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INTELLIGENT PROTECTION of MICROGRID

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Contents

I. Introduction

❑ Microgrid (MG) :

- Effective way to integrate the increasing penetration of distributed energy resources (DERs)
- Small scale medium or low voltage distribution network
- Normally work in grid-tied mode
- Can operate in Islanded mode →Faults in main utility

❑ Benefits of Microgrids:

- Reduce the power losses
- Provide uninterrupted service to customers
- Improve reliability & power quality
- Reduced emissions of greenhouse gases

I. Introduction

A. Challenges associated with microgrid operation

- **MG operation is different from traditional distribution networks:**
  - Bi-directional power flow in the feeders
  - Continuous switching between radial and looped topologies
  - Various operating scenarios → Grid-tied mode, and Islanded mode
- **The complex and multi-mode operation → protection and control challenges**
- **MG Protection can be divided into two sub-problems**
  - Anti-islanding protection/Islanding detection
  - Fault protection
    - Detection
    - Classification
    - Location of faults

B. Problem statement

- **Fault protection:**
  - **Bidirectional power flow** in the MG feeders
  - Different **fault current level** in different operating modes
  - **Microgrid switching** between radial and looped topologies
  - **Protection methods** of distribution network → **Not applicable** to MG

II. Research trend and previous work

A. Existing microgrid protection schemes

Microgrid Protection Schemes

Local Measurement Schemes

- Locally measured voltage and current signal
- Economical, but may isolate healthy part
- Overcurrent relays, under voltage etc
- Cannot guarantee protection in all modes

Communication Based Schemes

- Require communication links and sync. measurement
- Expensive, and exposed to communication failure
- Directional schemes, Differential protection, Adaptive protection

Intelligent Protection

- Extract features using signal processing methods
- Employ intelligent classifier to develop fault information
- Can protect MGs in all operating scenarios
- Wavelet, Fourier, ANN, SVM
- based schemes etc

II. Research trend and previous work

B. Problems of existing microgrid protection schemes

- **Local protection schemes cannot guarantee protection in both modes of operation**
- **Communication-based scheme**
  - Required synchronized measurement
  - Exposed to communication failure
- **Intelligent schemes**
  - Use fixed basis function to extract fault features
  - Cannot provide fault phase information
  - Did not consider the time-sequence of fault current signal
  - Most of the intelligent schemes have been developed for low voltage MG
  - Prone to communication failure

III. Contributions

- **Intelligent Scheme:** A Novel intelligent islanding detection and fault protection scheme for MGs based on **empirical wavelet transforms** (EWT) and **long short-term memory network** (LSTM) is proposed
- **Adaptive Feature Extraction:** Unlike existing methods, the proposed scheme **extracts the features** using **signal-adaptive filter banks**. The wavelet filter banks in the EWT are built based on the information contained in the input signals
- **Extension of EWT concept for islanding detection:** The EWT concept is **extended to islanding detection problems** to calculate the features from the three-phase voltage signals
- **Long short-term temporal features:** The proposed scheme uses LSTM to extract the long and short-term temporal dependencies within the voltage signal
- **Comprehensive Method:** The proposed method can protect MGs in all operating modes and can detect islanding events with small non-detection zone
- **The method can work in noisy conditions and does not use communication**

IV. Background theory

A. Empirical Wavelet Transform (EWT):

- **EWT designs signal-dependent adaptive wavelet-filters , which decompose a signal into empirical mode**
  - The empirical modes (Ems) are centered around a specific frequency with a compact frequency support
- **The empirical wavelet and scaling function are:**

$$\Psi_i(\omega) = \begin{cases} 1, & \text{if} \quad |\omega| \leq (1-\omega)\omega_i \\ \cos(\frac{\pi}{2}\beta(\gamma,\omega_i)), & \text{if} \quad (1-\omega)\omega_i \leq |\omega| \leq (1+\omega)\omega_i \\ 0, & \text{Otherwise} \end{cases} \quad (1)$$

$$\varphi_i(\omega) = \begin{cases} 1, & \text{if} \quad (1+\omega)\omega_i \leq |\omega| \leq (1-\omega)\omega_{i+1} \\ \cos(\frac{\pi}{2}\beta(\gamma,\omega_{i+1})), & \text{if} \quad (1-\omega)\omega_{i+1} \leq |\omega| \leq (1+\omega)\omega_{i+1} \\ \sin(\frac{\pi}{2}\beta(\gamma,\omega_i)), & \text{if} \quad (1-\omega)\omega_i \leq |\omega| \leq (1+\omega)\omega_i \end{cases} \quad (2)$$

