ADVANCED VECTOR SHIFT ALGORITHM FOR ISLANDING DETECTION

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ABSTRACT

In order to improve the reliability of vector shift based islanding detection an advanced vector shift algorithm has been developed. This algorithm can use all three phase voltages or a positive sequence voltage for vector shift detection and will not cause nuisance tripping of DG units due to other network disturbances. To validate the developed algorithm, a medium-voltage (MV) distribution network with DG units has been modelled in the PSCAD simulation software. The algorithm is validated for its dependability, stability and fast operation with simulated real islanding and different non-islanding events like faults, capacitor switching and connection of a parallel transformer.

INTRODUCTION

One of the key protection functionalities in Smart Grids will be reliable detection of islanding (or loss-of-mains, LOM). Although the trend in new grid codes is to require fault-ride-through (FRT) capability from distributed generation (DG) units and possibly also to allow island operation, there is still a need to reliably detect the islanding situation to make the correct operations, such as, change the setting group of a DG interconnection relay or change the control principles and parameters of a DG unit. Non-detection zone (NDZ) near power balance situations and unwanted DG trips due to other network events (nuisance tripping) have been the major challenges with traditional passive local islanding detection methods. If the number of DG units in the distribution networks increases, as is expected in the future, the risk of power balance situations will also increase. Therefore, the risk of possible operation in the NDZ of the traditional passive islanding detection methods also will increase. In addition, *f*, *U* and rate-of-change-of-frequency (ROCOF) will be used more often for defining the DG unit FRT requirements in the new grid codes to enable utility grid stability supporting functionalities from DG units [1], [2].

Due to the above-mentioned reasons in [1], a new, future-proof, passive islanding detection algorithm without NDZ has been proposed. On the other hand, in [2] it has been proposed that centralized active network management functionalities (CANM) at the MV level, like voltage control or losses minimization, could in the future include an algorithm which, in real time, confirms the operation of reliable islanding detection, even based on passive methods like voltage phase angle-based methods or voltage vector shift. The algorithm proposed in [2] continuously ensures that there is enough reactive power unbalance that the operation point remains constantly outside the NDZ of the used islanding detection method.

The focus of this paper is on development of traditional passive islanding detection based on voltage vector shift. Voltage vector shift is still used for islanding detection in many countries, although in Europe some countries, such as Germany and Denmark, have forbidden its use for LOM detection due to its sensitivity to nuisance tripping. However, in order to improve the reliability of vector shift based islanding detection (no or less nuisance tripping of DG units due to other network events), an advanced vector shift algorithm has been developed and is presented in this paper.

This algorithm uses all three phase voltages or positive sequence voltage for vector shift detection and will not cause nuisance tripping of DG units due to other network disturbances.

To validate the developed algorithm, a MV distribution network with DG units has been modelled in the PSCAD simulation software. The algorithm is validated for its dependability, stability and fast operation with simulated real islanding and different non-islanding events like faults, capacitor switching and connection of a parallel transformer. The developed vector shift algorithm is also implemented to the intelligent electronic device (IED) and the behavior of the algorithm is validated by injecting the simulated COMTRADE-files through an IED test setup.

In the following sections, the basic vector shift principle and the developed advanced vector shift algorithm are shown first. After that, the study network and example simulation results are presented followed by conclusions.

PROPOSED ADVANCED VECTOR SHIFT ALGORITHM

Basic vector shift principle

The principle of voltage vector shift after islanding is explained with the help of the following system example. Figure 1 shows a synchronous generator equipped with a vector shift relay operating in parallel with a distribution network.

