EFIKASNA SINHRONIZACIJA DIZEL GENERATORA U USLOVIMA PROMENLJIVE FREKVENCIJE

IMPROVED SYNCHRONIZATION OF DIESEL GENERATORS IN VARIABLE FREQUENCY CONDITIONS USING PREDICTIVE METHOD

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U radu je razmatrana sinhronizacija dizel generatora ostrvskog napajanja nominalne snage 2MW koji se često uključuju na mrežu. Efikasno korišćenje vetrogeneratora sa promenljivim generisanjem energije podrazumeva brzo i efikasno uključivanje i sinhronizaciju dizel agregata kako potrošači ne bi ostali bez napajanja. Razmatrana metoda prediktivne sinhronizacije ima znatnih prednosti nad konvencionalnih metoda sinhronizacije jer omogućuje sinhronizuaciju generatora za najkraće vreme. Primena adaptivnih neuro-fuzi sistema je metoda koja daje najbolje rezultate.

Ključne reči: *ostrvsko napajanje; sinhronizacija dizel generatora; prediktivna sinhronizacija; neuro-fuzi logika*

The synchronization of diesel generators of island power supply with a nominal power of 2MW, which are often connected to the network is discusses in this paper. Fast and efficient switching on and synchronization of diesel generators so that consumers do not run out of power implies efficient use of wind turbines with variable energy generation. The considered method of predictive synchronization has significant advantages over conventional synchronization methods because it enables generator synchronization in the shortest time. The application of adaptive neuro-fusion systems is the method that gives the best results.

Key words: *Island power supply; synchronization of diesel generators, predictive synchronization, neuro-fusion logic*

1 Introduction

The main sources of electricity in isolated power systems (IPS) are traditionally diesel generators. Diesel generators are a proven technology. With IPS, the maintenance of these systems has higher costs, so they must be robust enough to reduce maintenance costs. Some IPSs introduce wind turbines to reduce the cost of electricity generation and greenhouse gas (GHG) emissions. The large share of wind turbines is caused by large variations in the frequency of the system, which results in a long-term synchronization process, especially when diesel generators are synchronized. Long synchronization can compromise network stability, especially with small IPSs.

Unlike conventional networks, IPSs not only deliver less power (usually MW, not GW), but are also much smaller in space. Consequently, consumption is less predictable. Being smaller on the surface means that the supply from the RE source is more variable - such as a higher percentage of RE generators that are likely to be affected by the same weather events (e.g. wind calm or cloud formation).

In smaller IPS, the problem of variation is much smaller because mainly rechargeable batteries are used to stabilize the frequency [01] and satisfactory results are obtained.

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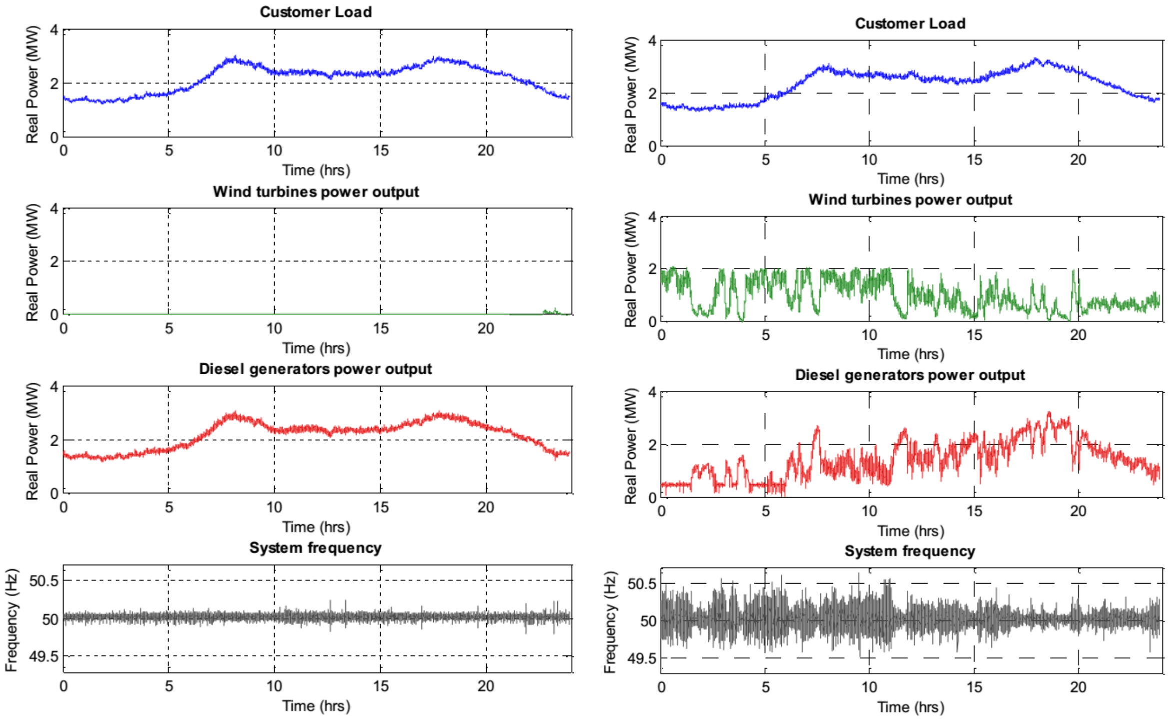
2 Standard generator synchronization

