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Protection of Distributed Generation Using Adaptive Frequency Relay

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Abstract: Distributed generation is local generation near local load that feeds the local load. This local load and local generation form a grid known as microgrid. Microgrid operates in two modes 1) islanded mode 2) grid connected mode. Protection scheme used in the islanded mode is not used in the grid connected mode because of threshold settings. Main three instability problems occur in the interconnected power system are Frequency, Voltage and Angle. This paper deals with the design of an adaptive frequency relay, which is used to protect the distributed generation against frequency variations in grid connected mode as well as in islanded mode. It is also used to detect islanding condition of the system. The modeling is done in MATLAB/SIMULINK environment.

Keywords: Distributed generation, Adaptive frequency relay, Phase locked loop (PLL)

I. INTRODUCTION

Now a day, the whole world has started implementation of distributed generation. Distributed generation and local load form microgrid. Microgrid operates in two mode 1) islanded mode and 2) grid connected mode. Because of the threshold settings, Protection scheme does not use in grid connected mode as well as islanded mode [2]. So, protection of the microgrid is challenging task for protection engineer. At present, most of relays are non adaptive in nature. So, they are not used for the protection in both modes. The frequency instability is the main problem in the interconnected power system. Frequency variations create some problems like damage turbine plates; misbehave of the power plant auxiliary system etc [1]. Main and costlier part of the generation is generator, which is damaged by large frequency variation. Owner of the distributed generation is small investor and they are much affected by this type of events.

In the past, main industrial practice to disconnect DG, if over or under frequency problems occur. At present, DG is used to continuously supply local load in islanded condition. Adaptive relays are digital relays, which can change their settings according to mode of operations. In this paper, main focus is on the designing of adaptive frequency relay, which is used to protect the distributed generation in grid connected mode as well as islanded mode against frequency variations. European grid standards are used for the frequency relay settings in islanded mode or grid connected mode[7].

Accurate measurement of frequency and islanding detection is heart of the adaptive frequency relay. Number of methods are used for the frequency measurement like kalman filter method, Prony Method, discrete Fourier transform (DFT), least square error technique and phase method. Generally, all practical relays use zero crossing method for frequency detection. This method is not much accurate compared to other method.

In this paper, phase locked loop method is used for the frequency measurement and rate of change of frequency (ROCOF) has been used for islanding detection.

II. FREQUENCY MEASUREMENT TECHNIQUES

Phase locked loop (PLL) method is used for the measurement of the frequency. PLL can give fast and accurate information of frequency and phase. Notches, disturbances, unbalance and harmonics effects are reduced using this method [4].

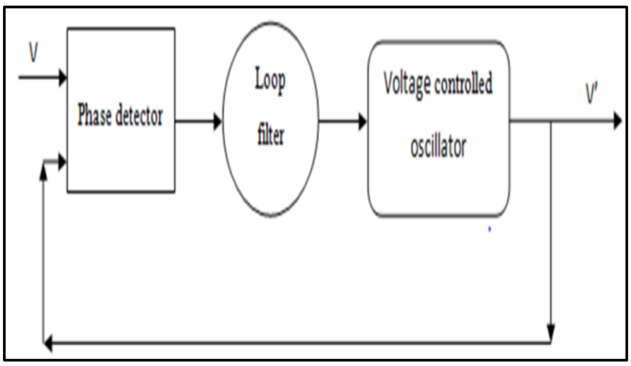

Figure 1 Basic structure of PLL

The simple basic structure of a PLL is shown in Figure 1. According to input signal v and output signal v’, phase detector generate output signal. High frequency AC components at PD output are removed using loop filter.

Loop filter is generally pi controller or first order differential low pass filter. Voltage-controlled oscillator generates an AC signal at output whose frequency is shifted with respect to a given central frequency ωc, as a function of the input voltage provided by the LF as shown in Figure 1.

