ADVANCED TECHNIQUE FOR SOFT SYNCHRONIZER IN CHP COGENERATION

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ABSTRACT
In this work, a controller has been used to synchronize between two parallel operations. Two AC systems, an electric power system and synchronous generator have been used in parallel operation. Due to many drawbacks in traditional control, a proper synchronization is not achieved. Here in a new idea and technology of soft synchronizer which is devised and lead to proper synchronization. To see the effectiveness of the proposed controller along with implementing new idea, a simulation study on MATLAB has been shown for effectiveness. The study showed perfect phase angle match for two parallel AC systems.

KEYWORDS: *Combined heat and power (CHP), cogeneration, signal conditioning, micro grids, simulation, synchronization, synchronizer, MATLAB.*

I. INTRODUCTION

The advanced features of the future power system that will be made up electrical and thermal loads as well as of large numbers of on-site distributed energy resources (DER) is shown by consortium for electrical reliability technology solutions (CERTS) micro grid concept [1]. As micro grid provides number of benefit is divided into two major groups as given one is the power quality and reliability factor and the other one is an economical and environmental factor [2]. Now days the fact is that the inverter-based generation is the general tendency for the renewable and new DER, an alternator based combined heat and power (CHP) cogeneration provides high energy efficiency as well as reliable performance compared to the other intermittent renewable energy resources. Hence, combine heat and power (CHP) cogeneration is concern as a core and the key requirement of the micro grid if it is applicable [3], [4].

As CHP provide high energy efficiency and for given input fuel it produce 80% output by utilizing both electricity and wasted heat it's getting lot of attention. One of the advantages in using a high efficient system is that it become less the total amount of carbon dioxide (CO_2) emission. It may increase the payment rate of the electricity by decrease the facility's peak demands. As a result of this we had developed a new, small CHP cogeneration system. The figure 1 below shows a block diagram of the CHP cogeneration system which includes the major controllers. The system consists of a synchronous generator and a gas engine that is controlled by an engine control unit (ECU) and a digital automatic voltage regulator (DAVR), respectively. And for the collection of wasted heat, a heat recovery unit was installed. The integrated control unit (ICU) is one of main controller of the CHP cogeneration system. The soft synchronizer plays an important role in the inauguration of the electric power system (EPS) parallel operation as one of the ICU's auxiliary functions.

