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# Harmonic Power Angle Monitoring for Unsymmetrical Fault Diagnosis in Distribution Network

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**Abstract:** In this paper identification of a faulty load bus has been done in a multi-bus power system for double line fault, monitoring the feeder operating points and load angles in presence of various frequencies in harmonic P-δ plane. The usage of a new advanced variable slack bus incorporated converged power flow analysis determines the load angle, real power and feeder operating points for normal and fault in various load buses of the network in presence of some chosen harmonic frequencies in the system. The characteristic operating point shifting of the normal and fault operating points in normal and fault P-δ planes, determines the rule sets for identifying the fault buses in the grid system considered. This analysis can also be extended for other fault analysis in both online and offline conditions of the system.

**Keywords:** Fault detection, Harmonic power, Load angle, Line to line fault, Operating point, Stability zone.

## 1. Introduction

Interruption of supply systems is a common issue for industrial distribution networks, since the system is prone to various faults occurring in the grid system [1]. These faults have to be identified and mitigated far before the damage of a system, which requires the presence of fast fault detectors in the network. Least square error technique can be used for arcing fault detection and fault distance calculation, which can be tested on simulated as well as for laboratory experimental networks [2]. Symmetrical and Unsymmetrical fault assessment can be done in simulated systems by observing the voltage and current signatures of the load buses in the network [3]. An educational tool using FACTS devices, simulated in MATLAB, can be used for fault diagnosis, complex power flow studies [4]. Wavelet analysis can be done for fault detection in single-core symmetrical phase shifting transformers [5]. A MATLAB based fault discrimination algorithm, based on Multi-Resolution analysis of discrete wavelet transform, can be used for fault detection in transmission systems [6]. Phasor Measurement units are suitable for fault detection and classification, using time synchronized values of current and voltage in digital form at normal and fault occurring in the system [7]. Single line to ground fault detection in wide area power system IEEE 14 bus network can be done using phasor data concentrator using WAMS technology [8]. A new relaying framework, using readings of the phase currents, during the first 1/4$^{th}$ of a cycle in an integrated method combining symmetrical components with principle component analysis can be used for fault detection in a system [9]. Analysis shows the deviation in harmonic power, load angle and feeder operating points at unsymmetrical fault in load bus of a system using a novel technique [10]. Identification of a faulty bus in a system can be done monitoring the operating points in P-delta plane [11]. None of the analysis, seen so far, deals with the double line (LL) fault identification, monitoring the load angle and feeder operating point shifting in harmonic P-δ plane to accurately depict which type of fault has actually occurred in the system at a specified bus.

In this work the technique proposed in [1] has been extended for double line fault identification in a multi-bus power system, monitoring the load angle and feeder operating point shifting in normal and harmonic P-δ planes. An advanced variable slack bus incorporated converged load flow solution is used for determination of the load angle and feeder operating points at normal and at LL fault, wherein the deviation of feeder operating points were assessed in normal and harmonic P-δ planes to depict the faulty bus in the network.

## 2. Fault Bus Identification Using Harmonic Power Versus Delta Plane

The fault bus identification technique has been implemented on a modeled IEEE 9 bus system with conventional line and bus data for acquiring the system data at line to line (LL) fault in a chosen load bus of the system, in presence of various harmonic frequencies in the network. The modeled network has been presented in Fig. 1.

However this analysis technique can also be implemented for other standard transmission and distribution systems, since this analysis technique has been checked with other standard bus systems for different unsymmetrical faults occurring in the network. In this analysis, the fault restoration time has not been considered.

Here $5^{th}$, $7^{th}$ and $11^{th}$ harmonic frequencies have been used to justify the effect of these frequencies in the detection of remote end faults in the system with the developed P-δ plane analysis technique. These frequencies were chosen since benchmark report, IEEE Std. 1459-2010 [12], uses some of these arbitrary frequency values for determining the performance of multi-bus power system networks.

The fault data obtained from the above analysis was used for building the harmonic P-δ planes at LL fault in buses 6 and 8 of the system in presence of certain harmonic frequencies in the system. The algorithm of the developed analysis technique has been shown in Fig. 2.

