Design & Construction of a Low Cost Quasi Automatic Synchronizer for Alternators

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***Abstract*— Synchronization of a generator to the power system must be done carefully to prevent damage to the machine and disturbances to the power system. The intention of this paper to provide an explanation of the automatic synchronizing process for three phase alternators to explore the considerations involved and to construct it in a cost effective manner. Synchronizing, in its simplest form, is the process of connecting additional generators electrically to an existing bus. Modern synchronizers have the capability to match precisely both speed and voltage as well as to operate for very slow slip rates. Automatic synchronizer furnished with voltage matching and frequency or speed matching circuits which will automatically adjust the voltage and frequency within limits acceptable. This design of automatic synchronizer includes individual voltage, frequency and phase sequence measurement in respect to the incoming generator. When these three measurements of both generators or generator and bus are matched then both are connected electrically using a relay circuit. With this design the whole synchronizing process can be done by only pressing some switches. This design reduces installation cost as well as maintenance cost for synchronization purpose in power plants. The proposed quasi automatic synchronization unit is fast, cost effective, reliable and precise to be used for monitoring, measuring and synchronization for three phase alternators.**

***Keywords*— Quasi Automatic, Automation in monitoring, Measurement & Synchronization, Cost effective, Fast.**

INTRODUCTION

There are lots of intensive and chronicle problems in the power distribution in Bangladesh. Many factors like: limited power generation capacity, unplanned load distribution, lack of maintenance, lack of system automation and so on, contributes to make the situation worse. To partially mitigate this problem, small size local electrical generators have been used when shortage of electricity is present. In some cases more than one electrical generator are used to supply the same load end. This is particularly important when a higher system reliability and flexibility is required. For example, the failure of one generator does not cause a total power failure to the load. Therefore, one can remove the failed generator for shutdown and preventive maintenance. Moreover, If only one generator is used and it is not operating at near full load, then it will be relatively inefficient. However, with several smaller generators, it is possible to operate only a fraction of them. The ones that do operate are operating near full load and thus more efficient. For efficient multi-generator system, synchronization between them is necessary [1]. Some of the benefits of operating multiple generators in parallel include increased reliability, expandability, flexibility, serviceability and efficiency. The redundancy inherent in parallel power generation provides significantly greater reliability for critical loads. In a parallel configuration, if one generator fails, the most critical loads are redistributed among the other units in the system. Utilizing multiple smaller generators instead of a single large unit offers greater location flexibility. With multiple generators available, individual units can be taken out of service for repair or maintenance without losing standby power for critical circuits. Parallel operation allows operating alternators around their rated load resulting operating with high efficiency [8, 9].This paper emphasizes on the automation in parallel operation where there is no need to use individual measuring tools, such as voltmeters, frequency meters, phase sequence meter and synchroscope for monitoring the conditions of parallel operation. The proposed automatic synchronization unit is cost effective, quick, reliable, stable and accurate to be used for monitoring, measurement and parallel operation of the alternators. [6]

Parallel operation of the alternators

The synchronization process usually involves a large amount of wiring. Reduce this complexity of wiring's disturbance is one of the main contributions of this project by developing a microcontroller based synchronization system. The main task of a synchronizer is to capture the voltage, frequency and phase differences between the generators accurately and rapidly. Generally, synchronization refers to matching three parameters between an incoming alternator and the existing bus bar before connecting to the actual load. They are: Magnitude of voltage, Frequency, Phase sequence. To illustrate the synchronizing definition, one can consider the function of the volt component supplied by any generator, which is as follows:

$$V = V_m \cos(\omega t + \Theta) \qquad (1)$$

Let the voltage of the first generator and second generator is $V_1\cos(\omega_1 t + \Theta_1)$ and $V_1\cos(\omega_2 t + \Theta_2)$ respectably. Then, in order to connect the two generators in one bus, the voltage components of each must be equal.

$$V_1\cos(\omega_1 t + \Theta_1) = V_2\cos(\omega_2 t + \Theta_2) \quad (2)$$

From this equation in order to connect two generators three parameters of them should be equal.

