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A New Strategy for Fault Diagnosis, Clustering and Observing In Floating Wind Farms

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ABSTRACT

In this article, a comprehensive strategy for real time fault diagnosis, segment determination, clustering and observing in floating wind farm (FWF) is presented. The proposed strategy is designed using the concepts of differential protection, current rectification during fault happening, and Artificial Intelligence (AI) tools. For categorization of the rectified current a parameter is defined used for fault clustering. The strategy can diagnose, categorize, locate, and fully observe the faulted reinforce cable connecting the floating wind farm to ground station. To validate the proposed strategy several simulations are obtained using MATLAB software package. The simulation validated the effectiveness of the proposed protection strategy.

KEYWORDS: FWF, AWEGS, HAWECS, Observation, High Altitude Satellite, Fault Diagnosis, Fault Clustering.

INTRODUCTION

Due to the location of a hug and vast layer of dense wind energy in upper atmosphere layer, there is an active seek in development of the floating wind farms (FWF), the next generation of wind energy conversion system, deployed in high altitudes. The high altitude wind energy is an attractive resource of energy with 100 times bigger than global energy demand [5]. Its importance becomes evident when the surface winds energy is only 7 times bigger than global energy demand [6]. On other hand the global consumption is increasing [7]

A FWF is consisting of several airborne wind energy generation systems (AWEGSs) tethered to corresponding ground stations as shown in Fig.1. Due to nature of AWEGS, the generated power at altitudes, about 8 km, should be transferred using a conductive tether.

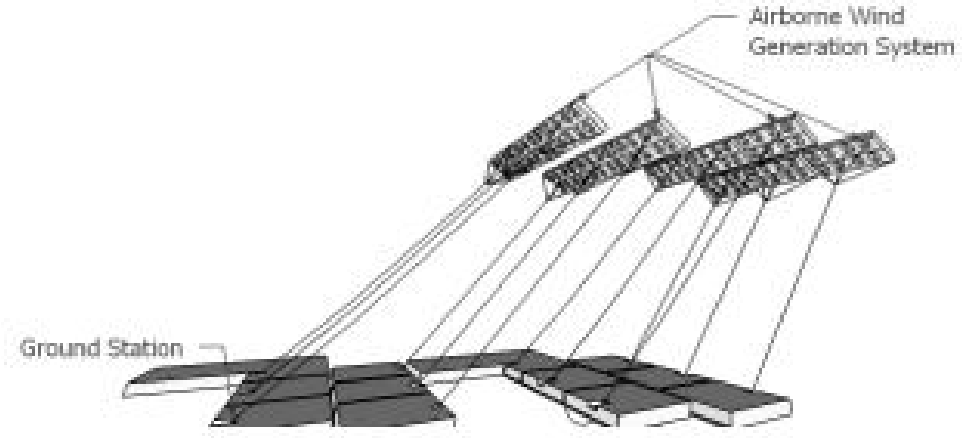

Fig. 1 an FWF consisted of several AWEGSs

Due to possibility of fault occurrence, in the tether or ground station, it is a problem in FWFs. Detection of fault current significantly can decrease the damages to the transmission line (the conductive tether) between the AWEGS and ground station. Not only the fault should be detected, but also the location of the fault along the tether should be located.

Also, to alleviate the local variability in electrical output generation of a FWF it was constructed as several sections which are located farm from together. Thus, another problem is that in which section the fault is occurred. Fault detection and monitoring multi section FWF, is a critical issue.

To detect and interruption of fault current, the over current relays also can sense fault currents and act quickly, and send a trip signals to circuit breakers. Nevertheless, there are mal-operations and inaccuracy in fault detection which is mainly is due to the current saturation of transformers and potential transformers occurring in high fault currents.

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To locate the location of the fault in transmission lines by wavelet transform can be able us for accurate location is proposed in [1]. In this method, the fault distance to reference a point is computed using the interval time between the incidents and reflected traveling waves from the faulted point. To detect the faulted zone or section, a new strategy for by distance relays and exchange of data between the local and remote relays is proposed in [2].

For classification of faults, an algorithm for fault detection and discrimination between grounded and ungrounded faults is proposed in [3].