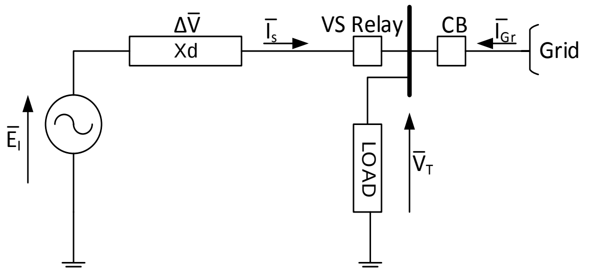

Figure 1. Equivalent circuit of a synchronous generator operating in parallel with the grid

When the generator current I_s is passing through the generator reactance X_d, there is a voltage difference ΔV between the terminal voltage V_T and the generator internal voltage E_I (Figure 1). Consequently, there is a displacement angle θ between the terminal voltage and generator internal voltage. The phasor diagram is shown in Figure 2(a). After the circuit breaker opens, the system consisting of the generator and load becomes islanded. At this same time instant, the synchronous generator begins to feed a larger (or smaller) load because the current I_{Gr} provided by the grid is interrupted. Due to this, the angular difference between V_T and E_I is suddenly increased (or decreased) and the terminal voltage phasor changes its position as shown in Figure 2(b). The sudden vector shift due to islanding can also be seen in the voltage waveform in Figure 2(c).

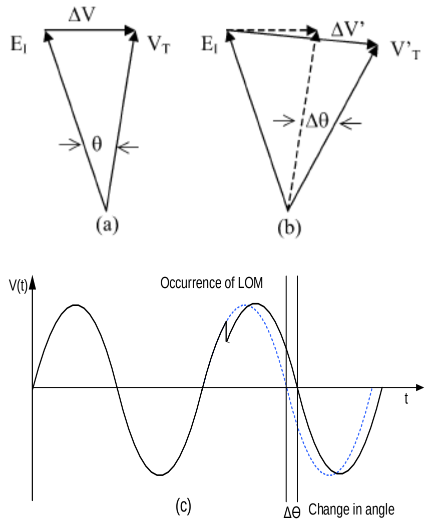

Figure 2. Internal and terminal voltage phasors: (a) before islanding (b) after islanding. (c) vector shift in voltage waveform

Generally, vector shift relays measure the duration of each cycle of the voltage signal from each phase. The duration of the present cycle is compared with the previous cycle (which is considered as reference). In an islanding situation, the cycle duration is either shorter or longer depending if there is excess or deficit of active power in the islanded system. If the measured vector shift angle $\Delta\theta$ in the terminal voltage exceeds a predetermined threshold α, a trip signal is immediately sent to the circuit breaker.

Some further analysis and comparisons related to different vector shift algorithms etc. can be found from references [3]-[5].

Advanced vector shift algorithm

The proposed advanced vector shift algorithm is presented in the form of a flowchart in Figure 3. This new algorithm uses all three phase voltages or a positive sequence voltage for vector shift detection. The developed algorithm takes simultaneously into account the behavior of voltage and frequency, adapts to steady-state frequency variations and has time-dependent correlation checks between phase voltages (when all three phase voltage are used). The vector shift algorithm is blocked, when any of the measured voltages drop below or increase above the threshold values.