$V_1 = V_2$; the amplitude
$\omega_1 = \omega_2$; the frequency
$\Theta_1 = \Theta_2$; the phase angle

The voltage in the alternator is matched by varying the excitation. The frequency is matched by varying the speed of the alternator by its prime-mover. The phase-sequence is matched by flipping any of the two phases if miss-matched [5]. Parallel operation of generators is achieved automatically with the control unit when all parallel connection conditions occur. Once synchronized properly, two alternators continue to run in synchronism. Any tendency in the part of one to drop out of synchronism is counteracted by the production of a synchronizing torque, which brings it back to synchronism. When in exact synchronism, the two alternators have equal terminal PDs and are in exact phase opposition, so far as the local circuit is concerned. Hence there is no circulating current round the local circuit.

PROBLEM ANALYSIS AND TECHNOLOGY SELECTION

Synchronizing a generator to the power system must be done carefully. The speed (frequency) and voltage of the isolated generator must be closely matched, and the rotor angle must be close to the instantaneous power system phase angle prior to closing the generator breaker to connect the isolated generator to the power system. Poor synchronizing can damage the generator and the prime mover because of mechanical stresses caused by rapid acceleration or deceleration, bringing the rotating masses into synchronism (exactly matched speed and rotor angle) with the power system. It can damage the generator and step-up transformer windings caused by high currents & cause disturbances to the power system such as power oscillations and voltage deviations from nominal. It prevents the generator from staying online and picking up load when protective relay elements interpret the condition as an abnormal operating condition and trip the generator. Traditionally, generator control systems include a synchronizing panel. The synchronizing panel includes indications of voltage, angle, and slip that show what adjustments the operator needs to make to the governor and exciter and when it is acceptable for the operator to close the breaker. [1]

The conventional technologies for parallel operation of the alternators like: three lamp method and digital synchronouscope requires a skilled operator for proper synchronization. In all methods, it is obligatory to check the three principles of synchronization.

In the dark lamp method, the lamps are connected across the alternator and busbar terminal. If the phase sequence is different, the lamps will brighten in a cyclic manner. Correct phase sequence is indicated by simultaneous darkening brightening of lamps. The switch is closed in the middle of the dark period. Once synchronized properly, the two alternators continue to run in synchronism.

Synchroscope is an instrument for indicating difference of phase and frequency between two voltages. It is essentially a split phase motor in which torque is developed if the frequencies of the two voltages differ. Voltages from corresponding phases of the incoming and running generators are applied to the synchroscope. A pointer which is attached to the rotating part of the instrument, moves over the dial face in either a clockwise or counter clockwise direction. Depending on whether the incoming machine is fast or slow, when the frequencies of the two alternators are equal, no torque is exerted on the rotating part of the instrument and so the pointer stops. When the pointer stops in vertical position, the frequencies are equal, the voltages are in phase, and the paralleling switch may be closed. [1, 10]

These methods of synchronization demand a skilled operator and the method is suitable for no load operation or normal frequency condition. Under emergency condition such as lowering of frequency or synchronizing of large machines a very fast action is needed, which may not be possible for a human operator. Synchronization by means of manually operated switching served well enough when the individual generators were relatively small, but with the growth of system capacity, it becomes necessary to use automatic devices to ensure the closing of the main switch of the incoming machine at the proper instant. Analog synchroscope is also a good example of automatic synchronization. But it is made of split phase motor; an inductive component causes higher power consumption. The installation & production cost of this type of analog synchronizer is much higher.

The main objective of this paper is to introduce a microcontroller based digital synchroscope showing the value of parameters (voltage, frequency and the phase sequence) on a 16x2 LCD screen and to confirm the proper automatic synchronization of the alternators using a relay switching circuit. Thus the device is not only an automatic synchronizer but also it works like a digital voltmeter, frequency meter and determines the phase sequence of the three phase alternators in a digital manner.

Microcontroller based quasi automatic synchronizer

As it is a microcontroller based synchronizer, the whole process will run with the help of microcontroller. There are three measuring parts in this design.

i. Voltage measuring circuit
ii. Frequency measuring circuit
iii. Phase sequence checker

The PIC 16C73 microcontroller reads the phase voltage and frequency of both generators and it is possible to see it through the LCD. If the voltage and frequency are not matched then one has to match it by changing excitation and speed of the generators. If the voltage and frequency are matched then it is possible to check the phase sequence of the generators by this system. This system is mainly designed for balanced system and for that reason phase difference is very little and it does not create damage to the system. When voltage and frequency are matched and phase sequence is also checked, both of the generators can be connected by pressing a synchronization switch.

