

Implementation and Analysis of Synchronization of Alternator with Busbar

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Abstract: This project presents a synchronization panel for continuous monitoring and synchronization of an alternator with a busbar (grid). It employs the synchroscope and one dark two bright lamp method, with a digital VAF meter and Phase-Sequence-Indicator for accurate measurements. Synchronization is facilitated via a Normally Open (NO) switch and maintained through a contactor hold circuit until a Normally Closed (NC) switch is pressed. The panel also includes power measurement capabilities. Once synchronized, the alternator maintains speed (frequency) and voltage generation despite changes in armature voltage and field excitation, thereby controlling active and reactive power flow. This enhances power system stability and performance.

Keywords: Alternator, Busbar, Design, Generator, Grid, Infinite Bus, Lamp method, Power Plant, Power System, Synchronization, Synchroscope.

1. Introduction

In modern power systems, the synchronization of alternators with busbars is crucial for ensuring the seamless and efficient operation of electrical grids. Synchronization involves matching the voltage, frequency, phase sequence, and instantaneous phase of an alternator with those of the busbar or grid, enabling safe and stable power transfer. This process is essential for maintaining the integrity and stability of the power system, preventing problems such as phase mismatches, voltage imbalances, and frequency deviations, which can lead to equipment damage, power outages, and operational inefficiencies. [1]

The need for precise and reliable synchronization becomes even more critical as power systems evolve to integrate

various energy sources, including traditional generators and renewable energy installations. In this context, advanced synchronization techniques are indispensable for managing the complexities of modern electrical grids.

This project presents an assiduously designed synchronization panel that seamlessly aligns an alternator with a busbar. Developed through careful design and implementation, the panel incorporates two effective synchronization techniques: the 2 bright 1 dark lamp method and the Synchroscope method. The 2 bright 1 dark lamp method is a time-tested technique that visually indicates the phase difference between the alternator and the busbar. When two lamps are fully bright and one is dark, it indicates that the phase difference is minimal, signaling the optimal moment for synchronization.

Complementing this method is the use of a digital synchroscope with LED indication, which offers a more precise and continuous display of the phase relationship between the alternator and the busbar. This digital synchroscope is a key feature of the panel, ensuring accurate and real-time monitoring of synchronization conditions as it also helps to know the speed of the generator is faster or slower than required.

With the use of a digital Voltage Ampere Frequency (VAF) meter, which is also multipurpose measuring equipment that can show power factor and active, reactive, and apparent power strategically integrated to measure and display the voltage and frequency levels comprehensively. Utilizing a clever design approach, a single VAF meter facilitates dual-side monitoring—both the alternator and the grid—through the use of a TPDT (Triple Pole Double Throw) switch. This innovative design optimizes cost

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efficiency by eliminating the need for multiple meters and simplifies the monitoring process without compromising performance.

Enhancing operational clarity and accuracy, the panel includes a phase sequence indicator. This device provides crucial insights into the phase sequencing of both the grid and the alternator connections, ensuring that the phases are correctly aligned before synchronization. Proper phase sequence alignment is vital to prevent phase-related problems that could otherwise lead to significant disruptions in power delivery.

Operational control within the panel is streamlined through the incorporation of Normally Open (NO) and Normally Closed (NC) switches, alongside a robust contactor hold circuit. The NO switch facilitates the initial synchronization process, allowing the alternator to be connected to the busbar once the conditions are met. The hold circuit within the contactor ensures that synchronization is maintained consistently even if the NO switch is released until the NC switch is activated, which safely disengages the synchronization process when necessary.

Beyond its primary synchronization capabilities, the panel is equipped with advanced features for controlling active and reactive power flow. Once synchronization is achieved, the panel ensures that the alternator maintains its speed (frequency) and generated voltage regardless of variations in armature voltage or field excitation. We can analyze the effect of varying the armature voltage of the DC machine and the DC field excitation of the alternator with the help of analyzing power flow. This capability is critical for managing the dynamic aspects of power systems, enabling precise control over power distribution and enhancing overall system stability.

In summary, this comprehensive synchronization panel not only addresses the fundamental need for accurate and reliable synchronization in modern power systems but also offers advanced functionalities that enhance operational efficiency and stability. By integrating synchronization methods, precise measurement tools, and robust control mechanisms, the panel significantly contributes to the optimization and reliability of the electrical grids.

