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A New Adaptive Wide Area Protection Algorithm for Distribution Networks with Distributed Generation

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ABSTRACT

This paper presents a new adaptive wide area protection (WAP) system consisting of a communication based algorithm that can detect the fault on any of the buses or feeders connecting the buses. This scheme utilizes an adaptive topology based on discrete wavelet transform (DWT) for all currents passing through the interconnected system. The algorithm utilizes the spectral energy of detail 3 coefficients in order to locate the fault and hence issue a trip decision for the faulted part. The system under study is a 9 bus interconnected distribution power system with two integrated distributed generators (DGs) that are wind farms located at two different buses in the system. The proposed protection scheme is used to avoid the impacts of integrating DGs into distribution power systems on the traditional protection schemes used for interconnected systems. The wind farms are accurately simulated using PSCAD software in which all the interconnected system is simulated. The proposed protection algorithm is modelled using MATLAB.

Keywords:
Wide Area Protection (WAP), Discrete Wavelet Transform (DWT), Distributed Generation (DG), Wind Farm, Adaptive Protection, Interconnected System, PSCAD, MATLAB

1. Introduction

Recently, for economic and environmental reasons, the international trend is to use renewable energy resources for electrical power generation leading to installation of Distributed Generation (DG) [1]. DG means a decentralized small power plant utilizes renewable energy resources, supplying into the distribution system of the electrical power grid [2]. But unfortunately, DGs integration into distribution systems may violate traditional protection systems which mainly consist of decentralized coordinated over-current protective devices to protect power systems from excessive currents caused by short circuit faults. DGs integration have some impacts on traditional protection systems such as loss of coordination and loss of sensitivity as consequences of its effect on characteristics and values of short circuit power and fault current levels [3]. Hence, a new protection scheme must be proposed to accommodate new fault currents.

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With sophisticated communication technologies, new protection schemes using comprehensive information are impelled and known as wide area protection (WAP). WAP is developed to analyze wide area information (WAI) gathered from local locations in the power system and sent to a central/master unit to oppose disturbances in the power systems by taking appropriate remedial actions centrally [4]. Every WAP system is unique as its design differs from utility to another depending on required functionalities and available technologies [5].

There are two different approaches to realize WAP. One approach is based on online adaptive settings (OAS), another based on fault element identification (FEI). Based on wide area communication system, OAS approach means that protection system is able to adjust its operating settings in response to power system changes. On the other hand, for FEI approach, by using WAMS information, the fault element can be determined [6-7].

WAP has different architectures and the main ones are enhancements to SCADA/EMS, flat architecture and multilayered architecture. First of all, for SCADA/EMS enhancement, system dynamic information may be gathered using phasor measurement units (PMUs). Secondly, flat architecture employs modern protective devices which have computing and communications capabilities. So, by interconnecting together, smart algorithms can be designed. Lastly, for multilayered architecture, it consists of three layers including PMUs, local protection centers (LPCs) to interconnect with PMUs and system protection center (SPC) which is the coordinator of LPCs [8].

In this work, the proposed WAP scheme compromises OAS and FEI approaches with flat architecture and employs Discrete Wavelet Transform (DWT) [9] for analyzing all currents passing through the distribution system. Thus, it's evident that that scheme needs a communication media with a reasonable propagation speed to transfer data between protective devices and a central unit which typically placed at the substation. Nowadays, there are many available communication technologies such as fiber optics, digital radio, microwaves and metallic media. Optical fiber media is frequently selected to be used for its reasonable communication speed, availability and low purchase and installation costs [10].

2. Simulated Distribution System Model

The simulated system in this paper is mainly based on the configuration of distribution level portions of IEEE 30 bus system [11] with some modifications. The simulated system is an interconnected system and its voltage level is 20kV at a frequency of 50Hz with 1.5GVA short circuit level at utility bus. The system consists of one utility, 9 buses, 9 feeders and two identical 6 MVA wind farms integrated at buses 3 and 8 separately. Buses refer to possible loading points and feeders consist of partly underground cables and partly overhead transmission lines with different lengths up to 5km. Each feeder is equipped by two protective relays (R), one relay at each end. The system single line diagram is as represented in Figure 1 and it is simulated using PSCAD version 4.2.1 [12].

