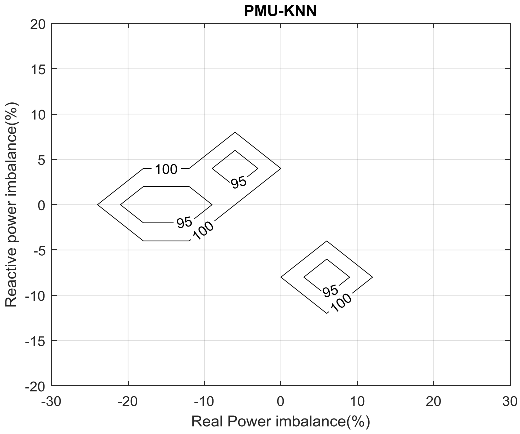

Fig. 9: NDZ of the PMU-KNN

At the end of this section, the results can be summarized in Table 2. This table presents the best accuracy at KNN for inverter-based DG and DT and KNN for rotating machine DG. Table 3 compares the results of the proposed algorithms with the best algorithms from the literature. From the table, the proposed algorithm has the lowest detection time for both DG types.

Table 2. The best accuracy of each method

| Test system | Classifier | Accuracy | Cycles |
|---|---|---|---|
| Inverter Based | SVM | 100% | 7 |
| | DT | 100% | 7 |
| | **KNN** | **100%** | **6** |
| | ANN | 100 % | 7 |
| Rotating Machine | SVM | 95% | 9 |
| | **DT** | **100%** | **9** |
| | **KNN** | **100%** | **9** |
| | ANN | 97% | 9 |

Table 3. result Validation

| Test System | Ref. | DT (sec) | Accuracy | NDZ |
|---|---|---|---|---|
| Rotating machine | [2] | 2 | 99.88 % | - |
| | [13] | 0.29 | 100 % | Zero |
| | [14] | - | 97.77% | Zero |
| | **Proposed** | **0.18** | **100%** | **Zero** |
| Inverter based | [2] | 1 | 94.71 % | - |
| | [13] | 0.37 | 100 % | Zero |
| | [14] | - | 97.22 % | Zero |
| | [15] | 0.5 | 97.1 % | <3% |
| | [16] | 0.188 | 100 % | <3% |
| | **Proposed** | **0.12** | **100%** | **Zero** |

# 5 Conclusion

In this paper, the PMU-Based Islanding detection method is proposed. Four artificial intelligence classification algorithms are used here: KNN, ANN, DT, and SVM. The proposed method is tested for both DG types; inverter-based DG and rotating machine-based DG. The four classification methods are evaluated using ROC curves and detection accuracy. The results show that the proposed algorithm can detect the islanding with 100% accuracy and zero NDZ within 6 and 9 cycles for inverter-based DG and rotating machine-based DG, respectively. The performance of the proposed algorithm concerning the real and reactive power mismatches is presented for the KNN algorithm at different sampling. Finally, the algorithm results are compared with different algorithms from the literature, and the effectiveness of the proposed algorithm is proven.

*References*


[1] Almomani, Mohammad, Ali S. Al-Dmour, and Seba Algharaibeh. "Application of Artificial Intelligence Techniques for Modeling and Simulation of Photovoltaic Arrays.", Jordan Journal of Electrical Engineering, 6(4), 2020, PP 296-314.

[2] Merlin, Victor Luiz, et al. "A new artificial neural network-based method for islanding detection of distributed generators." International Journal of Electrical Power & Energy Systems 75 (2016): 139-151.

[3] Ahmadipour, Masoud, et al. "Islanding detection method using ridgelet probabilistic neural network in distributed generation." Neurocomputing 329 (2019): 188-209.

[4] Matic-Cuka, Biljana, and Mladen Kezunovic. "Islanding detection for inverter-based distributed generation using support vector machine method." IEEE Transactions on Smart Grid 5.6 (2014): 2676-2686.

[5] Odienat, Abdullah, et al. "Low Frequency Oscillation Analysis for Dynamic Performance of Power Systems." 2021 12th International Renewable Engineering Conference (IREC). IEEE, 2021.

[6] M. M. Almomani, A. Odienat, S. F. Al-Gharaibeh and K. Alawasa, "The Impact of Wind Generation on Low Frequency Oscillation in Power Systems," 2021 IEEE PES/IAS PowerAfrica, 2021, pp. 1-5, doi: 10.1109/PowerAfrica52236.2021.9543283.