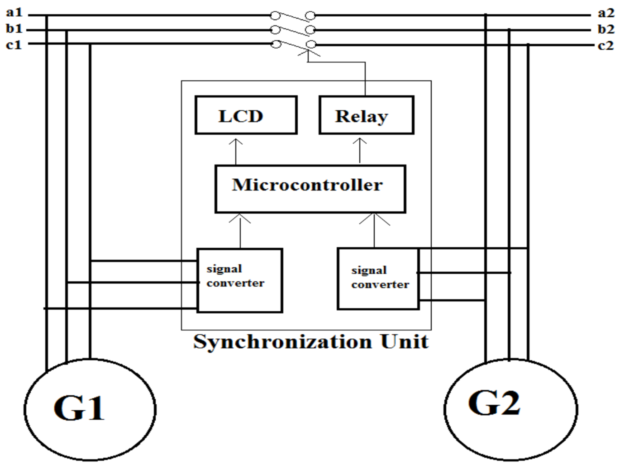

Figure 01: Block diagram of quasi automatic Synchronizer

The main features of this designed quasi automatic synchronizer are listed as below.

1. Synchronizer using PIC microcontroller
2. Low cost.
3. Continuous voltage and frequency measure.
4. Continuous voltage and frequency showing using LCD display before and after synchronization
5. Featured with phase sequence checking utility

VOLTAGE MEASURING CIRCUIT

There are several ways to measure the terminal voltages. Though the use of potential transformers makes the measurement circuit a bit bulky, resistive potential divider may be a good choice for conditioning the high terminal voltages to a small measurable voltage. The voltage signal, when fractioned by potential dividers, is then directly feed to the signal conditioning circuit for frequency and phase measurement. For voltage measurement, the fractioned AC signals are rectified and filtered to produce DC voltages which vary linearly according to the terminal voltages. This dc analog voltage signal is then fed to the internal Analog to Digital Converter (ADC) module of the processor unit to be measured in a programmatic way. [4].

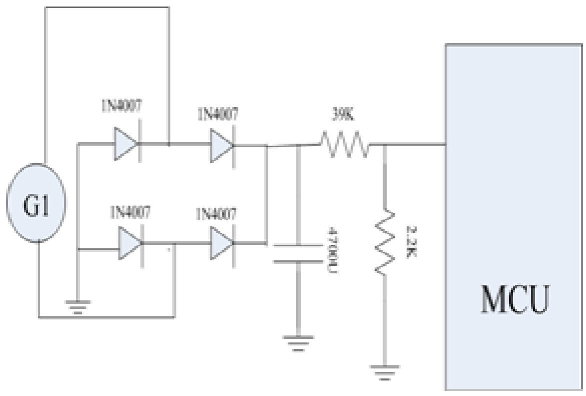

Figure 02: Voltage measuring circuit

Frequency measuring circuit

Digital frequency counters are the most accurate and flexible instruments available for measuring unknown frequencies. Frequencies from zero to the gigahertz range can be measured with digital frequency counters. In this module, a microcontroller is used to build the digital frequency counter.[7] For frequency measurement, the phase voltage of the generator is fed to the opto-coupler. Then output of the opto-coupler is given to the microcontroller. The microcontroller operates in counter mode for measuring frequency.

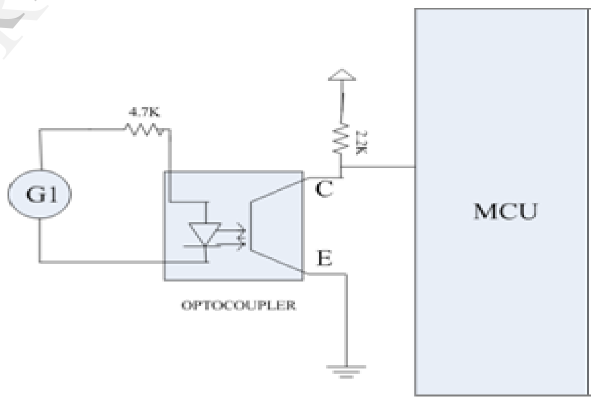

Figure 03: Frequency measuring circuit

The voltage scalar converts 220 V to 5 V AC. The 5 V AC is passed to through the sinusoidal to square waveform circuit with the help of opto-coupler. The frequency of the square signal is measured by PIC 16F877A with the help of software. The square wave signal from the buffer is fed as input frequency to TMR0. TMR0 is configured to measure the input frequency, at RA4 of the PIC 16F877A. The input frequency is “gated” for a precise duration of time. The precise “gate” is implemented in software as an accurate delay. An 8-bit value of the input frequency is now saved in TMR0, Registers and 3-bit prescaler. By concatenating the calculated value and the original value from TMR0, the 8-bit value for the frequency is determined. [7]