An example of a load curve for IPS with wind turbines is shown in Figure 1. The high variability of the load makes the operation of the diesel engine heavier and less efficient and requires more generator start-up during the day. As a result, the synchronization equipment installed for diesel generators works more often and in more difficult operating conditions.

The synchronization process enables the connection of the generator to the power system, so that the generator is set to correspond to the frequency and phase of the power network. When these two signals are close enough to each other, it is allowed to close the generator switch and after that the generator is electrically connected to the power supply system.

Classic analog synchronizers use signals for system voltage and generator phases. Based on the generator status signal and the power supply phase phase system, standard synchronization generator This signal is processed using an internal PI synchronizer (proportional-integral) controller. After processing, the signal is sent to the diesel engine controller. Diesel engines have a delay in responding to changes in steering, which is usually around 250 ms. When the generator starts to respond to the speed correction signal, it slowly changes to a new value [02]. When the synchronizer sees that the diesel generator and mains frequencies and phases are within the allowable limits, it commands the switch (CB) to react. The automatic synchronizer provides automatic connection of the unit to the network at the time of equalization of voltage, frequency and phase voltage of the generator and the network, ie reducing their difference to defined limits, where there are no excessive electromechanical stresses that could lead to damage or disconnection.



a) without wind turbines *b) with wind turbines*

Figure 1. Network frequency in IPS, as a consequence of load during the day and generation of electricity from wind turbines and diesel generators

Classic synchronizers use PID control loops and differ only in the way the state is calculated. [03]. A normal synchronization process takes less than 8 seconds, and extended synchronization can take more than 30 seconds.

3 Predictive synchronization method

Although a large share of wind has clear advantages because it uses cost reduction and emissions on the one hand, and on the other hand prolongs the process of synchronization of diesel generators and endangers the energy stability of the system. To maintain high wind usage while avoiding generator synchronization problems, a predictive synchronizer model has been developed to reduce synchronization time [04].

The basic idea of this predictive synchronizer is to predict the frequency and phase of the system two seconds into the future and then set the generator to meet that prediction. If the prediction is accurate accurate (e.g. ±10° phase), hunting between the synchronizing diesel and the system will be avoided.

The predictive synchronizer, whose functional diagram is shown in Figure 2, differs from the classic synchronizers in two ways:

a) It compares predicted, instead of current, frequency and phase signals to the power system frequency and phase. This is presented in Figure 3 as an additional functionality of the signal conditioning module.

b) It does not use a PID loop, but sends a step change into the governor speed reference signal. This is presented in the Figure 3 as a Step Command Module. Engine time delay is the same as diesel engine delay presented in figure 3. Operation of the predictive synchronizer can be described as a five-step process (Figure 3):

1. At the start of the synchronization process, the system frequency (f_{SYS}), the synchronizing generator frequency (f_{GEN}) and their phases (φ_{SYS} and GEN, respectively) are measured rom voltage signals V_{SYS} and V_{GEN} at a specific time interval and recorded. (Figure 3(a) shows this for system frequency only.) The differences between the system and generator frequencies ($\Delta f = f_{SYS} - f_{GEN}$) and the system and generator phases ($\Delta\varphi = \varphi_{SYS} - \varphi_{GEN}$) are calculated.
2. Based on the recorded time-series of the system frequency, $f_{SYS}\ (t-n), \ldots, f_{SYS}\ (t-2)$, $f_{SYS}\ (t-1)$, $f_{SYS}\ (t)$ and the system phase, $\varphi_{SYS}\ (t-n), \ldots, \varphi_{SYS}\ (t-2)$, $\varphi_{SYS}\ (t-1)$, $\varphi_{SYS}\ (t)$, a predictive module calculates the (very near) future values for the system frequency, $f_{SYS}\ (t+n)$ and its phase $\varphi_{SYS}\ (t+n)$, as presented in Figure 3(b). This figure practically shows system frequency brought a few seconds ahead in time based on the prediction.
3. Using frequency and phase difference (Δf, $\Delta\phi$) plus the predicted values for system frequency and phase (f_{SYS} (t +n), and ϕ_{SYS} (t +n)), the speed reference signals for the synchronizing generator governor are calculated based on the equal area criterion [05] and issued to the governor. Because both frequency and phase need to be within allowed limits, the synchronizer will issue two speed step commands to the synchronizing generator governor. The first step shifts the generator phase to the desired value, while the second step puts the generator in the predicted position for synchronization. The two steps are communicated as a step-up signal issued at t, and a stepdown signal at t, (Figure 3(c)).
4. After a short delay (engine delay), the generator responds to given speed correction commands from the synchronizer (Figure 3(d)).
5. If the frequency and phase predictions are within allowable limits, this adjustment of the speed will result in matching generator frequency and phase to the system. Synchronization has been achieved, so the Check Synch module issues CB close signal at (Figure 3(e)) to bring the generator online.

