new–SMFS islanding detection method like detection time and trip signal sent to the DG side circuit breaker.

6.1. Effect of Change in Accelerating gain ‘x’

In this case, keeping ‘Θ₀’ constant at 0.5 degrees, the value of ‘x’ has been changed from $x = 1.0$ to $x = 14.5$ in order to study its effect on the voltage signal at PCC and the trip signal that is sent to the circuit breaker on the DG side after islanding has been detected in the power system. The plots of PCC voltage and trip signal of the DG side circuit breaker are shown for various ‘x’ values.
Figure 15 Plots of PCC Voltage of new SMFS islanding detection method for (a). $1.0 \leq x \leq 4.5$
(b). $5.0 \leq x \leq 6.5$ (c). $7.0 \leq x \leq 11.5$ (d). $12.0 \leq x \leq 14.5$

From figures 15.(a) to 15.(k), it is observed that for $x = 7.5$ to $x = 11.5$, good detection time is obtained without re-closing of the circuit breaker on the DG side. For all other values of ‘$x$’, the circuit breaker on the DG side re-closes thereby causing either the disturbances to persist for a longer time due to quick re-closing action (as seen for $x = 1.0$ to $x = 6.0$ and for $x = 7.0$) or causing the disturbances to occur again after a relatively longer period of time due to slow re-closing action (as seen for $x = 6.5$ and for $x = 12.0$ to $14.5$). But this range of ‘$x$’ is not universal for all loads i.e. it keeps changing for different values of the load’s Q – factor and determining the optimal range of ‘$x$’ for which re-closing of the DG side circuit breaker
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does not occur is yet another challenge in this method. This range of ‘x’ is valid only for a load Q – factor of 6.19 as considered for this analysis. The above mentioned facts can be confirmed again from the plots of trip signal sent to the circuit breaker on the DG side after islanding as shown in figures 16.(a) to 16.(d).

16.(a)

16.(b)
Thus from figures 16.(a) to 16.(d) it is proved that for a load having a Q – factor of 6.19, re-closing operation of the circuit breaker does not occur for the range of accelerating gain ‘x’ from 7.5 to 11.5 thereby preventing any additional disturbances to be injected into the load in an islanded condition. For all other values of ‘x’, re-closing of the DG side circuit breaker occurs thereby introducing more disturbances into the system thus, increasing the detection time. The variation of detection time with respect to change in ‘x’ in the optimal range is seen from table 2 and from the plot shown in figure 17.
Table 2 Change in detection time for $7.5 \leq x \leq 11.5$

<table>
<thead>
<tr>
<th>ACCELERATING GAIN ‘x’</th>
<th>DETECTION TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>0.250 seconds</td>
</tr>
<tr>
<td>8.0</td>
<td>0.245 seconds</td>
</tr>
<tr>
<td>8.5</td>
<td>0.240 seconds</td>
</tr>
<tr>
<td>9.0</td>
<td>0.225 seconds</td>
</tr>
<tr>
<td>9.5</td>
<td>0.220 seconds</td>
</tr>
<tr>
<td>10.0</td>
<td>0.215 seconds</td>
</tr>
<tr>
<td>10.5</td>
<td>0.200 seconds</td>
</tr>
<tr>
<td>11.0</td>
<td>0.195 seconds</td>
</tr>
<tr>
<td>11.5</td>
<td>0.150 seconds</td>
</tr>
</tbody>
</table>

From table 2 and figure 17, it is clearly observed that the detection time reduces with increase in optimum accelerating gain ‘x’ in a non-linear manner. The next section deals with effect of additional phase shift ‘$\theta_0$’ on the voltage at PCC and the trip signal issued to the DG side circuit breaker during islanding in a power system.