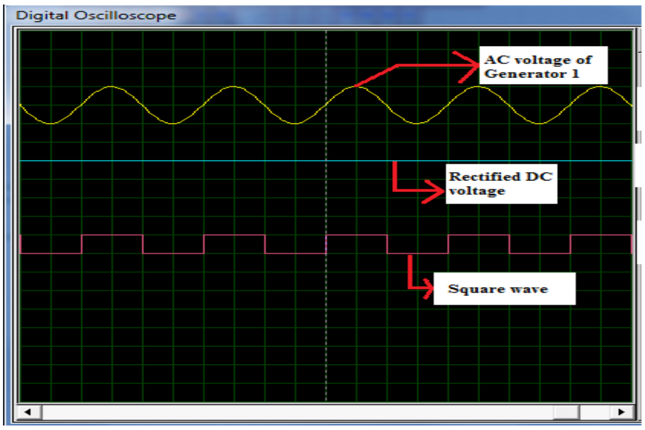

Figure04: Oscilloscope output of the Sinusoidal to square waveform

Phase sequence checker

For phase sequence checking all the three phases' voltage of each generator is fed to the base of three transistors simultaneously [3]. Then the output of transistor is given to the cathode of the opto-coupler. Then output of the opto-coupler is given to the microcontroller. The microcontroller checks which phase signal are coming one after another and it gives it a number and the LCD shows the number.

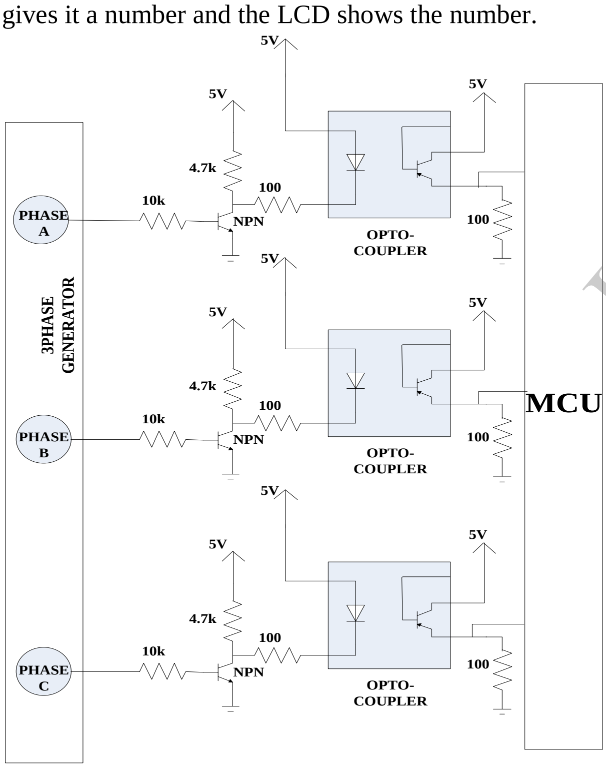

Figure05: Phase sequence checker circuit

Switching Unit

If voltage, frequency and phase sequence of alternator and busbar are same, then microcontroller checks the status of the auto-manual switch. If it is on auto position, microcontroller enables the switching. Since we are using an ac 3 phase contactor whose operating coil requires a 220V ac, we can't directly operate this contactor by microcontroller. So we need to add an interfacing circuit. Here we use a 12V DC relay. Since its operating voltage is 12 V, we use a transistor for its switching operation.

The high voltage available at the corresponding pin of PIC16F877A is applied across the base of the transistor through a base resistor. This resistor limits the base current to a safe value. Here the transistor is operated as a switch. This base voltage is sufficient to pull the transistor into its saturation region. Thus the relay gets energized which energizes the main contact.

Development of Firmware

The firmware for the system is responsible for all the measurement and sorting actions for the synchronizing operation, as well as generating appropriate switching instructions for the switching unit. Once the alternator is started, it develops some voltage at some frequency; following sequence of events will take place automatically: Detection of phase sequence, Frequency measurement and control, Voltage measurement and control, synchronizing the alternator with the existing busbar. Decision taking plan is shown in the flow chart.

