**Mohammad H. MORADI, Younes MOHAMMADI, Mina HOSEYNI TAYYEBI**

Bu Ali Sina University

# A novel method to locate the voltage sag source: a case study in the Brazilian power network (Mato Grosso)

***Abstract**. This article presents a novel method to locate the voltage sag source based on directional overcurrent (DOC) relay information. In this method the source of voltage sag is located by using the variation of magnitude of measured current positive-sequence component during sag and presag conditions and the sign of its phase-angle jump. The performance of the proposed method is compared with distance relay (DR) and phase change in sequence current (PCSC) methods by using PSCAD/EMTDC on a simulated case study. The results show the good and unique performance of the novel method in cases where only currents are recorded.*

***Streszczenie.** W artykule zaprezentowano nową metodę lokalizacji źródła zapadu napięcia bazującej na informacji o kierunkowym przeciążeniu prądowym. Źródło zapadu napięcia jest lokalizowane na podstawie pomiaru amplitudy i fazy prądu w czasie zapadu i przed zapadem. Porównano metodę z z dotychczas stosowanymi metodami DR i PCSC. (**Nowa metoda lokalizacji źródła zapadu napięciowego na przykładzie sieci brazylijskiej**) sieci*

**Keywords:** voltage sag, source location, directional overcurrent (DOC) relay, phase-angle jump.
**Słowa kluczowe:** zapady napięcia, lokalizacja źródła zapadu.

## Introduction

Voltage sag is a decrease to between 0.1 and 0.9 pu in rms voltage at the power frequency for durations of 0.5 cycle to 1 min [1]. This phenomenon reduces power quality (PQ) that affects on sensitive loads. Starting of large induction motors, transformer saturation, capacitor switching and overloads may cause voltage sag, but voltage sags are generally caused by faults. Occurred sags are not confined to the fault location and propagate through the system affecting loads connected far away from the fault location [2]. Locating the source of voltage sag is the first step towards mitigation of PQ problems and its improvement also plays fundamental role to decide about responsibilities and financial penalties in deregulated networks.

Many researches have been done on voltage sags source relative location and various methods have been reported. The first work was presented in [3] in which by investigating the concepts of “disturbance power and energy”, fault location and capacitor switching causing disturbances were determined. In [4], Li et al plotted the coordinates of $(I,|VCos\theta|)$ during sag and found the location of sag source by examining the polarity of the line slop. Later, the method was generalized by the same authors [5]. In this method locations of sag sources are found using the sign of real part of estimated impedance. In [6], the polarity of variation of the real current component is used to classify the sag source as upstream or downstream. In [7], the sag source is found using seen impedance by DR and its angle before and after sag. The method of DR also was used in [8] on an actual network and showing the best performance under symmetrical and asymmetrical faults compared with previous methods. In [9], a method based on the information of the voltage magnitude and phase-angle jump was proposed to classify sag source as internal or external to the end-user grid at the connection point of sensitive customers. In [10] the method based on voltage information only was introduced and in [11] concept of phase change in current positive-sequence component was applied to locate sag source in radial distribution systems (PCSC method).

Although lots of research has been done in this area, there is a need to even better methods with high accuracy and fewer measurement values. The previous methods except [9-11] need both the current and the voltage measurements to locate the source of the sag. However, during several voltage sag surveys, it has been observed that it is common practice to register and save current information only. Therefore, proposed method in this article uses magnitude of positive-sequence current and its phase-angle jump. This method is the only one capable when the voltage measurement is not available, because it uses the current information only (CBM[1]). In this article our results will show that performance of the PCSC method [11], in single source radial transmission networks is not reliable. In proposed method disadvantage of this method will be resolved.

The paper is organized as follows: First, DR and PCSC methods are briefly described and proposed method is presented. Then studied system is introduced and simulation results of the case study are expressed. Finally the discussion and conclusions are given.

## DR and PCSC Methods

In order to compare the results of proposed method with DR and PCSC methods, the rules of these methods are described first:

### a) DR Method

If $|Z_{sag}|<|Z_{presag}|$ and $\angle Z_{sag}>0$ then sag source is in downstream of the PQ monitor, else if $|Z_{sag}|\geq|Z_{presag}|$ or $\angle Z_{sag}<0$ sag source is in upstream [7].

### b) PCSC Method ( $\Delta\phi$ )

If $\Delta\phi>0$ then sag source is in upstream, else if $\Delta\phi<0$ sag source is in downstream [11].