$\beta(x)$ is an arbitrary $\mathcal{C}^k([0,1])$ function   ω= frequency

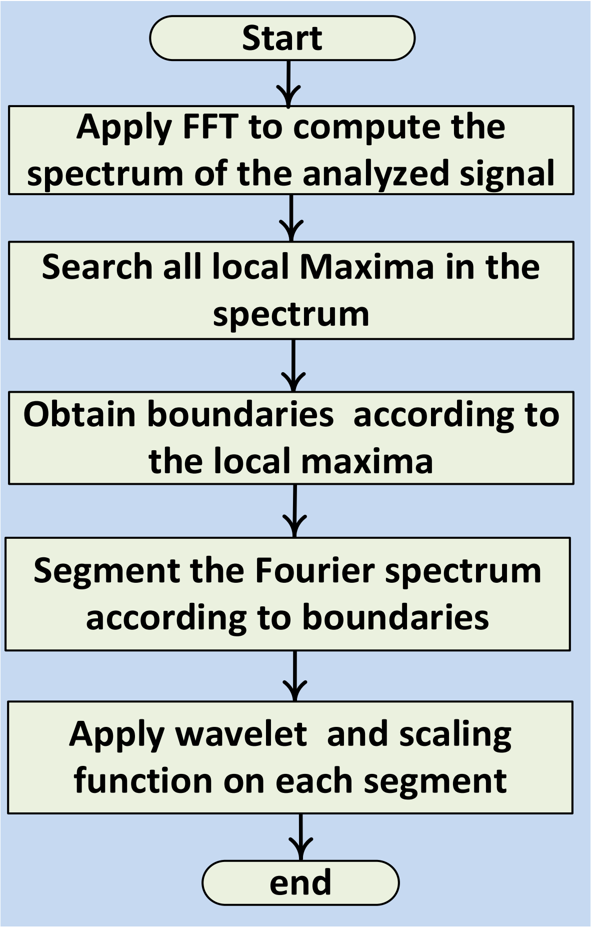


Fig.1a Flowchart of EWT

IV. Background theory

A. Empirical Wavelet Transform (EWT) – Cont.

$$\beta(\gamma,\omega_i) = \alpha\left(\frac{|\omega| - (1-\gamma)\omega_i}{2\gamma\omega_i}\right) \quad (3)$$

$$\gamma < min_i\left(\frac{\omega_{i+1} - \omega_i}{\omega_{i+1} + \omega_i}\right) \quad (4)$$

❑ **After obtaining empirical scaling and empirical wavelet function, the empirical modes are calculated using:**

$$f_0(t) = W_f^{\varepsilon}(0,t) * \phi_1(t) \quad (5)$$

$$f_k(t) = W_f^{\varepsilon}(k,t) * \psi_k(t) \quad (6)$$

$W_f^{\varepsilon}(0,t)$ **: Approximation coefficients**

$W_f^{\varepsilon}(k,t)$ **: Detail coefficients**

k : Number of modes

❑ **First three modes contains most of the signal information**

- This study considers **first three modes** only

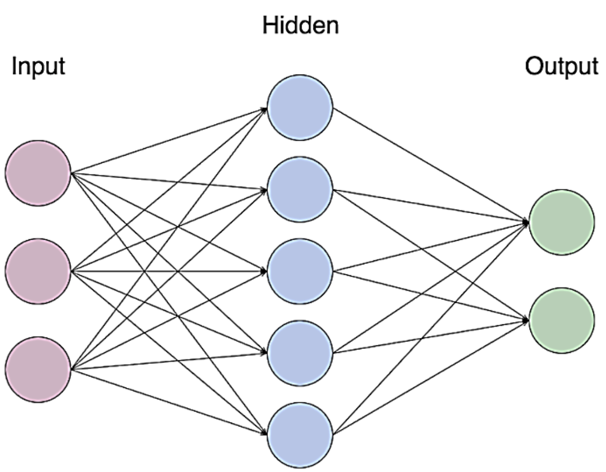
❑ **Hilbert transform** → Instantaneous **amplitude** of each empirical mode

→ Instantaneous **frequency** of each empirical modes

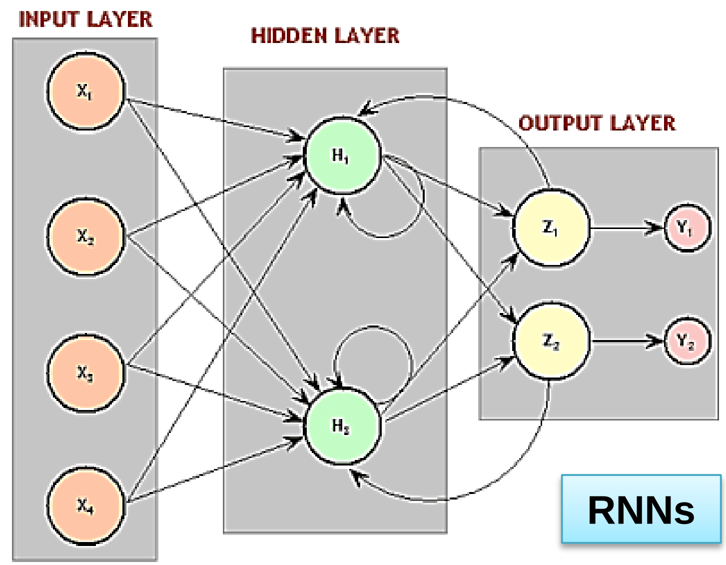
IV. Background theory

B. Long short-Term Memory network (LSTM)

- LSTMs are a type of recurrent neural network (RNN)
- RNNs receive inputs, update the hidden states depending on the previous computations, and make predictions for every element of a sequence
- RNNs are a neural network with memory



