

# Fault Location and Isolation Using Multi Agent Systems in Power Distribution Systems with Distributed Generation Sources

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**Abstract**—This paper presents a Multi Agent System (MAS) design with distributed intelligence for fault location and isolation in power distribution systems with the presence of Distributed Generation Sources (DGS). In the proposed MAS, agents all over the feeder communicate with their neighbors and use the local differential current information to locate the faulty zone and isolate the fault. Agents update their local knowledge by exchanging their voltage and current phasor data with their neighbors and monitoring the local current. The distributed generation penetration is considered to be up to 50 percent. The multi-agent models are simulated in Matlab® Simulink using user defined s-functions and the power system is modeled using the Simulink Simpower toolbox. The proposed method has been tested on a model of an existing Mon Power company circuit. Both faulted zone and fault type have been successfully identified.

**Index Terms**—Distributed generation, multi agent system, voltage and current phasors, Power distribution system, fault location and isolation.

## I. INTRODUCTION

Traditional Power Distribution Systems (PDS) are almost radial networks with single source of power. In the recent years, with the changes in regulatory markets of the generation, transmission and distribution, interest in using new generation technologies like Distributed Generation Sources (DGS) has increased. Using DGS will affect the operation of PDS and new technical issues will be created. High penetration of DG's changes the traditional passive networks with single direction of power flow to an active network where the power flows in various directions. These changes make the PDS more complicated and more exposed to faults which affect the system's reliability, security, and delivered energy quality. Power utility companies are often faced with the challenge of providing the right level of power quality service to meet the customers need for reliable and high quality power. Reliability of PDS is directly related to the time that utility companies spend on locating and isolating the fault. Fault locating with the minimum time delay can help a fast reconfiguration and restoration for PDS in case of fault

occurrence. Therefore fast and accurate fault locating is valuable asset for utility companies to increase their reliability [1].

Considering the existence of multiple laterals and sub laterals tapped of the main feeder in different locations of PDS, time varying unbalanced load profiles, power injection at different location of system by distributed generation, fault locating in PDS is a challenging task.

Several fault location methods have been proposed for PDS. Previous works could be categorized in three main categories; 1) Impedance based methods; these methods usually calculate the apparent impedance sequences using measurement points data and estimate the possible fault locations based on iterative algorithms [2]-[3]. Considering the multiple fault locations estimation in these methods and existence of many laterals in PDS is the drawback of impedance based methods. 2) Wavelet based methods, in which discrete Fourier transform or wavelet transform are used to analyze the fault waveform. It's difficult to guarantee the reliability of these methods because of variety of load characteristics and fault cause in PDS [4]-[5]. 3) Intelligent methods consist of artificial neural networks (ANN) [6], Expert systems, and multi agent systems (MAS) [7]-[9] and etc., ANN based methods need to be trained after any change in system and update the network weights, the other drawback with ANN based methods is that in case of complicated networks they became slow and may fall in local optimum. Expert system methods have a slow response time since they involve knowledge base maintenance and conventional inference mechanism.

Recently MAS based approaches became more popular for decentralized management of power systems and are applied to different areas like fault diagnosis, voltage stability, electricity market pricing, protection coordination, power system reconfiguration and restoration. An agent is defined as "an autonomous computational entity such as a software program that can be viewed as perceiving its environment through sensors and acting upon this environment through its effectors" [10]. A multi-agent system is a group of agents,

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which sense the environment and acts in order to achieve its objectives.

Most approaches for fault location in the literature consist of a master agent which makes the final decision based on the data received from other agents which cannot be considered as a distributed control since the master agent is behaving like a control center [11]. In some other works [12] each agent is considered to have its special functionalities e.g. acquiring data, analyzing data, managing situations, etc. In other words each step of decision making is done by a special agent. In [13] agents have hierarchical levels and higher level agents coordinate a group of lower level agents. In this work we're using a distributed architecture for our MAS in which agents have access to the voltage and current Phasor data of themselves and their neighbors to a defined neighborhood and use these data to locate the fault. Each agent calculates and monitors its upstream and downstream areas power usage and in case of fault can detect whether the fault is in neighborhood or not. Therefore each agent has a decision making capability.