Where $\Delta\phi$ is the angle difference of the after and before sag positive-sequence component of current (positive-sequence current phase-angle jump) are set within $-\pi$ to $\pi$.

## Proposed method (CBM)

This method is based on variation of the magnitude and phase-angle jump of the passing positive sequence current of the DOC relay in the after and before sag condition. For this purpose, the proposed method uses DOC relay information or employing its algorithm for sag source location. For the downstream fault ($F_2$) in the system shown in Fig. 1, according to DOC relay, below calculations can be cone for tripping the circuit, at the PQ monitor:

1- Current Based Method

(1) $|I| > Ipickup$ and $-\pi < \angle I < 0$

where: $Ipickup$ – the relay setting current, $\angle I$ – angle between reference phasor and fault current.

For upstream faults ($F_1$), the current direction will be reversed and the passing current will change in magnitude and angle both. Therefore, the magnitude and angle of the current computed from current phasor has a distinctive feature in identifying the faults in front of or behind the relay/PQ monitor. Considering the measured voltage at the relay/(PQ) monitor as a polarizing quantity and reference phasor, the rule for sag source location becomes: If $|Isag| > |Ipresag|$ and $\angle Isag < 0$ then the sag source is in downstream of the PQ monitor else if $|Isag| \le |Ipresag|$ or $\angle Isag > 0$ the sag source is in upstream. In this rule, $\angle Isag$ is current phasor angle during sag set within $-\pi$ to $\pi$. $Isag$ and $Ipresag$ are positive-sequence current phasor during sag and presag in monitoring point respectively. Now instead of using the $\angle Isag$, PCSC or positive-sequence current phase-angle jump ($\Delta\phi$) [11] is used and our proposed method is formed based on only current information. The rule for sag source location becomes: If $|Isag| > |Ipresag|$ and $\Delta\phi < 0$ then the sag source is in downstream, else if $|Isag| \le |Ipresag|$ or $\Delta\phi > 0$ the sag source is in upstream.

Where $\Delta\phi = \angle Isag - \angle Ipresag$ and is set within $-\pi$ to $\pi$. The current-plane representing the associated above rule logic with $\angle Ipresag = 0$, is in Fig. 2. Area below the real axis and outside of the inner semicircle shows downstream regions and the rest of the area identifies upstream regions.

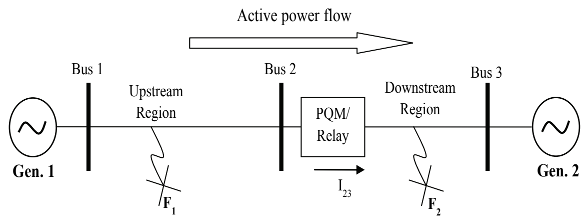


Fig.1. A system having sources at both ends for the voltage sag source location analysis

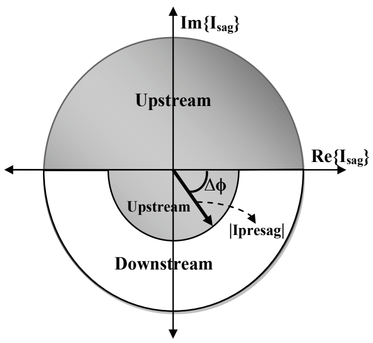


Fig.2. Current-plane representing the associated proposed rule logic with *angle (Ipresag) = 0*

By comparing peoposed method rule with DR method, it is found that peoposed method is based on the DR method somehow. However the proposed method only needs the positive sequence current phasor before and after sag. Thus for the calculations, the current is the only measurement variable needed.

This method is tested and intended to locate sag source at transmission and sub-transmission levels. At this level the influence of loads is not so evident and the effect of constant power loads may not affect the performance of the method.