Simple Artificial Neural Networks



RNNs

B. Long short-Term Memory network (LSTM) – Cont.

- An LSTM is a special kind of RNN architecture, capable of learning long-term dependencies
- **LSTM networks** outperform RNNs and Hidden Markov Models
- This is due to **the multiplicative gate units** that learn to open and close access to the constant error flow

- LSTM networks introduce **a new structure** called a memory cell
- **The memory cells** store the previous information and help in learning long term features from the input
- **The short term feature** learning capability is an **inherited property** of RNNs

B. Long short-Term Memory network (LSTM) – Cont.

❑ **Comprises of memory units**

- **Memory cell** stores **the temporal state** of the network
- **Input gate** regulate **input to update** the cell
- **Forget gate** decides about the information **to be discarded** from previous memory
- **Output gate** controls **the information to be taken as output** from the current state of memory cell

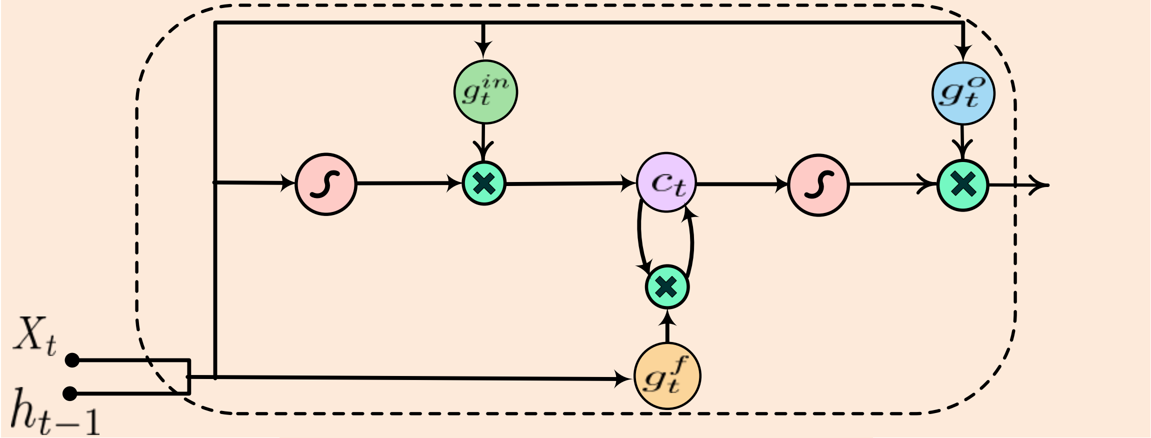


Fig. 2. LSTM memory unit

V. Proposed MG protection scheme

- **Input:** Three-phase current Signal
- **EWT → Features extraction**
- **Three units**
  - Fault **detection** unit
  - Fault **classification** unit
    - Triggered in case of unbalanced fault
  - Fault **location estimation** unit
    - Activated after fault detection
- **Each unit** → EWT based LSTM network
- **Finally, the generated fault information can be employed for fault isolation and recovery**

A. Feature extraction

- First, EWT is used to decompose each phase current into EMs
- Then, the following features are extracted from the first three EMs of each phase

1. Minimum value
2. Maximum value
3. Root-mean square (RMS)
4. Energy
5. Standard deviation
6. Coefficient of variation
7. Kurtosis
8. Entropy

- For each cycle of the three-phase current 72 feature are extracted
  - 3 (empirical modes) × 8 (features)× 3 (phases)=72
- The generated features are later inputted into the LSTM networks of each unit to develop the fault information

B. Fault detection unit

- **Input:** one cycle of **Three-phase currents**
- **Output:** Three 0,1 indicators (no-fault, unbalanced fault, and three-phase fault)
- **Dropout** helps in **mitigating** overfitting
- **LSTM layers** extract the **temporal dependencies** from the fault signals

