Fault Detection on Inverter Based Distribution Network

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Abstract

This paper compares the two voltage based techniques of detecting fault on the inverter based distribution lines. The system comprises of power width modulated inverter feeding distribution network. Fast detection of fault is prime requirement in an electric power system. A protection system is developed based on voltage transformations. Studies are carried out in MATLAB software package. The studies reveal that both the techniques lead to protection of system against shunt faults and could be viable option for future inverter based distribution network.

Keywords- *Distributed Generation (DG), Power electronic converter (PEC), Micro Grid.*

I. INTRODUCTION

In the last few years, increasing Co_2 levels in the environment have attracted the attention worldwide. One of the major causes of this is traditional plants for electricity generation i.e. coal/ diesel based plants. Moreover the demand of electricity is increasing day by day and building a new coal based/ hydro plant to meet this demand requires much time. Therefore one alternative is to use renewable energy source (RES), for generation of electricity. Some examples of renewable energy sources are solar plants, wind mills, fuel cell, micro turbines etc. But these plants have capacity of the order of 10Kw – few Mega Watts [1]-[2]. These generations are inserted in distribution system, hence are called distributed generation. A distributed energy source may be either a distributed generation or any other kind of storage. Sometimes these distributed energy sources are combined with distribution network by power electronic converters. Introduction of power electronic based generation sources have many advantages such as: 1) Easy active and reactive power controls, 2) Synchronization of two sources with different voltage and frequencies, 3) Flexible and fast controls [3].

But as distribution lines are radial i.e. meant for power flow in one direction only, therefore there may be overvoltage on line if generation increases than load or sometimes the situation is reverse of it. Therefore such networks have to be designed to tackle the worst cases of maximum load/minimum voltage or minimum load/ maximum voltage. With power electronics based distributed energy resources at distribution network; the main concern is on impact on protection co-ordination of distribution network. In the event of fault, these power electronic converter based distributed energy source contributes less current comparatively and thus detection of fault becomes difficult. It is reported that during fault power electronic converters limit the current to twice its rated current [5]. Therefore fault detection has to be done by detecting the changes in voltage at point of common coupling (PCC).

Fault on the power system creates unbalancing, which can be best studied by symmetrical components given by fortescue [6]. Symmetrical components define set of three voltages, positive sequence, negative sequence and zero sequence. For different types of faults power system is studied for different symmetrical component. Also three phase voltage can be transformed into d-q frame, as complex controls of three phase are simple in d-q frame.

The objective of this paper is:

- To generate disturbance signals for detection of different faults by Vabc-Vdq0 transformation.
- To generate disturbance signals for same faults by symmetrical components transformation.
- To compare the performance of different fault detection disturbance signals (Vdist.).

The proposed study is carried out in MATLAB software and a simulation model is developed. Section II of the paper discusses the system studied. Section III discusses the proposed technique. Section IV discusses about simulation studies, while section V deals with comparative analysis of the results. Conclusions are stated in section VI.

II. INVERTER BASED DISTRIBUTION NETWORK

A micro-grid is more or less like traditional power system but it is different in following ways: 1) different strategy of operation, 2) presence of large amount of power electronics based distributed energy sources, 3) need for fast synchronization, islanding detection, fault ride through, and reliable operation. Thus power electronics converters due to their complex controls make the concept of micro grid viable. The control loops of converters are either voltage controlled based or current controlled based, and thus are classified as voltage source converter or current source converter. Most of these converters employ complex current controlled loops. These power electronics converters are used to interface distributed generation with the grid [10].

A. Single line Diagram of System Under Study

For study purpose an equivalent AC source integrated with a ac-dc-ac power electronic converter is modelled as distributed energy source. With introduction of PWM technique in the converters, the harmonics intrusion in the network is negligible, the output obtained is a pure sine wave [7]. The transformer typically is a isolation transormer meant for excluding any transient to enter in the distribution network.

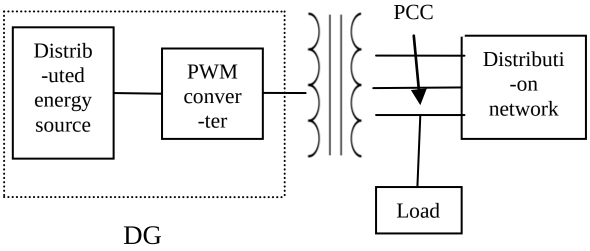

Figure 1.1 Inverter Based Distribution Network

B. Power Elecronic Converter

PWM converter is modelled as shown in figure 1.2. The PWM converter control comprises of outer voltage regulation loop and inner current controlled loop [8]. The circuit for a PWM converter is shown in figure 1.2.