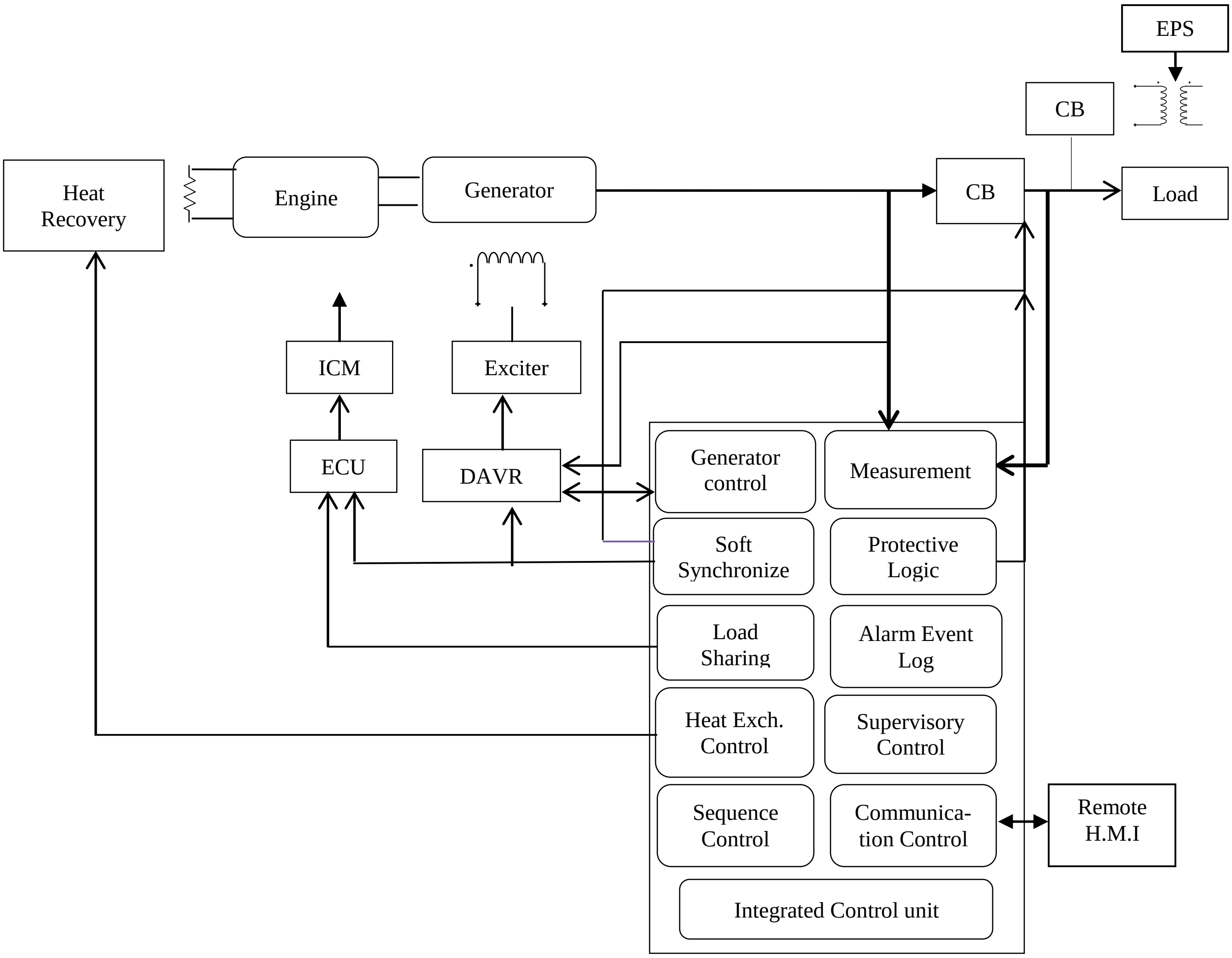

Figure 1: Block diagram of Combined Heat and Power (CHP) cogeneration system

Three conditions are referred to as the synchronizing criteria. Those are phase-angle, slip frequency, and the voltage difference has to be match as close as possible for paralleling ac generators. When those parameters are matched, two individual systems may begin a parallel operation by closing the breaker contact. In case of large scale generator that has less number of synchronization events per year [5], but in case of small CHP generator has frequent start/ stop/ synchronization events. According to a survey report, there are major four devices which mainly used for synchronization presently. These devices listed as voltage relays, Sync-check relays, automatic synchronizer and the synchronizing relays [5]. The belief handed down to posterity for measuring the synchronizing condition is use the zero crossing signals of two voltages. Due to high accuracy and simple structure Zero crossing method is widely used. The major disadvantage is that, particularly on long measurement period and is weak against harmonics and noises [6].

For getting better performance, strenuous exertions have been made such as Smart discrete Fourier transforms (DFT) or the modified zero-crossing. DFT-based frequency measurement has an advantage against harmonics. Despite this the calculation has a delay of N DFT samples. The phasor-based method used some microprocessor-based synchronizers and sync-check relays, [7]. So as to get the protection of slip frequency, most of the devices simply use a method of delaying a breaker. In this paper, a synchronizing technique is introduced. It contains novel approaches regarding the calculation of signals for the synchronizing criteria, signal conditioner, and zero phase-angle difference estimation. In this paper, a new synchronizing technique is introduced. It contains novel approaches regarding the calculation of signals for the synchronizing criteria, signal conditioner, and zero phase-angle difference estimation. In Section II, basic theory and advance synchronizing technique are explained. In Sections III and IV, Simulation and result of a comparison between traditional and proposed technique is evaluated by simulation.

II. ADVANCED SYNCHRONIZING TECHNIQUE

As we need to measure three major signals to begin parallel operation. In this part, we propose a simple but efficient solution to check the synchronizing criteria.

1. Identifying Signals for Synchronizing

Using frame transformation in symmetric three-phase variables (f_a, f_b, f_c) can be transformed into a stationary direct axis f^{α} , and a quadratic axis is f^{β} as

$$\begin{bmatrix} f^{\alpha} \\ f^{\beta} \end{bmatrix} = T_1 . \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}, \qquad T_1 = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{-\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \tag{1}$$

The relation in between stationary and rotating axis can be given as

$$\begin{bmatrix} f^{d} \\ f^{q} \end{bmatrix} = T_2(\theta_r) . \begin{bmatrix} f^{\alpha} \\ f^{\beta} \end{bmatrix}, \qquad T_2(\theta_r) = \begin{bmatrix} \cos\theta_r & \sin\theta_r \\ -\sin\theta_r & \cos\theta_r \end{bmatrix} \tag{2}$$