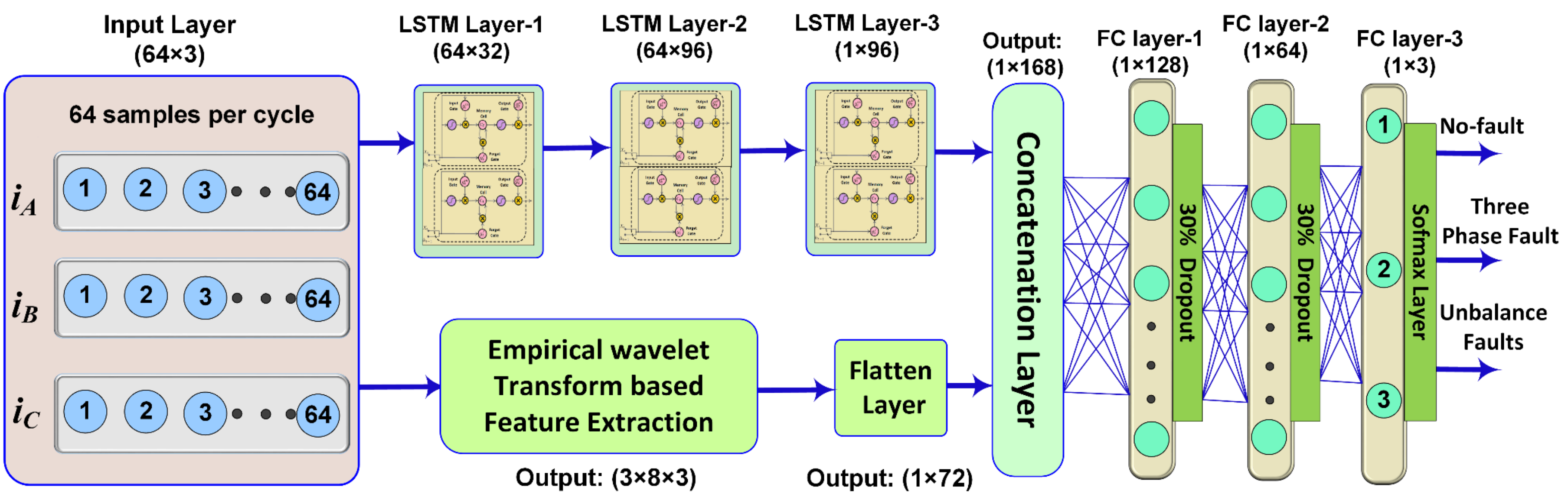


Fig. 3. Fault detection unit

C. Fault classification unit

- **Triggered:**
  - If the fault detection unit detects **an unbalanced fault** in the MG
- **Structure is same except last FC layer**
- **Last FC layer :**
  - Six 0-1 indicators
  - represent **the status** of each unbalanced fault

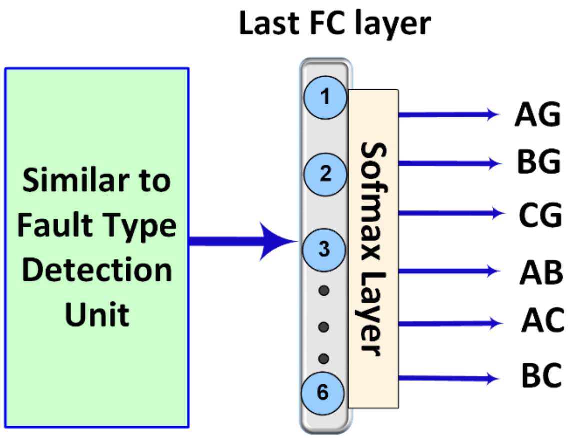


Fig. 4. Fault classification unit

D. Fault location estimation unit

- **Activated:**
  - If the fault detection unit **detected** an unbalanced/three-phase fault
- **Structure is same except last FC layer**
- **Last FC layer:**
  - Regression Task
- **Output:**
  - estimated fault location

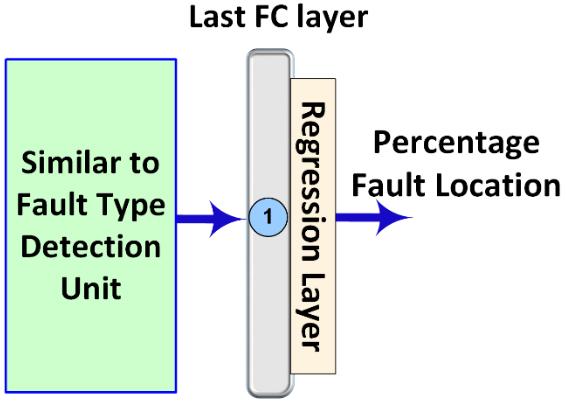


Fig. 5. Fault Location unit

A. IEC microgrid test system

Table 1. Conditions for simulating fault conditions

Parameter Details	Count
Fault on different distribution lines (DL-1, DL-2, DL-3, DL-4, and DL-5).	5
Fault at different locations (20%, 35%, 50%, 65% and 80%).	5
Fault resistances (0.1, 20, 45, and 75).	4
Fault inception angle (0°,45°, 90°, and 180°).	4
Topology (radial and looped).	2
Operating modes (grid-tied /islanded).	2
Types of Fault	10
Total Fault Cases	**16000**

Table 2. Conditions for simulating no-fault conditions

Parameter Details	Count
Abrupt load change.	6
Operating mode (Grid-tied/islanded mode)	2
Topology (radial/looped).	2
Capacitor switching at load buses and PCC.	6
Various DER penetration levels	2
Total no-fault cases	**288**