Although the mentioned literatures addressing the fault detection location and classification in transmission lines, due to novelty of FWFs three is not any literature to address the problem due the faults in FWFs. Thus, it is necessary to develop a complete algorithm for fault detection and it location along the tether, determination of the faulted section classification, as well as and graphical data about the fault monitoring in FWFs.

In this paper a complete algorithm for fault and section determination, location as well as classification is propose.

The rest of this paper organized as follow: In section 2, by definition of a differential index, a method for fault detection section determination using communications satellites is presented. In section 3, by definition of a rectification index, a new method for fault classification is presented. In section 4, the strategy of fault location along the tether with artificial neural network is presented. In section 5, the complete algorithm is presented and its details are described. To verify the proposed algorithm a case study is simulated and studied. Finally in section 6, the conclusion and a viewpoint over future works are presented.

Thus, the scientific contributions of this paper can be listed as follow: Rectified current during fault is characterized by definition of an index. A differential index for determination of faulted section is proposed. An algorithm for location of fault along the tether using artificial intelligence is proposed. A complete algorithm to provide an visual interface between the operation and the fault detection system is proposed. This algorithm allows to an accurate monitoring of the faulted points with inspection robots. This monitoring provides multimedia data about the fault point for the operator.

FAULT DETECTION AND SECTION DETERMINATION

Consider the tether between the ground station and the AWEGS due to section s as shown in Fig.2. As the fault occurs in tether$G_{sk} - A_{sk}$, the current in ground station will be significantly decreased. Current transformer will is sending contentiously the current values at the ends of tether to associate GPS with the area. We define a index of d indicates the difference between current in ends of tether. In normal condition this index value is in a normal range.

By occurrence of a fault in$G_{sk} - A_{sk}$, tether, the index value of d_{Sk} will be significantly increased in faulted tether over other tethers. In other word, the maximum value of index of d_{Sk} associate with the faulted tether:

$$d_{Sk} = A_{s,k} - G_{r,k} \quad (1)$$

$$\text{Faulted section} = Max\{d_{1,}d_{2,}\ldots,d_{n,}\} \quad (2)$$

For each k^{th}AWEGS of sth section:

$$d_{S1} = A_{s,1} - G_{r,k} > I_{critcal.1} \quad (3)$$

$$d_{S2} = A_{s,2} - G_{r,2} > I_{critcal.2} \quad (4)$$

$$d_{SN} = A_{s,N} - G_{r,N} > I_{critcal.N} \quad (5)$$

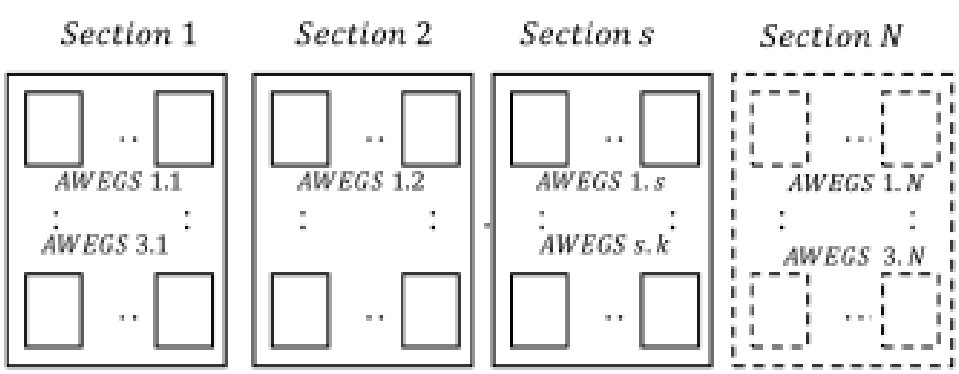

Fig. 3 an FWF consisted of N sections

Since sections are far from each together, to compare the index value of d_{Sk} in all sections should be sent to a center. Due to large distance between the sections, each the d_{Sk} in each section will be sent to nearest communication satellite. In the diagram is shown in Fig.4.

