A Comparison between Frequency Relays and Vector Surge Relays for Synchronous DG anti-islanding Protection

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Abstract— **Investigations show that reactive power mismatch affects frequency relays performances. Vector surge relays (VSRs) being frequency based relays are widely used for islanding detection in power systems. Considering similarities between frequency relays'(FRs') and VSRs' performances, it is suggested that FRs can detect islanding conditions as well as VSRs, however no evidence is presented for comparing FR and VSR performances in case of reactive power mismatch. This paper presents a comparison of FR and VSR islanding detection protection performances considering reactive power mismatch. The results confirm the validity of replacing VSRs with FRs.**

Keywords: Distributed Generation, Islanding Detection, Active Power Mismatch, Reactive Power Mismatch, Frequency Based Relay

I. INTRODUCTION

A distributed synchronous generator protection system must be able to follow the regional council requirements for off-nominal frequency performance and also it must be able to detect islanding situations within recommended time intervals. By definition islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system, yet continues to be energized by distributed generators [1], [2]. Energizing an islanded network may cause a number of problems for the distributed generator (DG) itself and connected loads. It may also harm utility personnel since it is thought that networks die after substation feeder breaker disconnection [3], [4]. Therefore all networks must acquire islanding protection system [5]. VSRs are usually used for this purpose. All synchronous DGs are also equipped with under/over frequency relays. Since these two relays act considering utility frequency, the possibility of replacing one with another should be investigated.

Simulation results presented in [1] have shown that frequency relays can detect synchronous DGs islanding as efficiently as VSR relays, then there is no need to use VSR relays for anti-islanding protection. FR relays can both detect islands and also meet frequency-tripping requirements. In [6] it has been proved that the frequency relay's performance curve depends on reactive power mismatch, but these effects were not considered in [1]. In this paper the two relays are compared considering effects of both active and reactive power mismatches. System parameters are adjusted in a manner that reactive power mismatch is fixed at the islanding instant of different studied cases. Active power mismatch is slightly varied. Following this procedure the impact of both active and reactive power mismatches can be studied.

The paper is organized as follows; Section II presents the system and load models under study. Section III compares FR and VSR performances for anti-islanding protection considering reactive and active power mismatches and Section IV summarizes the results and presents important conclusions.

II. FR / VSR RELAYS PRINCIPLE

Fig. 1 shows the test system used in this paper for anti-islanding protection studies. This system comprises a 30 MW synchronous generator (SG) connected to bus 5. The SG is equipped with an automatic voltage regulator represented by SCRX-19 model and also a governor controls the mechanical torque. The governor model is developed in [7]. Electrical loads do affect on a system islanding conditions so two constant impedance loads are connected to the network. These kinds of loads are used in simulations because they cause the worst conditions for frequency based relays to detect island situations adequately [3], [8]. The local system is connected to the utility, through a 33 MVA, 33/132kV Dyn power transformer. Transformers are modeled using T circuit.

A Computational model of the FR considered in this study is depicted in Fig. 2. System frequency f is determined using generator rotation speed; ω_e. The relay sends a trip command to the generator circuit breaker if the system frequency f passes pre-determined limits whilst generator voltage terminal magnitude is greater than V_{min}. FR relays consider terminal voltage magnitude to avoid tripping during generator start-up [2].

Load energizing causes an angle between terminal and internal voltage phasors of the generator. This angle is shown in Fig. 3 as δ. In the figure if CB opens, the generator must feed larger or smaller load, so the rotor speed decreases or increases respectively. Rotor speed variation causes change in δ.

