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# THE IMPACT OF SAMPLING FREQUENCY ON THE ACCURACY OF TRAVELLING WAVE-BASED FAULT PROTECTION METHODS

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*This paper investigates the impact of sampling frequency on the effectiveness of travelling wave-based fault detection and location in cases when the fault is very close to the relay location. The arrival times of consecutive reflected travelling waves in such situations may result in errors if the sampling frequency of the relay is too low. Effectively, this will limit the accuracy of estimated fault location. This issue is investigated by simulating a fault close to the relay and observing the extracted voltage travelling waves for different sampling frequencies. The results confirm a strong correlation and prove that high accuracy will require higher sampling frequencies.* References 7, figures 4.
***Keywords**:* Travelling wave, line protection, fault location, sampling frequency

**Introduction**. Technological advancement of microprocessors allows for more demanding algorithms to be implemented and at higher sampling rates. This also applies to power system protection schemes, which already have seen sampling rates as high as 1 MHz [1]. This opens new possibilities for practical application of methods, which so far existed only in the academic domain. One of such applications is the theory of travelling waves in transmission lines, which existed in the literature for several decades [2], but becomes more and more popular nowadays [3-7]. There are many advantages of applying travelling wave theory to fault detection and location in transmission lines, such as much shorter detection times, independence from fault resistance and high accuracy of fault location. On the other hand, disadvantages include the requirement for high sampling rates in order to capture the high frequency components, as well as the problem of the frequency range of traditional current and voltage transformers. This paper focuses on investigating the former, especially in the context of hypothetical single-end fault detection and location algorithms in cases when a fault is very close to the location of the relay. Such situation is problematic due to the fact that it creates multiple travelling wave reflections within a very short period of time. This, in turn, brings a question of the required sampling rate and its impact on the effectiveness of algorithms in such cases. For two-end methods with communication this may not be a problem, but methods based only on local measurements may have limited effectiveness for very close faults. The purpose of this paper is to perform a preliminary study in the aforementioned topic as it is often overlooked and faults closer than 4-5% of line length are not discussed when fault location algorithms are proposed. Additionally a wider range of sampling frequencies are investigated. Typically specific sampling frequency is assumed and investigated.

**Problem formulation**. Travelling wave theory states that a fault in a transmission line creates voltage and current travelling waves propagating with a constant speed, close to the speed of light, in both directions from the location of the fault (fig. 1). These travelling waves also undergo reflections, which happen at discontinuities created by network connection points, such as buses. The main concept of fault detection and location based on travelling waves assumes that knowing the propagation speed of travelling waves, the arrival times of direct and reflected travelling waves indicate whether the fault is in the protected line as well as the location of the fault in the line.

Fig. 1 depicts a case, in which the fault is close to bus A, where the relay is installed. It can be observed, that the travelling wave arrives several times at bus A before the initial travelling wave even reaches bus B. Assuming that a single-end algorithm is employed at bus A, the distance to the fault seen from bus A can be obtained with the following formula:

$$m = 0,5(t_2 - t_1)v \qquad (1)$$

where $t_1$ is the arrival time of the initial travelling wave; $t_2$ is the arrival time of the reflected travelling wave and $v$ is the travelling wave propagation speed.

It is obvious that as the distance to the fault as seen from bus A decreases, the difference between the arrival times of the initial and reflected travelling waves will also decrease. It can be expected that at some point the frequency of the arriving travelling waves will be so high, that the assumed sampling frequency may not be sufficient for accurate distinction of consecutive travelling waves. This paper assumes a small


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distance to the fault and investigates the impact of sampling frequency on the identification of consecutive travelling waves arriving at the relay location.

In order to obtain the travelling waves from instantaneous voltage signals the following procedure has been applied. First, to decouple the phase measurements, the popular Clarke transformation [4] is applied:

$$\begin{bmatrix} v^{(0)}(t) \\ v^{(1)}(t) \\ v^{(2)}(t) \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & \sqrt{3} \end{bmatrix}\begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \qquad (2)$$

where $v^{(0)}(t)$ is the ground mode; $v^{(1)}(t)$ and $v^{(2)}(t)$ are two aerial modes. The first aerial mode is then select for further processing, as it contains the necessary transient information. The high frequency content is then extracted using a discrete wavelet transform (DWT) [4]. For this purpose the optimal results were obtained with Daubechies 1 (db1) wavelet.