Correct prediction of the system frequency and phase on a very short-term time scale is a vital part of the proposed approach to synchronization in IPSs. In this chapter, very short-term prediction is defined as look-ahead period of 2 seconds. However, there is no reliable system for very short-term time-series prediction.

Both the frequency and phase represent a time series which can be defined as a set of observations of a parameter, or set of parameters, taken at a number of time intervals. These intervals are usually (although not always) of a regular length. Real-world time series are diverse. Some time series data changes slowly and relatively smoothly, for example monthly electricity demand. Other time series can exhibit chaotic behaviour, making their prediction very challenging. A frequency time series of an IPS with high wind penetration, such as in Figure 3, possesses these characteristics.

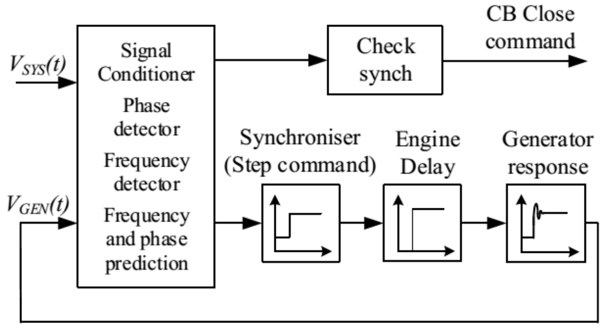


Figure 2. Functional diagram of the predictive synchronizer control loop.

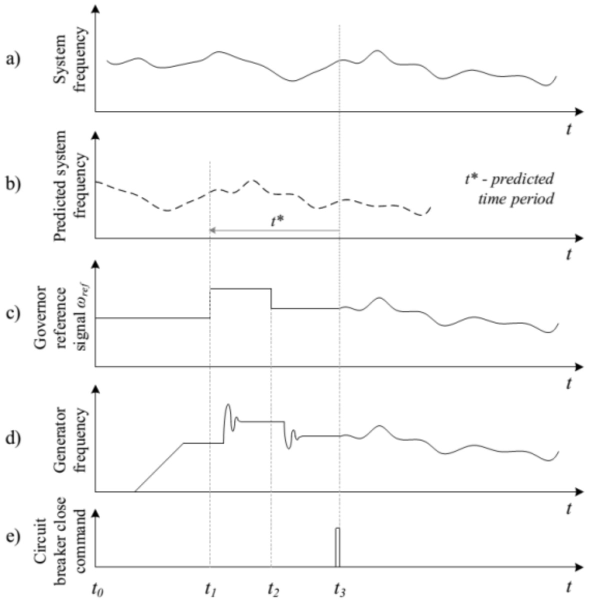


Figure 3. .Operation of the predictive synchronizer.

The time scale is important when trying to create a prediction system. Two main classes of techniques have been used for very short-term predictions. These are statistical methods and methods based upon artificial neural networks (ANN). The statistical methods are autorecursive. This means they use the difference between the predicted and actual values in the immediate past to tune the model parameters. The neural networks use past data taken over a longer time-frame to learn the relationship between the input data and output wind speeds. The accuracy of these methods degrades rapidly with increasing prediction lead time.

Prediction research is a growth area and increasingly often this research involves the use of artificial intelligence. In next text, a hybrid approach was investigated – a combination of an ANN and fuzzy logic for very short-term system frequency and phase prediction.

4 Application of neuro-fusion logic

The application of fuzzy (i.e. fuzzy logic based) and adaptive neuro-fuzzy (i.e. neural networks incorporating fuzzy logic) interference system (ANFIS) techniques for application in power systems with wind turbines and diesel generators has been proposed by several authors [06-08].