Despite of this, if it is transformed into the rotating axis at a speed of ω_r and if we assume $\omega_r = \omega$ then they look like being stand still on the rotating axis. This transformation can be expressed by the following equation:

$$\begin{bmatrix} f^{d} \\ f^{q} \end{bmatrix} = T(\theta_r) . \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \tag{3}$$

The transformation matrix is $T(\theta_r) = T_2(\theta_r)$

$$T(\theta_r) = \frac{2}{3}\begin{bmatrix} \cos\theta_r & \cos(\theta_r + \frac{2\pi}{3}) & \cos(\theta_r - \frac{2\pi}{3}) \\ -\sin\theta_r & -\sin(\theta_r + \frac{2\pi}{3}) & -\sin(\theta_r - \frac{2\pi}{3}) \end{bmatrix} \tag{4}$$

The angle between rotating f^d and stationary f^{α} is defined as the following equation:

$$\theta_r = \int_0^t \omega_r(T)dt + \theta_r(0) \tag{5}$$

Relating to the vector control, it is ordinary to synchronize ω_r to ω in order to decouple the variables as the torque and the magnetization component. And we synchronize them to the phase voltages by using the phase-locked loop (PLL).

The transformation above is known as “Park’s transformation and it commonly used in a three-phase electric machine. The magnitude and the angle of the original signal can be mark out by using the following equations.

$$\text{Mag} = \sqrt{f_q^2 + f_d^2} \tag{6}$$

$$\text{Angle} = \tan^{-1} {f_q}/{f_{d.}} \tag{7}$$

The three-phase voltages of the Electrical Power System are given as V_u, V_v, V_w and for the synchronous generator is V_r, V_s, V_t by taking the reference frame transformation we ($V^d_{(UVW)}$, $V^q_{(UVW)}$) and ($V^d_{(RST)}$, $V^q_{(RST)}$) can be obtained. The voltage difference is given by following equation.

$$V_{diff} = \sqrt{{V^d_{UVW}}^2 + {V^q_{UVW}}^2} - \sqrt{{V^d_{RST}}^2 + {V^q_{RST}}^2} \tag{8}$$

The phase-angle difference of θ_s is measured as

$$\theta_s = \left(\frac{\pi}{4} - \theta_1\right) - \left(\frac{\pi}{4} - \theta_2\right) = \tan^{-1}\frac{V^q_{RST}}{V^d_{RST}} - \tan^{-1}\frac{V^q_{UVW}}{V^d_{UVW}} \tag{9}$$

And the frequency between two voltages can be calculated as follows:

$$F_{slip} = \frac{\omega_s}{2\pi} = \frac{1}{2\pi}\frac{\partial\theta_s}{\partial t} \tag{10}$$

2. Signal Conditioner

Signal Condition is an easy algorithm in this angle is calculated at each sampling Period. Disadvantage of this feature is oscillation occurs in original signal. The excessive unbalance in signal is protected by a phase unbalance protector that prevents the generator breaker operation. Due to small amount of unbalance in source signal occurred, synchronizer regulate properly. By adding signal conditioner in the signal conditioning block we can calculate the phase of a positive-sequence phasor and the magnitude and we made virtual three phase symmetric signals with the same magnitude of the original phasor. As a result, we will get a better phase-angle measurement from the original signals. The positive-sequence voltage calculated by using following equation

$$V_1 = \frac{1}{3}(V_a + aV_b + a^2V_c) \tag{11}$$

We can create virtual three-phase signals by using the positive-sequence voltage and the phase operator that are symmetrical.

$$[\widetilde{V_a} \quad \widetilde{V_b} \quad \widetilde{V_c}]^T = [1 \quad a^2 \quad a]^T . V_1 \tag{12}$$

Those virtual signals were made by a positive-sequence voltage that has averaging effects on the original signals in magnitude and phase aspects.

3. Calculating Phase-Angle Difference

Now a day many of the current auto synchronizers make a decision of circuit–breaker (CB) closing by the place of time of a phase-angle difference with predetermined limits closing outside of the limit that will bring collision between two voltages [8].
The usual dwell time for the sync check relay is decided by the calculation from the desired slip frequency and the phase-angle difference limit. Therefore, the actual break closing may occur within the limit, but not exactly on the zero point of the phase-angle difference. We can calculate an estimated phase-angle difference right on the moment when the breaker will close as

$$\hat{\theta} = \theta_k + T_{bd}\frac{\theta_k - \theta_{k-1}}{\Delta t} \tag{13}$$

Where,

$\hat{\theta}$ − Estimated phase-angle difference
θ_k, θ_{k-1} − Phase-angle difference of k^{th} and $(k-1)^{th}$ step
T_{bd} − Breaker closing time delay
Δt − Sampling time

By performing frequent estimation and by using the very narrow phase-angle difference limits($\pm 1^0$), we had obtained a zero phase-angle difference for the actual breaker closing. The traditional measurement using the zero-crossing method can measure once or twice in a voltage cycle, but the new method based on reference frame transformation has better and faster performance because of its immediate measurement feature.