[7] Almomani, Mohammad M., and Seba F. Algharaibeh. "Modelling and Testing of a Numerical Pilot Distance Relay for Compensated Transmission Lines." International Journal of Scientific Research and Engineering Development 3.6 (2020): 776-786.

[8] Al-Momani, Mohammad M., Asmaa SM Hatmi, and Seba F. Al-Gharaibeh. "European Journal of Electrical Engineering." European Journal of Electrical Engineering 23.3 (2021): 197-205.
[9] Al-Odienat, A. I., et al. "Connectivity Matrix Algorithm: A New Optimal Phasor Measurement Unit Placement Algorithm." IOP Conference Series: Earth and Environmental Science. Vol. 551. No. 1. IOP Publishing, 2020.
[10] Vishwanathan, S. V. M., and M. Narasimha Murty. "SSVM: a simple SVM algorithm." Proceedings of the 2002 International Joint Conference on Neural Networks. IJCNN'02 (Cat. No. 02CH37290). Vol. 3. IEEE, 2002.
[11] Zhang, Min-Ling, and Zhi-Hua Zhou. "ML-KNN: A lazy learning approach to multi-label learning." Pattern recognition 40.7 (2007): 2038-2048.
[12] Rish, Irina. "An empirical study of the naive Bayes classifier." IJCAI 2001 workshop on empirical methods in artificial intelligence. Vol. 3. No. 22. 2001.
[13] Faqhruldin, Omar N., Ehab F. El-Saadany, and Hatem H. Zeineldin. "A universal islanding detection technique for distributed generation using pattern recognition." IEEE Transactions on Smart Grid 5.4 (2014): 1985-1992.
[14] Fayyad, Yara, and Ahmed Osman. "Neuro-wavelet based islanding detection technique." 2010 IEEE Electrical Power & Energy Conference. IEEE, 2010.
[15] Kumar, S. Ananda, et al. "A novel islanding detection technique for a resilient photovoltaic-based distributed power generation system using a tunable-q wavelet transform and an artificial neural network." Energies 13.16 (2020): 4238.
[16] Ahmadipour, Masoud, et al. "Islanding detection method using ridgelet probabilistic neural network in distributed generation." Neurocomputing 329 (2019): 188-209.

## APPENDIX A

Table A-1. DFIG-DG parameters

| Generator parameter /turbine | Value | Converter Parameter/ turbine | Value |
|---|---|---|---|
| Nom. Power (MVA) | 1.5/0.9 | Grid side current | 0.8 Pu |
| L-L Voltage | 575 V | Grid side inductance | 0.3 Pu |
| Frequency | 50 Hz | Grid side resistance | 0.003 Pu |
| Stator resistance | 0.023 Pu | DC voltage | 1150 V |
| Stator inductance | 0.18 Pu | DC bus capacitance | 1e-2 F |
| Rotor resistance | 0.016 Pu | Line filter capacitance | 120e3 |
| Rotor inductance | 0.16 Pu | Controller parameters | Value |
| Magnetizing inductance | 2.9 Pu | DC bus voltage (Kp) | 8 |
| Inertia constant | 0.685 | DC bus voltage (Ki) | 400 |
| Pairs of poles | 3 | Grid side converter (Kp) | 0.83 |
| Friction factor | 0.01 | Grid side converter (Ki) | 5 |
| Turbine parameter | Value | Speed regulator (Kp) | 3 |
| Output power (MW) | 1.5 | Speed regulator (Ki) | 0.6 |
| Wind speed (m/s) | 11 | Rotor side converter (Kp) | 0.6 |
| | | Rotor side converter (Ki) | 8 |
| Drive train parameters | Value | Pitch controller (Kp) | 3 |
| Wind turbine inertia | 4.32 s | Pitch controller (Ki) | 30 |
| Shaft spring constant | 1.11 torque/rad | Max pitch angle | 27 |
| Shaft mutual damping | 1.5 Pu | Rate of change of pitch angle | 10 |

