

Design and Implementation of Networked Control System via Ethernet for Self Excited Induction Generator Using OPC Server

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ABSTRACT

Induction generators are increasingly being used in nonconventional energy systems such as wind, micro/mini hydro, etc. The advantages of using an induction generator instead of a synchronous generator are well known. Some of them are reduced unit cost and size, ruggedness, brushless (in squirrel cage construction), absence of separate dc source, ease of maintenance, self-protection against severe overloads and short circuits, etc. In isolated systems, squirrel cage induction generators with capacitor excitation, known as self-excited induction generators (SEIGs), are very popular. Remote control applications over a wide area had been commonly used in the industries today. One of the common applications requires remote control and monitoring is output voltage control of SEIGs supplied insensitive frequency loads. Drive system has various types of controller, in order to perform some actions such as control the speed to control the output voltage of SEIGs, switching On or Off loads supplied by the generator. This control system can be done by Programmable Logic Controller (PLC), and with the rise of the technology, Ethernet module will be used in order to achieve the remote control system. Plus the PLC today can be controlled not only using its original software, but 3rd party software as well, such as LabVIEW. LabVIEW is a human machine interfaces design software that is user friendly. It can be easily communicate with different hardware using OLE for Process Control (OPC) server.

Keywords: Ethernet, LabVIEW, Networked Control System, PID controller, PLC, OPC Servers, Self Excited Induction Generator.

1. Introduction

Industrial control has been moving more and more towards distributed implementations of control systems. Networks are used to communicate the data instead of using traditional point-to-point communication. Networks require less wiring and less maintenance compared to a point-to-point architecture. Such networks carry a large number of small control signals between many nodes and these signals have to meet the delay constraints of real-time control systems. The main difference between such control networks and conventional data networks is that control networks must be able to support time-critical applications [1].

Networked Control Systems (NCSs) consist of sensors, controllers and actuators that communicate together over a network. Sensors send packets to the controllers which calculate the control action that should be delivered to the actuators, and these transmissions must meet the control system's deadline. There are four factors that affect the utilization of the network bandwidth: the sampling rate, the number of nodes requiring synchronous operation, the size of the information sent and the protocol used. Traditionally, for proper control, there are different protocols used which have a deterministic behavior such as DeviceNET and ControlNET [2, 3]. Also, many real-time applications were studied using protocols such as Controller Area Network (CAN), PROFIBUS and EtherNet/IP which is a merger between Ethernet and ControlNET [3, 4, 5, 6, 7].

Recently, Ethernet has been used in Networked Control Systems. Although Ethernet is a nondeterministic protocol, in many studies, that it can be used in NCSs. Ethernet is widespread nowadays in communication systems because it has been proven to be a very successful protocol. By using such a protocol, installation and maintenance costs can be reduced in industrial applications. In [8], real-time as well as

non-real time traffic were integrated without any changes to the IEEE 802.3 protocol. A system consisting of 16 sensors, one controller and 4 actuators was able to meet the required time constraints.

The system was running on-top-of Gigabit Ethernet. On the other hand, in [9], The architecture with an integrated control design was also a possible solution where each actuator would have its own controller integrated in the same node instead of one controller for the entire system. This same concept is implemented in Sensor Actuator Networks (SANETs) where group(a) of sensors and actuators are distributed geographically and communicate together through wired or wireless networks.

Previously, engineers and scientists had been designing the engineering systems that require a lot of hardware. It is merely impossible to design distance control of the system as more hardware and wiring were needed. In addition, with the rise of the technology, programmable logic controller (PLC) have eased the engineering design and reduce materials required, it is because the entire design is implemented in software programming Pattern. PLC had been commonly used in the industry, including controlling both digital and analog signals. Design distance control machinery is now possible, even by using Ethernet as the communication device between the computer and the PLC [10].

Apart of design the program structure by its own proprietary software, the convenience part of PLC is the accessibility and controllability by other software. Such software must have driver utility of the particular PLC. Therefore engineers can use LabVIEW [11], which has various types of industrial applications which are in virtual instrument (VI) instead of the real and heavy instrument, to control the PLC.

2. Project Design Configuration & Preparation

2.1. OPC Server

OLE for Process Control (OPC), which stands for Object Linking and Embedding (OLE) for Process Control, is the original name for a standard specification developed in 1996. The standard specifies the communication of real-time plant data between control devices from different manufacturers. OPC is a software interface standard that allows Windows programs to communicate with industrial hardware devices as illustrated in Figure 1.