In this work, wind farms utilize permanent magnet (PM) synchronous generators to convert the output energy produced by the wind turbines to beneficial electrical energy. PM synchronous generators are modeled by using excitation voltage equals 1pu for synchronous machine model provided in PSCAD library. Then, the PM synchronous generator output is passed through a converter stage AC-DC-AC to be fed into the grid (where constant voltage and frequency must be maintained). Consequently, there are two vital conditions to be considered at the connection points between wind farms and the distribution system to avoid loss of system stability. The first is that voltage at connection points must be regulated to be 1pu (20kV). So, a PWM drive is used in order to regulate that voltage. The other is that a phase locked loop (PLL) must be used to obtain the inverter frequency locked on the grid frequency [13].

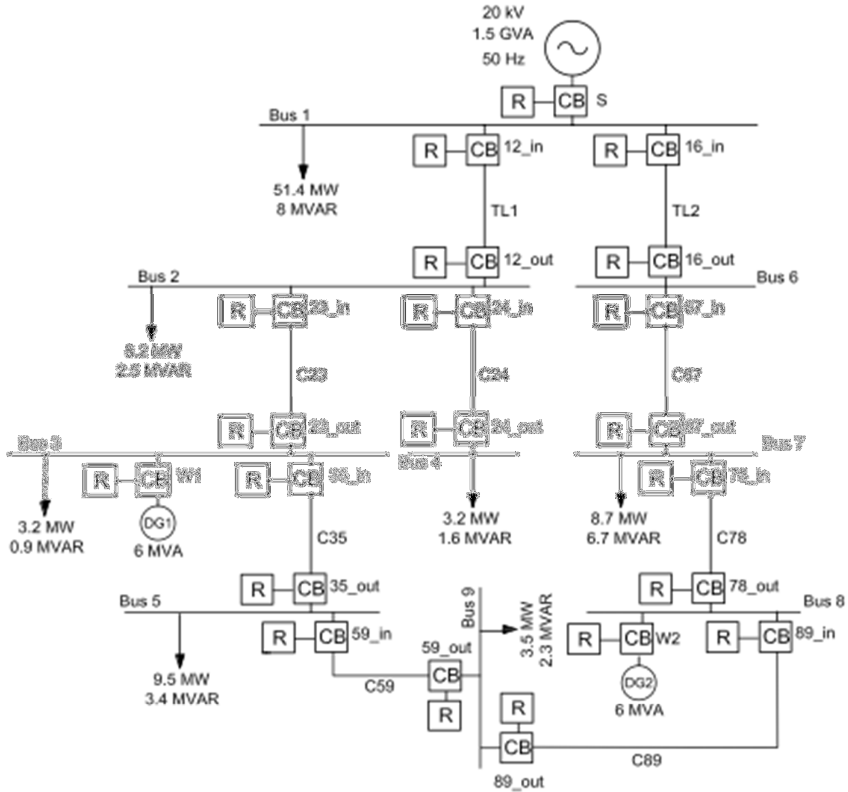


Fig. 1. SLD of the distribution system with integrated wind farms

3. Proposed Adaptive Wide Ares Protection Scheme

Virtual manufacturing and modelling have contributed hugely to manufacturing industries in various perspectives. This gives us a knowledge on how virtual manufacture could be utilized to cross over any barrier between different offices engaged in the production of products, therefore sparing important time and saving cost. Also, modelling and virtual manufacture assumed an essential part in production planning and prototyping process, though constructing it physically devours additional time and is likewise costly. Virtual manufacturing when combined with simulation tools can reduce design and production cost, as well ensure product quality, and reduce the time required to go from product concept to product realization, while being highly responsive to continually changing and competitive market and world condition.

Due to the drawbacks of traditional protection systems in attendance of DGs, novel protection schemes based on WAP approaches and architectures are being proposed. In this paper, the proposed WAP scheme compromises OAS and FEI approaches and employs flat architecture. That scheme is able to adapt relay settings according to different fault types. It is vital to be noticed that these systems make decisions and take actions in different times depending on employed communication media and how many data transportation processes would be taken for collecting data to make a proper decision.