**The case study: Brazilian power network (Mato Grosso)**

In order to test the performance of the methods to locate the sag source a set of simulations are implemented in the Brazilian network (Mato Grosso). The simulations are realized using the PSCAD/EMTDC program and the output data are processed via MATLAB codes. The faults are located in 3 buses ($F_1$…$F_3$) and also 2 monitoring points are selected ($M_1$, $M_2$), as shown in Fig. 3. Radial parts of the power system have been used to test methods (see Fig. 3) and there are both single source and two source networks. In each fault location 4 different types of faults have been simulated (LLLG, LG, LLG and LL). The $M_1$ monitor has been installed at the border of a single source radial 138 KV sub-transmission network with 230 KV transmission network and the $M_2$ monitor has been installed in border of a two source radial sub-transmission network with transmission network (due to the presence of a DG in downstream region). The 230 kV transmission and the 138 kV sub-transmission grids are operated by two different utilities, therefore it is relevant to locate the source of the sag taking into account the borders between the two utilities. It is necessary to recall that upstream/downstream is related to the active power flow. In the monitored buses $M_1$ and $M_2$ the active power flow is from the 230 kV system to the 138 kV (black arrows in Fig. 3). downstream region is in the direction of the active power flow and upstream is in the opposite direction of it.

**Results**

In this section the simulation results of the CBM method along with DR and PCSC methods (for comparison) are presented. The results are organized in Table 1 (for LLLG faults at $F_1$, $F_2$, and $F_3$) and Tables 2, 3 and 4 (for LG, LLG, LL faults at $F_1$, $F_2$ and $F_3$, respectively). The $F_1$ is located downstream for $M_1$ and upstream for $M_2$. The $F_2$ location is upstream with respect to $M_1$ and downstream to $M_2$ and the location of $F_3$ is upstream for both $M_1$ and $M_2$. Locating the source of voltage sag in the CBM method is based on the magnitude of the positive sequence current and $\Delta\phi$, for PCSC method, it is based on $\Delta\phi$ and for DR method, it is based on the impedance and the its angle.

In Table 1 all the methods work properly (except the PCSC in $M_1$ monitor and for upstream faults at $F_2$ and $F_3$). In Table 2 the CBM method has successfully found the location of the voltage sag source similar to the other two methods.

Table 1. Voltage sag source location for symmetrical faults at $F_1$, $F_2$ and $F_3$

| Faults at $F_1$,$F_2$&$F_3$ | $F_1$ | | $F_2$ | | $F_3$ | |
|---|---|---|---|---|---|---|
| Monitors | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ |
| $\lvert Z_{presag}\rvert (\Omega)$ | 1318 | 436 | 1324 | 435 | 1324 | 436 |
| $\lvert Z_{sag}\rvert (\Omega)$ | 124 | 433 | 1324 | 56 | 1324 | 35 |
| $\angle Z_{sag}$ (deg) | 67 | -17 | -38 | 68 | -38 | -99 |
| *DR Result* | DS | US | US | US | US | US |
| $\lvert I_{presag}\rvert$ (KA) | 0.09 | 0.26 | 0.09 | 0.26 | 0.09 | 0.26 |
| $\lvert I_{sag}\rvert$ (KA) | 0.7 | 0.26 | 0.09 | 0.75 | 0.08 | 0.28 |
| $\Delta\phi$(deg) | -107 | 0.6 | -0.1 | -80 | -0.5 | 64 |
| *PCSC Result* | DS | US | DS! | DS | DS! | US |
| ***CBM Result*** | **DS** | **US** | **US** | **DS** | **US** | **US** |