III. SIMULATION

The effectiveness of the new synchronization can be verified as shown in the block representation of MATLAB Simulink of Diesel engine generator connected to electrical power system by the synchronizer. For the simulation of electrical power systems which contains equipments such as three-phase machines, trans-formers, R-L-C loads, transmission lines, three-phase breakers, in MATLAB, SimPower Systems is one of the designing tool that allows users to build models rapidly and easily [9].

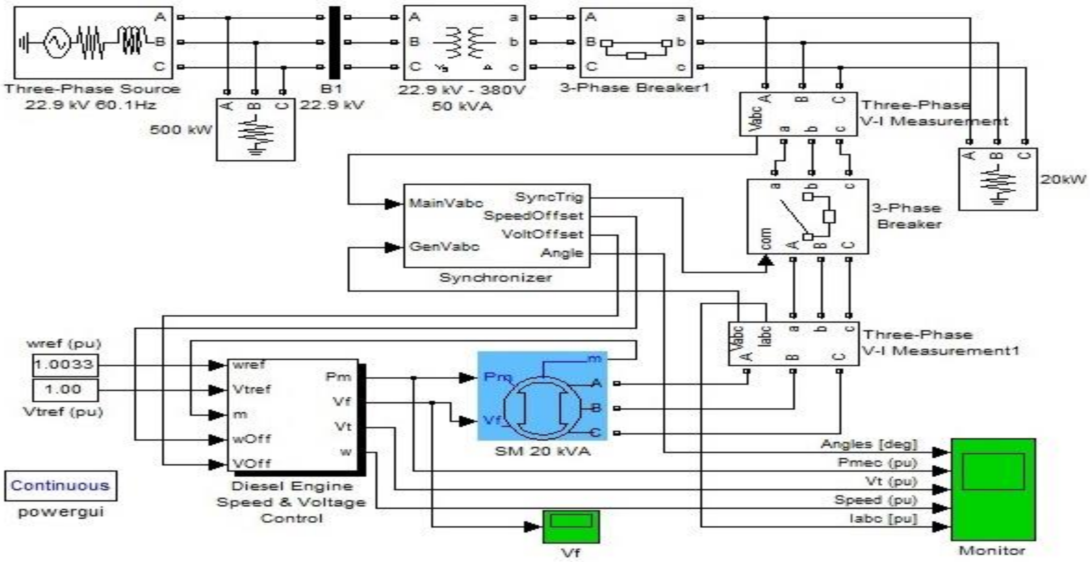

Figure 2. Simulation model of the diesel engine generator connected to the electric power system by the synchronizer

The above figure shows representation of Diesel engine generator connected to electrical power system by the synchronizer**.** The synchronization is an essential process while an individual ac generator has to be operated with another ac power system, for the parallel operation. The figure above shows an entire block diagram. At start during initially a load is connected to the Electrical Power System through a transformer (3-ϕ Source) and a three-phase breaker. At the same time, when a diesel engine generator is start to operates in an isolated mode. Synchronizer logic is tack place to controls the speed and the voltage of the diesel engine to match the synchronizing criteria. Once all the synchronizing criteria satisfied, the synchronizer generates a breaker closing signal and the breaker is closed and system is operated in synchronous mode, in this way the synchronization is done.

IV. RESULTS

The result shown in below figure 3 and figure 4 gives the clear difference between the traditional synchronizer and the proposed soft synchronizer. We needed to calculate the dwell time setting in case of demonstration. By Enabling the slip frequency of 0.1 Hz and phase-angle difference limit of $\pm 10^0$ the synchronizer and the dwell time was calculated.

We may assumed that the relay operation time as 1/2 cycle (0.058 sec) and a breaker closing time an as three cycles. In case of max slip frequency, the breaker will actually close at a phase-angle difference of $\pm 12.09^0$ [10]. A traditional synchronizer with a dwell time setting shows in below simulation result the anglesθ_1, θ_2 are phase angles of the electrical power system and the diesel generator. In case of making the slip frequency as 0.1 Hz, we had been set the frequency of the electrical power system and the diesel generator. As expected that the above the actual breaker closing was completed when the phase-angle difference is about(θ_s). Due to a consequence of this phase-angle mismatch large oscillations in voltages, speed, power and the phase currents were generated.