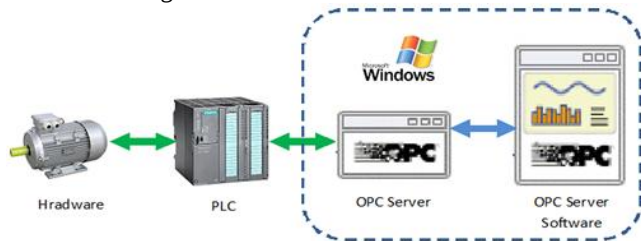


Figure 1. OPC server.

The basic concept in OPC is that we have an OPC Server and one or more OPC Clients that communicate with the server in order to write or read data. An OPC server has implemented a set of services, and the clients are using these services.

OPC is implemented in server/client pairs. The OPC server is a software program that converts the hardware communication protocol used by a PLC into the OPC protocol. The OPC client software is any program that needs to connect to the hardware, such as an HMI. The OPC client uses the OPC server to get data from or send commands to the hardware.

Although OPC is primarily designed for accessing data from a networked server, OPC interfaces can be used in many places within an application. At the lowest level they can get raw data from the physical devices into a SCADA or DCS, or from the SCADA or DCS system into the application. The architecture and design makes it possible to construct an OPC Server which allows a client application to access data from many OPC Servers provided by many different OPC vendors running on different nodes via a single object. Figure 2 shows the OPC server structure.

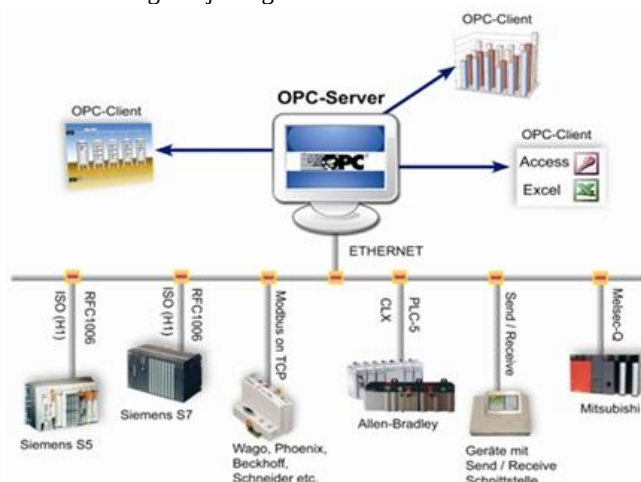


Figure 2: OPC server, OPC clients and different OPC vendor's hardware devices.

The value of OPC is that it is an open standard, which means lower costs for manufacturers and more options for users. Hardware manufacturers need only provide a single

OPC server for their devices to communicate with any OPC client. Software vendors simply include OPC client capabilities in their products and they become instantly compatible with thousands of hardware devices. Users can choose any OPC client software they need.

Tags are used a lot in the process industry and are normally assigned to a piece of information. A tag consists of a name describing a single point of information so a process system can consist of hundreds and even thousands of tags. The OPC server has one tag for each measurement points and controller points in the plant and it is the responsibility of the OPC server to get the information from the controllers. This is one of the reasons for the complexity of the servers, they need to have drivers for a lot of controllers and measurement systems.

2.2. NI OPC Server

The NI OPC Servers Bridge converts proprietary industrial protocols to the open OPC Classic and OPC Unified Architecture (UA) protocols. This conversion to OPC then enables NI LabVIEW software to communicate to many different programmable logic controllers (PLCs) and third-party devices through the OPC Client that is included with the Lab VIEW Data logging and Supervisory Control (DSC) Module. The combination of NI OPC Servers and LabVIEW provides a single platform for delivering high-performance measurements and control to industrial systems.

The OPC Client I/O servers for communicating with any server implementing the OPC Foundation OPC server interface. This allows LabVIEW to communicate with any PLC that is interacting with an OPC Server. An OPC Client I/O server will list all available OPC servers that are installed and running on a local or network computer. Figure 3 shows the relationship of the components involved in communication between LabVIEW and a PLC.

PLCs publish data to the network. An OPC Server program uses the PLC's proprietary driver to create OPC tags for each physical I/O on the PLC. NI OPC Servers contains a list of drivers for many of the industry's PLCs. The OPC Client I/O servers provided with the DSC Module can connect to each OPC tag using the OPC DA standard. The configuration of the multiple OPC Client I/O servers in the SVE with different update rates, dead band percentages, and reconnect poll rates can be done easily. The SVE provides a PSP (PublishSubscribe Protocol) URL for each OPC tag that other Shared Variables can bind to by enabling aliasing. Once you deploy the Shared Variables in the SVE and the Shared Variables receive values, LabVIEW can easily read and write to the Shared Variables using a VI.