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III. ADAPTIVE FREQUENCY RELAY

Digital adaptive frequency relay consists of two units: 1) frequency measuring unit 2) frequency detection unit, as shown in Figure 2

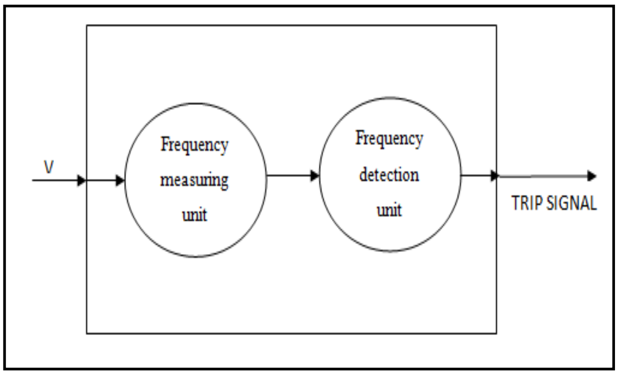

Figure 2 Block diagram of frequency relay

A) Frequency measuring unit: - Matlab model of the PLL shown in the Figure 3. Park transformation is used to transform three phase voltage quantity abc to stationary reference frame dq0. Stationary reference frame is converted into rotating reference frame.

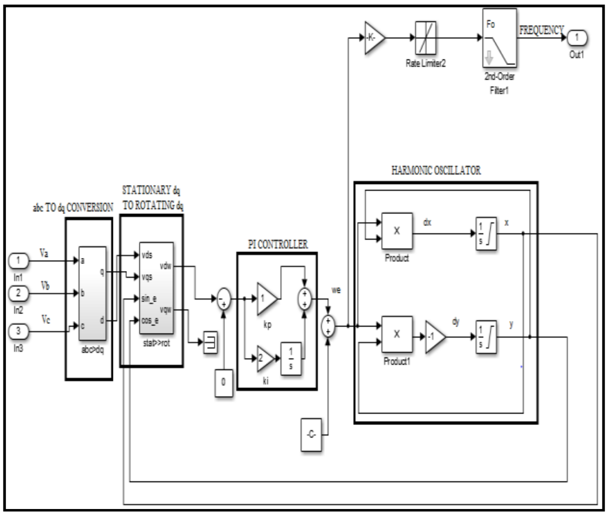

Figure 3 Frequency measurement unit

Representation of rotating vector as shown in Figure 4.

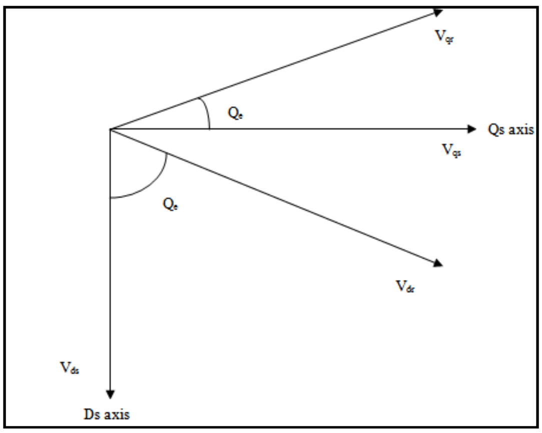

Figure 4 Synchronous rotating frame dq

$$V^r_d = V^s_q \sin\Theta + V^s_d \cos\Theta$$

$$V^r_q = V^s_q \cos\Theta - V^s_d \sin\Theta$$

Differential equation of an oscillator generates sine and cosine waveforms and is given by

$$\frac{d^2y}{dt^2} = -W^2Y$$

Where 'Y' is a function that is changing with time and W is the angular frequency in rad/sec (W=2πF) [4]. Harmonic oscillator output is supplied to the transformation block as shown in the Figure 3. pi controller is used to reduce error. Instead of pi controller, first order low pass filter is also used. Estimate the frequency at output of pi controller by multiplying angular frequency with 1/2π.