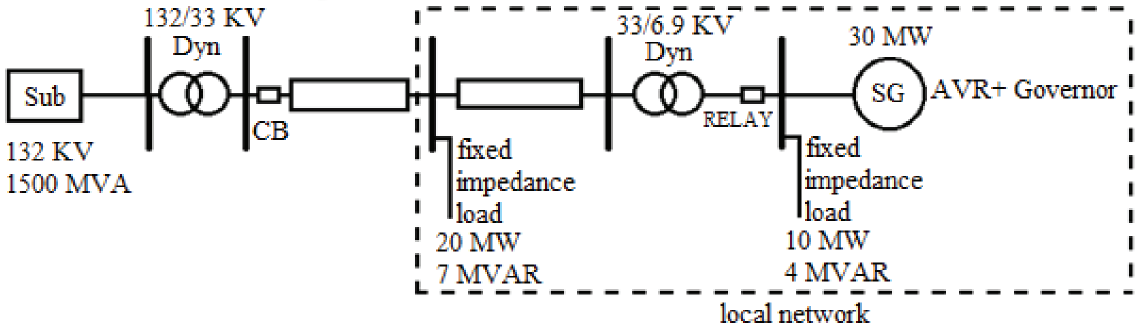

Fig. 1. Single line diagram of the test system

In Fig. 4 point A relates to an islanding instant. As it can be noticed, terminal voltage magnitude and frequency change at the islanding instant. VSR relays are developed based on these variations.

VSR relays start measuring voltage duration time at each zero rising instant. Each duration time is compared with the previous one. Variations of the cycle duration results in a proportional variation of the terminal voltage angle $\Delta\delta$. If difference between the recent $\Delta\delta$ and the previous $\Delta\delta$ exceeds a pre-determined threshold whilst terminal voltage magnitude is greater than V_{min}, the relay sends a trip signal to the generator circuit breaker [9].

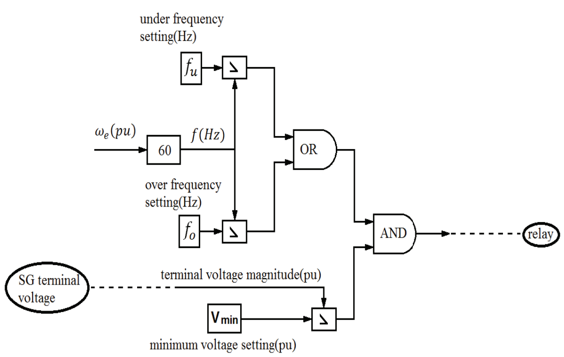

Fig. 2. Computational model of an FR

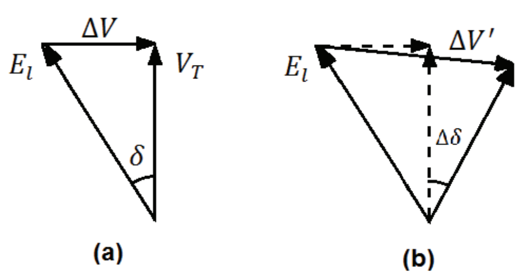

Fig. 3. Internal and terminal voltage phasors: a) while CB is closed, b) after CB opening.

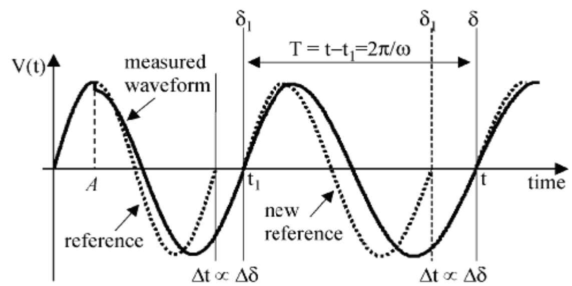

Fig. 4. Voltage vector jump at islanding instant and the VSR cycle-by-cycle measurements.[3]

To get an analytical insight about the relationship between active power imbalance and frequency based relays operation, studying the following equations can be beneficial. Synchronous generators swing equation is:

$$\begin{cases} \dfrac{2H}{\omega_0}.\dfrac{d\omega}{dt} = P_M - P_L = \Delta P \\ \dfrac{d\delta}{dt} = \omega - \omega_0 \end{cases} \tag{1}$$