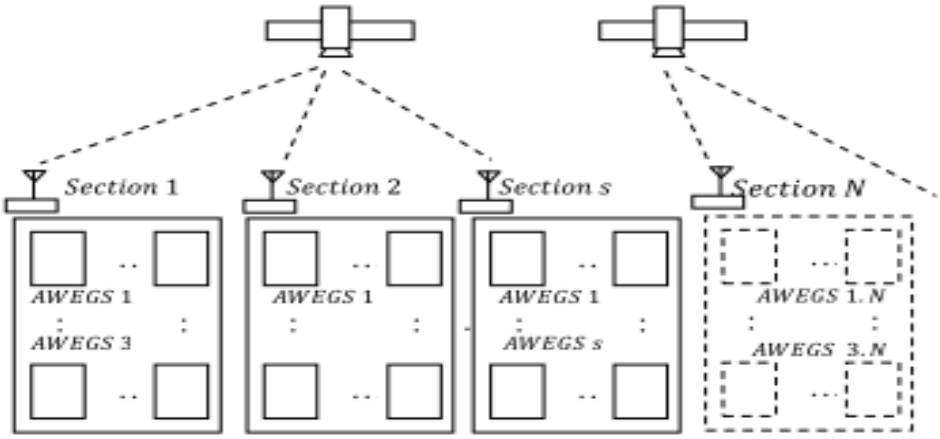

Fig. 4 transmission of end's tether data to satellites

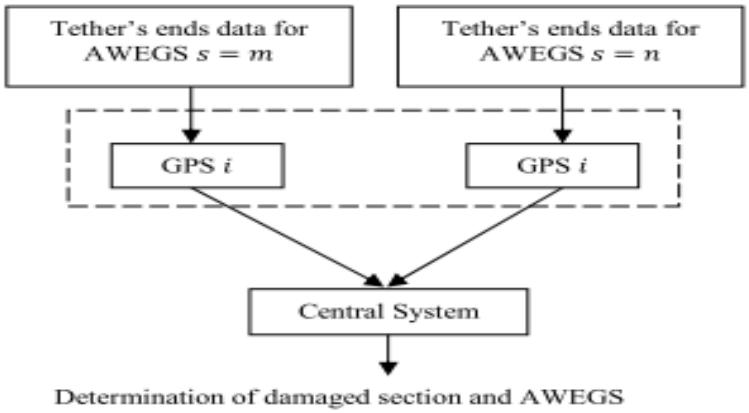

Fig. 5 An FWF Consisted Of N Sections

FAULT CLASSIFICATION

The fault detection and classification algorithm used for transmission lines by index for showing how much the current was rectified. Rectified current during fault interval time and using of this index in the proposed algorithm can detected and classified the fault to the ground and ungrounded fault.

This classification is based on the current is rectifying during occurrence of the arc in any fault. As shown in Fig.6, by occurrence of fault and the electric arc, the alternative current will be approximately rectified. The fault current will be rectified during the time interval when the fault is on. In [4] is shown based on this phenomenon, some rectifier devices are designed and used.

Although during the fault, current will not be rectified completely, the approximately rectified currents at small interval time when the fault is on is including valuable information about the fault can be used for fault classification. In bolted faults, we have not rectified current during the entire of time interval that the fault is on. The bold faults have not any consistent arc with larger period of the time. Thus, we can use it for fault type discrimination between, bolted faults and ungrounded faulted. Furthermore, we can classified all types of the fault to line to line fault, line to ground fault, three line to ground fault based on the rectified faulted phases. The current in the faulted phase which is not solidly grounded is rectified. If only one phase current was rectified in line to ground fault, similarly if current in phase, and phase b was rectified we have line-line fault, and finally if current in phase was rectified, three phases to ground faulted. It should be noted that, in double lines to ground fault one phase is rectified so that minus cycle was eliminated and other phase are rectified so that positive cycle was eliminated. In Fig.6 faulted phase which not solidly grounded in fault location are presented.