The West Virginia Super Circuit (WVSC) project is part of the Modern Grid Initiative aiming at demonstrating and testing new technologies to enable the deployment and the implementation of Smart Grids. This work is part of the WVSC project which consists of designing MAS for fault detection and isolation applications.

This paper is organized as follows. Section II presents the West Virginia Super circuit (WVSC) and the problem statement. Section III introduces multi agent system structure and details of proposed fault location isolation algorithm. Section IV describes the simulation models. Section V presents simulation results. Finally, section VI concludes the paper and points out future research directions.

## II. WEST VIRGINIA SUPER CIRCUIT AND PROBLEM STATEMENT

The distribution systems are easily exposed to faults, most of which are temporary faults. Fault location and isolation plays an important role in power systems security and reliability. Traditional approaches are mostly centralized and all the information is sent to a data center to be processed and actions are taken. At the same time, sending such a large amount of data demands high communication capabilities. On the contrary, Multi-Agent System (MAS) can realize distributed control through cooperation between agents with less required communication capacity. Focus of this paper is on application of advanced technologies like MAS in fault detection and isolation processes.

The West Virginia Super-Circuit (WVSC) project will demonstrate improved performance, reliability, and security of electric supply through the integration of distributed resources and advanced technologies such as the Multi Agent System [13]. The West Virginia super-Circuit is divided into different zones connected through controllable switches as shown in Fig.1.

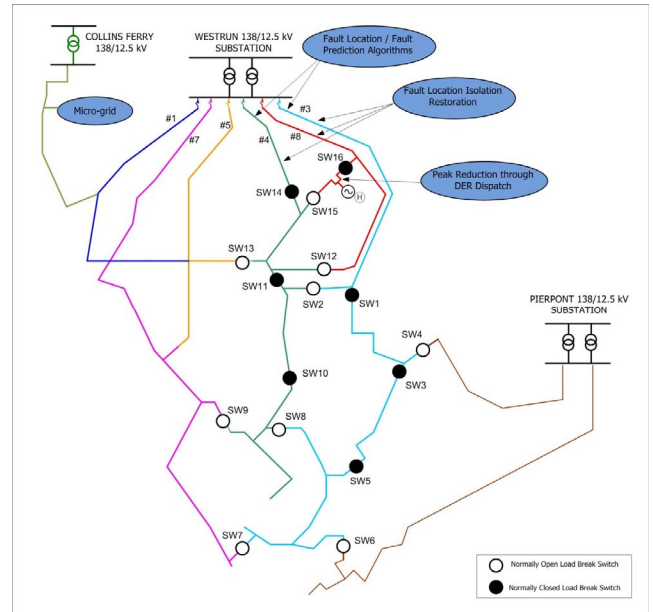


Figure 1. West Virginia Super Circuit

The West Run Substation has five feeders, two of which (WR-3 and WR-4) are monitored for faults. Once a fault is detected, MAS will locate and isolate the faulted zone and restore power to the unaffected zones. In this work, the fault location and isolation part of the project are investigated. Fault location isolation algorithm is applied to the two feeders (WR-3 and WR-4) of WVSC.

Fig.2 shows the Zones for the WR-3 and WR-4 feeders of WVSC. WR-3 zones are with blue color and WR-4 with green.