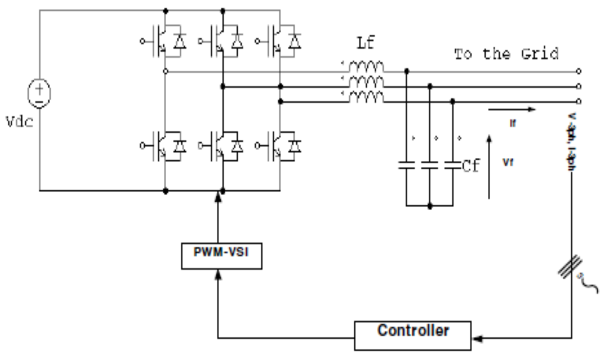

Figure 1.2 Power Electronic Converter

Here controller works on error signals obtained from proposed voltage transformations. Switching transients at the output are filtered by L-C filter. Pulse width modulation is used to provide gate signals to three phase converter.

III. PROPOSED TECHNIQUE

This paper discusses two voltage based fault detection methods,

A. Three Phase Voltage(Vabc) to Rotating d-q Transformation

The three phase voltage is transformed into reference frame. It becomes easy to perform control in d-q frame. Now this d-q values are used to detect the fault [7]. Figure 1.3

Shows proposed model for fault detection using abc to d-q transformation. Three phase stationary voltage is transformed into rotating d-q frame according to the following equations [7]:

$$Vds = \frac{2}{3} * Va - \frac{1}{3} * Vb - \frac{1}{3} * Vc$$
$$Vqs = 0 - \frac{\sqrt{3}}{3} * Vb + \frac{\sqrt{3}}{3} * Vc$$
$$V0s = \frac{1}{3} * Va + \frac{1}{3} * Vb + \frac{1}{3} * Vc$$

(1)

Here Vds, Vqs, V0s are transformation of Va, Vb, Vc in stationary d-q frame. Further,

$$Vdr = \cos wt * Vds - \sin wt * Vqs \qquad (2)$$

Vdr, Vqr are d-q values in rotating reference frame. These Vdr and Vqr are then used to detect the fault. It can be detected either by constructing a protection model similar to shown in fig.1.2 or by utilizing various wavelet transforms.

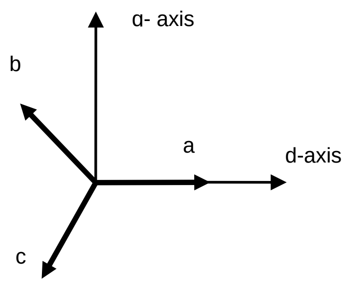

Figure 1.3 Relation Between Three Phase And D-Q Frame

B. Three phase voltage(Vabc) to symmetrical components(V012) transformation

During faults system enters in unbalanced condition, and unbalanced faults are dealt with study of symmetrical components. Therefore voltage at PCC is being converted into positive, negative and zero sequence component.

The governing equations for this transformation are,

$$a = e^{j2\pi/3} \qquad (3)$$

Transformation equations are:

$$\begin{bmatrix} V0 \\ V1 \\ V2 \end{bmatrix} = \frac{1}{3} * \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} * \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (4)$$

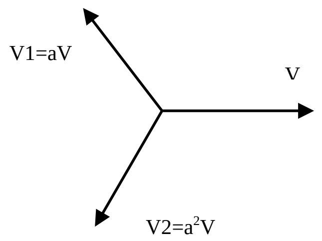

Figure 1.4 Relation Between Three Phase Voltage and Symmetrical Components.

Here V', V'', V represents positive, negative and zero sequence component respectively [9]. The protection model for fault detection is represented in figure 1.5. Three phase oltage from power electronic converter is first transformed into said transformation, i.e either in d-q reference frame or in symmetrical components. Thus any disturbance during fault is also get transformed. This disturbance signal (Vdist.) is then compared with their reference values in respective transformation frames and obtained signal is error signal. Based on this error signal fault is detected. This is depicted in equation (5):