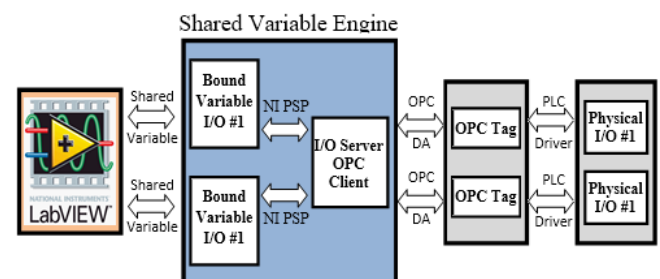


Figure 3: LabVIEW and the SVE Can Communicate with PLCs through OPC.

NI OPC Server has Siemens TCP/IP Ethernet driver that allow the communication between SIMATIC S7-300 CPU315F-2 PN/DP PLC with LabVIEW. Siemens supplies their customers with Profinet gateway, interfacing software that communicates with the PLC and its proprietary software, SIMATIC MANAGER over the Ethernet network.

With the Siemens Ethernet driver in NI OPC, users can setup the server by just a few simple setups and create variable tags that can be linked directly to the PLC's registers. These tags are named as OPC tags. The NI OPC Servers also have NI OPC Quick Client that enable users to monitor the status of the PLC in real-time.

As long as the OPC tags had been created, the communication between the LabVIEW and PLC had been simplified as the driver can automatically apply the relevant Profinet commands provided the tags are correctly configured [3]. Meanwhile in LabVIEW, the program can be design by using Shared Variables which is link to the OPC tags.

LabVIEW is a graphical development environment for generating flexible and scalable design, control, and test applications rapidly at minimal cost. With LabVIEW, engineers and scientists are able to interface with real-time signals, analyses data for meaningful information, and share results through intuitive displays, reports, and the Web. Regardless of programming experience, LabVIEW makes development fast and easy for all users.

The programming language used in LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram on which the programmer connects different function nodes by drawing wires.

These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. Multi processing and multi-threading hardware is automatically exploited by the built-in scheduler, which multiplexes multiple OS threads over the nodes ready for execution. Similar to other conventional programming, LabVIEW has standard features such as looping structures, data structures, event-handling, object-oriented programming. LabVIEW also has an extensive library of math functions similar to MATLAB libraries and also formula nodes that allow text-based programming for certain sections of the code that require complex logical structures. Besides that, LabVIEW also has networking library functions that can easily allow users to reference.

Compared to other software like Microsoft Visual Basic, LabVIEW is a better option as it comes together with a library of functions included Shared Variables Project Library, which is bound to the OPC tags that allow server and client communication

by connecting relevant icons with the Shared Variables. If Microsoft Visual Basic (VB) is used, the Siemens Ethernet driver must be developed using the MS Comm. function and this would require more time to develop the code [12].

In general LabVIEW has two main elements: the front panel and the block diagram. The front panel allows the user to build the controls and indicators. The controls are including knobs, push buttons, dials, and other input mechanism. Indicators are graphs, LEDs, and other output displays. Meanwhile, the block diagram let user to add code using VIs and structures to control the front panel objects. The elements are illustrated in Figure 4.

LabVIEW has front-end interface applications that allow user to design and then use for controlling systems. Shared variable is a library function variable that allows sharing of data between applications or different data sources across a network. There are many existing data sharing method in LabVIEW, such as UDP/TCP, LabVIEW queues, and Real-Time FIFO [12, 13].

2.3. Programmable Logic Controller

The PLC used for this implementation is SIEMENS SIMATIC S7-300 series. There are 4 modules in addition Power Supply Unit PS307 used in the PLC controller:

Module1: CPU Unit with Ethernet function (6ES7-315-2FH13-0AB0) the Benefits of the CPU is reduction of stock-keeping by saving components, One controller for standard and safety automation, Coexistence of standard and safety programs on one controller is possible, one PROFIBUS or PROFINET transmitting medium for standard and safety communication to SIL 3/Category 4 ,one distributed I/O configuration with standard and safety I/O modules, high speed scan rate (CPU processing time for bit operation is 0.1μ sec.)and automatic detection of transmission rate 10/100 Mbit/s

Module2: An accurate resolution analog input (AI8 12 BIT -331-7KF00-0AB0)

Module3: High speed digital input and output module (6ES7-322-1BH01-0AB0), is used for digital operation like On/Off the whole system, switch On/Off load different loads supplied by the generator.