The real power, load angle and feeder operating points of 9-8 feeder has been analyzed at fault in buses 6 and 8, considered only one at a time, in presence of some chosen harmonic frequencies ($5^{th}$, $7^{th}$ and $11^{th}$). The data of the above analysis has been shown in Table 1- Table 2. In Table 1 - Table 2, "F" denotes the frequency values, "h" denotes the data at healthy condition of the system, "$f_{LL6}$" and "$f_{LL8}$" denotes the data of the system at fault in buses 6 and 8 considered one at a time.

From the data obtained in Table 1 - Table 2, harmonic P-δ curves have been developed (Fig. 3), wherein the feeder operating points have been placed.

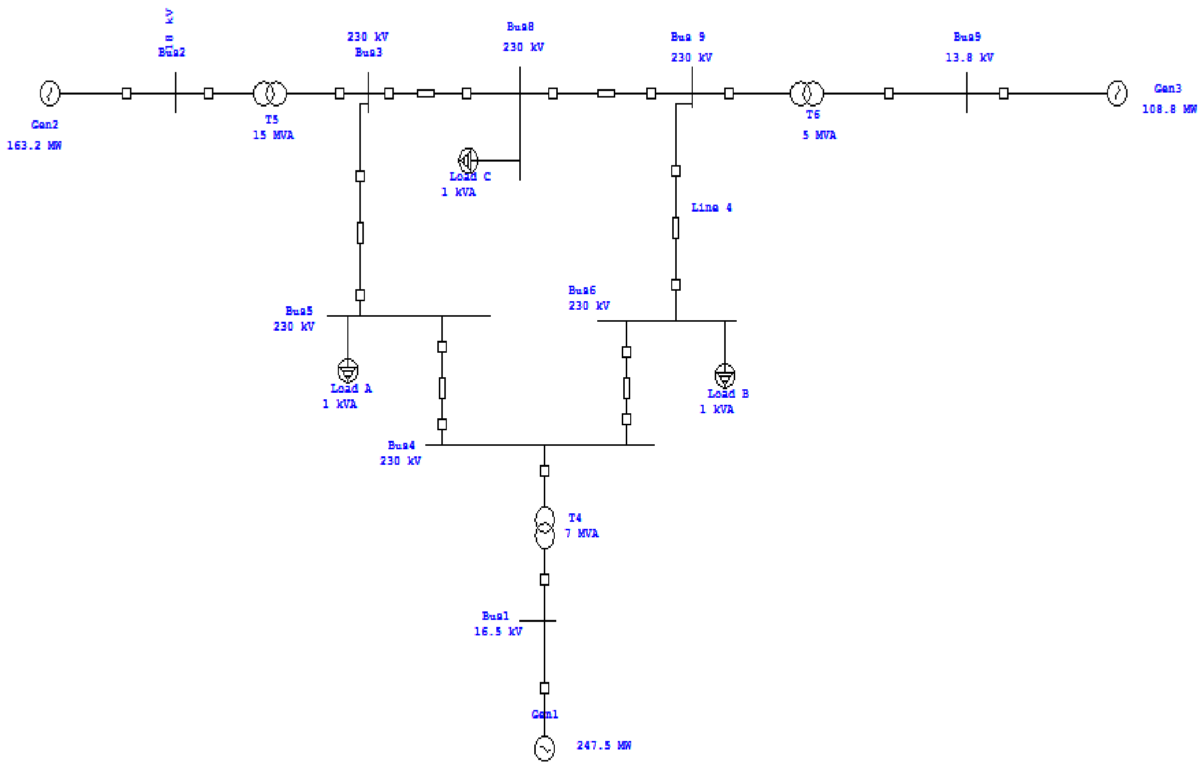


**Fig. 1.** IEEE 9 bus system model for analysis purpose.

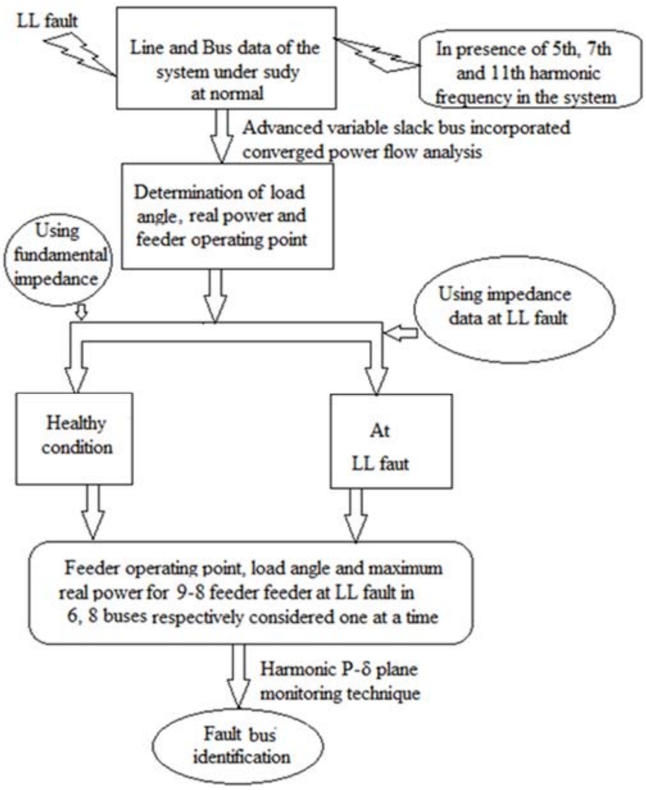


**Fig. 2.** LL fault analysis technique using harmonic P-δ plane.

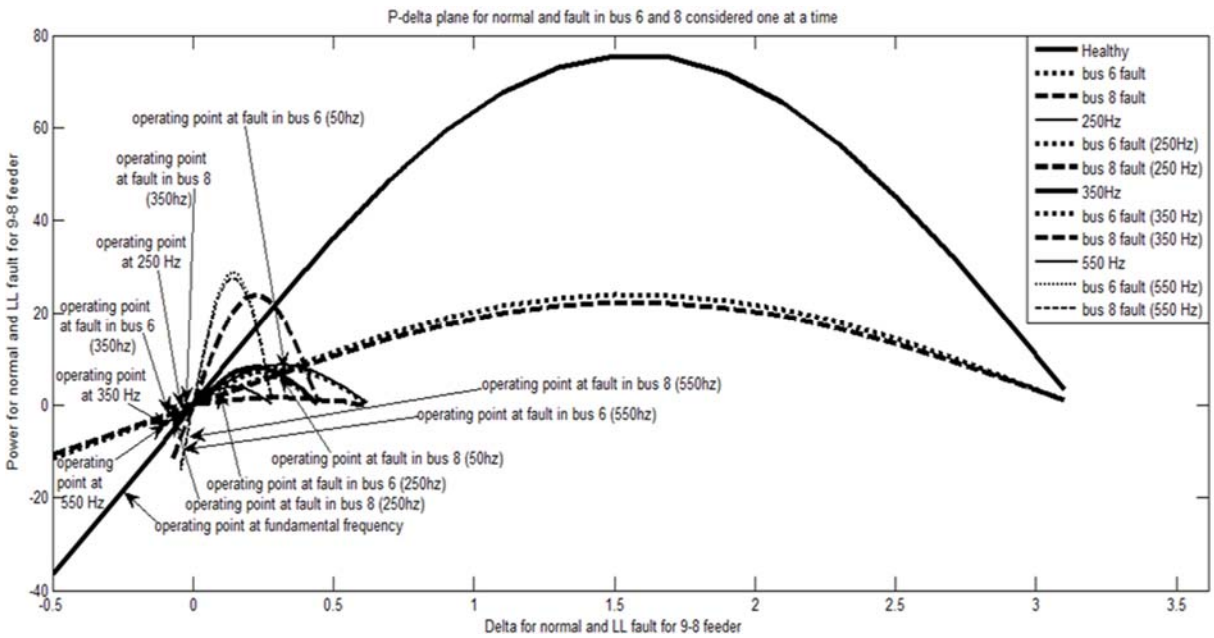


**Fig. 3.** Harmonic P-δ plane for 9-8 feeder at LL fault in Bus 6, 8 considered one at a time in presence of fundamental, $5^{th}$, $7^{th}$ and $11^{th}$ harmonic frequency.