2. Approach

Some conditions need to be fulfilled before the synchronization which can be ensured using the methods discussed below.

The conditions that need to be ensured are:

- 1) The magnitude of the incoming voltage becomes equal to the grid.
- 2) The frequency of the machines remains the same with the grid.

- 3) The phase sequence of the machine matches with the grid.
- 4) The instantaneous phase of the machine and the grid.

2.1. Method Overview

As mentioned earlier, there are two methods of synchronization used in the panel. These two methods are explained below:

2.1.1. The two bright one dark lamp method [2]

The 2 bright 1 dark lamp method provides a more detailed indication of the phase relationship. When two lamps are bright and one is dark, it indicates that the phases are close to alignment, specifically close to 0° . Unlike the all-dark lamp method, which can show all lamps dark at both 0° and 180° , the 2 bright 1 dark method helps to distinguish between these two conditions, thereby avoiding the risk of synchronizing at 180° .

In this method, one lamp is connected between corresponding phases whereas the two others are cross-connected between the other two phases. It is shown in Fig. 1.

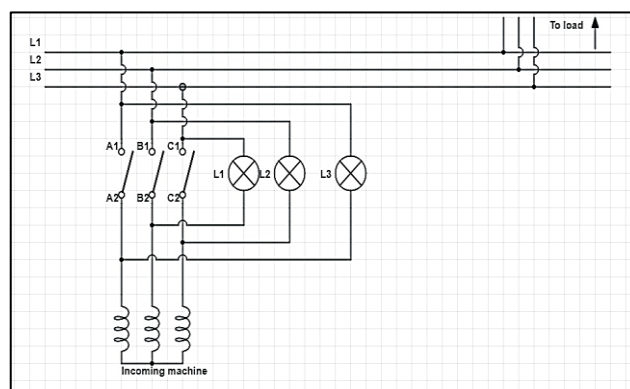


Fig. 1. Two BRIGHT One DARK lamp method of Synchronization [3]

Here, A1 is connected to A2, B1 to C2, and C1 to B2. The prime mover of the incoming machine is started and brought up to its rated speed. The excitation of the incoming machine is adjusted in such a way that the incoming machine induces the voltage EA1, EB1, and EC1, which is equal to the Busbar voltages VA1, VB1, and VC1. The diagram is shown in Fig. 2. The correct moment to close the switch is obtained at the instant when the straight-connected lamp is dark, and the connected cross lamps are equally bright. If the phase sequence is incorrect, no such instant will take place, and all the lamps will be dark simultaneously.

The direction of rotation of the incoming machine can also be checked with the help of the Phase Sequence Indicator. The direction of rotation is changed by interchanging the two lines of the machine. Since the dark range of the lamp extends to a considerable voltage range, a voltmeter V1 is connected across the straight lamp. The

synchronizing switch is closed when the voltmeter reading is zero.

Thus, the incoming machine is now floating on the Busbar and is ready to take up the load as a generator. If the prime mover is disconnected, it behaves as a motor. Three lamps and a synchroscope are used to parallel small machines in power stations.

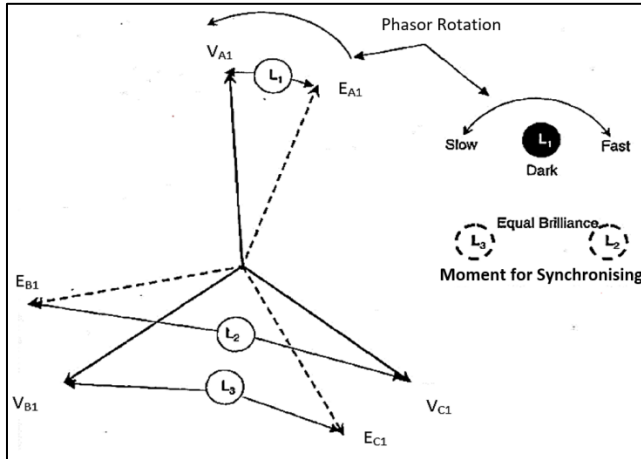


Fig. 2. Vector Diagram for two BRIGHT one DARK lamp method [4]

2.1.2 The Synchroscope Method [1]

The connection using the Synchroscope method is shown in Fig. 3.