Module4: AO4 12bit -332-5HD01-0AB0) basic digital output Unit (6ES7-321-1BH01-0AB0).

All these modules can be connected by assembled and connected them together via backplane plugged in the back of the modules In order to let the PLC to operate through the Ethernet, the PLC must be given an IP address with a Destination node number that is not a duplicate of other IP addresses in the network. The destination node number is also known as the last octet of an IP address.

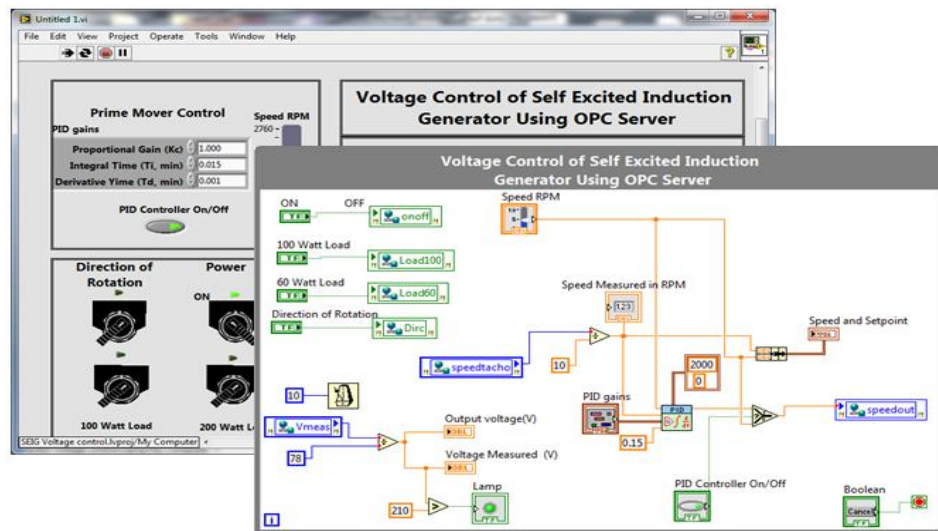


Figure 4: Two main elements of LabVIEW software.

2.4. Self Excited Induction Generator

Induction machines acts as a generator when the slip of machine is negative i.e. the rotor rotates with speed above synchronous speed. When slip is negative, the rotor e.m.f., rotor current and power becomes negative. Under such condition, the electric torque developed is negative (opposite to prime mover) and the machine delivers power to supply mains or loads. The induction generators are two types depending upon the source of magnetizing current:

1. Self-excited induction generator
2. Separately-excited induction generator

Self-excited induction generator (SEIG) means cage rotor induction machines with shunt capacitors connected at their terminals for self-excitation. The shunt capacitors may be constant or may be varied through power electronics. A capacitor bank supply the reactive power to the induction generator for self excitement process and as well as to the load.

2.4.1 Advantages of Induction Generator over Synchronous Generator

- IGs are capable of generating power from variable speed as well as constant speed prime movers.
- Rugged in construction, low cost and easily available.
- Parallel operation is possible without hunting.
- The induction generator has self-protection feature. In the case of the short circuit or overloads, if a fault occurs on its terminals, the excitation fails, and the machine stops the generation itself.
- It needs less auxiliary equipment, do not need a separate DC exciter and other equipment such as field breaker and synchronization circuit.
- Require very less maintenance.
- It does not have to be synchronized to the supply line as that of the synchronous generator.

2.4.2 Single-Phase Power Generation

In remote and rural areas, the population is sparsely distributed and most of the electrical loads are of single-phase type. Single-phase supply is suitable up to the load of 20 kW due to cost effectiveness of the distribution system. Also, load balancing becomes difficult in three-phase SEIG for small-scale power generation. Single-phase induction motors can be

operated as single-phase SEIG, but these are limited to small power outputs, i.e., up to 5 kW. Above this load, three-phase machines are cheaper, more readily available and have higher efficiency than equivalent sized single-phase machine. For these reasons, three-phase machines may be used for single-phase power generation, the main schemes for single phase power generation using three-phase machine are as follows:

1. C – 2C scheme for delta connected machine as shown in Figure 5.
2. Csh – Cse configuration
3. Cp – Cs scheme

The power system as a whole runs on a single frequency and in order to maintain stability as well as efficiency the frequency of the system must remain constant at every point of time. The transients can occur at any stage of power system but when talk about frequency, load is one of the biggest driving factor which needs to be monitored.