Having the above equation one can conclude:

$$\omega = \frac{\omega_0.\Delta P}{2H}.t + \omega_0 \tag{2}$$

and then:

$$\omega_0 + \Delta\omega = \frac{\omega_0.\Delta P}{2H}.t + \omega_0 \Rightarrow \Delta\omega = \frac{\omega_0.\Delta P}{2H}.t \tag{3}$$

Substituting ω with $2\pi f$ results the next equation:

$$\Delta f = \frac{f_0.\Delta P}{2H}.\Delta t \tag{4}$$

Which means that Δt seconds after islanding occurrence, the terminal voltage frequency of the synchronous generator in the island whose inertia constant equals H gets $f_0 + \Delta f$ if the active power imbalance in the island equals ΔP .

III. Comparing FR and VSR Islanding Detection Capabilities Considering Reactive Power Mismatch

Simulations are performed on the test system of Fig. 1. The reactive power of the SG is set at a fixed point and the local network is islanded by opening the CB at t=195s. Fig. 5 shows the active power output of the generator and Fig. 6 shows its terminal voltage frequency. These figures are related to the situation that active power imbalance (ΔP) is 0.51pu at the islanding instant and the reactive output power of the SG is 0.14pu.

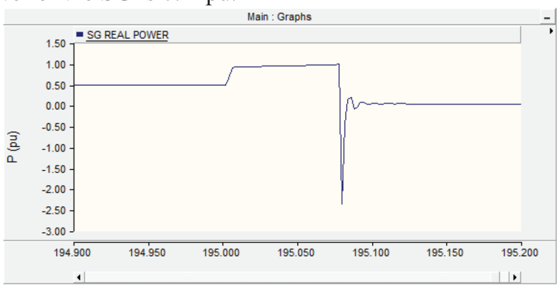

Fig. 5. SG active power

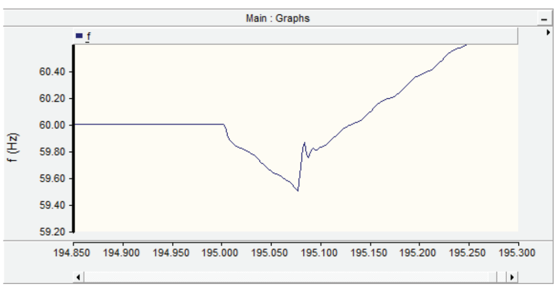

Fig. 6. SG terminal voltage frequency

As it can be observed the output active power is increased due to governor operation after islanding. Since generated active power affects system frequency, governor effects should be considered in simulations.

The governor increases output active power after islanding but even this increase cannot meet demanding power. The terminal voltage diminishes as a consequence. After generator disconnection at instant $t = 195.075$ sec the SG terminal voltage increases.

On the following, islanding detection capabilities of FRs and VSRs are compared considering different reactive power mismatches. The local system is islanded by opening the circuit breaker CB. At each case, reactive output of the SG is adjusted at one specific amount and the active power output of the SG is slightly varied. So relays performance curves at different active power imbalance quantities for a specific reactive output would be obtained.

For different reactive power output quantities, the performance curves of the VSR and the FR are represented respectively in Fig. 7 and Fig. 8. Results show that performances of both relays depend on SG reactive power output. So it is necessary to compare the relays performance curves at different SG reactive output to determine whether they behave similarly in different conditions.

In the following figures minus Qout means that the SG is absorbing reactive power, a viable condition which occurs while a synchronous generator is under-excited.