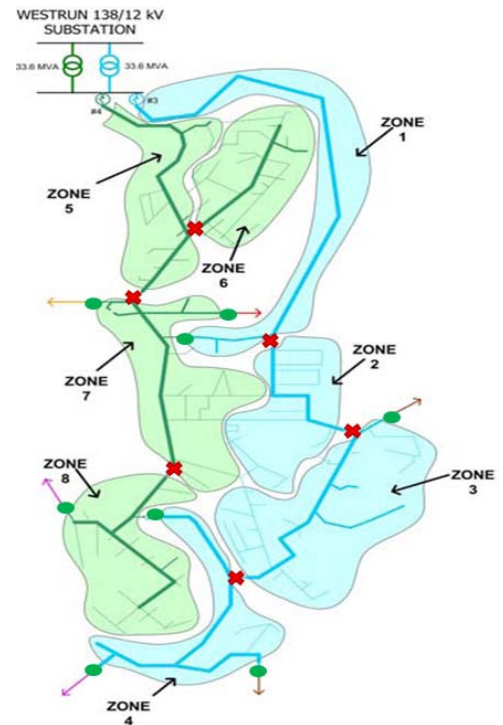


Figure 2. Zones for WR-3 and WR-4 Feeders

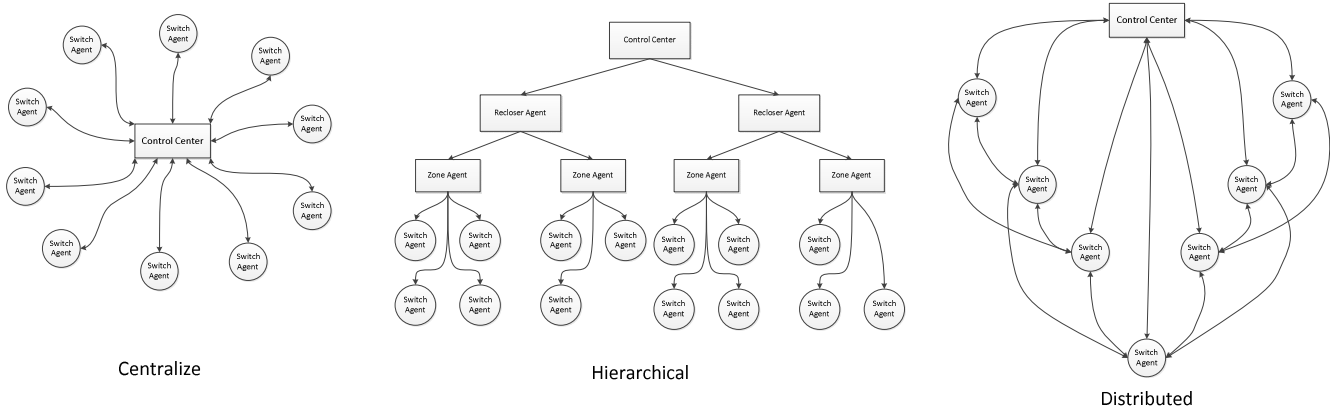


Figure 3. Multi agent system Architectures

West Run substation feeders are equipped with reclosers. When there is a fault in the system, the recloser will go through its trip and close operations as configured. Fault location and isolation system will start its fault location, isolation processes following a recloser lock-out signal sent to MAS. Fault location isolation system will not take any action when recloser trips on a temporary fault and remains closed after a close operation.

Time Current Characteristic (TCC) information at two current levels for WR-3 and WR-4 reclosers is given in Table 1. These reclosers are programmed to operate three times before locking out. The first reclosing operates on A-curve and the following two reclosings operate on D-curve. The approximate clearing times for A-curve and D-curve are also listed. The reclosers wait for 60 cycles between the each reclosing operation.

TABLE I. RECLOSER SETTINGS FOR WR-3 AND WR-4

TCC	A curve		D curve	
Current	2000A	6000A	2000A	6000A
Clearing Time	5 cycles	3 cycles	43 cycles	8 cycles

### III. MULTI AGENT SYSTEM ARCHITECTURE

The architecture of an agent is shown in figure 3. The body of each agent is composed of the sensors, communication interfaces, and processing engines. There is a block responsible for communicating with the other agents as shown in Fig.4.