**Table 1.** Study of maximum real power at LL fault in buses 6 and 8.

| F (Hz) | Changes Observed | | |
|---|---|---|---|
| | $P_{max}$ (MW) | | |
| | h | $f_{LL6}$ | $f_{LL8}$ |
| 50 | 75.79 | 24 | 22.26 |
| 250 | 8.8 | 8 | 1.51 |
| 350 | 8.15 | 7 | 23.87 |
| 550 | 3.96 | 28.86 | 27.56 |

**Table 2.** Study of load angle and feeder operating points at LL fault in buses 6 and 8.

| F (Hz) | Changes Observed | | | | | |
|---|---|---|---|---|---|---|
| | P (MW) | | | δ (radian) | | |
| | h | $f_{LL6}$ | $f_{LL8}$ | h | $f_{LL6}$ | $f_{LL8}$ |
| 50 | -18.31 | 6.07 | 5.75 | -0.5 | 0.7 | 0.8 |
| 250 | 0.948 | 4 | -1.84 | 6.18 | 3.19 | -3.19 |
| 350 | -4.89 | -3.41 | -2.42 | -6.18 | -3.1 | -3.18 |
| 550 | -3.5 | -15.12 | -14.3 | -3.26 | -3.11 | -3.2 |

The P-δ curves were plotted from the concept of occurrence of individual harmonic frequencies in a system [10-11]. The deviation of the feeder operating points and the change in direction of load angle of the feeders has been identified for depicting the faulty bus in the system. In this developed P-delta plane, the conventional positive P-delta curve was improvised and negative P-delta characteristics have been introduced, to detect the stable and unstable operating zones of the respective feeder under analysis.

## 3. Exact Fault Bus Identification and Related Stability Assessment

The data obtained from Table 1 - Table 2 and the Fig. 3 has been analyzed to extract some feature for depicting the fault bus in the system. Monitoring the operating points at normal and at fault, operating zone of the feeders were identified and depending on the changes obtained in the load angles at fault from normal rule sets have been developed for exact fault bus identification in the system, which has been presented in Table 3 - Table 4.

## 4. Specific Outcome of the Analysis

This analysis shows how a faulty load bus can be identified in a multi-bus power system, monitoring the feeder operating points and load angle change in normal and fault P-δ planes. Here, advanced variable slack bus incorporated converged power flow analysis has been used for finding the bus voltages, load angles and real powers at normal and at fault. Table 3 - Table 4, clearly shows that, for 9-8 feeder the power flow direction reverses from healthy condition both for fault in bus 6 and bus 8, but if the feeder operating point can be assessed in P-δ plane it can be seen that the deviation of feeder operating point at fault in bus 8 is much more that for fault in bus 6. Depending on the change in sign of load angle of the system a logic has been developed to clearly depict the LL fault bus in the system, which has been depicted in Table 4. In Table 4, 'N' denotes negative and 'P' denotes positive. Thus, code 'NPNN' denotes the system is healthy, 'PPNN' denotes LL fault in bus 6 and 'PNNN' denotes LL fault in bus 8.

**Table 3.** Stability assessment for the system at normal and at LL fault in buses 6, 8.

| Frequency | Location of operating points | | |
|---|---|---|---|
| | At healthy condition | At fault in bus 6 | At fault in bus 8 |
| 50 Hz | Stable motoring zone | Stable generating zone | Stable generating zone |
| 250 Hz | Stable generating zone | Stable generating zone | Stable motoring zone |
| 350 Hz | Stable motoring zone | Stable motoring zone | Stable motoring zone |
| 550 Hz | Stable motoring zone | Stable motoring zone | Stable motoring zone |

**Table 4.** Identification of Exact Fault bus in the system.

| Operating conditions | Changes in δ | | | | Logic |
|---|---|---|---|---|---|
| | 50 Hz | 250 Hz | 350 Hz | 550 Hz | |
| Healthy system | - | + | - | - | [NPNN] |
| LL fault in bus 6 | + | + | - | - | [PPNN] |
| LL fault in bus 8 | + | - | - | - | [PNNN] |

## 5. Conclusions

This paper presents a novel technique for identifying the faulty bus in a multi-bus power system, monitoring the deviation in the feeder operating points and corresponding load angles in normal and fault P-δ planes. Previously some analysis done [1] has been extended in this research and it has also been seen that for line to line fault, occurring in a load bus, the harmonic and fault power magnitudes sometimes becomes larger than fundamental power magnitudes in P-δ planes and there lies a wide range of variation of the feeder operating points in P-δ planes from -90° to +90° for LL fault in different load buses of the system.

Thus this analysis is well suitable for fault bus identification, monitoring the feeder operating points and the direction of power flow in a multi-bus power system in a specific zone of operation of the network.


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