B) Frequency detection unit: - Frequency measuring block measures the frequency of voltage signal and sends the measured frequency to frequency detection block. If the frequency is greater than over frequency setting or lower than under frequency setting then frequency detection block sends trip signal to circuit breaker to disconnect the variable load or disconnect DG. The adaptive frequency relay use in this paper has two settings. First, upper level settings for grid connected mode and lower level settings for islanded mode as shown in Figure 5. Over frequency and under frequency settings are 50.5HZ and 49.5Hz respectively for grid connected mode. For islanded mode, the upper level and lower level settings are 51HZ and 49HZ respectively. If the system frequency goes above or below these set values, the adaptive frequency relay sends trip signal. Figure 5 shows upper level settings for grid connected mode and lower level settings for islanded mode. Islanding detection equipment continuously supplies signal 1(high) when microgrid is operated in grid connected mode. As shown in Figure 5, relay sends trip signal according to upper level settings because input of AND gate at lower level is 0. After islanding, islanding detection equipment sends signal 0 to upper AND gate. Low level signal is passed through NOT gate and hence supplies high signal (1) to lower level AND gate. So, the relay takes decision according to islanded mode settings. In this way, the adaptive frequency relay changes their setting according to mode of operation automatically.

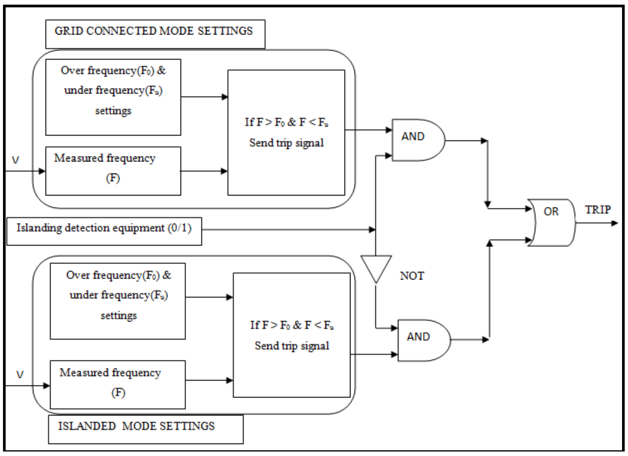

Figure 5 Block Diagram of adaptive frequency relay

Mode of operation	Maximum frequency variation limit
Grid connected mode	± 1 % (± 0.5 HZ)
Islanded mode	± 2 % (± 1 HZ)

TABLE 1 European grid code

IV. ISLANDING DETECTION

Islanding detection methods (IDM) are classified by two types: remotely controlled or locally controlled systems. Further, the Local IDMs can be classified into passive and active methods.

Passive anti-islanding detection methods observe electrical quantity like harmonic distortion, ROCOF, phase displacement, voltage and frequency at the PCC of a DG set[6]. When the DG set is working in islanded mode, these parameters change and when it crosses the adaptive frequency relay settings (higher settings or lower settings), trip signal is passed to the circuit breaker to disconnect the generator.

Active anti-islanding detection methods introduce disturbances to the connected circuit and then monitor the response to determine if the utility grid with its stable voltage and frequency is still connected or not. Depending on the level of disturbances, the adaptive frequency relay considers either islanded mode condition or grid connected mode condition. For smaller disturbance the relay considers grid connected mode condition and for larger disturbance the relay considers islanded mode condition [6].

In this paper, passive islanding method (rate of change of frequency (ROCOF)) is used to detect islanding condition. ROCOF relays are efficient for high-speed islanding-detection and they are having comparatively low cost.

V. MATLAB MODEL FOR ROCOF

The rate of change of frequency is calculated by comparing the difference of the frequency of the present sample and of the frequency at three periods earlier [8]. Matlab model of rate of change of frequency is shown in Figure 6.

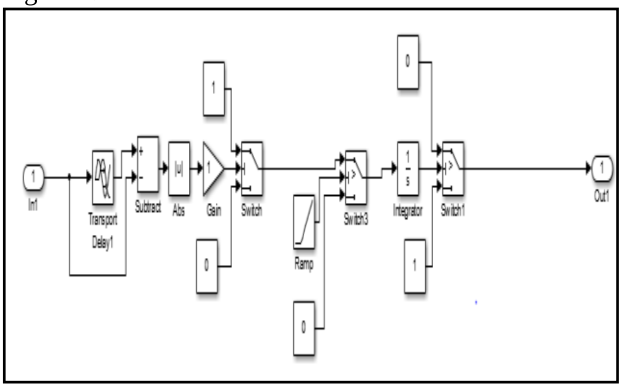

Figure 6 Matlab model of ROCOF

As shown in Figure 6, the transport delay is applied to measure frequency signal and then it is subtracted from the existing signal. This output of subtract block indicates rate of change of frequency. If ROCOF is greater than the threshold value, then relay sends trip signal to the circuit breaker (here to isolate the utility load).