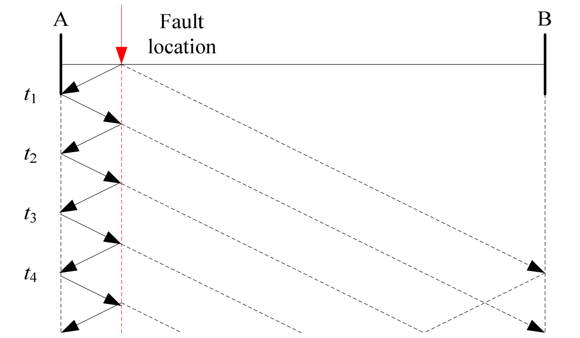


**Fig. 1**

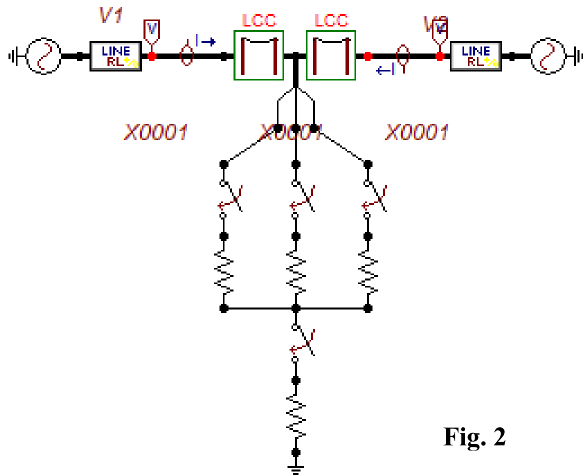


**Fig. 2**

**Results.** A simple test system depicted in fig. 2 and modelled in ATP/EMTP software has been used to obtain the test signals. The base simulation frequency has been set to 10 MHz and was later decimated to lower frequencies with the use of an appropriate anti-aliasing low-pass filter.

A 3-phase fault has been simulated 1 km from the relay location, whereas the line is 240 km long. Often testing for faults below 5 % of line length is neglected and in this case the fault is located at 0.42 % of line length. During the testing 4 different sampling frequencies have been used - original 10 MHz, 1 MHz 0.5 MHz and 0.2 MHz. The fault starts a $t$=50 ms.