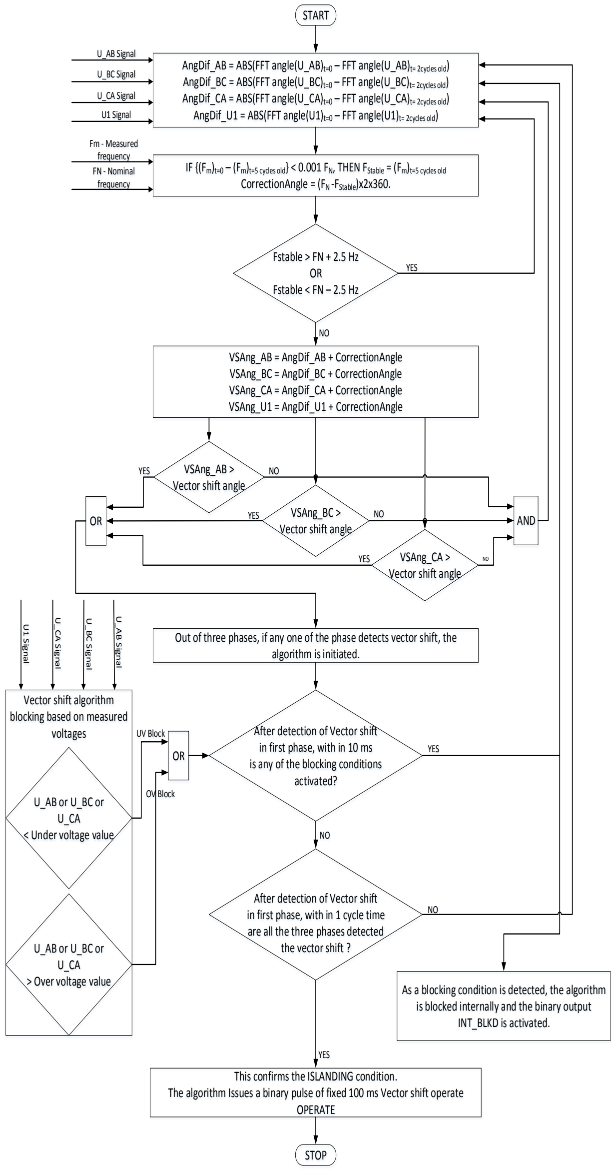

Figure 3. Flowchart of the developed advanced vector shift algorithm

VALIDATION OF DEVELOPED NEW VECTOR SHIFT ALGORITHM

Study network

A typical MV distribution network with DG units has been modelled in the PSCAD simulation software (Figure 4). In the study network, the HV network is at 110 kV, the MV network at 21 kV and the LV network at 0.4 kV voltage levels. The load is mainly constant impedance-based passive load (cos(φ)=0.965 with larger MV island and cos(φ)=0.98 with smaller MV island and cos(φ)=0.9725 with cable lines), and small part of the load is constant power load. The system line types and line parameters are also presented in Figure 4. Simulations were done with a directly connected synchronous generator (SG) based DG unit at the MV feeder and other DG units as well as de-centralized compensation coils were disconnected (Figure 4).

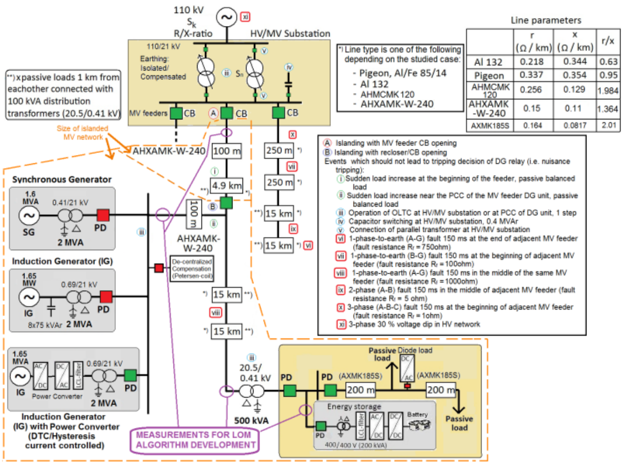

Figure 4. Study network used in PSCAD simulations

The advanced vector shift algorithm is tested for its dependability and stability in different simulation cases. The simulated islanding cases consist of testing the dependability of the algorithm in cases where the algorithm is supposed to operate. All these islanding cases are simulated by opening the MV feeder CB (‘A’ in Figure 4) or the recloser CB (‘B’ in Figure 4) at time 20.0 s and by closing the CB 0.3 s later i.e. at 20.3 s. The faults and other network disturbances related simulation cases, i.e. cases where the algorithm should not operate, were done to test the stability of the algorithm.

During the PSCAD simulations from different cases, the phase-to-phase voltage measurements (U_{AB}, U_{BC}, U_{CA}) from the MV network and the LV network are recorded to a COMTRADE-file format. The proposed algorithm is tested with these voltage measurements from different simulated cases and the results are presented in the following sections. During the testing, the algorithm pick-up value setting, i.e. vector shift angle, was 5 degrees and the algorithm blocking settings for undervoltage was 0.80 pu and for overvoltage 1.2 pu.