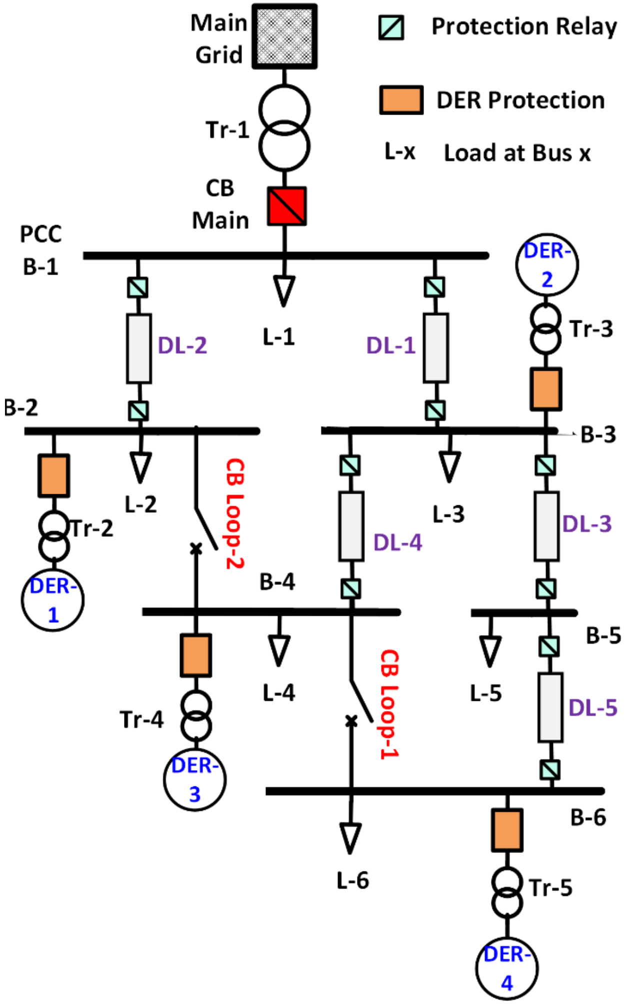
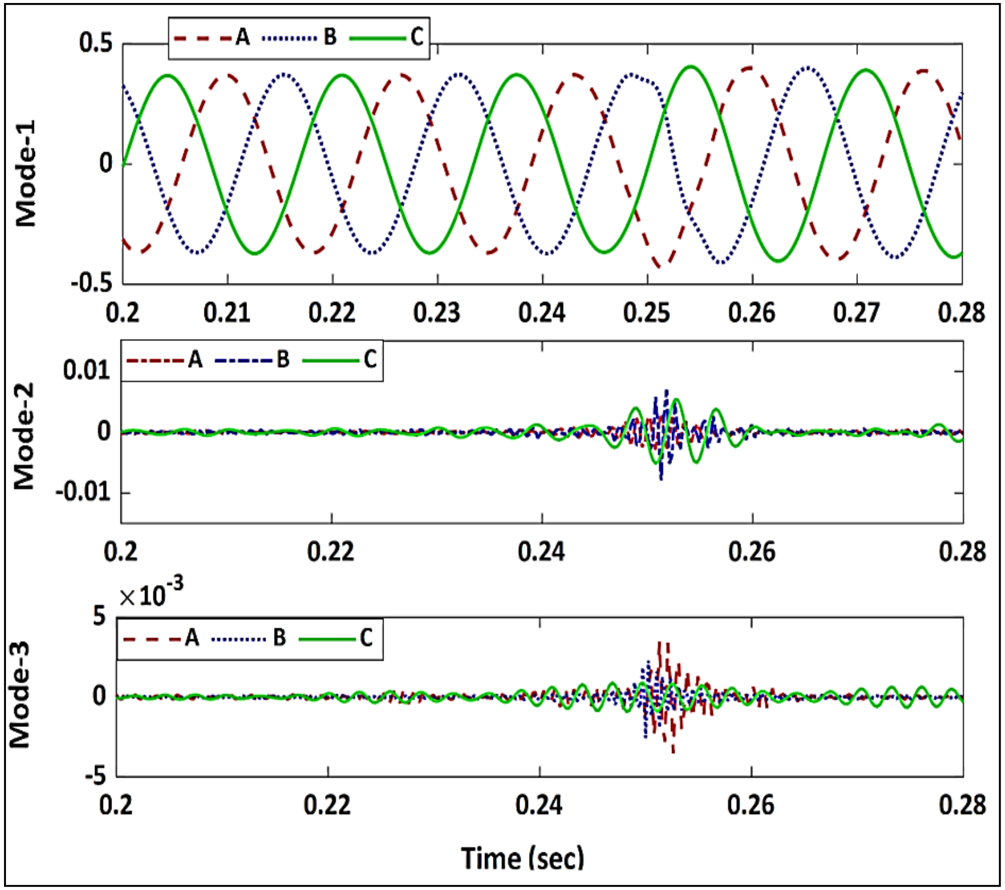


