A REVIEW OF AUTOMATIC GRID SYNCHRONIZATION USING PROGRAMMABLE LOGIC CONTROLLER

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Abstract - *In the age of Intelligent Power Systems (IPS) having automatic control system the power plant can be controlled remotely. When an alternator is connecting to a power grid it is to be synchronized with the grid. Synchronization means connecting the alternator in parallel with another alternator or common bus bar. The state of the incoming alternator affects the state of the present system, so the synchronization should be done in proper manner with almost care. Manual synchronization needs human efforts and there will be error in it, as a small error will damage the system high is required. As the system is becoming automate, the synchronization is to be also automated. This paper suggests the study of synchronization of alternator using Logic controllers or PC based controllers. PLC is a digitally operating electronic apparatus that uses a programmable memory for the internal storage of instructions that implement specific functions such as logic, sequence, timing, counting and arithmetic to control machines and processes. The PLC based system is highly flexible and be modified easily. Trouble shooting is very easy and reduces downtime.*

Key Words: **Synchronization, Synchroscope, Programmable Logic Controller, Alternator, Ladder Diagram, Breaker, Automation, Relay.**

1.INTRODUCTION

Electrical load on a power supply or at a production plant varies with time. The number of generating units linked to a system bus bar is modified appropriately to satisfy the necessity of varying load, both cheaply and for ensuring supply continuity. The synchronization of an incoming alternator to the system bus necessitates the fulfillment of conditions such as the same phase sequence, voltage and frequency equality between the incoming machine and the bus bar, and frequency between the incoming machine and the bus bar.

The present method for synchronization of alternators is manual synchronization in which the breakers are closed manually from the control room after obtaining synchronization permit from the Synchroscope. In this method precision of operator is the major factor. This paper suggests the study of synchronization of alternators and the automated model for synchronization using PLC.

1.1 Synchronization

The operation of connecting a synchronous generator to an infinite bus bar is known as synchronization. Often the electrical system, to which the alternator is connected, has already so many alternators and loads connected to it that no matter what power is delivered by the incoming alternator, the voltage and the frequency of the system remain same. Before the synchronization, the incoming alternator should have the same.

1. Voltage
2. Frequency
3. Phase Sequence
4. Phase angle as that of the existing supply.

A difference of voltage between the incoming alternator and the infinite bus causes a short circuit effect momentarily and flow of high current. But the transient due to the armature reaction of this current will cause it to die out rapidly. Hence an incoming alternator having low voltage will draw a leading current from the bus, which will assist the magnetization of the field produce normal voltage conditions. A difference of less than 5 % will not cause much instability during the synchronization.

A surge takes place if the paralleling is done with a frequency difference. But the synchronizing torques developed in sufficient to correct the difference in momentum. The eddy current losses developed in the motor will normally damp the oscillations out. It is a common practice to set the frequency of incoming alternator slightly higher than the infinite bus during the synchronization.

The phase difference at the time of paralleling causes electrical as well as mechanical disturbances, which will be transmitted to the foundation of the alternator. In general, the phase angle error should not exceed 30. It is a common practice to parallel the machine when its ahead of the bus so that the leading component of the synchronizing current increases the field strength and the torque.

The voltage of the incoming machine is made equal to the existing supply by adjusting the field current of the machine. The interchanging of any two phases of the incoming machine corrects the phase sequence, if necessary.

By varying the speed of the prime mover, the frequency is made equal. Synchronization is done at that moment when the phases of the existing supply and the machine are same.

The conditions for the synchronization are checked by the Synchroscope. The phase-difference is indicated by the position of the dial and the frequency by the direction of motion of the dial. The voltage and phase sequence are predetermined. The synchronization of the machine is done at zero-phase point.