![Figure 17 Variation of detection time with respect to change in accelerating gain ‘x’ in the optimal region](image)

**Figure 17** Variation of detection time with respect to change in accelerating gain ‘x’ in the optimal region

### 6.2. Effect of Change in Additional Phase Shift ‘$\theta_0$’

In this case, keeping ‘x’ constant at 11.5, the value of additional phase shift ‘$\theta_0$’ is changed from 0.0 to 1.9 degrees in order to study its effect on the voltage signal at PCC and the trip signal that is sent to the circuit breaker on the DG side after islanding has been detected in the power system. The plots of PCC voltage and trip signal of the DG side circuit breaker are shown for various ‘$\theta_0$’ values.
Figure 18 Plots of PCC Voltage of new SMFS islanding detection method for (a). $0.0 \leq \theta_0 \leq 0.9$

(b). $1.0 \leq \theta_0 \leq 1.9$

From figures 18 and 19, it is observed that for some values of additional phase shift ‘$\theta_0$’, re-closing operation of the DG side circuit breaker occurs whereas for some values it does not occur. The values of ‘$\theta_0$’ for which re-closing does not occur follows a random pattern unlike that for different values of ‘$x$’ which gives a definite range of values to avoid re-closing of the circuit breaker. Thus, the variation of detection time with change in ‘$\theta_0$’ cannot be plotted. The reason for not obtaining a definite range of values of ‘$\theta_0$’ for which re-closing of the DG side circuit breaker does not occur, is that it is associated with a non – linear function as given
by equation (6) whereas for the same purpose, a definite optimal range is found in case of ‘x’ as it is associated with a linear function as seen in equation (5). But there is a certain value of ‘θ₀’ which at a given value of ‘x’ gives the best detection time and in this case for x = 11.5, best detection time and ability to damp out disturbances during islanding is found for θ₀ = 0.5 degrees. Since the optimal range of ‘x’ to avoid re-closing of the DG side circuit breaker depends on the Q – factor of the load, it is again another challenge to find out the appropriate value of ‘θ₀’ for a given optimal value of ‘x’.

Figure 19 Plots of trip signal sent to the DG side circuit breaker of new SMFS islanding detection method for
(a). 0.0 ≤ θ₀ ≤ 0.9 (b). 1.0 ≤ θ₀ ≤ 1.9
In order to summarize the above analysis, a comparison has been made between the original SMFS and the new SMFS islanding detection method in table 3 as follows:

<table>
<thead>
<tr>
<th>Comparison criteria</th>
<th>SMFS Detection Method</th>
<th>New – SMFS Detection Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Time for voltage wave</td>
<td>0.30 seconds</td>
<td>0.15 seconds</td>
</tr>
<tr>
<td>Detection Time for current wave</td>
<td>0.15 seconds</td>
<td>0.05 seconds</td>
</tr>
<tr>
<td>Non-Detection Zone</td>
<td>Big NDZ (increases beyond $Q_f = 2.5$)</td>
<td>Small NDZ (increases beyond $Q_f = 70$)</td>
</tr>
<tr>
<td>Re-closing of DG side circuit breaker</td>
<td>Re-closing occurs (disturbance is more)</td>
<td>No re-closing for $x = 7.5$ to $x = 11.5$ for given RLC load</td>
</tr>
<tr>
<td>Phase perturbation in reference current wave</td>
<td>Not noticeable after islanding occurs</td>
<td>Noticeable after islanding occurs</td>
</tr>
<tr>
<td>Dynamic Stability</td>
<td>Less</td>
<td>More</td>
</tr>
</tbody>
</table>

7. CONCLUSIONS

In this paper, a new SMFS islanding detection method has been proposed which is an improvement over the original SMFS islanding detection method. It has drastically improved detection time, better ability to damp out the disturbances during the instant of islanding thus, increasing the overall dynamic stability of the power system. The deterioration in the system’s power quality has also been substantially reduced. The NDZ zone has been reduced drastically as well making it almost negligible thus, increasing the reliability of the proposed technique. All of this has been achieved by combining a linear and a non – linear term in the governing equation of the detection method as given by (5) and eliminating the stable operation points in the frequency tolerance region. Furthermore, the change in NDZ and the detection time has been studied due to the individual effects of accelerating gain and additional phase shift. But as mentioned earlier, the choice of an optimal range of accelerating gain and a proper value of additional phase shift for different $Q – f$ factors of load is still a challenge that can be solved in the future by using an adaptive algorithm.

REFERENCES


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