VI. POWER SYTEM MODEL

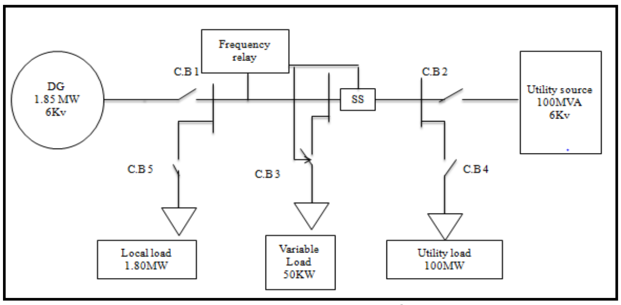

Figure 7 Single line diagram of power system

The simple one line diagram of power system model is shown in Figure 7.System shown in figure 7 is tested on different conditions such as normal condition and load variations (over load/under load). Here, utility load is supplied by the utility grid whereas local load is supplied by the distribution generation (as shown in the figure 7). Variable load changes according to change of demand. Voltage signal is derived from the P.T. This voltage signal is sent to the frequency measuring unit of digital frequency relay. Output of the relay frequency detection unit is sent to the circuit breaker of the variable load.

VII. MATLAB MODEL OF POWER SYSTEM

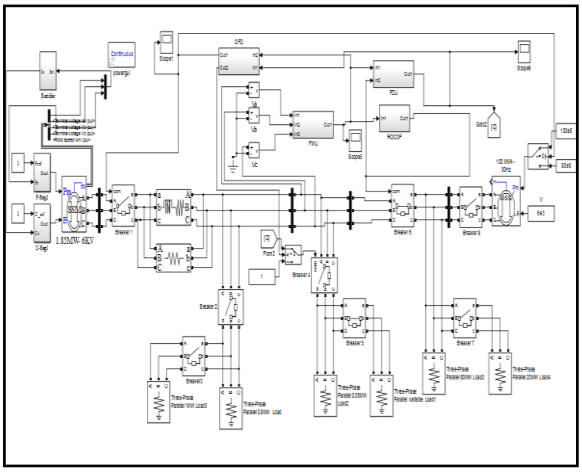

Figure 8 Matlab model of power system

As shown in Figure 8, 100MVA, 6KV utility generation and 1.85MW distributed generation feed the load. Frequency relay tested on this network. Frequency relay sense abnormal condition and try to bring back stability of system.

VIII. SIMMULATION AND RESULTS

Relay is tested under three conditions 1) Normal condition 2) Under frequency condition 3) Over frequency condition. Over frequency condition is tested under

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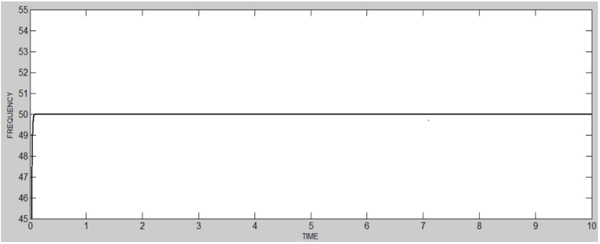
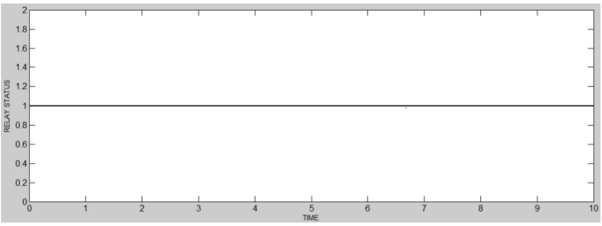
instantaneous and time delay settings because under frequency condition is controlled by load shading on other hand in over frequency condition controlling is very difficult. These all conditions tested on grid connected mode as well as on islanded mode.