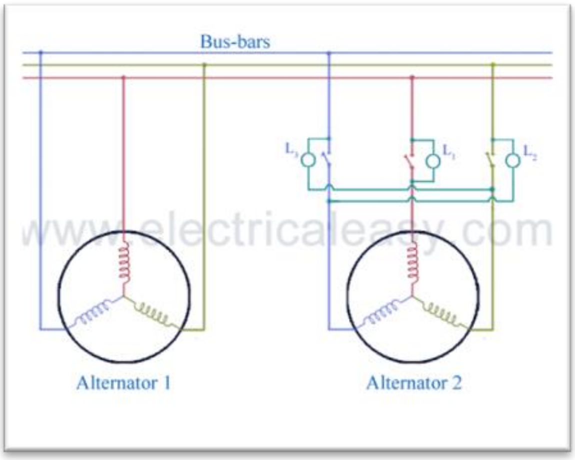


Fig-1: Synchronization of Alternators

1.2 Synchroscope

The Synchroscope is designed to provide an illuminated indication of the actual phase difference between the BUS voltage (reference voltage) and the GENERATOR voltage (Incoming voltage). It denotes the actual frequency difference corresponding to the inverse of time taken for one rotation of the illuminated vector spot. When two alternators are to be paralleled, it is necessary

1. Frequency must be equal
2. Phase must be same.

Synchroscope is, hence used to indicate the phase and frequency difference between two ac machines which are to be paralleled. The instrument is used in switch boards and control panels for such applications.

Fig-2: Synchroscope

The rotation of the vector slot is with reference to the bus voltage

1. If the vector spot turns clockwise, the GENERATOR frequency is greater than bus frequency. It means the speed of the generator must be reduced by the operator
2. If the spot turns anticlockwise, GENERATOR frequency is less than BUS frequency. In this case speed of the generator must be increased. If 'T' is the time taken for one rotation in seconds, the frequency difference can be calculated as follows.

$$1/T = \Delta f \text{ in Hz.}$$

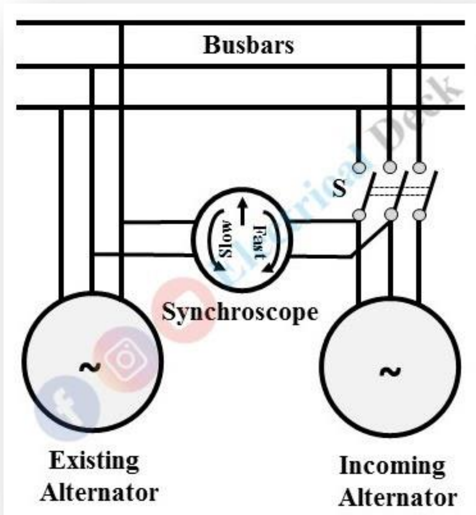


Fig-3: Synchroscope Synchronization of Alternator or AC Generator

2.Programmable Logic Controller

Imagine an automated manufacturing line in 1960's and 1970's. There was always a huge wiring panel of control system. The wiring panel could cover an entire wall. Inside the panel were messes of electromechanical relays. These relays were all hardwire together to make the system work. Hardwiring means that an electrician had to install wires between the connection of the relays. An engineer would have to design the logic of the system and the electricians would be given a blueprint of the logic and would have to wire the components together. There were hundreds of electro-mechanical relays in a system before Programmable Logic Controller (PLC) was developed.

A Programmable Logic Controller which is usually called a PLC is a solid state digital industrial computer. A programmable controller may seem to be more than a black box with wires bringing in and other wires sending signals out. It might also appear there is some magic being done inside that somehow decides when field devices should be turned on. The PLC is a computer, and someone had told it what to do. The PLC knows what to do through a program that was developed and then entered its memory. The PLC is a computer, however, without a set of instructions telling it what to do, it is nothing more than a box full of electronic components. The user program is the list of instructions that tells the PLC what to do. Computers such as PLCs can be wonderful tools; however, although it might appear otherwise, they only do exactly what human programmer told them to do.