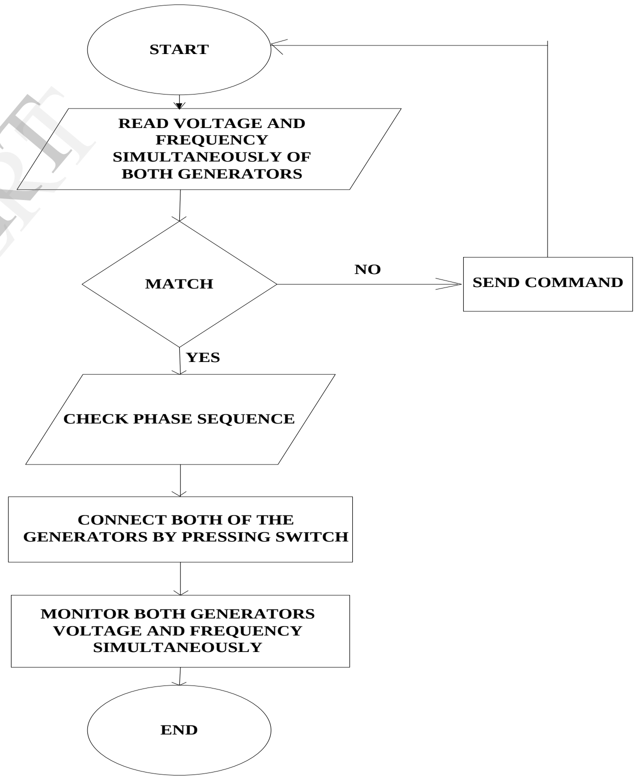

Figure 06: Flow Chart of the developed firmware

The flow chart indicates how a microcontroller is programmed to take decision. At first microcontroller reads the voltage and frequency of both generators. Then it takes first decision whether it is matched or not. If no then it will continuously measure the voltage and frequency. If yes then by pressing a switch it will check the phase sequence. If phase sequence is correct then by pressing synchronizing switch both the generators will be connected through a relay switching circuit which will run by the microcontroller. [2]

Then the system voltage and frequency will be continuously measured by the microcontroller and it will be shown in the LCD display.

Schematic Diagram

It is the schematic diagram of quasi automatic synchronizer which can measure voltage and frequency simultaneously. The LCD displays both of the generators voltage and frequency simultaneously. The push button switch is the synchronizing switch. The relay switching circuit is also shown. When the conditions are fulfilled then it is necessary to press puss button which energizes the magnetic field of the relay and both of the generators are connected with each other. In case of balanced system the most important thing is to match both of generators voltage and frequency precisely which is done by this system. The feature of phase checking utility can also be served by this design.