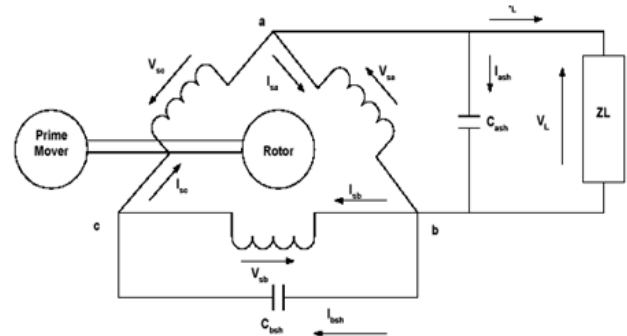


Figure 5: Connection of Self Excited Induction Generator of C-2C Scheme.

When we talk of total change in electrical power of the system we consider both frequency independent sources and non-frequency sources. For resistive loads, such as lighting and heating loads, the electrical power is independent of frequency. But for motor loads and other variable loads, such as fans and pumps, electrical power change with frequency due to change in motor speeds. Thus the concept of non sensitive and sensitive frequency loads arise.

2.4.3 Classification of Induction Generators:

Depending upon the prime movers used and their locations, generating schemes can be broadly classified as under

- **Constant speed constant frequency [CSCF] :**

In Constant speed constant frequency scheme, by continuously adjusting the blade pitch and/or generator characteristics the prime mover speed is made constant. At a slip of 1% to 5% above the synchronous speed, an induction generator can operate on an infinite bus bar. Induction generators have many advantages like they are easier to operate, control, maintain, and do not have any synchronization problems.

- **Variable speed constant frequency [VSCF]:**

The variable-speed operation of wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable-speed operation.

- **Variable-Speed Variable Frequency [VSVF]:**

The performance of synchronous generators can be affected with variable prime mover speed. For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads, which are essentially frequency insensitive. This scheme is gaining importance for stand-alone wind power applications.

3. Implementation

3.1. Implementation Process

The Ethernet control systems presented in this paper is to control output voltage of Self Excited Induction generator (SEIG). In order to achieve the objectives, the establishment of the communication between PLC and LabVIEW is crucial as LabVIEW is 3rd party software using OPC server. Thus, the implementation used LabVIEW to perform the start and stop operation of the prime mover, either in forward or reverse direction, and varying the speed by changing the frequency of the motor using **Micromaster 420** inverter and connect or disconnect an electrical load to output terminal of Induction generator. However, this system is also a supervisory control and data acquisition (SCADA) since there is practical data measurement acquire from the actual output of the system, this feedback is the output voltage of the SEIG and the actual speed that can be read from the tachogenerator install at the same shaft.

3.2 PID controller

One of the control system strategies to dominate like this close loop system is PID "Proportional-Integral-Derivative" controller to achieve the objectives parameters, to tune the controller parameters K_p , T_i , and T_d . The PID control algorithm is a robust and simple algorithm that is widely used in the industry. The algorithm has sufficient flexibility to yield excellent results in a wide variety of applications and has been one of the main reasons for the continued use over the years [23, 24].

However, it is difficult to design when the accurate model of plant is complicated or the environment of the load on the plant is variable. So there is no PID hardware were designed and implemented, in this paper, the PID controller of control design and simulation toolbox of LabVIEW is used, a basic PID loop controller structure is shown in Figure 6.

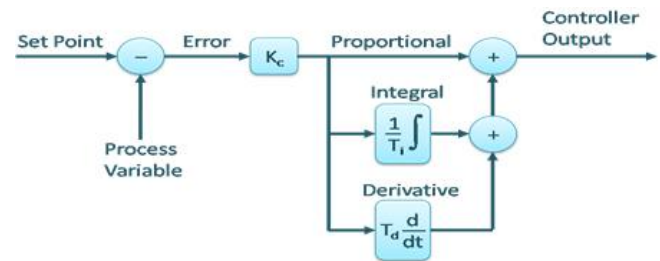


Figure 6: Basic PID loop controller structure.

Proportional action is the controller gain times the error, the PID VIs express the proportional component in terms of controller gain. In integral action (Trapezoidal Integration) there are several options for discretizing integral action, such as forward difference, backward difference, and trapezoidal approximation, which is also known as Tustin or Bilinear transformation. The PID VIs use trapezoidal integration to avoid sharp changes in integral action when there is a sudden change in PV or SP. Abrupt changes in SP can generate bumps to the output of the controller as a result of applying derivative action to the error e . These bumps are referred to as derivative kick. To avoid derivative kick, you can apply derivative action to the PV only, and not to the error e . Controller output is the summation of the proportional, integral, and derivative action, as shown in Figure 6.