A) Grid connected mode

1) Normal condition: - In normal condition, system is in stable condition. Measured frequency is nominal frequency 50HZ and relay status is 1as shown in Figure 9



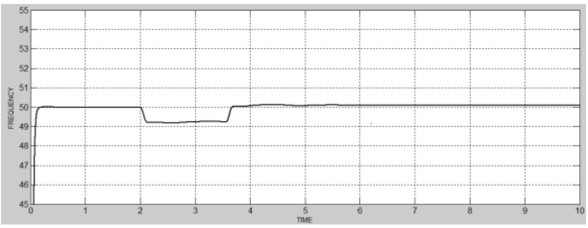
(a)



(b)

Figure 9 (a) Frequency (b) relay status

2) Under frequency condition test (time delay settings):- If increase variable load up to 15 MW (at 2sec), under frequency condition occurs. Frequency goes down below 49.5Hz and after threshold time delay (here 1.5sec) relay send trip signal(0) to circuit breaker to shade variable load as shown in Figure 10. Frequency back in prescribe limit and System bring back in stable condition.



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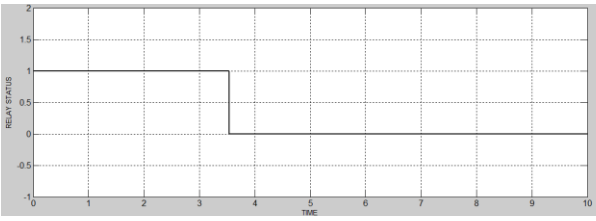


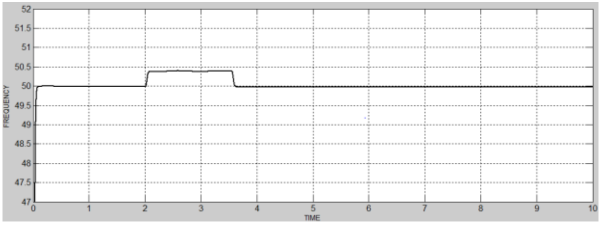
(b)

Figure 10 (a) Frequency (b) relay status

3) Over frequency test

i). Over frequency test with Time delay settings.
ii). Over frequency test with Instantaneous settings.

i). Over frequency test with time delay settings:-Utility load is decreased from 100 MW to 85MW then over frequency problem is occurs. Frequency goes above set frequency 50.3HZ and relay send trip signal and change utility generation from 100MVA to 85MVA after threshold time (here 1.5sec) as shown in Figure 11.



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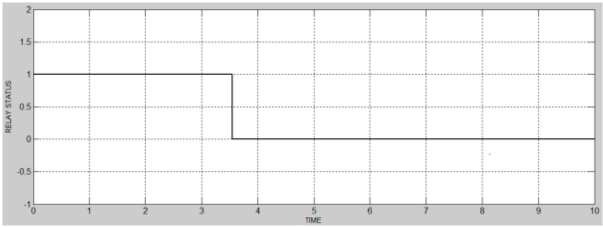
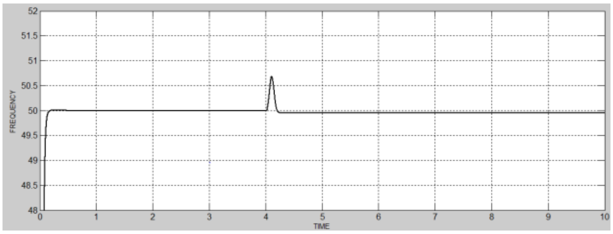


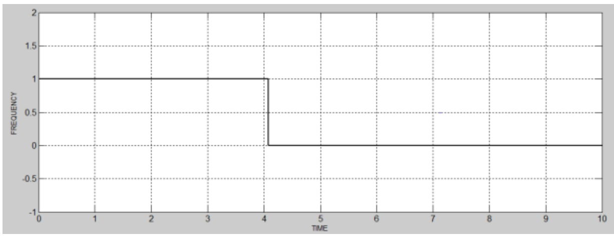
(b)

Figure 11 (a) Frequency (b) relay status

ii) Over frequency test with instantaneous settings: - Utility load is decreased from 100 MW to 80MW (at 4sec) then over frequency problem is occurs. Frequency goes up to 50.5HZ and relay send trip signal instantaneously and change utility generation from 100MVA to 80MVA. Also, relay send trip signal to breaker 1 and disconnect D.G from system as shown in below Figure 12.