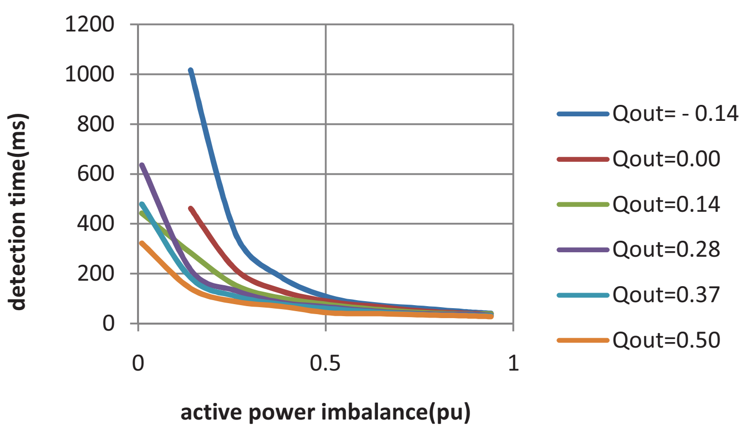

Fig. 7. Performance curves of an FR for different amounts of SG reactive output

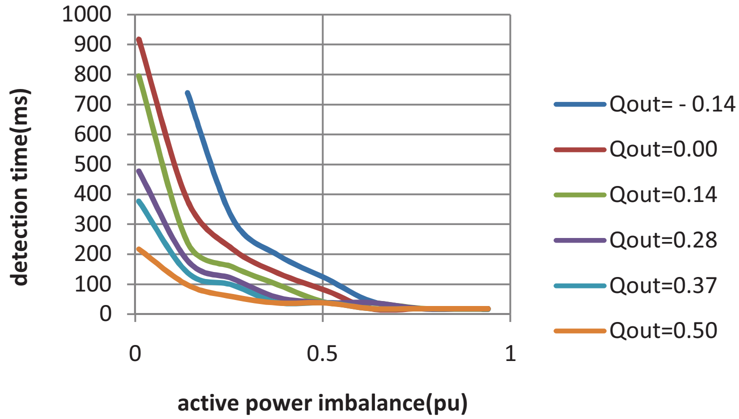

Fig. 8. Performance curves of a VSR for different amounts of SG reactive output

In all related figures detection time decreases with an increase in active power imbalance. Since at high active power imbalance the islanded system electric quantities deteriorate very quickly, this is a desirable operation.

In Figs. 9, 10 and 11 performance curves of FR and VSR relays at different reactive output of SG are compared. Both relays behave very similarly at different SG reactive output then it can be concluded that installing a VSR is unnecessary for islanding detection. Besides it can be noted that increasing SG reactive output leads to detection time shortage, so it can be stated that by adjusting SG reactive output at higher levels, one can reduce islanding detection time.

One can determine how much active power imbalance a relay needs to detect islanding condition within a specific time using the following figures. Islanding condition must be detected within 200ms in some networks while there are networks in which a 1sec detection time is acceptable [1]. In Fig. 10 for example, FR needs at least 0.11pu active power imbalanace to detect islanding within 200ms while VSR needs 0.1pu.

Given active power imbalance quantity, detection time can be obtained using performance curves. In Fig. 9 for instance, the FR detects islanding after 320ms if there is 0.2pu active power imbalance while it takes 280ms for the VSR to detect islanding in the same condition.

Although at both cases discussed above the VSR shows better performance for islanding detection, the difference is not significant. Besides protecting system simplicity and economical savings would be very attractive.