In general there are three kinds of control strategies in controlling agents in MAS, centralized, hierarchical and distributed. Fig.3 shows this architectures and agents connections. Centralized approaches are mostly conventional and tend to be inadequate for future power systems.

Hierarchical structures are also similar to centralize ones and cannot be considered as a distributed control approach. In the distributed architecture which is used in this paper all agents just communicate with their neighbors and have decision making capability.

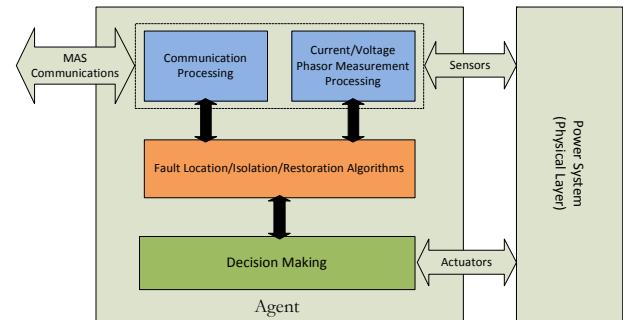


Figure 4. Single Agent Architecture

In this work MAS and power system model are working in real time. It means that MAS and Power system model communicate in real time and the data is accessible to agents without any delay in simulation time. Since most previous works [8] use two different softwares for modeling MAS (JADE, EPOCHS...) and power system (OpenDss, EPDS, ...), there are some problems with interfacing the two softwares. In this work both MAS and power distribution system are simulated in MATLAB and there is no need for interfacing the two softwares.

Figure 5 shows the fault location, isolation algorithm flowchart. In normal operation, agents update their load profile data and also update their neighbor's data. Agent's pull out the meters recorded data during the last recloser trial with highest resolution and compare the data with recent normal operation data.

Each agent has access to its neighbor agent's data and can calculate the current injected to area between itself and

upstream or downstream agents by using the Kirchoff's law, i.e.

$$\sum_{i=1}^n I_{Entrance_i} - \sum_{j=1}^m I_{Exit_j} = I_{Zone}$$

Where,

$I_{Entrance_i}$  is the  $i$ th current entering the zone,  $I_{Exit_j}$  is the  $j$ th exiting current and  $I_{Zone}$  is the zone current. Fig.6 shows the sketch of the message exchange between two agents.