Real Islanding Cases

Islanding in Small Power Unbalance

When islanding in small power unbalance, the local generation is a bit larger (or smaller) than the local load in the MV network. When the generation is larger than the load, the power is exported to the utility grid. Respectively, if the local generation is smaller than the local load, then the deficit power is imported from the utility grid. However, results for the vector shift algorithm are similar in both cases if the size of the power unbalance is equal. In Figure 5, phase-to-phase voltage magnitudes, voltage vector shift angle behaviour and binary output signals (operate and internal blocking) for vector shift algorithm are presented.

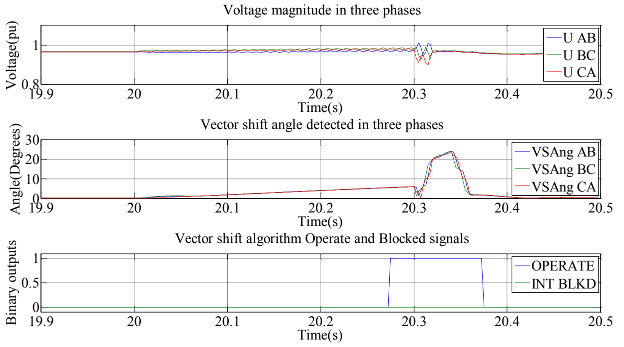

Figure 5. Vector shift algorithm operation during islanding in small power unbalance

From Figure 5, it can be seen that after islanding at 20.0 s, the vector shift angles start to increase in all three phases. After the detected vector shift angle has increased above the pick-up setting, the algorithm issues an OPERATE pulse output at around 20.25 s, because no blocking conditions have been activated.

Islanding in Large Power Unbalance

This case is similar to the previous one, but the power unbalance before islanding is now larger (Figure 6).

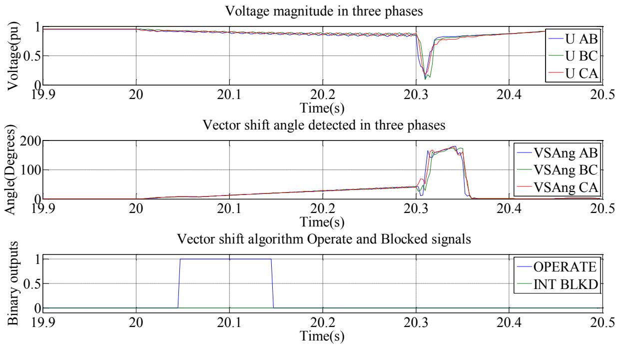

Figure 6. Vector shift algorithm operation during islanding in large power unbalance

From Figure 6, one can see that after islanding at 20.0 s, the vector shift angles start to increase in all three phases. When compared with the islanding in small power unbalance, the vector shift can now be detected faster as expected. In this case, the algorithm issues an OPERATE pulse output at around 20.05 s.

Faults and Other Network Disturbances

Phase-to-Earth Fault

In this case, the phase-to-earth (A-G) fault for 150 ms, is applied in the middle of the same MV feeder (‘viii’ in Figure 4), i.e. 15 km from the recloser CB. Fault resistance R_f = 1000 Ω. In Figure 7, phase-to-phase voltage magnitudes, voltage vector shift angle behavior and binary output signals for vector shift Operate and blocking are presented.

From Figure 7, it can be observed that during the A-G fault, the vector shift angles are only 0.3 degrees in two phase-to-phase voltages (U_{AB}, U_{CA}). Because the detected vector shift angles are less than the pick-up setting and the vector shift is not detected in all three phases, the developed vector shift algorithm is not operated.

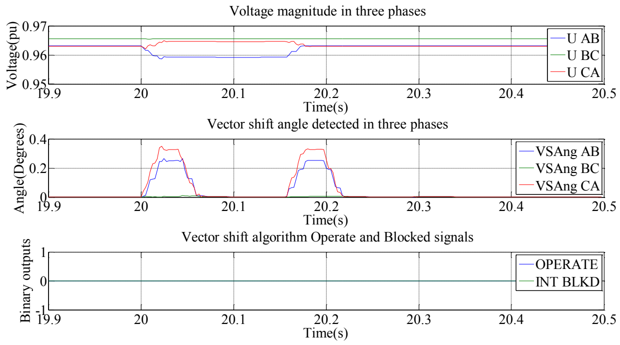

Figure 7. Vector shift algorithm behavior during A-G fault in the middle of the same MV feeder

Phase-to-Phase Fault

In this case, the phase-to-phase (A-B) fault for 150 ms is applied in the middle of the adjacent MV feeder ('ix' in Figure 4). Fault resistance R_f = 5 Ω. The results are presented in Figure 8.