The loop-cycle time, or interval in seconds, at which this VI is called this VI calculates the time since it was last called using an internal timer with 1 ms resolution.

The system has three-layer network architecture illustrated in Figure 7. As illustrated in Figure 8, user gets the authority to control through the host computer, which is a laptop.

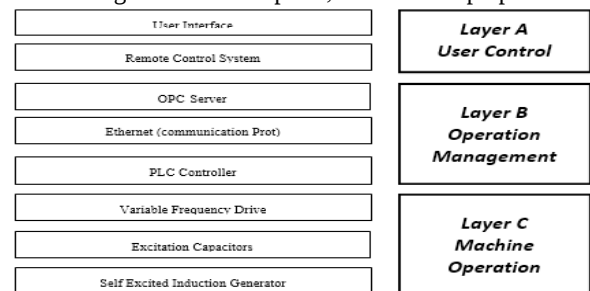


Figure 7: Three layer network architecture.

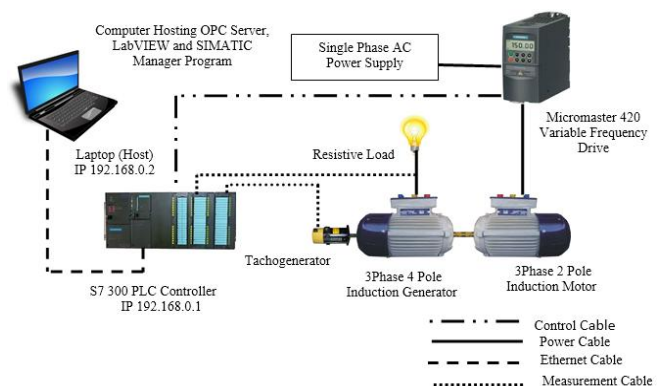


Figure 8: Actual network configuration.

3.3. Implementation of VI Design

The objective of the VI program is to allow user to make the decision of the start and stop operation of the prime mover, either in forward or reverse direction, and varying the speed by

changing the frequency of the motor, by perform two simple step. Firstly select the turning direction by press the push button in the VI Front Panel, which is either forward or reverse. Secondly, vary the speed by turning the Frequency slider to the value of the frequency that the user desire. Figure9 illustrates the V I Front Panel of the LabVIEW project.

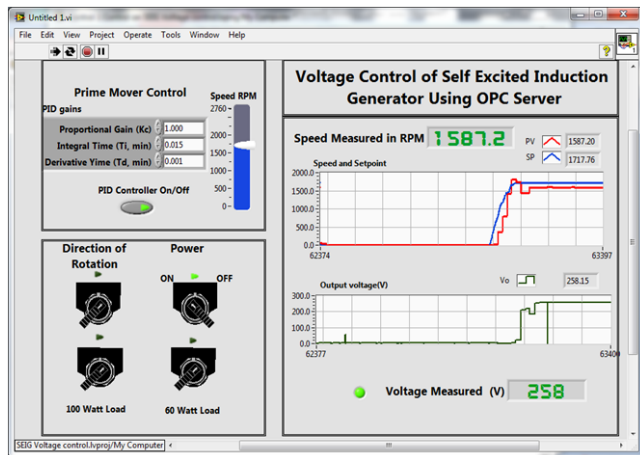


Figure 9. VI front panel of the project.

Before running the VI, make sure all the hardware have been switched on and configured correctly, and launch the NI OPC Quick Client so that the OPC tags can be browsed by the shared variables in this VI. There are 7 OPC tags was created and used in the implementation, and the details of the tags have been tabulated in Table 1.

Table 1. The details of OPC tags and its PLC Addresses.

OPC Tags	PLC Addresses	Data type	Description
Dir	M60.0	Bool	To Change the Direction
load100	M60.1	Bool	To Switch Load 100 Watt
Load60	M60.2	Bool	To Switch Load 100 Watt
On/Off	DB1.DBX8.2	Bool	To Switch On/Off Prime Mover
speed tach	MD18	Double word	Measure the Actual Speed
Vmeas	IW290	word	Measure the Actual Output Voltage
vout	DB1.DBW0	word	Control Voltage of the Inverter

By referring to Figure 9, the Power switch is to switch the prime mover on and off and the direction of rotation switch is turning in forward direction and backward direction. The slider labeled as “Speed RPM” is the key program to control the frequency as well as the speed of the motor. The PID gains can be adjusted by tuning the proportional gain K_p , integral time T_i and derivative time. The upper waveform chart for data logging of set point speed and the actual speed of the generator via Tachogenerator and the output voltage of the generator is plotted in the lower waveform chart.