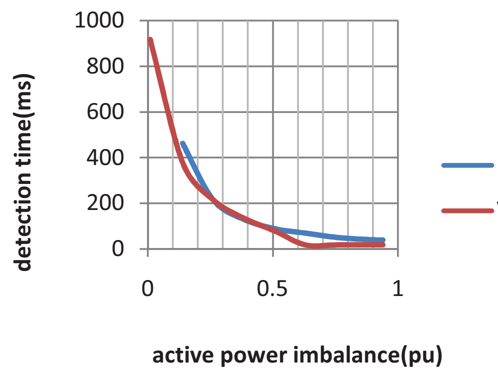

Fig. 9. Performance curves of the FR and the VSR at $Q_{out} = 0.00$

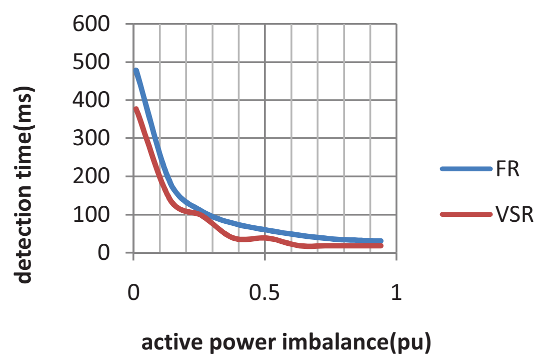

Fig. 10. Performance curves of the FR and the VSR at $Q_{out} = 0.37\ pu$

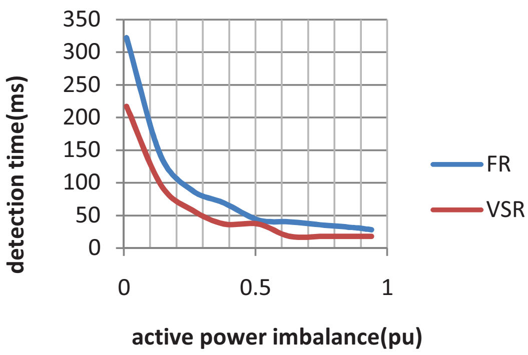

Fig. 11. Performance curves of the FR and the VSR at $Q_{out} = 0.50\ pu$

IV. Conclusion

This paper presented a comparison between an FR and a VSR capabilities for synchronous generator anti islanding protection. The following important notes are concluded:

- VSRs and FRs present very similar performances for anti-islanding detection at different reactive output power of DG. An FR can both handle frequency deviation and anti-islanding protection so there is no need to install a VSR relay for islanding detection.
- At higher levels of SG reactive output, FRs can detect island faster so adjusting DGs at higher reactive output is recommended.

References

[1] J.C.M. Vieira; W. Freitas; Wilsun Xu; A. Morelato, "Performance of Frequency Relays for Distributed Generation Protection", *IEEE Trans. Power Del.*, vol. 21, No. 3, July 2006.

[2] Vieira, J.C.M.; Freitas, W.; Morelato,A.; Leo, J.C., "Dynamic Models of Frequency and Voltage Based Relays for Distributed Generation Protection", in *Power Tech, 2005 IEEE Russia*

[3] W. Freitas, Z. Huang, and W. Xu, "A practical method for assessing the effectiveness of vector surge relays for distributed generation applications," *IEEE Trans. Power Del.*, vol. 1, pp. 57–63, Jan. 2005

[4] Maki, K.; Kulmama, A; Repo, S.; Jarventausta, P., "Problems related to Islanding Protection of Distributed Generation in Distribution Network,"in *Power Tech, 2007 IEEE Lausanne*

[5] Far, Hamed Golestani; Rodolakis, Anthony J.; Joos, Geza.; "Synchronous Distributed Generation Islanding Protection Using Intelligent Relays", in *IEEE Trans. Smart Grid,* vol. 3, pp. 1695-1703, Dec. 2012.

[6] H. H. Zeineldin, "Application Region of Frequency Relays for Distributed Generation", in *Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*

[7] P. Kundur, Power System Stability and Control. New York: McGraw Hill, 1994

[8] Zhu, Yanwei W.; Shi, Xin-Chun.; "Analysis of the influence of load to islanding passive detection method", in *Information Management and Engineering (ICIME), 16-18 April 2010*

[9] Vieira, J.C.M.; Freitas, W.; Xu, W.; Morelato, A., "Evaluation of the Distributed Generators Frequency Protection Due to Changes in the Anti-Islanding Requirements", in *Power Engineering Society General Meeting, 2006. IEEE*