As result shown in below figure 4 for the proposed soft synchronizer the breaker was exactly closed at the zero point θ_s due to this an entire signals showed no oscillation. While comparing these two result figures, the oscillation of speed and mechanical power are caused only by the electrical phase-angle difference. Because the voltage magnitude and the frequency slip are identical for both simulation cases.

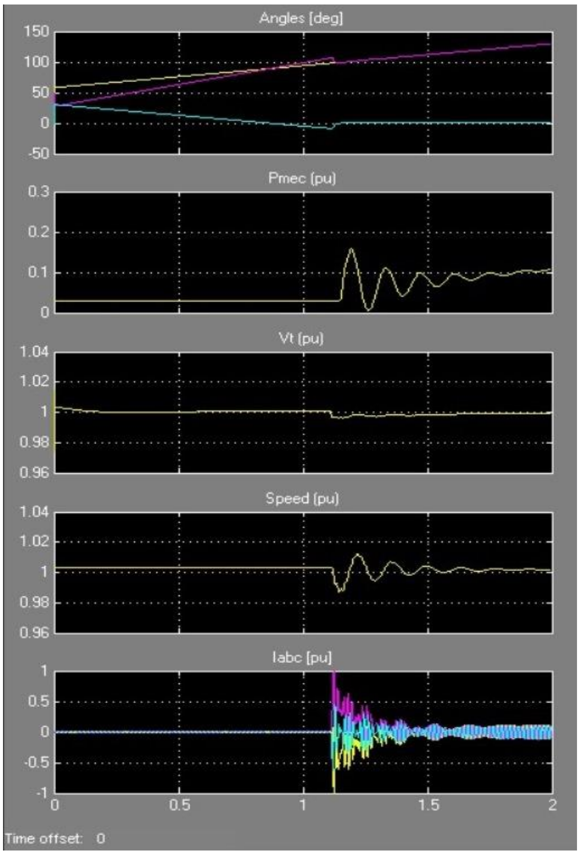

Figure 3. Case of the traditional synchronize

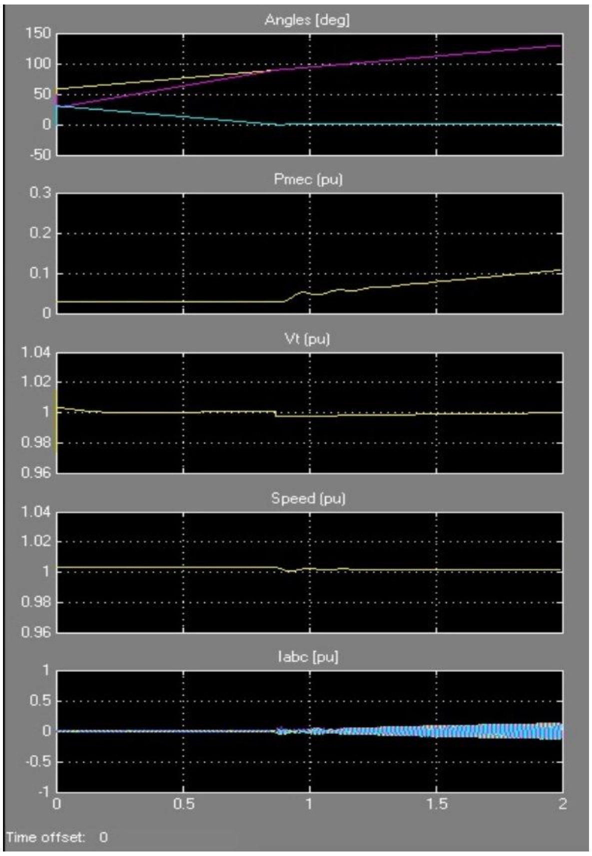

Figure 4. Case of the soft synchronize

V. CONCLUSION AND FUTURE WORK

This paper provides the synchronization in soft way technique. By using this proposed technique we get a simple and clear measurement of the results. The results enable the smooth and soft connection between the electric power system and the synchronous generator. By using a reference frame transformation-based synchronizing criteria measurement, the signal conditioner and the phase-angle difference estimation, the perfect match between the electrical power system and the synchronous generator through the simulation and the validation of the proposed technique was performed. This technique (soft Synchronization) gives the noticeable comparative results with the traditional techniques.

As mention in entire paper with the help of soft synchronization technique we can perform parallel operations in automation and other electrical systems. But this technique is limited to a single pair of AC systems. In future it might be possible to use this soft synchronization technique for two or more than two pair of AC system, which will be helpful in high level and large scale synchronizers.

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