Two ANFIS systems have been developed for system frequency and phase prediction, one for frequency prediction and the other for phase prediction. ANFIS model proposed by Roger Young [09] is a modern neural network. ANFIS uses a hybrid algorithm that combines least squares estimation and gradient drop methods. First, the initial activation functions are assigned to each membership neuron. The functional centers of the neurons connected to the input are set so that the domain is divided equally, and the widths and slopes are set to allow sufficient overlap of the corresponding functions. In the ANFIS training algorithm, each training epoch is composed of back and forth passes.

In the anterior transition, a set of input pattern training (input vector) is presented to ANFIS, the neuron outputs are calculated at The layer-by-layer and parameters that follow from the rules are identified. A detailed description of ANFIS is given in [10].

It should be mentioned that the regulator helps maintain the stability of the power system during faults and transient processes. This is achieved by using subfrequency load rejection (UFLS), where some loads are switched off, so that most of the system loads are saved. Because dynamic processes occur very quickly during faults (within a few seconds), the diesel generator synchronization process cannot be used.

5 Results of application of the predictive synchronization method

Finally, a synchronizer using ANFIS as a prediction technique is simulated. The result shows an average time of 18 s, which is an improvement over both the conventional synchronizer and the simulated synchronizer with the basic prediction technique.

It is important to note that the simulation results show that the predictive synchronizer has achieved statistically better performance compared to the classical synchronizer. However, the presented result does not mean that the predictive synchronizer will work better in every possible scenario.

It is also interesting to compare the accuracy of the prediction between the moving average and the ANFIS prediction technique. error prediction frequency than ANFIS.

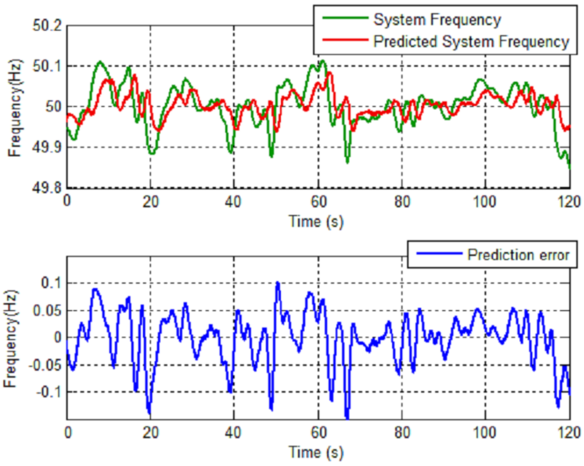


Figure 4. Moving average prediction results. Mean frequency prediction error was ~0.043Hz

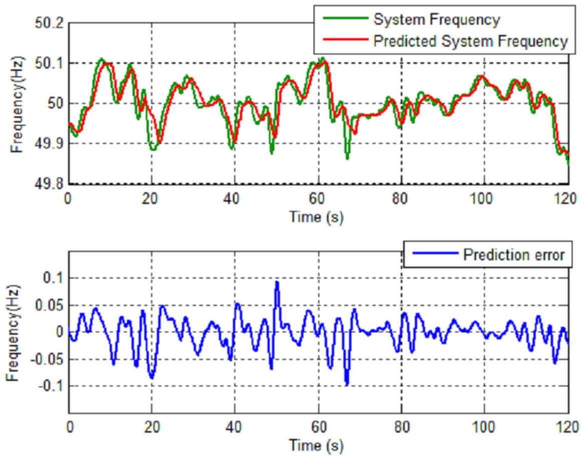


Figure 5 ANFIS prediction results and prediction error example.
Mean frequency prediction error was ~0.019Hz

Although only examples of frequency prediction are shown in Figure 4 and Figure 5, phase prediction shows similar results.

6 Conclusion

This chapter identifies some synchronization challenges in IPSs with strong wind penetrations. As a solution to the problem of extended synchronization, the concept of the proposed synchronization of diesel generators in these IPSs in future synchronizers for diesel generators operating in IPSs with high RE penetration is proposed. The model of the predictive synchronizer was developed and tested on the recorded data of the actual wind power supply system.

Two main conclusions can be drawn from Figure 4 and Figure 5:

a) ANFIS prediction technique is more suitable for use in predictive synchronization of processes due to higher prediction accuracy.

b) ANFIS technique is accurate enough to be used in the IPS diesel generator synchronization process, because it reduces the synchronization time and thus increases the stability of the system

Finally, further ANFIS neural network adjustments, better processing power, and future prediction techniques could predict even better results in the next prediction of synchronization devices.

The simulation results showed that the predictive synchronizer provides statistically better performance results compared to the classical synchronizer. This results in a significantly reduced synchronization time (on average) of diesel engines during periods of strong wind penetration.

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