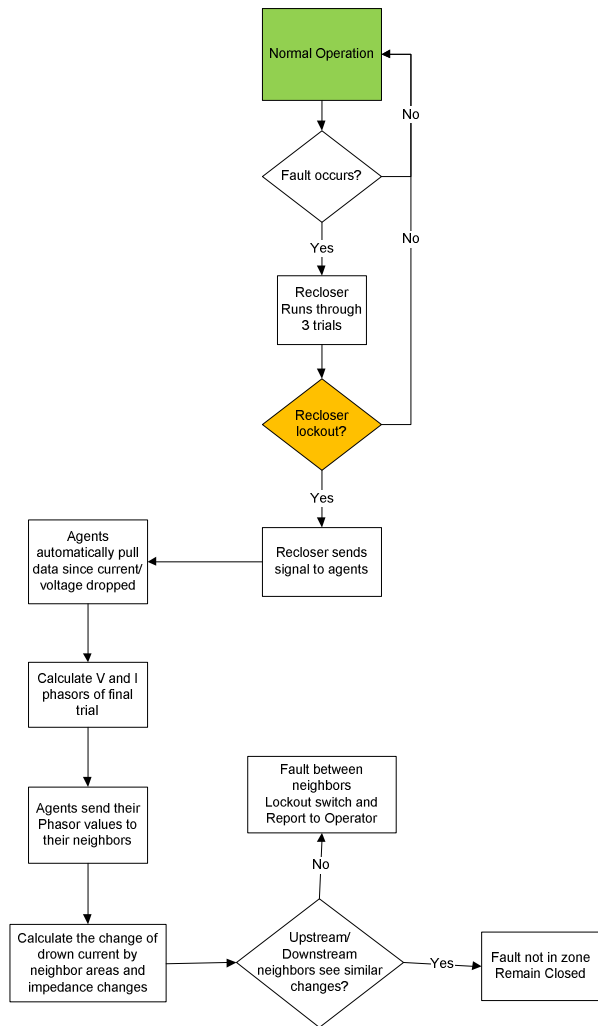


Figure 5. Fault location, isolation algorithm flowchart

In an engineering context, “inform” and “request” could relate the agent's data transferring where the message contents contain the information (Fig.6). After “inform” and sending each data packet, agents wait for acknowledgement. The data should be resend if the acknowledgment is not received. Because agents need the synchronized data of their neighbors for decision making process.

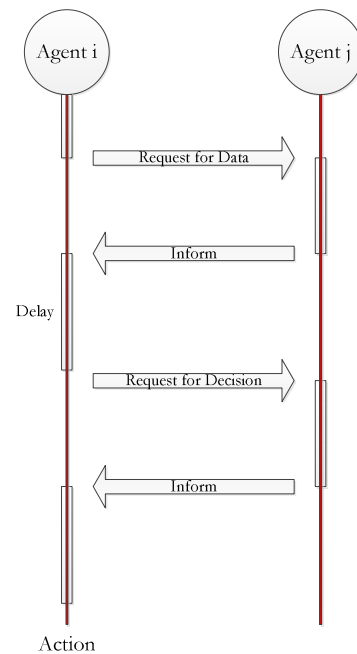


Figure 6. Message exchange sketch

#### IV. SIMULATION MODELS

The simulation model has two parts. The first part is for simulating power system distribution network which is the WSC by MATLAB Simpower Toolbox. The second part is the multi agent system which is implemented in Simulink by using user defined S-functions. In the following both parts are discussed in detail.

##### A. Power System Model

Two feeders of West Virginia Super Circuit (WR-3 and WR-4) which are shown in Fig.2 are modeled in MATLAB using Simpower Toolbox. There are 16 switches and 2 reclosers installed in these two feeders to enable the system. Switches are Cooper DAS-15 type three-phase vacuum switches with 15kV, 630 A ratings. 7 switches are normally closed and the other 9 switches will be used for reconfiguration and restoration applications. Fig. 7 shows the Simulink model for WR-3 and WR-4 feeders. Transformers in each feeder are 138/12.5 KV and 33.6 MVA. Simulation results are calculated based on per unit values. The base MVA, voltage values are 6 MVA, 8.5 Kv.

A block is designed to generate reclosers operation. Whenever recloser senses overcurrent, it locks out after three operations according to the time periods mentioned in Table.1, if the fault is not cleared.

Lines are modeled based on the positive, negative and zero sequence impedance values. Different types of faults such as single line to ground, line to line, and three phase faults are modeled with a fault block in Simpower Toolbox and ground resistance is considered to be 0.1ohm. Feeder loads are modeled with active and reactive power. DGS are also modeled as a three phase source in series with R-L branch.

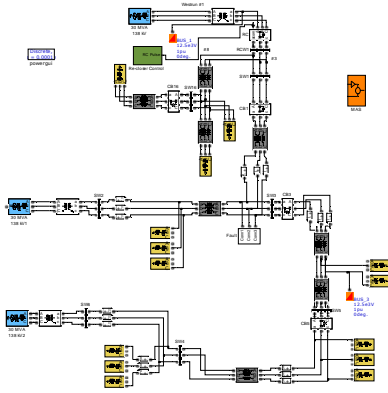


Figure 7. Power distribution system Simulink model

The power system model could simulate in discrete, continuous or phasor modes. Since continuous model is more accurate the power system is modeled using the continuous mode.