2.1 BASIC ARCHITECTURE OF A PLC

A PLC is essentially meant to replace relays, timers and sequencers in traditional relay control systems. Unlike computer control, the PLC does not require very sophisticated programming, debugging and maintenance technique.

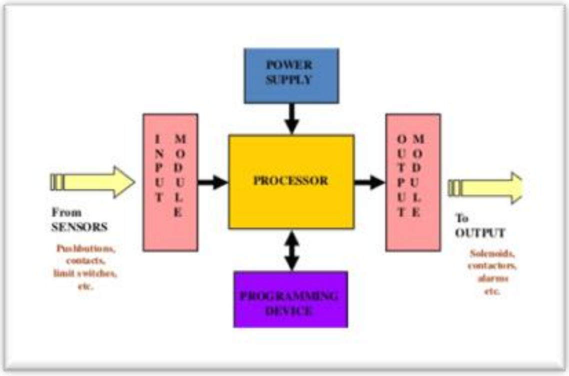


Fig-4: Architecture of a PLC

2.1.1.CPU:

The CPU is the heart of the PLC. It requires instructions from memory and generates commands to the output modules. Input commands, device status ae logic signals "I" or "O". These logic signals are then processed by CPU.As in traditional ladder diagrams NO/NC contacts of the filed devices activate relays and timers, PLC process logic signals and activate output TRIACS or TTL contacts that can be normally energized or de-energizes. In a relay control NO/NC contact from relays are available for use in control systems. In a relay control system, NO/NC contacts from relays are available for use in the control scheme, similarly in a PLC, internal and output contacts have NO/NC configuration that can be used in logic scheme. In contract to hard-wired relay control scheme, no wiring is needed for implementing the control logic in a PLC. All sequence control logic is internal to the PLC and is processed by CPU.

2.1.2. Memory:

The programs are normally stored in a Random-Access Memory (RAM). This is volatile and hence battery backup is required. Storing the program is RAM gives the under the facility to change the program easily even when the PLC is running. Other types of memory used in PLC are EEPROM-Electrically Erasable Programmable Read Only Memory, which is used to store data or instructions which can be kept, unaltered for a long time.

Input Output(I/O) interface is placed between the application devices and the processor. Input gives interface to for filed signals for the system. They provide the data necessary for the processor to make it control decisions. Outputs are required to switch the machine/process loads, under direction from the processor.

The common input and output devices are

Table-1: Input and Output devices

Input	Output
Limit switches	Solenoid valves
Push Buttons	Motor starters
Pressure switches	Alarms
A/D Converters	Solid state device

2.1.3 Programming Device:

This acts as a man machine interface. All instructions are programmed using this configuration. Modern PLC's have RS 232 interface to connect it directly to a PC and all programming can be done in the PC.

The instructions are classified into condition instruction and output instructions

Table-2: Classification of Instructions

Condition Instruction	**Examine ON**
	Examine OFF
	Branch OPEN
	Branch CLOSE
Output Instruction.	**Output Energize**
	Latch
	Unlatch
	Retentive Timer OFF delay
	Retentive Timer ON delay
	Up Counter
	Down

2.2.1 LOGICAL CONTINUITY

In a relay ladder electrical continuity is checked for energized the output contact, while in PLC ladder diagrams logical continuity is checked. Each instruction is liked to a status bit in the data table. The bit will be either ON or OFF.

For this we use the Examine ON instruction we are making the controller to "Examine the status bit for an ON condition". If the status bit is ON, then the instruction is TRUE. If the bit is OFF, then the instruction is FALSE. Similarly, the Examine OFF instruction means" Examine the status but for an OFF condition. If the status bit is OFF, the instruction is TRUE: If the bit is ON, the instruction is FALSE.

For example, consider the ladder diagram given below.