Figure 10 and Figure 11 illustrate the Time response of the speed and the output voltage when the PID controller gains are $K_p = 1.0$, $T_i = 0.0015$ min., $T_d = 0.001$ min. after applied a resistive load of 60 watts and 100 watts respectively.

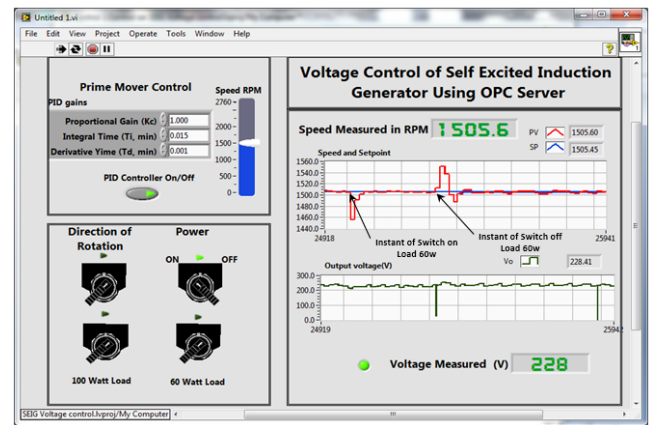


Figure 10: Time response of the speed and the output voltage when the PID controller gains are $K_p=1.0$, $T_i=0.0015$ min., $T_d=0.001$ min. after a resistive load of 60 watt is applied.

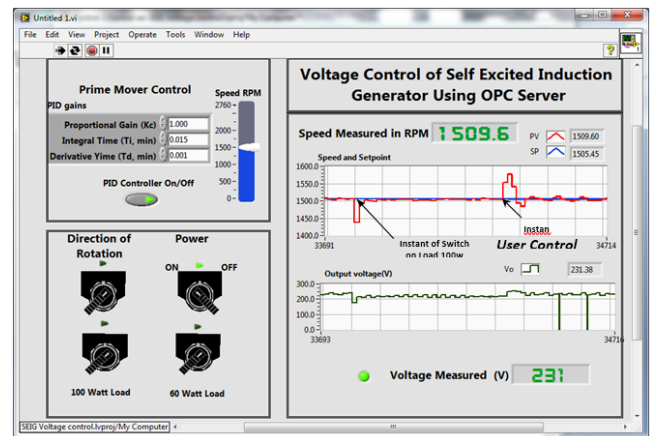


Figure 11: Time response of the speed and the output voltage when the PID controller gains are $K_p=1.0$, $T_i=0.0015$ min., $T_d=0.001$ min. after a resistive load of 100 watt is applied.

The time response of the speed and the output voltage when the generator is regulated the PID controller gains are $K_p = 1.0$, $T_i = 0.0015$ min., $T_d = 0.001$ min. for deactivate and Activate the PID controller while startup are shown in Figure 12 and Figure 13 respectively.

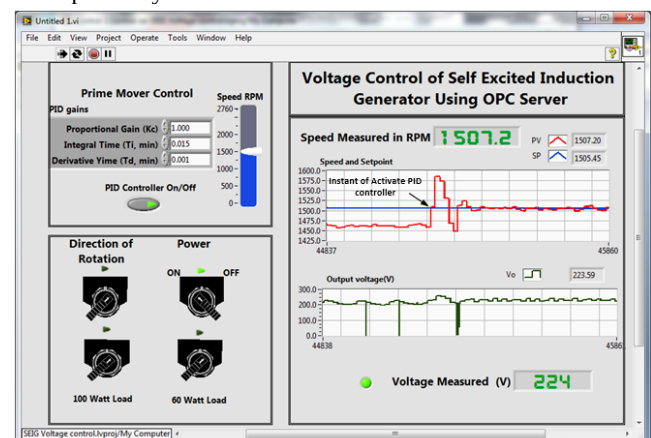


Figure 12: Effect of PID Controller When Activated.