### B. Multi agent system Model

The multi agent system is implemented using the S-function blocks of MATLAB Simulink. Each agent is modeled by an S-function. S-functions (system-functions) provide a powerful mechanism for extending the capabilities of the Simulink® environment. An *S-function* is a computer language description of a Simulink block written in MATLAB®. S-functions use a special calling syntax called the S-function API that enables you to interact with the Simulink engine. They follow a general form and can accommodate continuous, discrete, and hybrid systems [14]. Fig.8 shows the MAS model.

Since the MAS is mainly including agents communication, and communications are intrinsically discrete in time, MAS works in discrete mode and it also provide the base to model communication delays and latency.

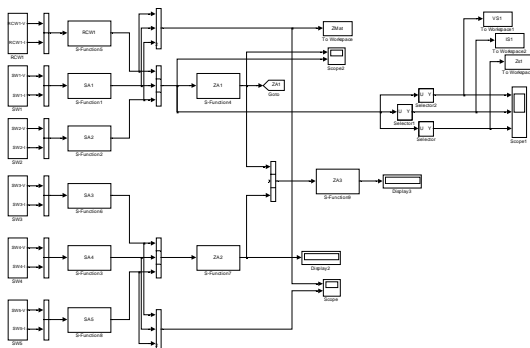


Figure 8. Multi agent system model in MATLAB Simulink

Since the measured data resolution is 16 samples per cycle, the agents can access to power system model simulation data with 16 samples per cycle resolution, the MAS discrete step simulation time should be 0.001 second. The switch agents have access to voltage and current measurement data and they calculate the indices value using the voltage and current Phasor data. The data packets that switch agents send to their

corresponding neighbors have 13 elements. These elements are time tagged voltage, current Phasor of three phases.

$$(V_{abc}, I_{abc}, \psi_{Vabc}, \psi_{Iabc}, t)$$

## V. SIMULATION RESULTS

In order to investigate the effect of DG sources on the fault location and isolation application, different penetration level of DG sources from 0 to more than 50 percent are simulated. Fig.9 shows the calculated I zone for zones 1, 2 and 3 while a single line to ground fault is located in zone 2 and without the DG penetration. Fig.10 shows the results for the same scenario but with the 50% DG penetration. In this scenario DGS are located in zone 2 and 4. The red line shows the faulty phase.

The I-zone index just increased in the faulty zone and in the other zones the index is decreased in both cases with or without DG generation.

Fig.11 shows the I-zone index for DG penetration of 50% with a line to line fault in zone 2. I-zone index increased in both zone 1 and 2, but change percentage in zone 2 is a lot bigger than the zone 1. Table II show the results for more scenarios.

TABLE II. I ZONE CHANGE FOR DIFFERENT SCENARIOS

Scenario		I- zone 1 Change Percentage	I- zone 2 Change Percentage	I- zone 3 Change Percentage
1	DG Penetration =0%	90%	-65%	-65%
	Single line to ground Fault at Zone 1			
2	DG Penetration =50%	60%	-35%	-40%
	Single line to ground Fault at Zone 1			
3	DG Penetration =0%	-50%	-65%	150%
	Single line to ground Fault at Zone 3			
4	DG Penetration =50%	-15%	-50%	120%
	Single line to ground Fault at Zone3			
5	DG Penetration =50%	200%	-100%	600%
	line to line Fault at Zone3			
6	DG Penetration =50%	400%	1400%	-100%
	Three phase to ground Fault at Zone2			