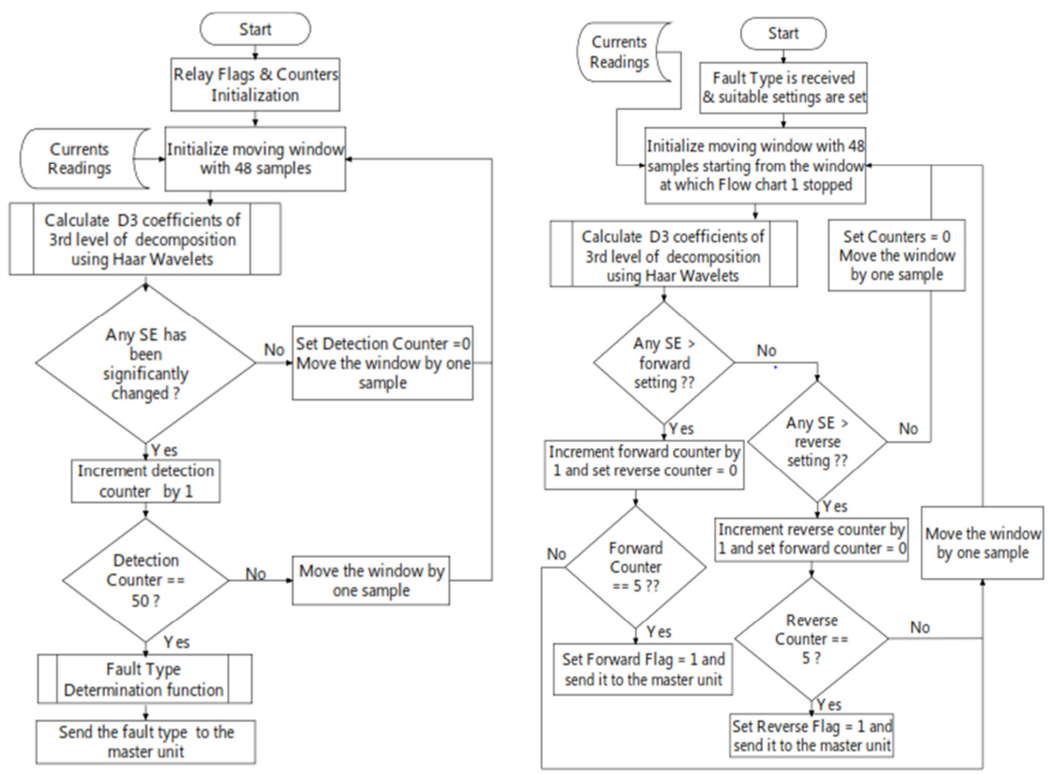
Firstly, all currents passing through the distribution system are measured and readings are recorded each 200 micro-seconds (Sampling Frequency = 5 kHz). Then, by using relays' built-in algorithms, readings are analyzed using DWT at level three of decomposition using Haar wavelet and a moving window with 48 samples. It must be noted that level three of decomposition is chosen to avoid any disturbances on the protection system performance due to the highest frequencies transients. Thereafter, using decomposition results, a quantity is calculated by the norm of detail 3 coefficients (cD_3) of each phase current as given in (1) and it is known as 'Spectral Energy (SE)' [14]

$$(SE_{cD_3})_{Phase} = \left[\sum_{j=1}^{6} |cD_3\,(j)_{Phase}|^2 \right]^{1/2} \quad (1)$$

where phase may be phase a, b or c. Each relay checks spectral energies of its relevant currents if any has been significantly changed as described in (2)

$$[SE_{cD_3}(k)]_{Phase} - [SE_{cD_3}(k-100)]_{Phase} \geq 1 \quad (2)$$

where k is the number of the current analysis window and (k-100) is the number of the analysis window one cycle earlier. The relay, which detects this change, enables a function within its algorithm to determine the fault type as illustrated in the flow chart shown in Figure 2-a.