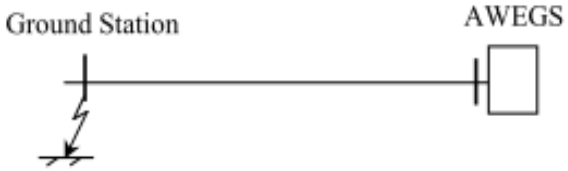

Fig. 6 the tether between the AWEGS and ground station

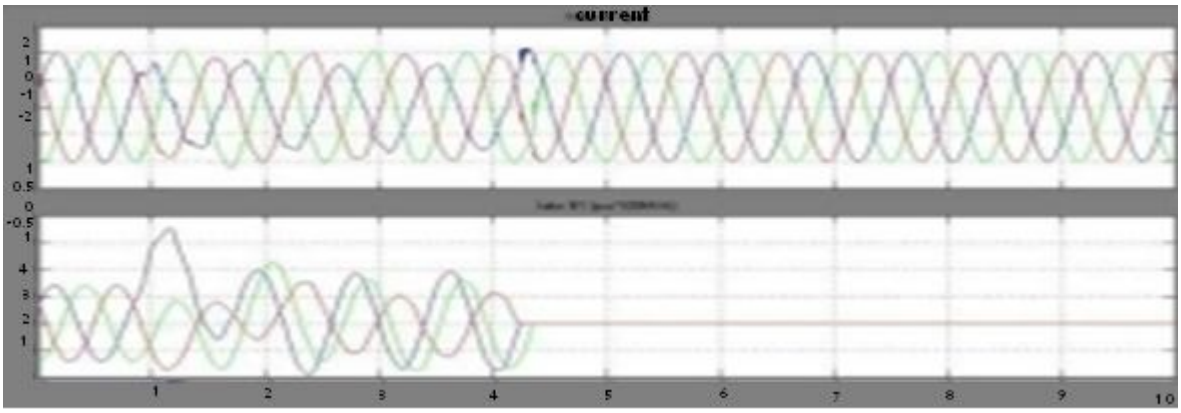

Fig. 7 rectification current during LLLG faults

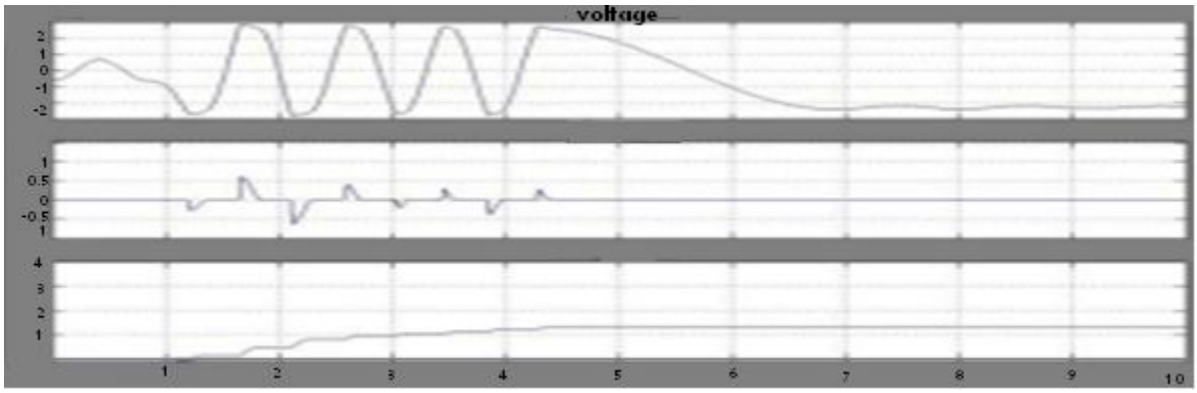

Fig. 8 rectification current during LG faults

For characterization of this phenomenon, the index H is defined. This index shows how much the current of I is rectified in each phase or not .i.e. H_a indicate value of H in phase a. Index H associated with phase x,$AWEGS\ k$ and section s:

$$H_{k\,s\,x} = \sqrt{\frac{1+\frac{V_k}{|V_k|}}{1+K\frac{I}{\int_0^{1/f} I_k(t)dt}}} \qquad (6)$$

Where
V: Voltage at associate with ground station k
f : System Frequency
I : Current at bus associate bus
K: Coefficient due to Physical Dimension Of line
We define H^k so that:

For $H_{k\,s\,x}$>1 $H_{k\,s\,x}$ = 0
For $H_{k\,s\,x}$<1 $H_{k\,s\,x}$ = 1

The convince used for this algorithm shown in TableI

Table I: connivance used for this paper

Index	Fault type
0	Solidly Grounded
1	Grounded through

We defined the index of H for fault classification presented in proceeding in the following algorithm. Table 2 shows how classification can be done by obtained values of index H at each after detection of phase. Faulted and classification that which phase and which kind of fault was occurred tripping signal will be send to circuit breakers associated to faulted phase in faulted phase.