(a)



(b)

Figure 12 (a) Frequency (b) relay status

B) Islanded mode

1) Islanding detection

ROCOF method is used for detect the islanding condition. Here ROCOF derived by comparing previous few cycles with present cycles. If output value is greater than threshold value then relay send signal to breaker and disconnect utility load as shown in Figure 13.

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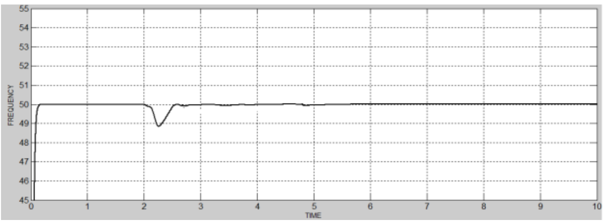

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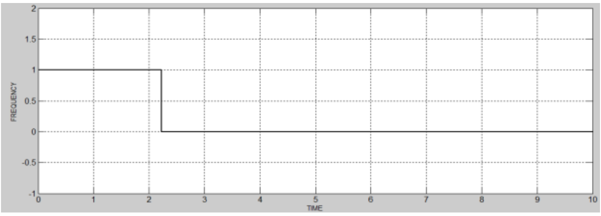
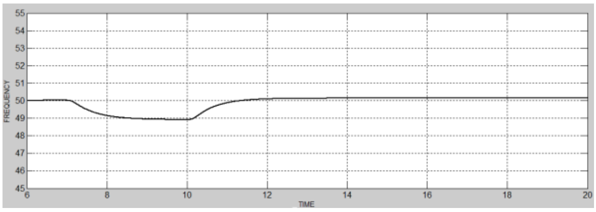


b)

Figure 13 (a) Frequency (b) relay status

2) Under frequency condition

After islanding condition, relay take decision according to islanded mode settings. Relay automatically changes their settings. If Increase variable load to 0.5 MW at 7sec after islanding then frequency is decline below 49HZ. After threshold settings relay send trip signal to breaker and shade prescribe load as shown in Figure 14. Frequency comes within a limit.



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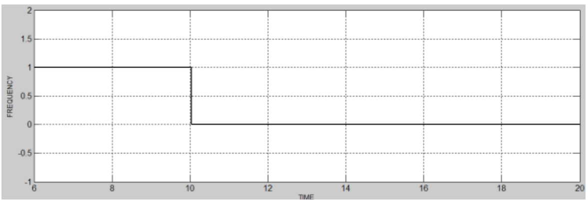
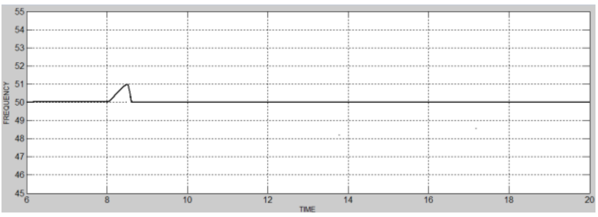


b)

Figure 14 (a) Frequency (b) relay status

3) Over frequency condition

If 0.8MW load is disconnected (at 8sec), over frequency problem occurs and frequency is increase up to 51 Hz. When frequency crosses relay settings (here 51 Hz), relay sends trip signal to breaker 1instantaneously and disconnect D.G. After disconnecting D.G, voltage and current are zero and pll indicate nominal frequency as shown in the Figure 15.



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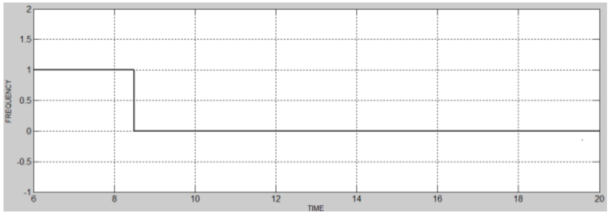

b)

Figure 15 (a) Frequency (b) relay status

IX. CONCLUSION

Modeling and simulation results in both mode 1) islanded mode 2) grid connected mode has been presented in this paper. An adaptive relay proposed in this paper, changes its settings automatically, according to mode of operation and protect DG against frequency variations, if abnormalities persist. Adaptive frequency relay proposed in this paper makes protection scheme more reliable and less costly.

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