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Design of SCADA for Load Frequency Control prototype using PLC controller with PID algorithm

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Abstract. Frequency deviation from the nominal value of 50 Hz must be within the allowable tolerance limit of 2%. Load changes contributes to vary the frequency then settings are needed using LFC (Load Frequency Control) which controls speed of generator. From the issue, the research is about of making a learning prototype for the control system. Frequency is set using a Programmable Logic control (PLC) Twido TWDLMDA20DUK by using a Proportional Integral Derivative (PID) algorithm and can be supervised via SCADA. The results of experiments were analysed their stability of frequency and speed. PID values are obtained from Ziegler Nichols method and Auto Tuning. Close loop experiments shows that with a value of Kp = 1 Kd = 0.115 Ki = 0.49 can improve the frequency 49.41 Hz at 3.5 Nm load. The transient response at steady state which is 50 Hz, the Ziegler Nichols method has a rise time value greater than the other methods of 21.09 ms, the overshoot is relatively small, 0.492% , settling time 0.03s and steady state error of 0.004 so that when the load changes the stability response of the Ziegler Nichols method is faster than the other methods.

1. Introduction

Frequency deviation from the nominal value of 50 Hz must be within the allowable tolerance limit. For the interconnection system of the decline and the maximum frequency value increase is 2% while for its own consumption system, the increase and decrease is limited to a range of 6% [1]. Frequency setting can be controlled and supervised through a device for quality and reliability in the power system is fulfilled. From the issue, the research is about of making a learning prototype for the control through one of the problems often occur i.e. the frequency setting if there is a change of load that can be adjusted Automatically and can be supervised directly.

The outcomes of sensor may be implemented on controller for load frequency control unit in power system [2]. The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits [3]. Almoataz Y introduce Load Frequency Controller Design via Artificial Cuckoo Search Algorithm [4]. Supervisory Control and Data Acquisition (SCADA) / Human to Machine Interface (HMI) systems developed for didactic purposes [5]. Frequency is set using a Programmable Logic control (PLC) Twido TWDLMDA20DUK by using PID and can be supervised via SCADA. Load frequency control of power system using new control structure with PID controller [6]. The proposed system provides an analysis of the simulation and components required for the implementation of an automated level control system by the help of Programmable Logic Controller

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(PLC). Supervisory Control and Data Acquisition (SCADA) was established and the HMI was created. This method is proposed by Behera Srinivasa Rao also SCADA Application for Control and Monitoring by Petar Mišljen another researcher also doing Online Monitoring of PLC Based Pressure Control System [7,8]

Helen Maria Sabu and Monitoring and Control of a Variable Frequency Drive Using PLC and SCADA by Rinchen Geongmit Dorjee [9,10]

The results of the control are expected to be faster and stable, although there are changes in the load. The goal of the control technique is to generate and supply power in an interconnected system as economically and reliably as feasible at the same time maintaining the voltage and frequency inside permissible limits [2]. Many researcher introduce varies methods regarding LFC controller using PID with varies algorithm which are Serhat DUMAN using Gravitational Search Algorithm [11]; D. K. Sambariya using Elephant Herding Optimization Technique [12]; Md Nishat Anwar with direct synthesis approach [13]; Genetic Algorithm by A. Tammam1 [14]; Rajendra Fagna with fuzzy Logic Controller [15]; Tawfiq Hussein also using the same fuzzy methods [16]; The PID controller parameters are tuned by expanding controller dynamics using Laurent seriesby Sujit S. Kulkarni [6]; Vikas Singh is Using JAYA Algorithm [17]; Using Particle Swarm Optimization by Gummadi Srinivasa Rao [15].

2. Theoretical background

2.1. Load frequency control

The operation objectives of the LFC are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchange schedules. The change in frequency and tie-line real power are sensed. Which is a measure of the change in rotor angle the error to be corrected. The error signal are amplified, mixed, and transformed into a real power command signal, which is sent to the prime mover to call for an increment in the torque.

The prime mover, therefore, brings change in the generator output by an amount Pg which will change the values of f and Ptie within the specified tolerance. The first step in the analysis and design of a control system is mathematical modelling of the system. The two most common methods are the transfer function method and the state variable approach. Also the change in frequency due to changes in load can be controlled to restore normal frequency by applying the sensor output to the controller which in turn controls fuel supply and therefore frequency in load affected power system [19].

2.2. Frequency stability

The system stability will be explained with mechanical torque = Electric torque which means there is no acceleration experienced by the rotor. Because there is no acceleration, the rotor rotates at a fixed speed so that it is able to reduce voltage with a constant frequency. This situation occurs when the balance is reached between the amounts of energy raised with the energy absorbed by the load.