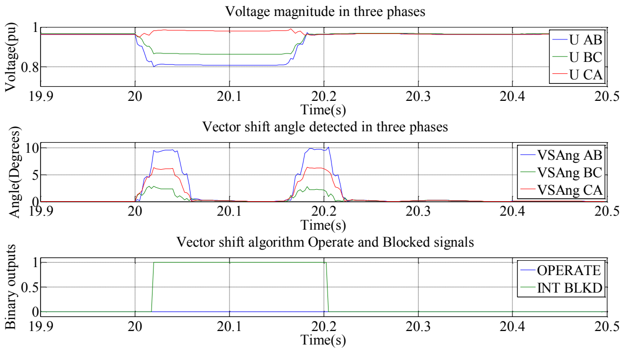

Figure 8. Vector shift algorithm behavior during A-B fault in the middle of the adjacent MV feeder

From Figure 8, it can be seen that during the A-B fault, the U_{AB}, U_{CA} voltages vector shift angles are above the pick-up setting (5 degrees), but the vector shift angle of U_{BC} is below the setting. The U_{AB} voltage magnitude is just below the set undervoltage value (0.8 pu), which caused activation of the algorithm internal block (INT_BLKD). Due to these issues, the developed vector shift algorithm is not operated.

Three-Phase Fault

In this case, the 3-phase (A-B-C) fault with fault resistance R_f = 1 Ω for 150 ms is applied at the beginning of the adjacent MV feeder ('x' in Figure 4). The results are shown in Figure 9.

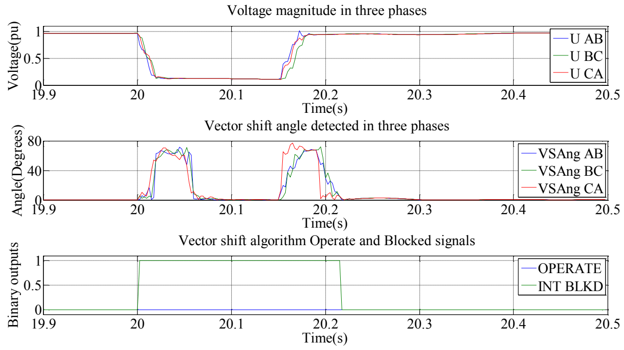

Figure 9. Vector shift algorithm behavior during A-B-C fault at the beginning of the adjacent MV feeder

From Figure 9, one can see that during the A-B-C fault, all three phase-to-phase voltages vector shift angles are significantly above the pick-up setting (5 degrees). But the three phase-to-phase voltage magnitudes are below the set undervoltage value (0.8 pu), which caused activation of the algorithm internal block (INT_BLKD). Due to this internal blocking the developed vector shift algorithm is not operated.

30% Voltage Dip in HV Network

In this case, the 3-phase 30 % voltage dip is simulated in a 110 kV HV network ('xi' in Figure 4). The results are presented in Figure 10.

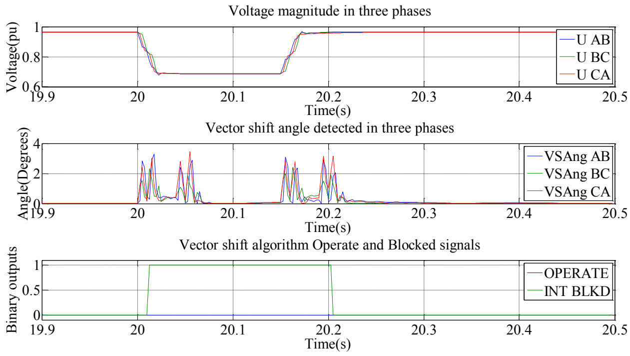

Figure 10. Vector shift algorithm behavior during a 3-phase 30% voltage dip in HV network

From Figure 10, it can be observed that during a 30 % voltage dip in the HV network, all three phase-to-phase voltage magnitudes are below the set undervoltage value (0.8 pu), which caused activation of the algorithm internal block (INT_BLKD).