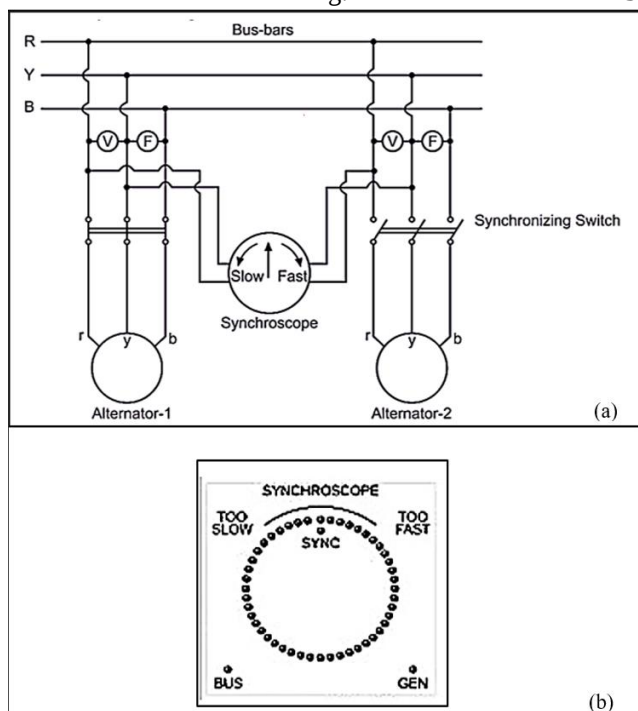


Fig. 3.(a) Synchroscope Method of Synchronization and **(b)** Synchroscope[5] [6]

The Synchroscope is a device used to determine the phase angle differences between two or more machines or between the machine and the grid at the time of the synchronization. For the parallel operation of the three-phase machines, they must be in phase with each other. The phase sequence of the device is correct at the time of the installation. The synchroscope compares the incoming voltage of the machines with that of the three-phase system. It has LEDs placed circularly on the device. The glowing LED shows the phase difference between the incoming voltage and the infinite machines/busbar/grid. The Synchroscope marks with two arrows which indicate the direction of rotation of the glowing LED. The pattern of glowing LEDs can be clockwise or counter-clockwise.

The clockwise glow pattern shows too fast movement and the counter-clockwise direction shows slow rotation of the incoming machine. If the frequency of the incoming machine is more than that of the grid, the LEDs will glow toward the direction of the fast mark. And if the frequency of the incoming machine is less, the LEDs will glow toward the direction of the slow mark. When the frequency of the incoming machine voltage and the infinite machine becomes equal, the green LED at the 12 o'clock position remains glowing. When their frequency differs, again the LED will start to glow in either direction. The frequency and phase position are controlled by the input of the prime-mover.

When the LED glows slowly and passes through the green LED at the 12 o'clock position, the NO switch is pressed and the incoming alternator connects to the bus. This method contains less chance of human error than the two bright one dark lamp method of synchronization. The Synchroscope does not give any information about the phase sequence. It shows a relation only in one phase. So, for that, the Phase Sequence Indicator is used.

2.2 Circuit Design for Panel

The circuit design and wiring diagram is for the panel which includes both the lamp and the synchroscope method. The wiring diagram is shown in Fig. 4.