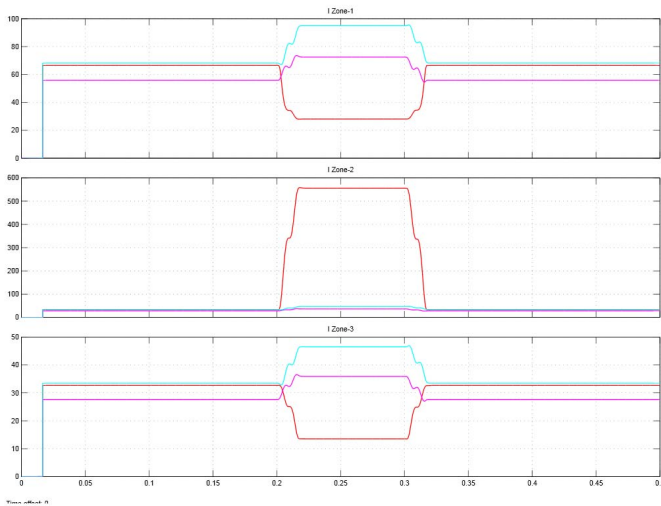


Figure 9. Calculated index for DG penetration of 0%

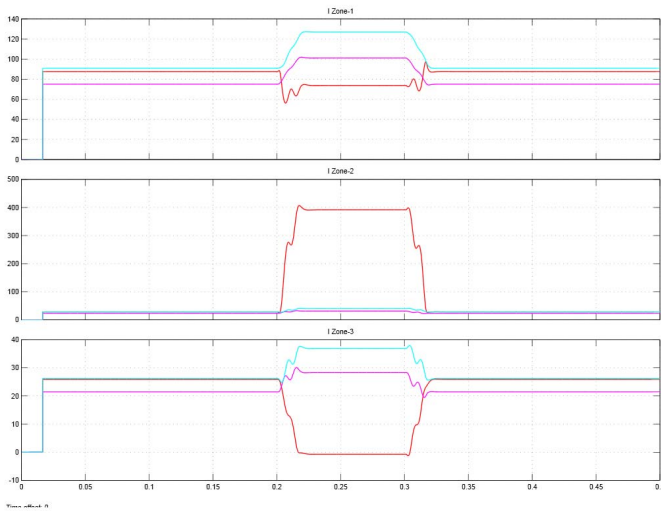


Figure 10. Calculated index for DG penetration of 50 %

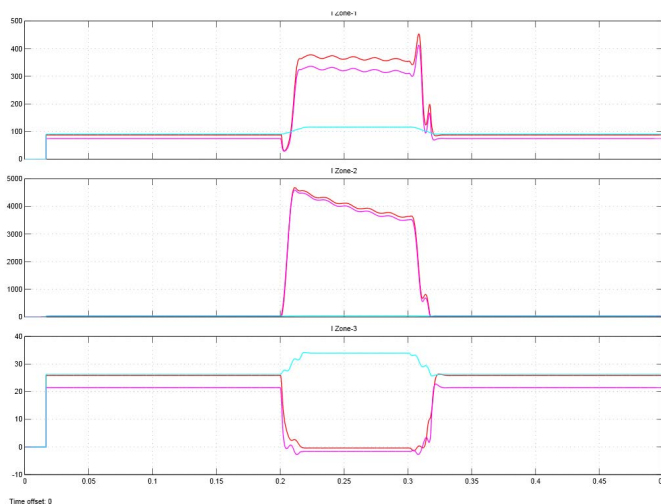


Figure 11. Calculated index for DG penetration of 50 %

## VI. CONCLUSION

This paper presents a decentralized multi agent system (MAS) which works in real time with a power distribution system for fault detection applications. The agents use local voltage and current Phasor values to calculate an index which is used for fault location and isolation. Both MAS and power system models are implemented in MATLAB Simulink, and therefore, there is no need for an interface between the two models. This advantage provides a simpler and more accurate simulation model for investigating MAS applications in power systems.

The proposed approach is tested on an existing Mon Power circuit with DG penetration up to 50% and the results confirmed the accuracy of the algorithm. Both faulted zone and fault type have been successfully identified.

In future works this simulation model will be used to support our research in using multi-agents for restoration and reconfiguration processes after fault location and isolation.

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