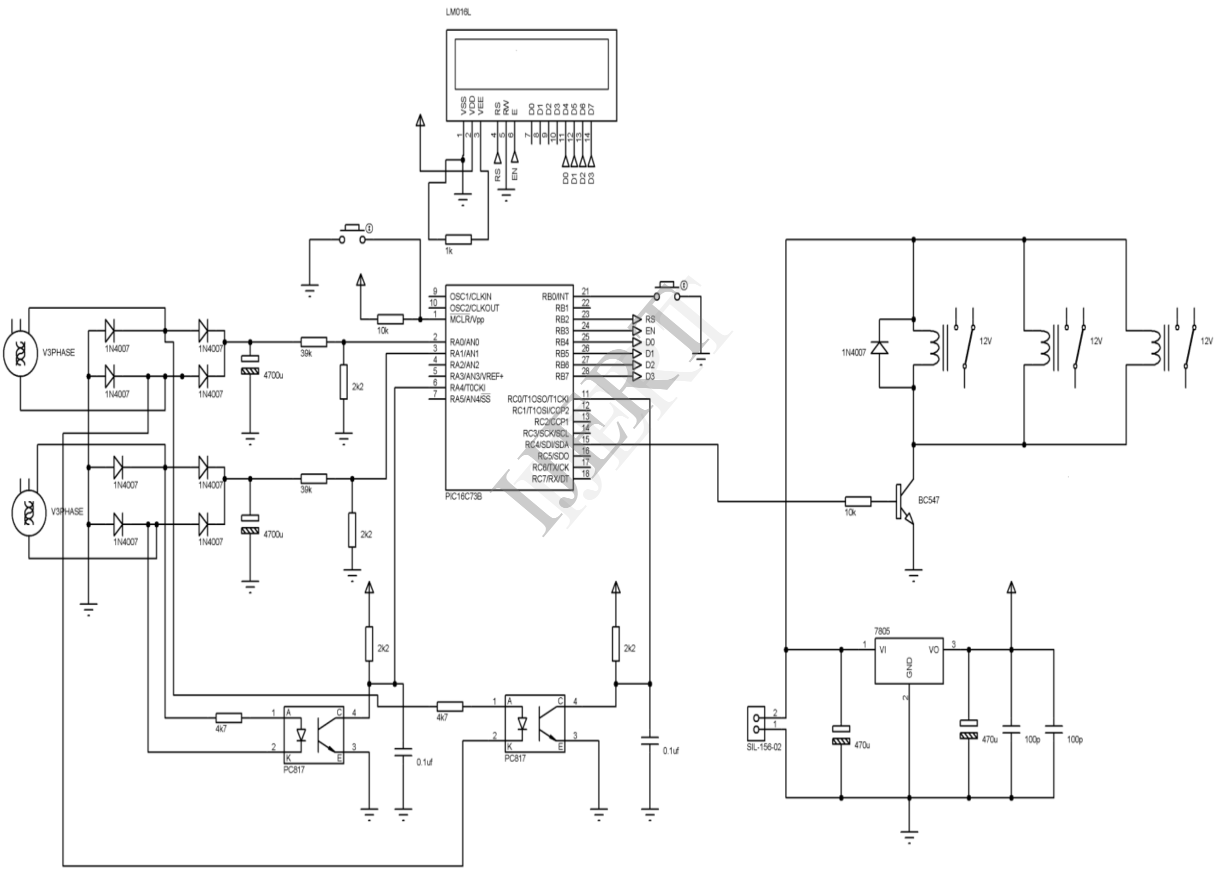

Figure 07: Schematic Diagram

Hardware Implementation

The designed quasi automatic synchronizer has been implemented in CUET machine lab to synchronize two De Lorenzo identical generators which ratings are:
V1= 24/42volt; f=50Hz; I1= 26/1.5A; Rotor speed= 3000 rpm; V2=30 volt; I2=1.3 A; Power, W=110 watt.

The design of the prototype of the synchronizer is given below:

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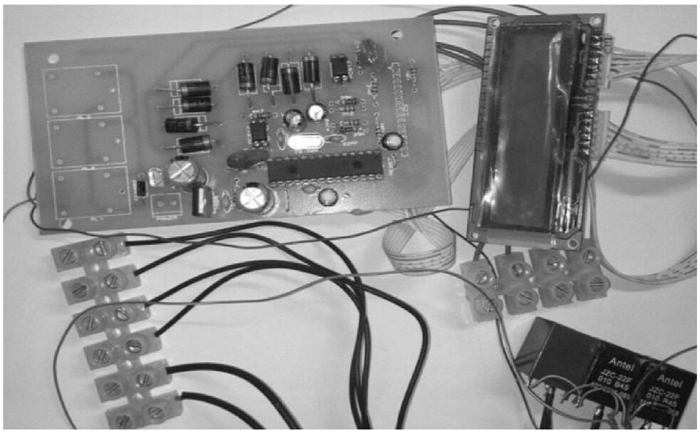

Figure 08: Hardware of quasi automatic synchronizer

This quasi automatic synchronizer is designed as a prototype. It has been developed for installing in laboratory. For industrial use, further development is required.

CONCLUSION

The designed quasi automatic synchronizer has some spectacular features those can make it different from the conventional technologies. It can be manufactured with a very low price i.e. about $50 only. It doesn't require the most efficient operator to handle because the whole synchronizing process is done by only pressing some switches. As it is the microcontroller based instrumentation and control system, it provides the maximum accuracy and makes the system more user friendly than conventional systems. It also exploits the advantage of superior performance of the microprocessor like accuracy speed and reliability. It decreases the risks of unwanted occurrence and accidents occurred in power systems. This technology can be implemented in the existing power plants instead of the conventional synchronizing systems paying a very small amount. And obviously for the power plants under construction and for the upcoming, it may be the best technology to improve the efficiency of the whole system.

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Nomenclature

Symbol	*Meaning*	*Unit*
V	Voltage	(V)
f	Frequency	(Hz)
I	Current	(Amp)
W	Power	(Watt)