US: Upstream, DS: Downstream, red color: wrong performance

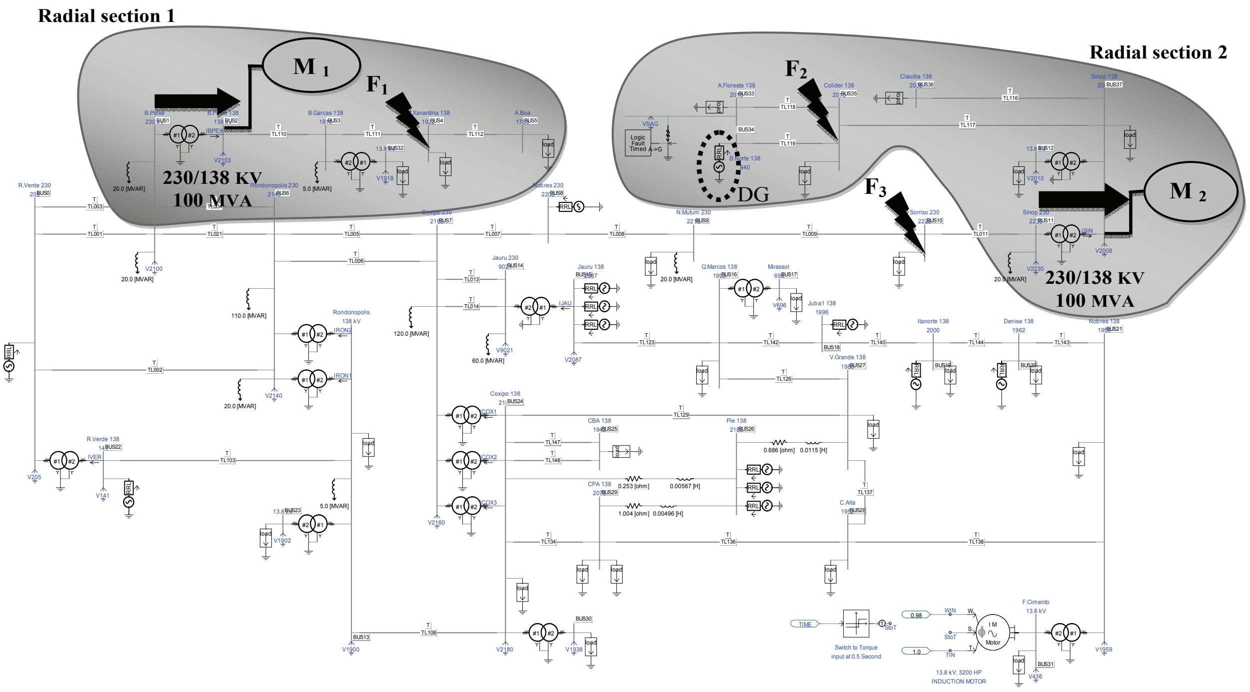


Fig. 3. Brazilian power network One-line diagram, fault locations, monitors and active power flow are indicated

For example, for a LG fault at $F_1$, the magnitude of the positive sequence current has raised from 0.09 KA to 0.13 KA and its phase-angle jump ( $\Delta\phi$ ) is -66 degree (the sign is negative) which indicates a downstream (DS) fault in $M_1$ Monitor for CBM method and also the PCSC method. For DR method, the impedance had changes from 1318 Ω to 844 Ω and its angle is positive which shows a DS fault too.

In Tables 3 and 4, the CBM method and DR method has found the location of the voltage sag source correctly but the PCSC method has not worked properly for locating the upstream (US) faults in $M_1$ monitor which is related to a single source radial system. For example, for a LLG fault at $F_3$ location in $M_1$ monitor, the magnitude of the positive sequence of the current has changed from 0.09 KA to 0.08 KA which shows a US fault for the CBM method but the phase-angle jump is -0.3 degree which indicates a DS fault incorrectly for the PCSC method, for DR method, the impedance has not changed which shows a US fault.

## Discussion

The proposed method (CBM) in this article has following features in comparison with PCSC and DR methods:

1) The CBM method only needs the positive sequence current phasor before and after sag thus for the calculations to locate the voltage sag source the current is the only measurement variable needed but in DR method both voltage and current phasors need to be measured before and after sag.

2) Fewer variables in the CBM method lead to less computational time for data processing and accelerate the voltage sag source location algorithm.

3) Since the CBM method only needs the current measurements, it saves the cost of voltage sensors and it is the only method applicable in places where the voltage is not measured.

4) Using CBM method, the performance of the PCSC method has been enhanced in transmission and sub-transmission levels by adding amplitude of positive sequence current.

Table 2. Voltage sag source location for asymmetrical faults at $F_1$

| Fault at $F_1$ | LG | | LLG | | LL | |
|---|---|---|---|---|---|---|
| Monitors | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ |
| $\lvert Z_{presag}\rvert(\Omega)$ | 1318 | 436 | 1318 | 436 | 1318 | 436 |
| $\lvert Z_{sag}\rvert(\Omega)$ | 844 | 436 | 258 | 434 | 293 | 435 |
| $\angle Z_{sag}$ (deg) | 27 | -17 | 61 | -17 | 61 | -17 |
| DR Results | DS | US | DS | US | DS | US |
| $\lvert I_{presag}\rvert$ (KA) | 0.09 | 0.26 | 0.09 | 0.26 | 0.09 | 0.26 |
| $\lvert I_{sag}\rvert$ (KA) | 0.13 | 0.26 | 0.38 | 0.26 | 0.34 | 0.26 |
| $\Delta\phi$ (deg) | -66.27 | 0.09 | -101 | 0.30 | -100 | 0.29 |
| PCSC Results | DS | US | DS | US | DS | US |
| **CBM Results** | **DS** | **US** | **DS** | **US** | **DS** | **US** |