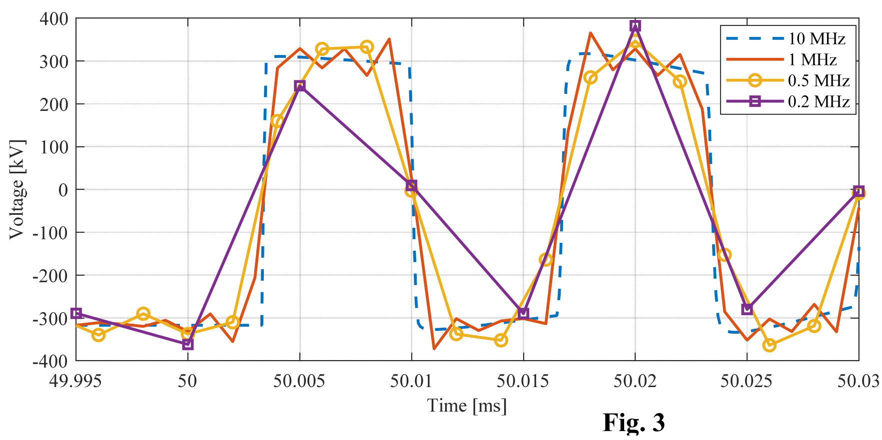


**Fig. 3**

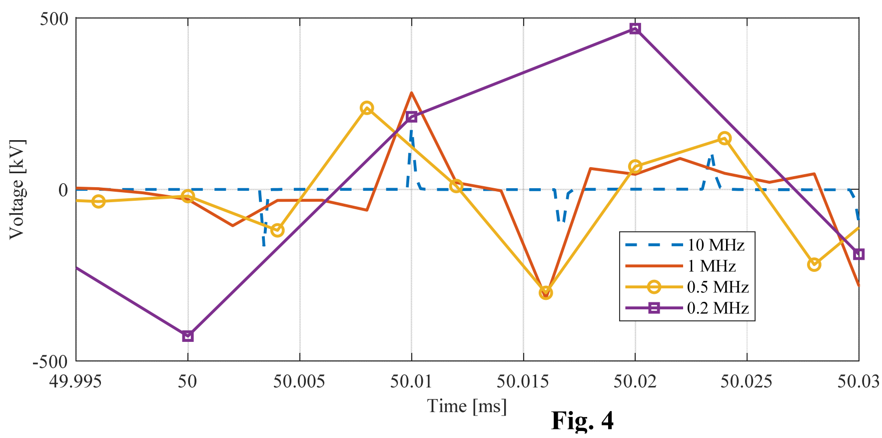


**Fig. 4**

Fig. 3 shows the instantaneous values of phase *a* voltage $v_a(t)$ for different sampling frequencies. It can be clearly observed that as the sampling frequency decreases the amount of detail to be extracted for further processing also decreases and the time information may not be accurately maintained anymore. The details extracted by the DWT presented in fig. 4 show that accurate arrival time of consecutive voltage travelling waves is maintained only for the highest sampling frequency. Lower sampling frequency of 1 MHz retains part of the information with 2 peaks being visible, but the accuracy is already limited by the time resolution. The arrival time information is almost completely lost for lower sampling frequencies.

**Conclusions.** This paper presented a short investigation into the impact of sampling frequency on the effectiveness of traveling wave-based protection methods for faults located very close to the relay. An extreme case of a fault located 1 km from the relay has been tested for 4 different sampling frequencies from 10 MHz to 0.2 MHz. It has been observed that only the highest sampling frequency retains accurate arrival time information of the voltage travelling waves. With a sampling frequency of 1 MHz part of the details has been retained, but the time information was not as accurate anymore due to the time resolution. The lowest tested sampling frequencies had too low time resolution to allow extraction of any details.

It should be noted that these observations are specific to the DWT used in this work and it is possible that other methods of detail extraction could perform better. Nevertheless, the strong impact of the sampling frequency will always be visible for very short distance to the fault.


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УДК 621.314

**ВЛИЯНИЕ ЧАСТОТЫ ДИСКРЕТИЗАЦИИ НА ТОЧНОСТЬ ОПРЕДЕЛЕНИЯ МЕСТА КОРОТКОГО ЗАМЫКАНИЯ ПО МЕТОДУ БЕГУЩИХ ВОЛН**

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*Проведен анализ влияния частоты дискретизации сигналов, основанный на принципе бегущих волн, на эффективность локализации места повреждения, когда короткое замыкание расположено вблизи локализатора. В такой ситуации время регистрации последовательных отраженных волн может подвергаться помехам. Это явление анализируется с помощью компьютерных симуляций коротких замыканий вблизи локализатора путем наблюдения бегущих волн напряжения при изменении частоты дискретизации регистрированных сигналов. Результаты испытаний подтверждают строгую корреляцию этих явлений и тот факт, что высокая точность оценки места повреждения требует применения высокой частоты дискретизации наблюдаемых сигналов.* Библ. 7, рис. 4.

***Ключевые слова:*** бегущая волна, защита линии, локализация короткого замыкания, частота дискретизации сигнала

**ВПЛИВ ЧАСТОТИ МОДУЛЯЦІЇ НА ТОЧНІСТЬ ВИЗНАЧЕННЯ МІСЦЯ КОРОТКОГО ЗАМИКАННЯ ЗА МЕТОДОМ БІЖУЧИХ ХВИЛЬ**

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*Проведено аналіз впливу частоти дискретизації сигналів, заснований на принципі біжучих хвиль, на ефективність локалізації місця пошкодження, коли коротке замикання розташоване поблизу локалізатора. У такій ситуації час реєстрації послідовних відбитих хвиль може піддаватися завадам. Це явище аналізується за допомогою комп'ютерних симуляцій коротких замикань поблизу локалізатора шляхом спостереження біжучих хвиль напруги за зміною частоти дискретизації реєстрованих сигналів. Результати випробувань підтверджують чітку кореляцію цих явищ і той факт, що висока точність оцінки місця пошкодження вимагає застосування високої частоти дискретизації спостережуваних сигналів.* Бібл. 7, рис. 4.

***Ключові слова:*** хвиля, що біжить; захист лінії, локалізація короткого замикання, частота дискретизації сигналу

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