Table A-2. DFIG-Based System parameters

| TR1 parameters | Value | TL1 Parameters/Km | Value |
|---|---|---|---|
| Vector group | YgD1 | Frequency | 50 Hz |
| Nominal power | 12 MVA | Pos. seq. resist. (Ohm) | 0.1153 |
| Frequency | 50 Hz | Zero seq. resist. | 1.05e-3 |
| V1/V2 | 25e3/575 | Pos. seq. Inductance | 0.413 |
| Win. 1 Resistance | 0.001 Pu | Zero seq. Inductance (H) | 3.32e-3 |
| Win. 1 Inductance | 0.025 Pu | Pos. seq. capacitance(F) | 11.33e-9 |
| Win. 2 Resistance | 0.001 Pu | Zero seq. capacitance(F) | 5-e9 |
| Win. 2 Inductance | 0.025 Pu | Line length (Km) | 10 |
| Mag. Resistance | 500 | TL2 Parameters/Km | Value |
| Mag. Inductance | Inf. | Frequency | 50 Hz |
| TR2 parameters | Value | Pos. seq. resist. (Ohm) | 0.1153 |
| Vector group | YgD1 | Zero seq. resist. (Ohm) | 1.05e-3 |
| Nominal power | 12 MVA | Pos. seq. Inductance | 0.413 |
| Frequency | 50 Hz | Zero seq. Inductance | 3.32e-3 |
| V1/V2 (KV) | 120/25 | Pos. seq. capacitance(F) | 11.33e-9 |
| Win. 1 Resistance | 0.001 Pu | Zero seq. capacitance(F) | 5-e9 |
| Win. 1 Inductance | 0.025 Pu | Line length (Km) | 20 |
| Win. 2 Resistance | 0.001 Pu | Grid Parameters | Value |
| Win. 2 Inductance | 0.025 Pu | Pos. seq. resist. (Ohm) | 0.576 |
| Mag. Resistance | 500 | Zero seq. Resist. | 1.728 |
| Mag. Inductance | Inf. | Pos. seq. Inductance | 0.0183 |
| | | Zero seq. Inductance | 0.055 |

Table A-3. PV parameters

| PV parameters | Value | Converter Parameters | Value |
|---|---|---|---|
| Parallel strings | 88 | Number of bridge arms | 3 |
| Series module | 7 | Snubber resistance | 1e6 ohm |
| Max. Power (W) | 414.801 | Power electronic device | IGBT/ Diodes |
| Cells per module | 128 | Internal resistance (Ron) | 1e-3 ohm |
| $V_{Oc}$(V) | 85.3 | IGBT forward volt. | 0 |
| $I_{Sc}$ (A) | 60.9 | Diode forward volt. | 0 |
| $V_m$(V) | 72.9 | Filter parameters | Value |
| $I_m$ (A) | 5.69 | R (m ohm) | 0.3745 |
| $\alpha$ (%/deg.C) | -0.299 | L (mH) | 0.0994 |
| $\beta$ (%/deg.C) | 0.03076 | C ($u$F) | 0.1061 |

Table A-4. PV-Based Test System parameters

| TR1 parameters | Value | TL Parameters/Km | Value |
|---|---|---|---|
| Vector group | YgD1 | Frequency | 60 Hz |
| Nominal power | 25 MVA | Pos. seq. resist. (Ohm) | 0.1153 |
| Frequency | 60 Hz | Zero seq. resist. (Ohm) | 1.05e-3 |
| V1/V2 | 25e3/250 | Pos. seq. Inductance | 0.413 |
| Win. 1 Resistance | 0.0012 Pu | Zero seq. Inductance (H) | 3.32e-3 |
| Win. 1 Inductance | 0.03 Pu | Pos. seq. capacitance(F) | 11.33e-9 |
| Win. 2 Resistance | 0.0012 Pu | Zero seq. capacitance(F) | 5-e9 |
| Win. 2 Inductance | 0.03 Pu | Line length (Km) | 14 |
| Mag. Resistance | 200 | Grid Parameters | Value |
| Mag. Inductance | 200 | Pos. seq. resist. (Ohm) | 0.576 |
| TR2 parameters | Value | Zero seq. resist. (Ohm) | 1.728 |
| Vector group | YgD1 | Pos. seq. Inductance | 0.0183 |
| Nominal power | 47 MVA | Zero seq. Inductance | 0.055 |
| Frequency | 60 Hz | Laod (2) parameters | Value |
| V1/V2 (KV) | 120/25 | V (KV) | 25 |
| Win. 1 Resistance | 0.0027 Pu | F (HZ) | 60 |

| | | | |
|---|---|---|---|
| Win. 1 Inductance | 0.08 Pu | P | 30MW |
| Win. 2 Resistance | 0.0027 Pu | QL | 2MW |
| Win. 2 Inductance | 0.08 Pu | QC | 0 |
| Mag. Resistance | 500 | Mag. Inductance | 500 |