Fig. 6. A standard IEC MG test system

VI. Simulation results

B. EWT decomposition



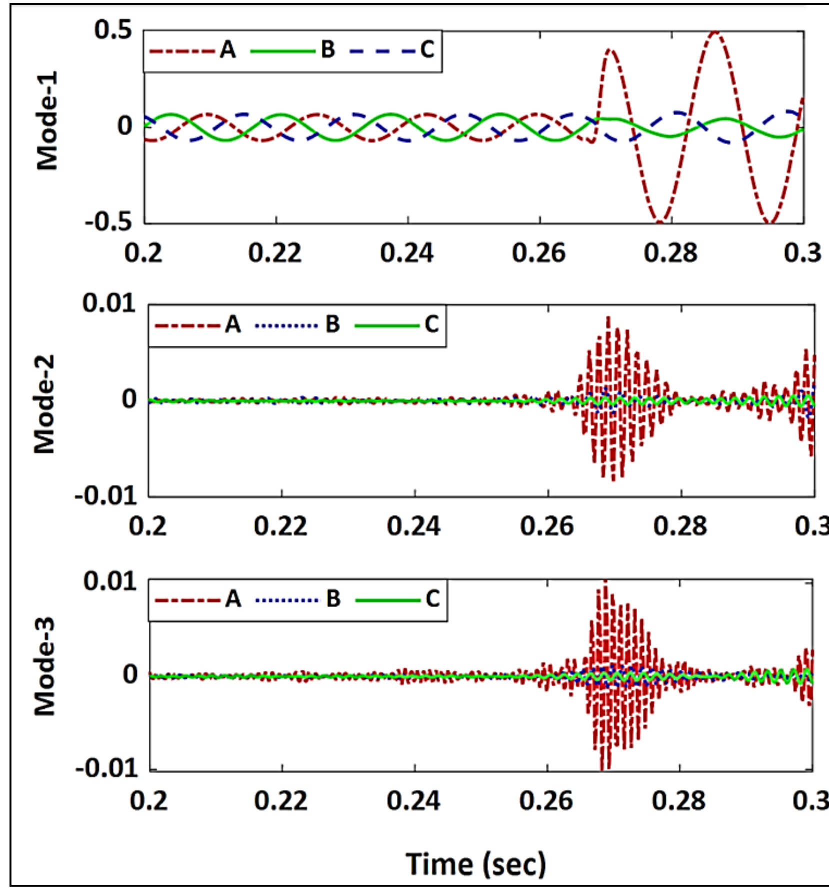


Fig. 7. First three empirical mode of three-phase current during capacitor bank switching at 0.25

Fig. 8. First three empirical mode of three-phase current when a AG fault hits the MG at 0.27sec