$$V_{error} = V_{reference} - V_{disturbance} \quad (5)$$

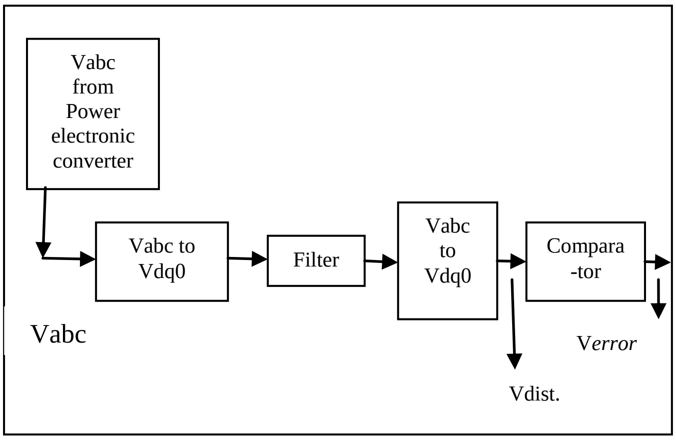

Figure 1.6 Proposed Protection model

IV. SIMULATION STUDIES

To implement fault detection method MATLAB is used to build time domain simulation model of figure 1.1.system implemented is rated according to table 1.1-1.2. simulations are performed for a fault duration of 0.1 second – 0.2 second.

Table 1.1 Distributed Energy Source Specifications

S.NO.	RATING	
1.	Phase to phase voltage	25Kv
2.	frequency	60Hz
3.	Three phase S.C level	10MVA

Table 1.2 Filter Specifications

S.NO.	ELEMENT	LOAD SIDE FILTER	INVERTER SIDE FILTER
1.	Capacitor	3×10^{-3} Farad	5×10^{-3} Farad
2.	Inductor	2×10^{-3} Henry	2×10^{-4} Henry

The two methods for fault detection are simulated for three different faults and voltage disturbance signals are generated.

A. *D-q Transformation:*

Simulations are performed for three different faults:

1) *Three Phase to Ground Fault.*

Voltages in dq0 frame are shown in figure 1.7. the error signal for fault detection is obtained by comparing Vd, Vq and V0 with their respective reference values and then mean value obtained is the error signal.

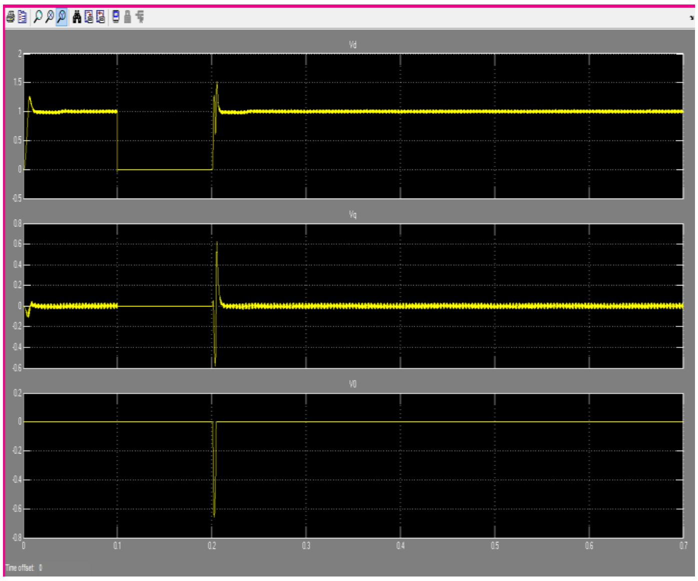

Figure 1.7 Vd, Vq, V0 For Three Phase To Ground Fault.

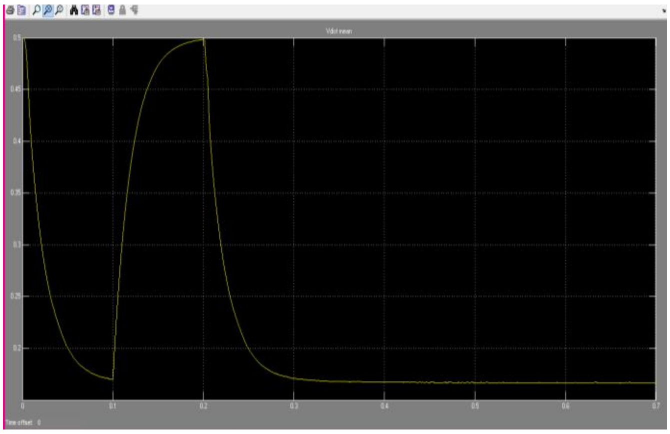

Figure 1.8 Vdq Error Signal For Three Phase To Ground Fault

From figure 1.7-1.8 it is observed that the error signal is decaying but as soon as fault occurs the error signal increases at once, now this rate of change can be detected easily and thus is helpful in fault detection.