US: Upstream, DS: Downstream

Table 3. Voltage sag source location for asymmetrical faults at $F_2$

| Fault at $F_2$ | LG | | LLG | | LL | |
|---|---|---|---|---|---|---|
| Monitors | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ |
| $\lvert Z_{presag}\rvert(\Omega)$ | 1324 | 435 | 1324 | 435 | 1324 | 435 |
| $\lvert Z_{sag}\rvert(\Omega)$ | 1324 | 340 | 1324 | 160 | 1324 | 186 |
| $\angle Z_{sag}$ (deg) | -38 | 9.53 | -38 | 48 | -38 | 47 |
| DR Results | US | DS | US | DS | US | DS |
| $\lvert I_{presag}\rvert$ (KA) | 0.09 | 0.26 | 0.09 | 0.26 | 0.09 | 0.26 |
| $\lvert I_{sag}\rvert$ (KA) | 0.09 | 0.29 | 0.09 | 0.46 | 0.09 | 0.42 |
| $\Delta\phi$ (deg) | -0.04 | -27.5 | -0.07 | -65 | -0.05 | -63 |
| PCSC Results | DS! | DS | DS! | DS | DS! | DS |
| **CBM Results** | **US** | **DS** | **US** | **DS** | **US** | **DS** |

US: Upstream, DS: Downstream, red color: wrong performance

## Conclusions

This article proposes a novel voltage sag source location method based on directional overcurrent (DOC) relay information and current measurement only; it has been done by analyzing the variation of magnitude of current positive-sequence component and also the sign of its phase-angle jump during sag and presag conditions. The results of the simulated case study (Brazilian power network) have been presented and show that the CBM method similar to DR method in all of cases locates the voltage sag source correctly for both single source and two source networks and also symmetrical and asymmetrical faults but the CBM method uses current information only instead of both voltage and current in DR method. In contrast PCSC method acts incorrectly in cases for single source radial transmission networks and for upstream faults. The proposed method can effectively locate the source of voltage sags in large scale actual power networks such as Brazilian power network with great accuracy, less computational burden and time and since it does not use voltage measurements it is also more economical.

Table 4. Voltage sag source location for asymmetrical faults at $F_3$

| Fault at $F_3$ | LG | | LLG | | LL | |
|---|---|---|---|---|---|---|
| Monitors | $M_1$ | $M_2$ | $M_1$ | $M_2$ | $M_1$ | $M_2$ |
| $\lvert Z_{presag} \rvert (\Omega)$ | 1324 | 436 | 1324 | 436 | 1324 | 436 |
| $\lvert Z_{sag} \rvert (\Omega)$ | 1324 | 398 | 1324 | 235 | 1324 | 268 |
| $\angle Z_{sag}$ (deg) | -38 | -31 | -38 | -59 | -38 | -51 |
| DR Results | US | US | US | US | US | US |
| $\lvert I_{presag} \rvert$ (KA) | 0.09 | 0.26 | 0.09 | 0.26 | 0.09 | 0.26 |
| $\lvert I_{sag} \rvert$ (KA) | 0.09 | 0.23 | 0.08 | 0.23 | 0.08 | 0.23 |
| $\Delta\phi$(deg) | -0.13 | 12.73 | -0.30 | 39.33 | -0.24 | 33.67 |
| PCSC Results | DS! | US | DS! | US | DS! | US |
| **CBM Results** | **US** | **US** | **US** | **US** | **US** | **US** |

US: Upstream, DS: Downstream, red color: wrong performance

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***Authors**: Mohammad H. Moradi, Department of Electrical Engineering, Bu Ali Sina University, Hamedan, Iran, E-mail: Mh_moradi@yahoo.co.uk; Younes Mohammadi, Department of Electrical Engineering, Bu Ali Sina University, Hamedan, Iran, E-mail: Mohammadi.yunes@gmail.com; Mina Hoseyni Tayyebi, Department of Civil Engineering, Bu Ali Sina University, Hamedan, Iran, E-mail: Mina.h.tayyebi@gmail.com.*

The correspondence address is: *Department of Electrical Engineering, Bu Ali Sina University, Hamedan, Iran*

e-mail: *Mh_moradi@yahoo.co.uk*