Table II: available mode under different index values

Fault Type	Phase Current and associated Index Value					
	I_a	H_{ask}	I_b	H_{bsk}	I_c	H_{csk}
LG	1	0	-	-	-	-
LG-R_f	1	1	-	-	-	-
LL	1	-	1	-	-	-
LLG	1	0	1	0	-	-
LLG-R_f	1	1	1	1	-	-
LLLG	1	0	1	0	-	-
LLLG-R_f	1	1	1	1	1	1
LLL	1	0	1	0	1	0

FAULT LOCATION

We tend to develop an algorithm for location of the faults in the FWF. Since the faults may be occurs in several AWEGS in several section, this algorithm should determine the location of the faults in corresponding tethers.

Since different AWEGS's characteristic such as different tether characteristic, conductor coefficient, physical length, and critical current $I_{critcal}$, the location of the faults can be determined using an artifitial neural network.

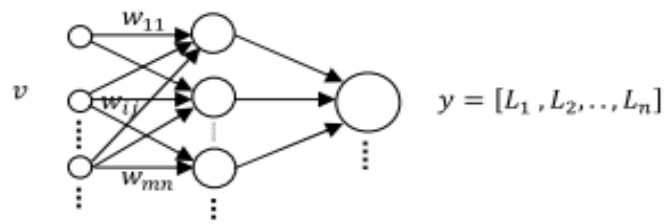

Fig. 9 The neural network designed for fault locating

That it's input vector will be:

$$v = [|V|, |I|, |\varphi|, R_f, H_{ask} , H_{bsk}, H_{csk}] \quad (7)$$

Where the variable are presented in follow:

$|V|$: Voltage phasor magnitude (in volts)

$|I|$: Current phasor magnitude (in amps)

$|\varphi|$: Phase Angale between the voltage and current phasors (in radians)

R_f: Fault resistance due to arc

H_{ask}: Defined index due to phase a, AWEGS k and, section s

H_{bsk}: Defined index due to phase b, AWEGS k and, section s

H_{csk}: Defined index due to phase c, AWEGS k and, section s

And output y is the location of fault points in the faulted tethers which are

$$y = [L_1 , L_2, .., L_n] \quad (6)$$

This neural network will be trained using historical data. The advantage of using neural network is fast and accurate fault detection with future development possibilities.

ALGORITHM FOR FAULT DETECTION, LOCATION CLASSIFICATION AND MONITORING

Using the developed algorithm for fault detection, section determination, and fault locating as well as monitoring a complete algorithm is developed. The conceptual representation of this algorithm is shown in Fig.10. We review the principle of this algorithm. Input ends data due to each AWEGS in each section are being continuously sending to nearest communication satellite. The entire end's data will be sent to the central center. There is a PC in the central system which this algorithm will be processed at it. By occurrence of fault, it will be simplicity detected by calculation of index d. As the fault is detected, the faulted section will be founded. The type of the fault can be founded by index H. The fault location will be performed using the neural network, which provides the locations of the faults. Using the determined section and tether, the inspection robot will provide the photographical data about the fault for the operator. These photographical data can able us to accurate monitoring and fixing the damaged point the tether or AWEGS.