VI. Simulation results

C. Fault detection unit

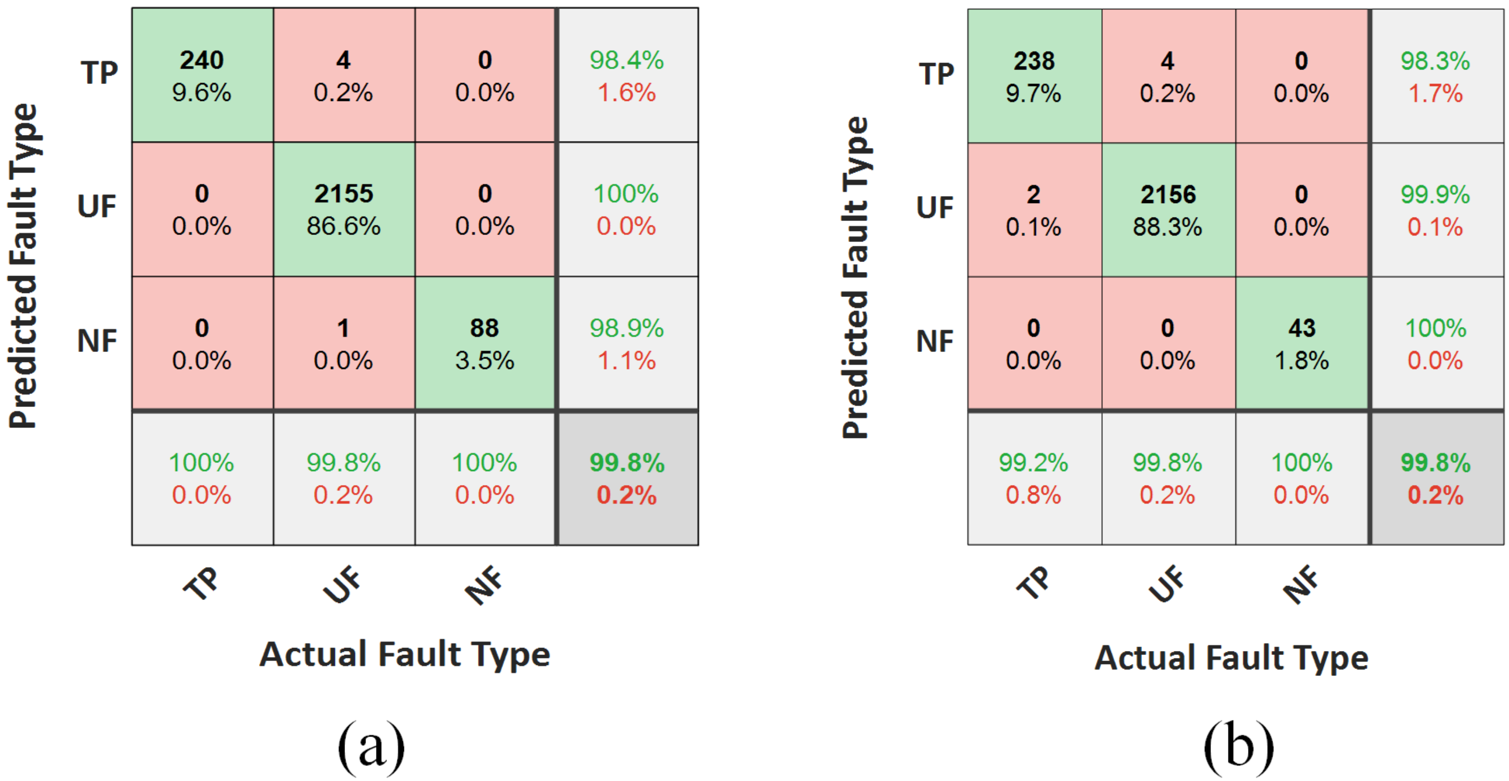
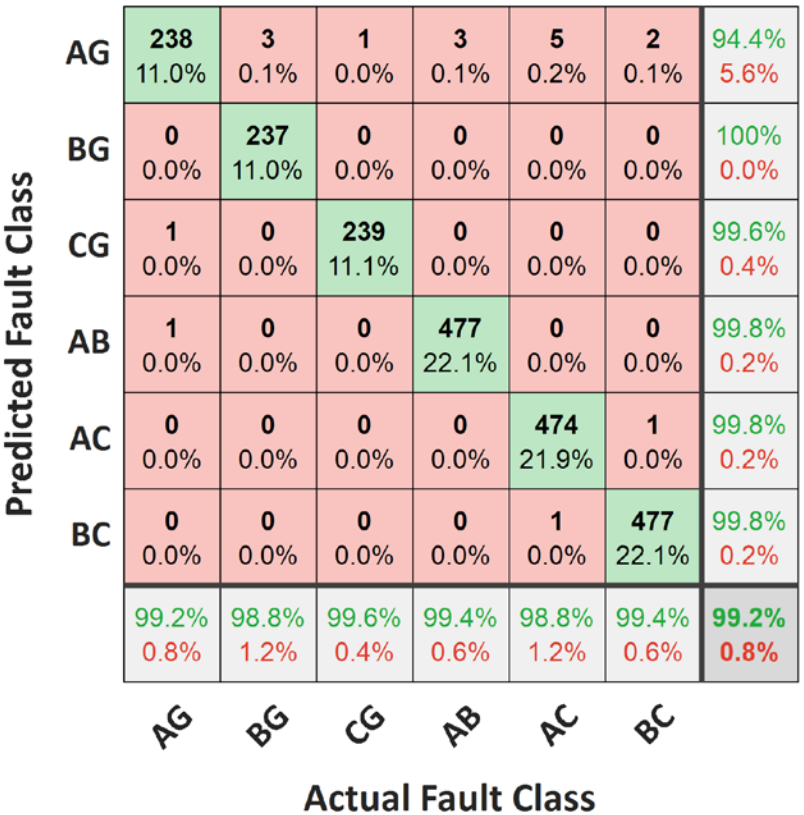


Fig. 9. Confusion Matrices of the testing dataset of fault detection unit during:
(a) grid-tied mode, (b) islanded mode