Capacitor Switching at HV/MV Substation

In this case, the capacitor switching at the HV/MV substation is simulated ('iv' in Figure 4).The results are presented in Figure 11.

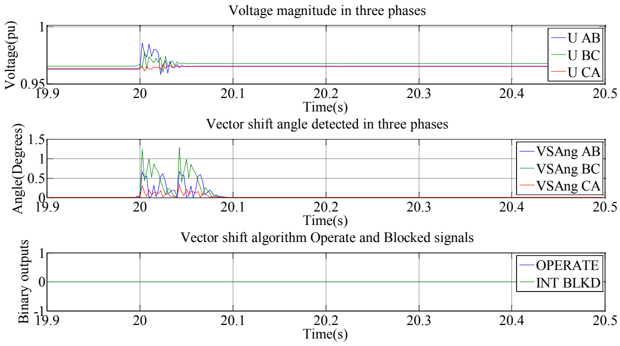

Figure 11. Vector shift algorithm behavior during capacitor switching event

From Figure 11, it can be seen that during capacitor switching, the voltage magnitudes are stable around 1 pu and the vector shift angles around 1 degree. The detected vector shift angles are less than the setting and vector shift is not detected in all three phases. Due to these issues the proposed vector shift algorithm is not operated.

Connection of Parallel Transformer at HV/MV Substation

In this case, parallel transformer at the HV/MV substation is connected to the system ('v' in Figure 4). The results are presented in Figure 12.

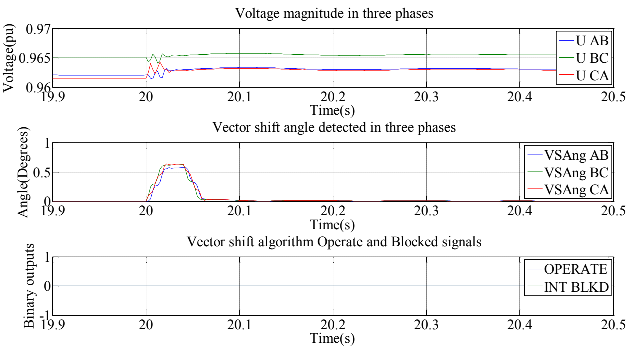

Figure 12. Vector shift algorithm behavior when connecting a parallel transformer

From Figure 12, one can see that when connecting a parallel transformer, the voltage magnitudes are stable around 1 pu and the vector shift angles around 0.5 degrees. The detected vector shift angles are less than the setting and therefore the proposed vector shift algorithm is not operated.

CONCLUSIONS

In this paper a new advanced vector shift algorithm is presented to improve the dependability and stability of the voltage vector shift based islanding detection. The developed algorithm can adaptively correct the measured vector shift angle based on the steady-state frequency variations, which makes the algorithm immune to steady-state frequency variations. Based on the presented test results, it can be concluded that the developed algorithm successfully detects the islanding condition during small and large power unbalances. In addition, the algorithm can reduce DG unit nuisance tripping because it is stable during various network disturbances like faults, capacitor switching and connection of parallel transformer.

Although the proposed vector shift algorithm guarantees fast and reliable islanding detection in nearly all operational conditions when the DG unit is running in parallel with the utility grid supply, certain cases may still cause mal-operations. If the power unbalance before islanding is very small and the detected vector shift angle is therefore also small, the function may not operate. This means that the vector shift algorithm, like many traditional passive islanding detection methods, still has NDZ near a power balance situation. Therefore, other passive methods for detecting the islanding without NDZ should be further developed. Potential methods to deal with this NDZ issue could be, for example, the multi-criteria based passive islanding detection method [1] or use of active MV network management [2].

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