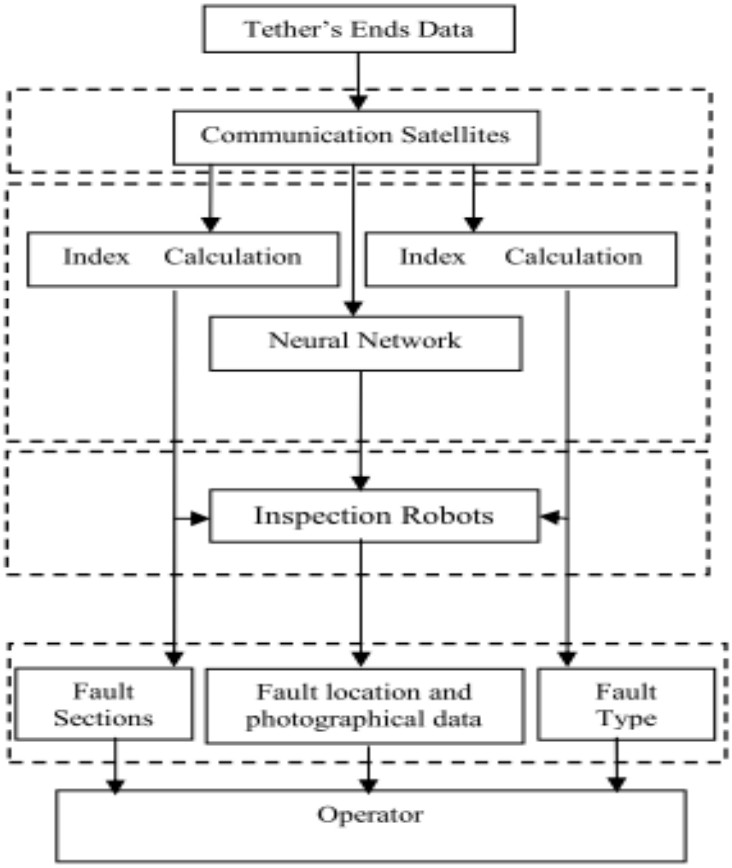

Fig. 10 The proposed algorithm for fault detection, section determination, fault classification, and monitoring

VERIFICATION OF THE ALGORITHM

Verification of the proposed algorithm can be tested by simulation of a five sections FWF shown in Fig.11. For simulation of satellite equipment, we use blocks operate as based on the satellite protocols shown in Fig.12. Another block in this simulation is fault detection and section determination. The third block is fault location and classification based on the proposed algorithm. By occurrence of the fault in fifth section of FWF as shown in Fig 13, the proposed algorithm is performed for fault detection, classification.

The obtained results for fault detection and classification are presented in table.3.

Also, the associate satellite to each section of FWF is shown. Due to nature of simulation, the faulted point's photographical data will be sent to ground station are not available at this study case.