2) Two Phase to Ground Fault:

Vdq0 signals and error signals are shown in figure 1.9 - 1.10.

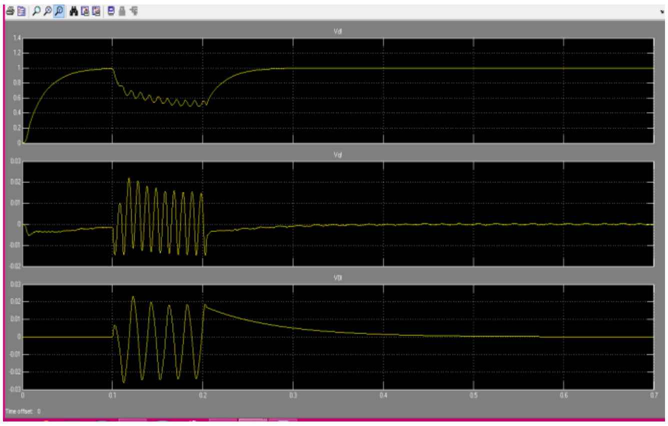

Figure 1.9 Vd, Vq, V0 For Two Phase to Ground Fault.

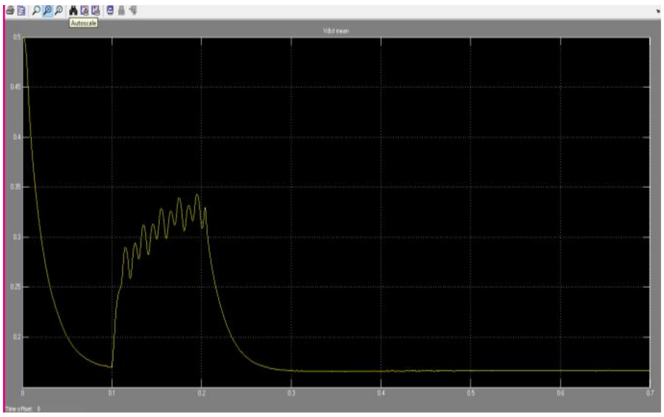

Figure 1.10 Vdq Error Signal For Two Phase to Ground Fault

The non-linearities presesnt in signal needs to be to be processed by a filter. A low pass FIR filter diminish these non-linearities.

3) Single Phase Toground Fault:

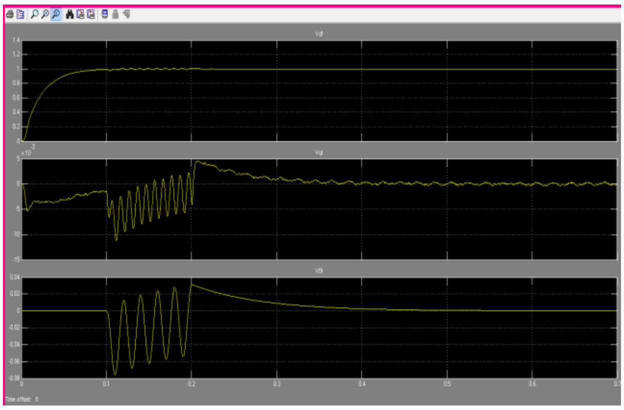

Figure 1.11 Vd, Vq, V0 For Single Phase To Ground Fault

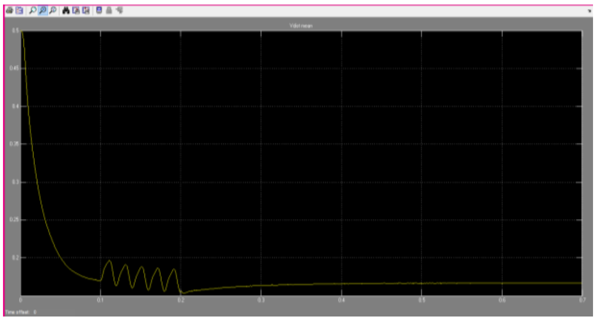

Figure 1.12 Vdq Error For Single Phase To Ground Fault

Figure 1.11 - 1.12 reveals the Vd, Vq, V0 signals and error signal for fault detection during single phase to ground fault. The error signal shows disturbance in duration 0.1 second to 0.2 second.