Conditional Instructions Output Instruction

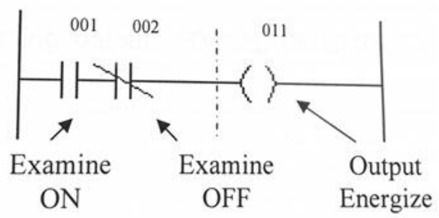


Fig-5: Ladder Diagram

As stated earlier, each instruction is linked to a status bit in the data table. The bit will be either ON or OFF to indicate the status of instruction. Thus "Examine ON" instruction we are asking the controller to examine the status bit for an ON condition. If the status bit is ON, then the instruction is true: if the bit is OFF the instruction is false. Similarly, the "Examine OFF" instruction also works as mentioned above.

The Output Energize instruction asks the controller to "set the status bit of the addressed Output Energized instruction to ON when rung conditions are true." When the conditions are true the status bit of Output instruction will be set to ON.

In terms of continuity, when there is a continuous path of TRUE conditional instructions in a rung, logical continuity exits; accordingly, the output instruction is TRUE, and its status bit will be set ON.

2.2.2 SYSTEM THROUGHPUT

Throughput is the time it takes for the controller to sense and input to the time of controlling a corresponding output. Typical throughput for a 500-instruction program is 1.5ms.

2.2.3. PROCESSOR

During each operating cycle, the processor examines the status of input device, executes the use program and changes output accordingly. This cycle is repeated about 67 times each second for a typical 500 Word Program.

A single operating cycle or scan is illustrated in figure. Note that it is divided into two different parts I/O scan and the program scan.

2.2.4.I/O SCAN

During this part of cycle, data associated with external outputs is transferred from data table to the corresponding output terminals. In addition, input terminals are examined, and the associated status bits are changed accordingly.

2.2.5. PROGRAM SCAN

The updated status of the input devices is applied to the user program during this part of the cycle. The processor executes the entries sent to instructors in the same order they were entered. Status bits are updated according to logical continuity rules as the program scan moves from the instruction to instruction through successive ranges.

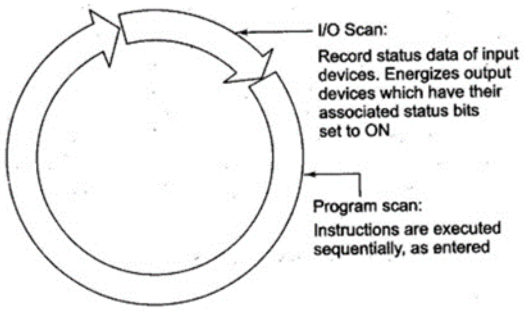


Fig-6: Single PLC scan

Typical I/O scan time is 2.6ms. Typical Program scan time is 12.4ms (depends on program content and length).

2.3 RELAY TYPE INSTRUCTIONS

Relay type instructions are used for external I/O points as well as for internal control. These include

- Examine ON, Examine OFF (Condition instructions).
- Output Energize.
- Branch Open, Branch Close
- Output Latch, Output Unlatch (Retentive Instructions)

2.3.1. BRANCH INSTRUCTION

These are used to create parallel paths of condition instructions, allowing more than one set of conditions to establish continuity in a rung.

2.3.2. RETENTIVE INTRUCTIONS-OUTPUT LATCH, OUTPUT UNLATCH

These are retentive output instructions, used as a pair at the same address. When a rung containing an Output Latch instruction goes TRUE, the Output Latch status bit is set to ON. The bit can only be turned OFF by an Output Unlatch instruction located in a separate rung.

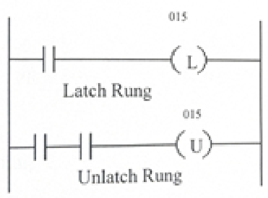


Fig-7: Ladder diagram representation

2.3.3. TIMER INSTRUCTION

Retentive Timer ON-Delay-(RTO)- and Retentive time OFF-Delay (RTF) -both requires the use of reset instruction. The timer instruction functions as internal "Clock" counting one second intervals. The number of intervals counted is called Accumulated Value (AC). Counting takes place under TRUE/FALSE rung condition.