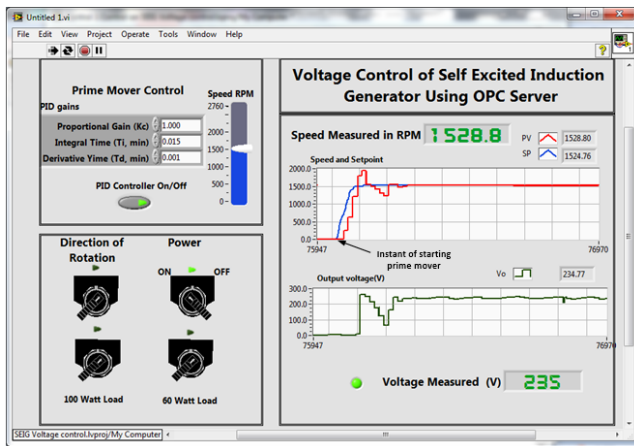


Figure13: Effect of PID Controller When Starting up.

4. Testing and Verification

After the implementation, test is performed in order to verify that the system is working smoothly. Figure 14 shows the front view of the system. Figure 15 shows the PLC Ethernet Module light indicators that light up when the project VI is executing.

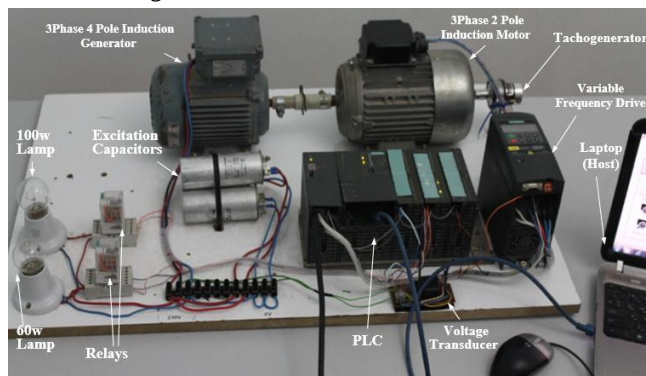


Figure 14. Shows the Front View of the System.



Figure 15. PLC Ethernet module light indicator status.

5. Conclusions

The objective, scope and fundamental requirements of the project had been achieved. A major system design requirement for Networked Control Systems (NCSs) is to meet real-time delay requirement for sensors, controllers and actuators. Different protocols were purposed to maintain requirements of speed and correctness such as Controller Area Network (CAN) and PROFIBUS. ETHERNET in NCS is now one of the most widespread and low cost protocols available. The time response of the controller used Ethernet protocol was encouraging, there

is no considerable end-to-end time delay during the execution, the scan rate of OPC server and the loop-cycle time, in VI is 10 ms, when the project VI is executing by Laptop (Intel(R) Core(TM) i7-2670QM-CPU@2.20 GHz and 8Gb RAM and integration time of the PID controller was 0.15 second.

From the operation of an induction machine under standalone generating mode and a generating scheme for constant voltage and variable frequency by a proportional gain control technique. A laboratory test is performed where the induction machine is controlled as a self excited induction generator. The effect of rotor speed is observed. From the experimentation, it is confirmed that as the rotor speed is increased at a particular speed, voltage builds up faster and the magnitude of voltage increases due to availability of more VAR. But frequency remains constant. As the speed increases at a fixed capacitance, both magnitude and frequency of generated voltage increases, self excited induction generator C-2C scheme used with the alternative energy sources, such as windmills or with energy recovery systems in the industrial processes. They are also used to supply additional power to a load in a remote area that is being supplied by a weak transmission line.

In overall, choosing LabVIEW as the human machine interface (HMI) for the implementation is a proper decision as it has various types of applications and functions that are easy to understand and use. Additionally, this approach is more economical as the objectives of the system implementation have been achieved with only basic functionality of the LabVIEW toolkits used, which are shared variables and NI OPC Servers.

The CPU processing time of Siemens S7 300 series PLC was able to meet the required time constraints, and the control unit is easy to install and setup. Both hardware and software configuration can be easily done. It can carry out additional functions by simply add more units with various functions, like the digital/analog modules or Ethernet units.

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APPENDIX-A

3 ϕ induction motor(Prime mover) parameters:

Connection	Rated Voltage	Rated power	Full load current	Motor speed
YY	400V	0.6kW	1.6A	2760 rpm
Δ	400V	0.45kW	1.5A	1320 rpm

3 ϕ induction generator parameters:

Connection	Rated Voltage	Rated power	Full load current	Motor speed
Y	220V	0.37kW	1.85A	1395 rpm
Δ	380V	0.37kW	1.1A	1395 rpm