B. Symmetrical Component Transformation

Simulation studies with this transformation are carried out for three faults:

1) Three Phase to ground fault:

Figure 1.13 & 1.14 displays V0, V1, V2 for three phase to ground fault & V*012 error* signal.

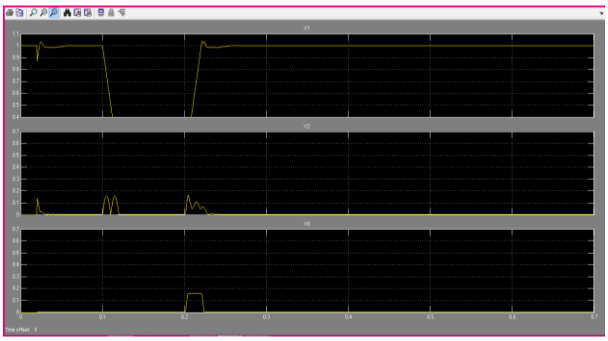

Figure 1.13 V012 For Three Phase to Ground Fault.

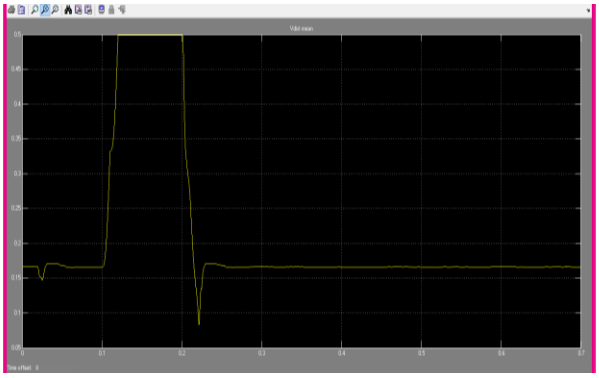

Figure 1.14 V012 Error Signal For Three Phase To Ground Fault.

For a three phase to ground fault the error signal observed is produce instant change as soon as fault occurs.

*2) **Two Phase to ground fault:***

Symmetrical components for this fault is shown in the figure 1.15 & 1.16

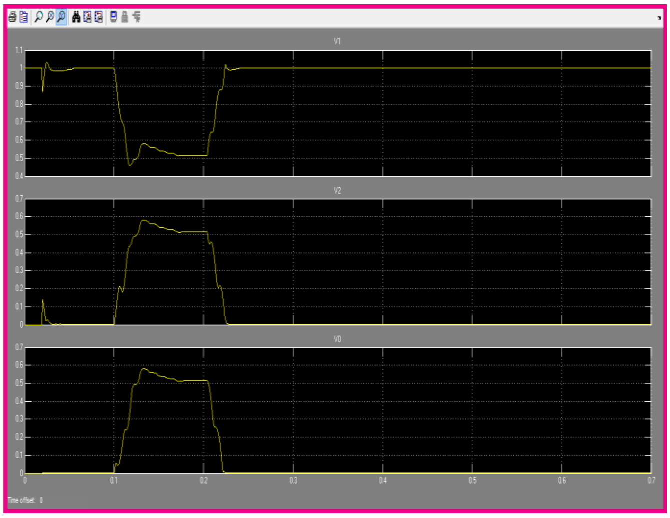

Figure 1.15 V012 For Two Phase To Ground Fault.

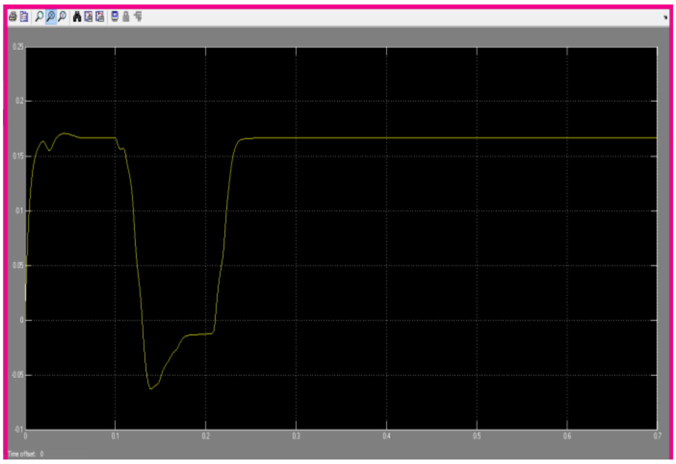

Figure 1.16 V012 Errror For Two Phase To Ground Fault.