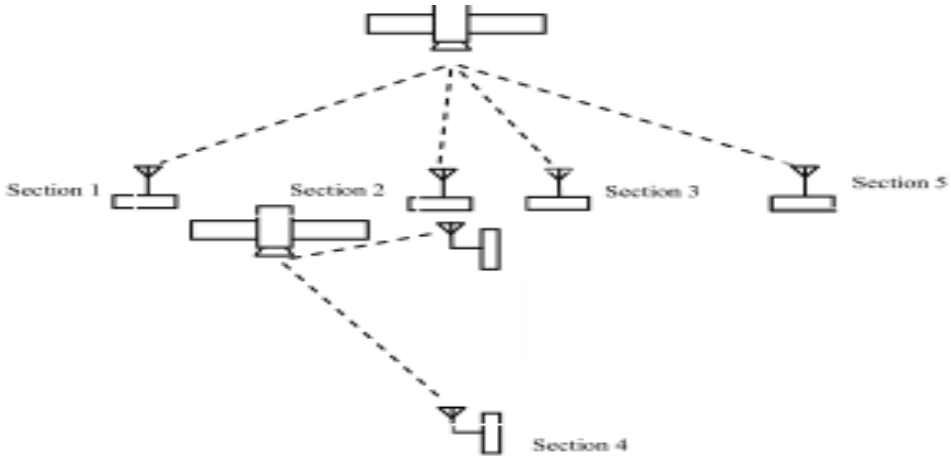

Fig. 11 the FWF with five sections

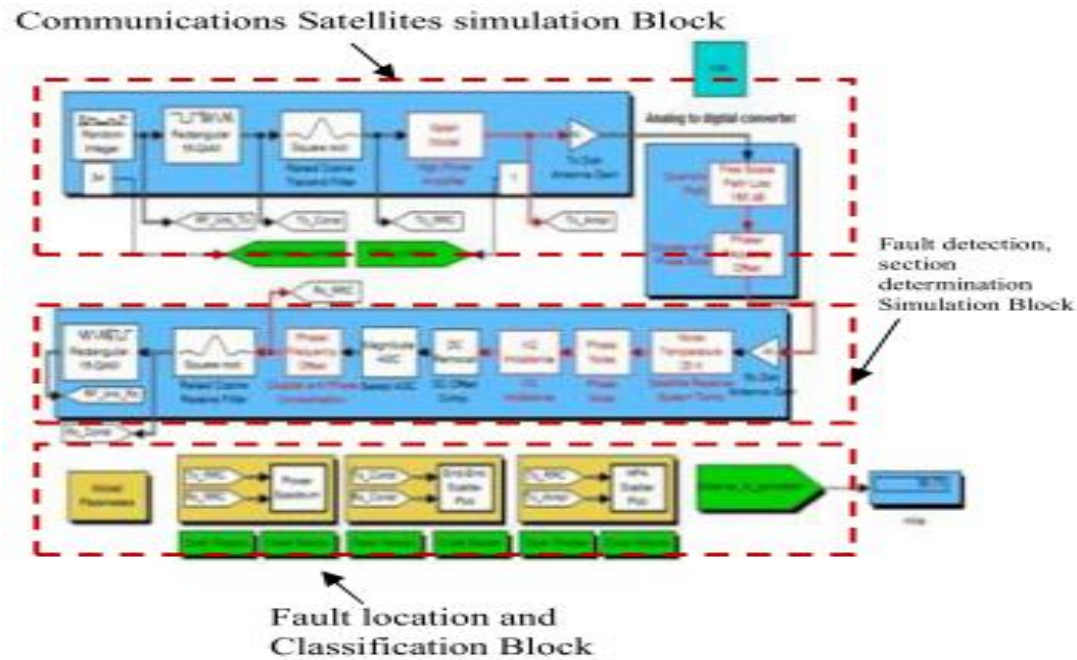

Fig. 12 the simulations block in the MATLAB software

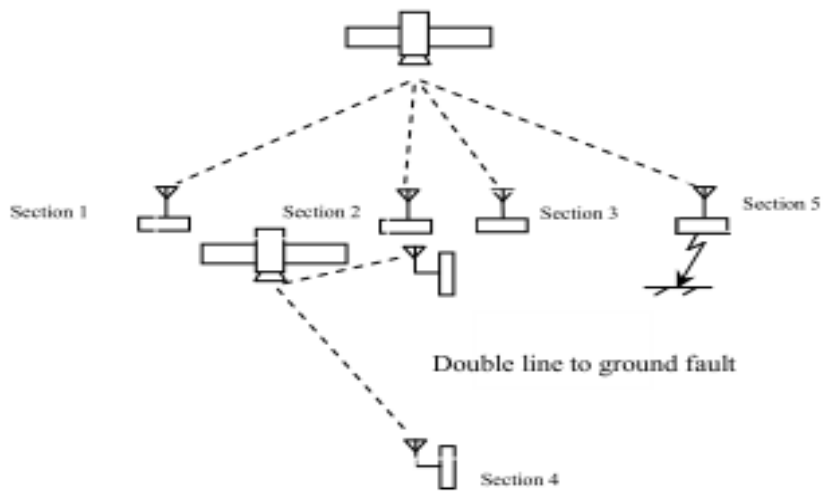

Fig. 13 the simulated fault in fifth section of FWFs

Table 3: Simulation result for tether phases

Fault Type	Phase Current and associated Index Value					
	I_a	H_a	I_b	H_b	I_c	H_c
LLG	1	0	1	0	-	-

This simulation was carried using MATLAB software package. The source code was developed in FORTRAN software. It was assumed that LLG fault thought arc resistance was occurred in ground station of one of the AWEGS in the fifth section of FWF are shown in Fig.13.

CONCLUSION

A novel algorithm for fault detection, classification and monitoring in high altitude wind power stations is proposed. Two indexes respectively for fault detecting, and section determination and fault classification are defined. To verify the algorithm a FWF with five sections is simulated as a case study. Spite of complexity of the algorithm, the results of several simulation and verifications demonstrate the viability and accuracy of the proposed algorithm.

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