(a) **(b)**

Fig. 2. Proposed Scheme Flow charts. **a-** Flow chart of each relay subprogram to detect that a fault has been occurred and to determine its type **b-** Flow chart of each relay subprogram to set detection flags

Using fiber optics communication medium, the relay transfers the fault type to the master unit which spreads the fault type among other relays to be able to set adequate forward and reverse settings to assure that protective relays will operate for fault currents flow from both directions. It is very important to note that a numerous number of simulations have been performed at all buses and feeders for all fault types to calculate appropriate settings for each relay. Finally, as described in (3) and (4), each relay checks if any of its relevant phase currents' spectral energies exceeds either its forward or reverse setting to set either forward or reverse, respectively, detection flag to 1.

$$(SE_{cD_3})_{Phase} \geq \text{Relay Forward Setting} \tag{3}$$

$$(SE_{cD_3})_{Phase} \geq \text{Relay Reverse Setting} \tag{4}$$

Detection flags set to 1 are sent to the master unit as illustrated in the flow chart shown in Figure 2-b.

According to detection flags, the master unit makes its decision by checking different combinations of flags set to 1 to determine the faulty element and order appropriate relays to respond to isolate it. From explained earlier, it's obvious that several communication processes between the master unit and relays will happen before making a tripping decision. So, a suitable time delay must be taken into account to predict the tripping time accurately. For fiber optics, medium propagation time is around 48.9 micro-seconds for path length equals to 10 km and around 97.8 micro-seconds for path length equals to 20 km [10].

4. Results and Discussion

The distribution power system model as illustrated earlier is simulated on PSCAD and current readings are recorded. And the protection algorithm is modeled using MATLAB software as M-files [15]. The proposed scheme has been verified and some case studies are listed in Table 1.

Table 1
Different case studies for testing the proposed protection scheme

	Fault Type	Location	Fault Inception Time (seconds)	Tripping Time (seconds)	Relays to trip
1	Three phase to ground	At feeder 12 (2km away from its upstream ends)	3	3.016	12_in and 12_out
2	Phase A to ground	At bus 2	4.25	4.268	12_out, 23_in and 24_in
3	Phase B to ground	At feeder 23 (0.5km away from its upstream ends)	5	5.017	23_in and 23_out
4	Phase C to ground	At bus 3	5.75	5.7662	23_out and 35_in
5	Phase A to Phase B	At feeder 35 (in the middle)	6.25	6.2666	35_in and 35_out
6	Phase B to Phase C	At bus 5	7	7.0164	35_out and 59_in
7	Phase C to Phase A	At feeder 59 (in the middle)	7.75	7.7692	59_in and 59_out
8	Phase C to Phase A	At bus 9	4	4.0208	89_out and 59_out
9	Three phase to ground	At feeder 89 (in the middle)	2.5	2.5158	89_in and 89_out
10	Phase B to ground	At bus 8	3.25	3.2664	78_out and 89_in
11	Phase A to ground	At feeder 78 (0.25km away from its upstream ends)	4	4.0182	78_in and 78_out
12	Phase A to Phase B	At bus 7	3	3.0166	67_out and 78_in
13	Phase B to Phase C	At feeder 67 (1.5km away from its upstream ends)	7	7.0162	67_in and 67_out
14	Phase A to Phase B	At bus 6	4	4.018	16_out and 67_in
15	Three phase to ground	At feeder 16	5.5	5.516	16_in and 16_out

*** For all case studies, the master unit orders relays W1 and W2 to respond to isolate wind farms in the same tripping times listed in the table.*

It must be mentioned that adequate delays for communication processes using fiber-optics and data analyzing are taken into account. In these results, it is considered that the approximate time at which relays respond would be delayed by about quarter a cycle. Also, it must be noted that wind farms must be turned off if any fault occurs because its control system depends on the grid voltage and reactive power flow between the wind farm and the grid which are significantly affected by faults.

5. Conclusion

A novel WAP algorithm compromises OAS and FEI approaches and based on flat architecture is proposed to update traditional protection systems to avoid the impacts of DGs integration into distribution systems. It utilizes DWT for analyzing currents and fiber optics media for communication processes. It effectively detects various fault types and conditions in presence of DGs and preserves its selectivity and reliability.

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