*3) **Single phase to ground:***

For single phase to ground the symmetrical components and error signal are depicted in the figure in 1.17 & 1.18 respectively.

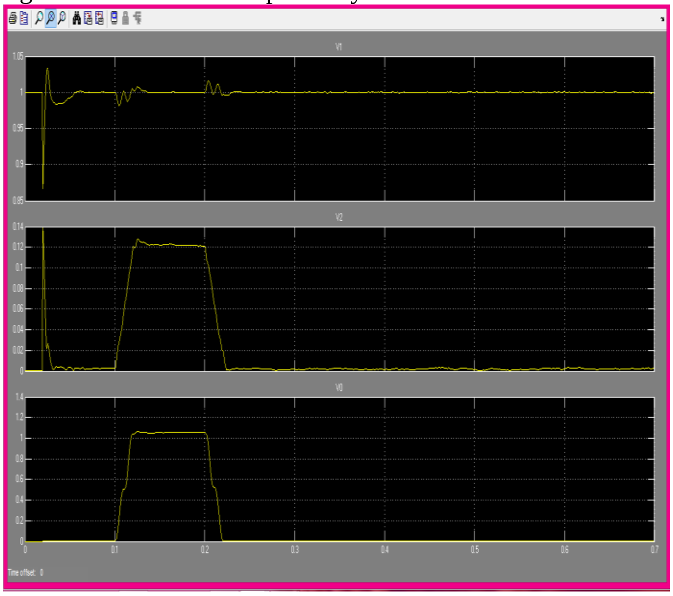

Figure 1.17 V012 For Single Phase Faults.

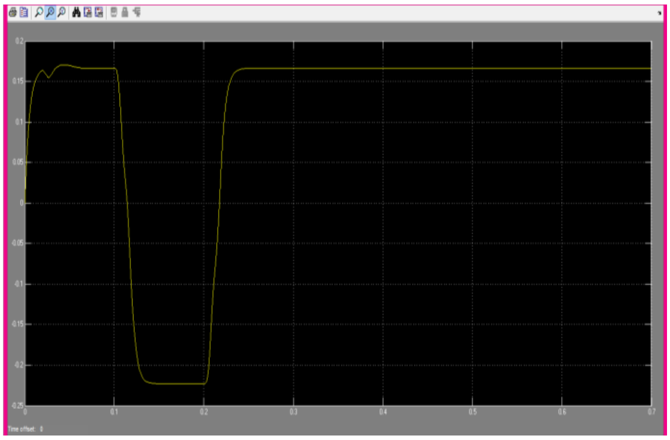

Figure V012 Error For Single Phase To Ground Fault.

V. RESULTS & ANALYSIS

During both the scenarios studied on existing system, disturbance signals show good response to fault occurrence. Thus a definite rate of change can be observed from point where fault starts and it ends.

A. For Three Phase to Ground Fault :

Thus error signal is more linear, abrupt and constant in symmetrical component transformation and detect fault in no time, but signal is somewhat negative so it is required to calculate its mean value.

B. For Two Phase to Ground Fault:

With two phase fault the error signal in d-q transformation is non-linear, while error signal in symmetrical component it is still linear, abrupt and constant. The mean value of this error signal of V012 transformation gives an abrupt and linear signal.

C. For single Phase to Ground Fault:

It is observed that the error signal obtained in single phase to ground fault during d-q transformation is more non-linear while that of symmetrical transformation is still linear.

Thus fault detector best works on mean error signals of symmetrical component transformation while error signals obtained with d-q signals need to be processed first. Thus on inverter based distribution networks instant changes in error signals reveals fast detection of faults.

VI. CONCLUSION & FUTURE SCOPE

It is observed that disturbance signal obtained by d-q transformation exhibits following properties:

- For three phase faults it is approximately linear.
- For two phase to ground fault it is almost linear but have some fluctuations.
- For single phase to ground fault it shows ripples.

Symmetrical components transformation exhibits following properties:

- For three phase faults it is extremely linear and changes abrupt from 1 to 0.
- For two phase to ground fault it is linear but it goes negative for a while but mean of this signal is taken for controller.
- For single phase to ground fault it is linear and exhibits negative nature, so mean of this signal is better for controller to operate.

With concept of DG, protection of inverter based system has become a prime issue. Based on developed disturbance signal, new fault detectors can be developed such as:

- By calculating THD of the disturbance signal.
- By performing wavelet analysis on disturbance signal.
- By developing an adaptive relay based on these disturbance signal.

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