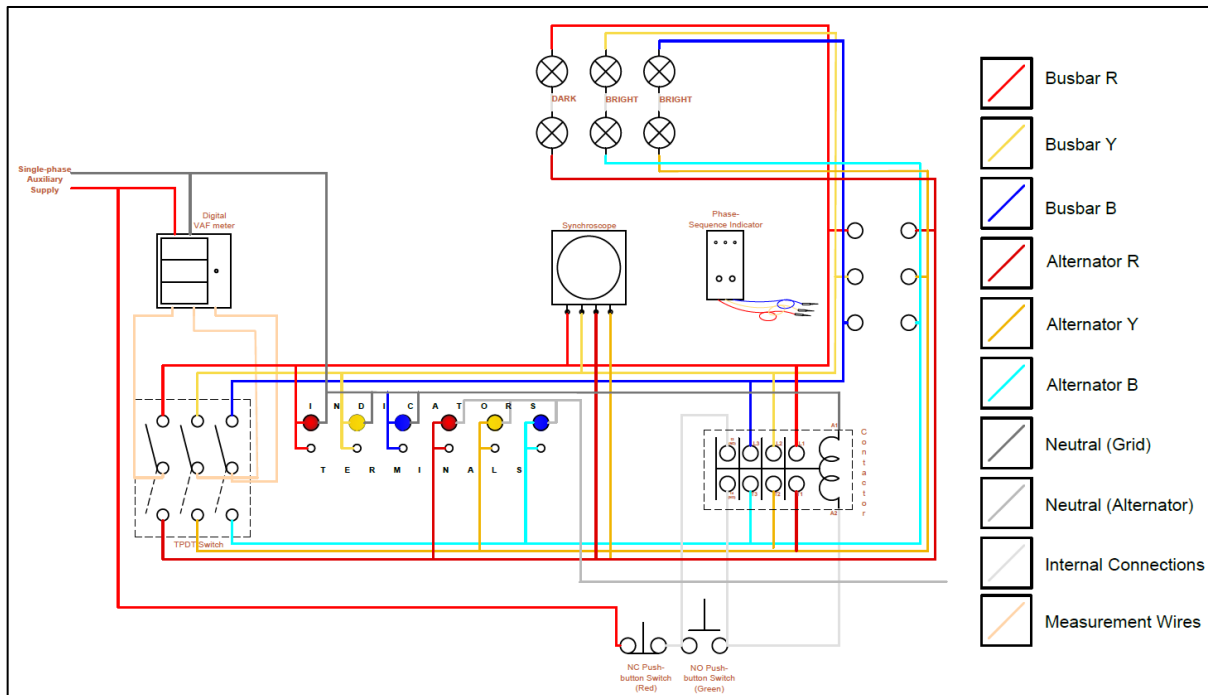


Fig. 4. Wiring Diagram of the Panel [7]

3. Result analysis and discussion

The focused photo for observation is shown in Fig. 5. The condition of Lamps and Synchroscope can be observed after Synchronization. The first pair of Lamps is DARK whereas another two pairs can be observed as BRIGHT. The synchroscope is showing the perfect 12 o'clock instant with a green LED.

Here in Fig. 6, the designed panel for the Synchronising Alternator with the Busbar (Grid) is shown which also includes the conditions after the synchronization is done. We can observe both the lamps and the synchroscope.

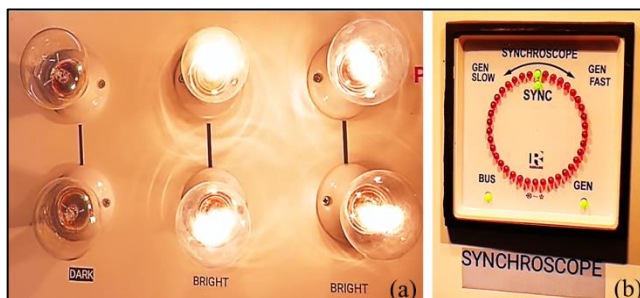


Fig. 5. Condition after Synchronization (a) Lamps (b) Synchroscope



Fig. 6. Panel (a) Before Synchronization (b) After Synchronization

4. Conclusion and Future work

[7] AutoCAD

We have designed a synchronization panel that seamlessly aligns an alternator with a busbar. We have practically performed on our panel by two standard methods, The two bright one dark lamp method & the Synchroscope method. It provides practical exposure to the synchronizing process of the alternator with the busbar/grid. Future work involves the analysis of the power in which we can put the power analyzer to measure the alternator's active and reactive output power delivery by varying the speed of the prime mover and field excitation of the alternator once the alternator is synchronized.

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Author contributions

The author **Nisha Lodha** was involved in Writing-Review and managing the paperwork, **Hitendrasinh Vaghela** was involved in Methodology and Data curation, **Bhagya Buch** was involved in the design and Writing-Original draft preparation, and editing, **Parth Vadhvan** was involved in Visualization of the project and Field study, **Paras Joshi** was involved in Visualization and Investigation, **Jay Solanki** and **Ravi Solanki** were involved in Fieldwork and hardware part development.

Conflicts of interest

The authors declare no conflicts of interest.

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