2.3.4.RTO AND RTF RUNG INSTRUCTION

Address:901 -932 (internal)

Range:0.1 to 999.9 sec

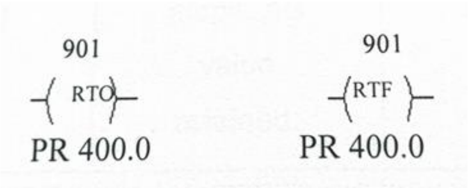


Fig-8: RTO and RTF Rung Instruction

The timer instruction functions as an internal clock, counting 0.1 second intervals. The no. of intervals counted is called Accumulated Value (AC). Counting takes place under the following TRUE/FALSE rung conditions.

a. RTO Timer Rung Conditions.

Table-3: Conditions for RTO Timer Rung

TRUE	FALSE	TRUE
Timer is counting	Counting stops. AC value retained	Counting resumes.
AC value represents the cumulative time during which rung is TRUE.		

b. RFT Timer Rung conditions

FALSE	TRUE	FALSE
Timer is counting	Counting stops. AC value retained	Counting resumes
AC value represents the cumulative time during which rung is FALSE		

The RTO Status bit is set ON when AC value reaches the PR value. RTF status bit is set off when the AC value reaches the PR value. The RTF status bit is set OFF when the AC reaches the PR value. Examine ON instructions at the status bit address go FALSE, Examine OFF instructions go TRUE. The overflow bit is given the timer address plus 50 (901 +50=951). The overflow bit is set to ON when the AC value "Overflows" from 999.9 to 0000.

2.3.4. Reset Instruction:

The reset (RST) instruction is given the same addresses as the timer instruction.

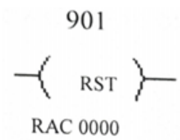


Fig-9: Ladder diagram for Reset Instruction

When the RST instruction goes TRUE, status bits and overflow bits are set of OFF, and AC value is reset to RAC value. The RST instruction must go false again before the time can resume counting.

2.3.5. CTU AND CTD Counter Instructions:

Counter instructions count successive FALSE or TRUE transitions of the rung containing the counter instruction. After each count, the rung must return to FALSE before another count can take place.

The existing count is called the Accumulated Value (AC). For up counters, the AC value increases, the AC value increase by 1 for each FALSE-TRUE transition. For down counter, the AC value decreases by 1 for each FALSE-TRUE transition. Up down counters have both an up counter rung and a down counter rung. The clock figure below represents the AC value. An output can be obtained data particular count by programming a preset value (PR). In this case the PR value is set at 1000.

2.3.6. Statis and Overflow/Underflow Bits.

The counter status bit has the same address as the counter instruction. The status bit is set ON when the AC value reaches the PR value. Examine ON instructions at the status bit address go TRUE, Examine OFF instruction go FALSE.

Overflow and underflow bits are assigned the counter address plus so. (901 +50 =951). The overflow bits are set ON when the AC value "Overflow" from a count 9999 to 0000.The underflow bit is ON when the AC value "Underflows" 0000 to 9999.

3. Single Line Diagram of Capacitive Power Plant and Receiving Station.

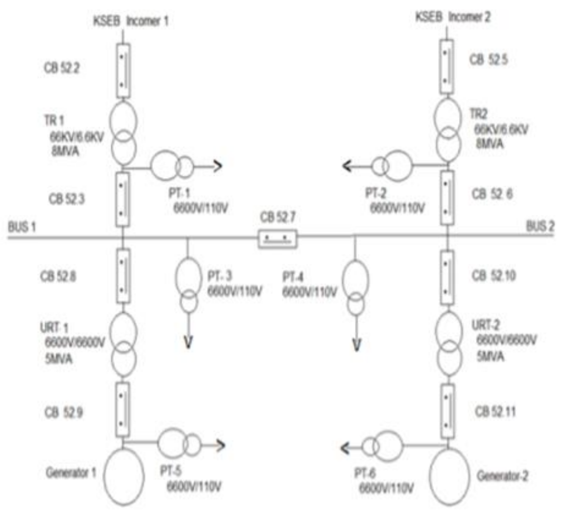


Fig-10: Single Line Diagram

Following Breakers are involved in synchronizing/Dead Bus closing 52-3,52-6,52-8 and 52-10.