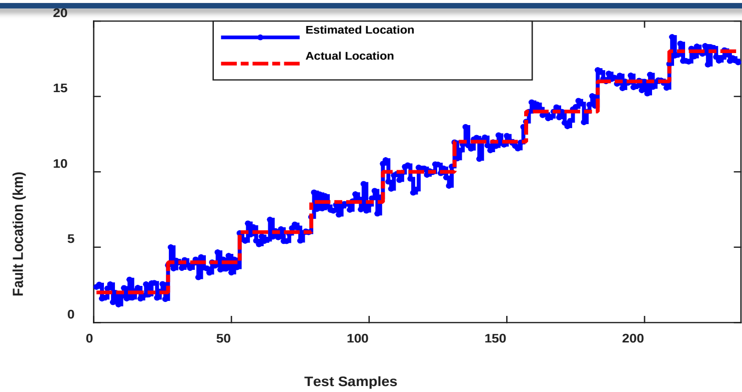
D. Fault classification unit

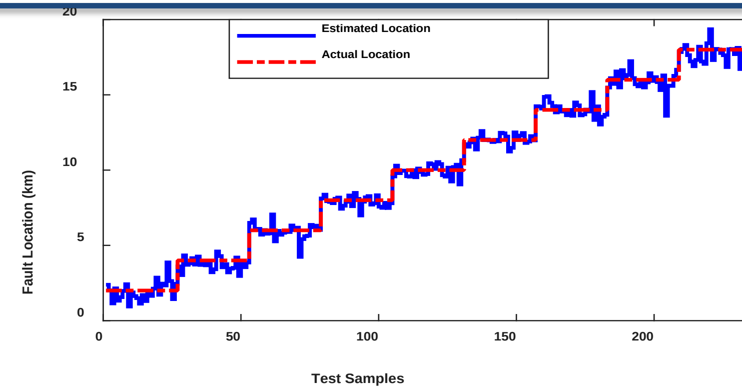


(b)

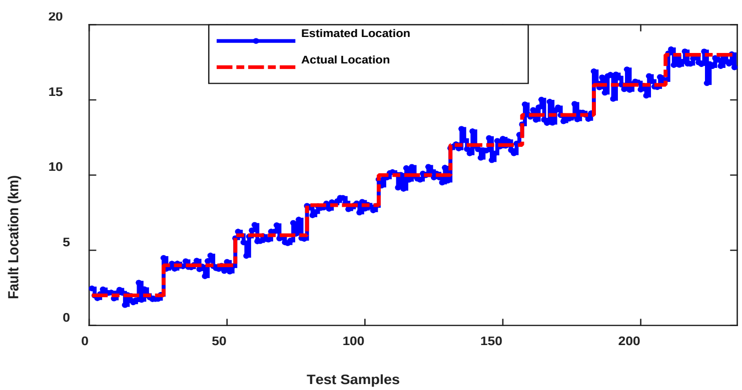
Fig. 10. Confusion Matrices of the testing dataset of fault classification unit during: (a) grid-tied mode, (b) islanded mode

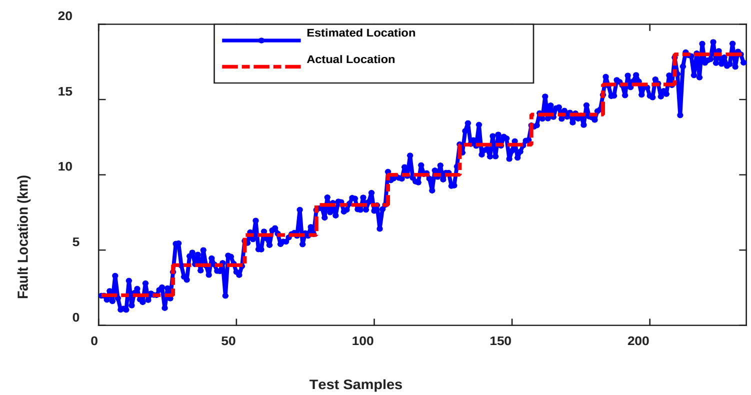
E. Fault location unit





(b)





(d)

Fig. 11. Comparison of the actual fault location vs estimated fault location:
(a) For DL-1, (b) For DL-2, (c) For DL-3, and (d) For DL-4

F. Comparison with existing schemes

Table 5: Comparison with existing fault detection schemes in grid-tied mode

Scheme	Dependability	Security	Accuracy
Support vector machine [12]	99.60%	97.06%	98.33%
Decision Tree[12]	99.80%	98.24%	99.02%
Proposed Scheme	**99.96%**	**100.0%**	**99.97%**

$$Dependability = \frac{Total\ \ fault\ cases\ predicted}{Actual\ \ fault\ cases}$$

$$Security = \frac{Total\ nofault\ cases\ predicted}{Actual\ nofault\ cases}$$

Table 6: Comparison with existing fault detection schemes in Islanded mode

Scheme	Dependability	Security	Accuracy
Support vector machine [12]	100.0%	98.06%	99.03%
Decision Tree [12]	99.60%	99.35%	99.47%
Proposed Scheme	**99.97%**	**100.0%**	**99.97%**

VII. Conclusions

- A novel **intelligent islanding detection** and **fault protection** for MGs based on **EWT** and **LSTM** was **proposed**
- The proposed scheme **extracted the features** from the power system signals using **signal adaptive wavelet filters**
- **Long-term temporal features** within a cycle were extracted using **LSTM networks**
- **Extensive simulation** were performed to verify the proposed schemes
- The results showed that the **proposed schemes** provided **better performance** as compared to existing IDMs and MG protection techniques
- The proposed schemes **does not require** any **communication link** for their operation

Thank you for your attention !