Interlocks will be provided to ensure the following.

- 52-2 can be closed when 52-3 is open
- 52-5 can be closed when 52-6 is open.
- 52-8 can be closed when 52-11 is closed
- 52-10 can be closed when 52-11 is closed.
- 52-9 can be closed when 52-8 is open
- 52-11 can be closed when 52-10 is open.

4. Procedure for Synchronization

1. Start G -1 with 50Hz frequency & 6.6KV voltage and power up circuit breaker and load set.
2. Voltage and frequency readings are recorded until 2.5MW is reached.
3. The circuit breaker will be tripped, and the full load will be turned off.
4. Readings of voltage & frequency is noted on no load
5. The procedure is performed two or three times if the values differ.
6. Repeat same method is for G-2
7. The generator will now be taken over to synchronize with the KSEB grid distribution
8. Using a double scale voltmeter, a double scale frequency meter, and a synchronizing synchroscope, the characteristics of the Generator set will be matched to those of the grid supply.
9. Then circuit breaker of Generator set will be closed

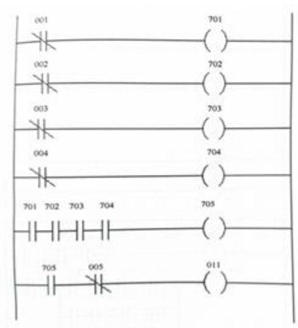
4.1: Connections of Synchronizing Equipment

Table-5: Synchronizing equipment connections

Breaker to syn.	Operating Condition	Incoming volts	Running volts	Control signal to….
52-3	G1 ON G2 OFF	PT 3	PT 1	G-1
52-3	G2 ON G1 OFF	PT 3	PT 1	G-2
52-6	G1 ON G2 OFF	PT 4	PT 2	G-1
52-6	G2 ON G1 OFF	PT 4	PT 2	G-2
52-7	52-3 OFF 52-6 OFF 52-8 ON 52-10 ON	PT 4	PT 3	G-2
52-7	52-3 ON 52-8 ON 52-10 ON 52-6 OFF	PT 4	PT 3	G-2
52-7	52-6 ON 52-3OFF	PT 3	PT 4	G-1
52-8		PT 5	PT 3	G-1
52-10		PT 6	PT 4	G-2

5.Ladder Diagram:

5.1 Breaker 52-3/52-6 Closing condition for synchronization.



001-Local/Remote S/W Local

002- Synchronization S/W ON

003-Synch Mode Auto/Manual-A

004-Breaker Open

705-Synch Condition OK

005- Synch Permit from 85 Relay

Fig-11: Ladder diagram for breaker 52-3/52-6

5.2 .Breaker 52-8/52-10 Closing Condition for Synchronization

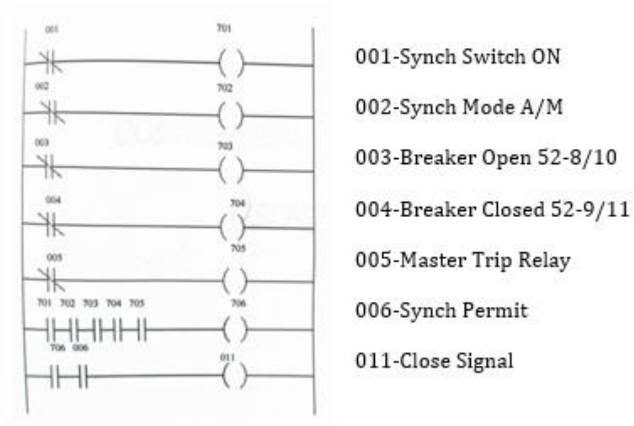


Fig-12: Ladder diagram for Breaker 52-8/52-10

5.3 Breaker 52-7 Closing Condition

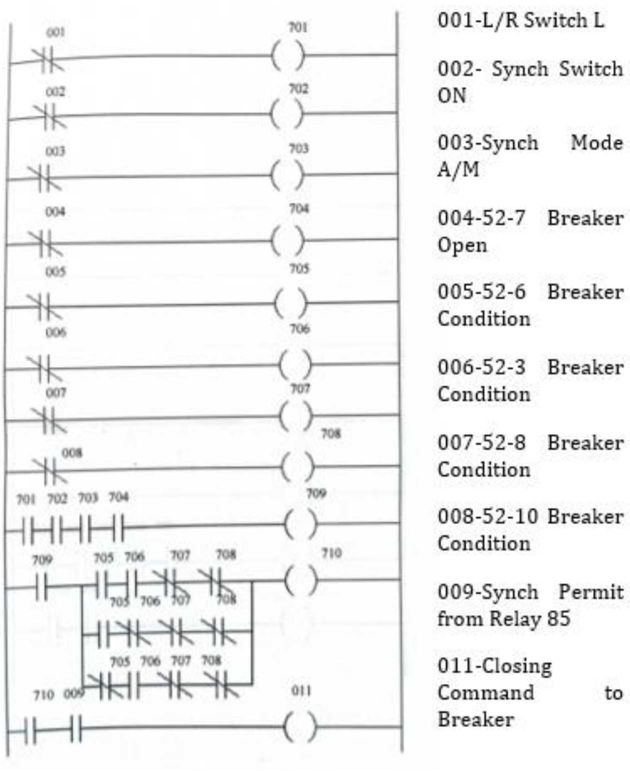


Fig 13: Ladder diagram for Breaker 52-7

6. Advantages of Modified system

Interlock system using PLC

By changing the existing electromechanical relay based to a PLC based system, we will get all the benefits of a programmable controller. The advantages of PLC over Relay system are

1. Space: Save space required for mounting.
2. Cost: In a system requiring about 6 to 8 control relays, a PLC can become more cost effective.
3. Maintenance: Because a PLC is an intelligent device, it could provide diagnostics to aid in troubleshooting in the event a failure occurs.
4. Flexibility: PLC can be fitted into a wide range of application.
5. Compatibility: Most PLCs can be easily interfaced with the entire control products line including drivers, pushbuttons, limit switches, proximity switches, photo sensor and so on.
6. Usability: PLCs are programmed using symbols, which are familiar to people in industry. It is not a high-level language such as PASCAL, FORTAN etc. Relay ladder logic is the industry standard.
7. Reliability: Since PLC are solid state devices, it has no moving parts. This differs greatly form the standard relay system which are subject to mechanical failure due to wearing out of mechanism along with and dirt build-up. Generally, the longer a solid-state device operates, longer it will continue to operate.
8. Visual Observation: A PLCs circuit operation can be seen during the operation directly on CRT screen. The operation or miss operation of a circuit can be observed as it happens.
9. Pilot Running: A PLC Programmed circuit can be pro-run and evaluated in the office or lab. The program can be typed in, tested, observed, and modified if needed, saving valuable factory time.
10. Documentation: An immediate printout of the true PLCs circuit is available in minutes if required. There is no need to look for blueprint of the circuit in the remote files.

7. CONCLUSION

Advanced technology is producing more flexible complex control system and strongest plant safety requirements. By using automated system using PLC, the speed and easiness of synchronization process increases. Thus, the reliability of the power system increases. So, it is preferable to use automated PLC system in Grid Synchronization Control. Using PLC, we would develop a highly reliable flexible and compact system avoiding the elaborate hard-wired relay wired system.

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