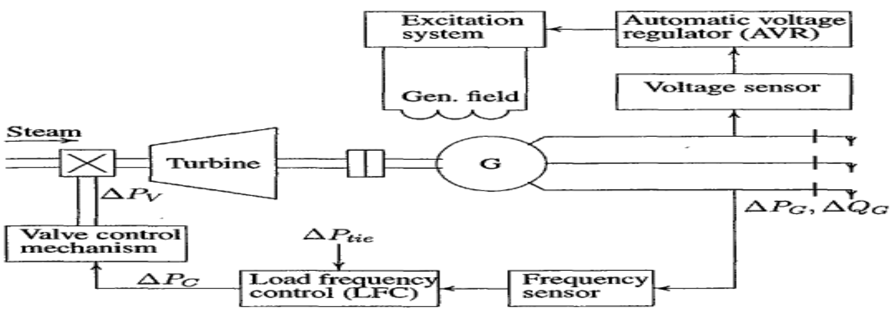

Figure 1. Schematic diagram of LFC and AVR of a synchronous generator.

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There is handling step that can be done when the system frequency value is < 50 Hz, which is utilize the LFC (Load Frequency control)/AGC facility that controls the speed of generator according to load fluctuations. Frequency stability in an electric power system is one of the conditions that must be maintained in order to work optimally at certain frequency limits only-50 to 60 Hz). Frequency control is not merely to satisfy the customer alone, this action also aims to maintain the stability of the system.

3. Experimental and design methodology

3.1. Arrangement of a load frequency control system component

Generator that will be used on the prototype of the load frequency control using a 3-phase synchronous motor. The current motor will be connected with an induction motor star connected as a prime mover to obtain an output voltage of 380 V with a current flow of 1.7 A. The output power of the generator will be supplied to the motor that is connected to the torque meter (load magnetic brake) as a load.

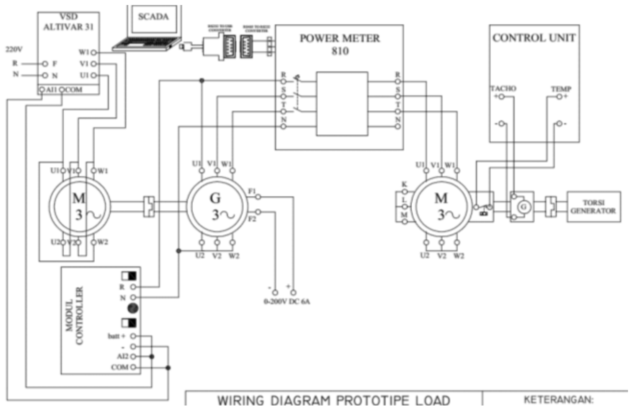

Figure 2. Block diagram design of LFC.

3.1.1. Design of synchronous motor used as generator. In the prototype of LFC, prime mover was selected using a 3-phase induction motor. This Motor will be controlled by the Variable Speed Drive (VSD) for a steady speed operation despite the load changes and expected frequency remains constant at a frequency of 50Hz. The prime mover in LFC module is operated at 60% full load so that the following calculations are obtained:

$$\text{P motor} = \frac{\text{P generator}}{\text{effisiensi}} = \frac{1000}{\frac{60}{100}} = 1.666{,}67 \text{ Watt}$$

According to the calculation of known power from the prime mover of 1.6 kW if the selected efficiency of 60% then the induction motor can be selected as a large prime mover of 1.5 kW.

3.1.2. Design of VSD as a speed control. The Speed of the 3-phase induction motor used as a prime mover can be adjusted to the desired speed using VSD (variable speed drive). If there is a load changes then frequency of the generator will also vary due to the speed reduction of prime mover connected to the generator, so that the speed is stable in case of load change, the VSD is required to remain on normal frequency.

In the VSD selection you need to review the motor power to be controlled by VSD. In accordance with the design that has been made the induction motor as the prime mover with a power of 1.5 kW. In order to be able to operate nominally the power of VSD should be the same as the prime mover power.

3.1.3. Design of PLC as PID control. The prototype system of LFC requires an automatic adjustment then use of PLC as frequency controller when load changing. The inputs from the PLC are obtained from the frequency sensor while the PLC output is used as a VSD input. The Output of the frequency sensor is in the form of digital data 0-10 V so that in the selection of PLC must have an analogue to digital inputs because the PLC is only able to read digital data, then it is chosen by the brand of type PLC TWIDO TWDLMDA20TDK that has an analogue data input to Digital, but for the output of the PLC type is still in digital data so that must be added to the expansion module digital to analogue because the input Variable Speed Drive is also an analogue data 0-10 V. In the expansion module selection should also pay attention to how Output to be used. In this LFC prototype has only one output which will be used as input VSD. Therefore the expansion Digital to analogue module chosen is TWIDO type TM2AM01HT.

3.2. Determination of PID for the LFC prototype

To determine values of the PID in an unknown system, it is necessary doing a test to get the value of the equation on the system and then approach several methods to get the appropriate PID value. proposed controller gives better dynamic responses of the power system in terms of Settling time, Peak Overshoot and Peak Undershoot proposed by D K Sambariya [20] Tests conducted on the LFC prototype system by providing a varied frequency input in the VSD and then seen the response from the frequency of generators. Following data on VSD test results.

Table 1. VSD test results with varying frequencies.

VSD freq (Hz)	Generator freq (Hz)
20	51
25	70
30	70
35	35
40	39,5
45	44,5
50	49,6

From table 1. Known frequency response generator if given input varies through VSD. The results of the frequency measurements will be processed into a two-order polynomial form on Excel software to determine the equation of the system. The graph is shown by the following:

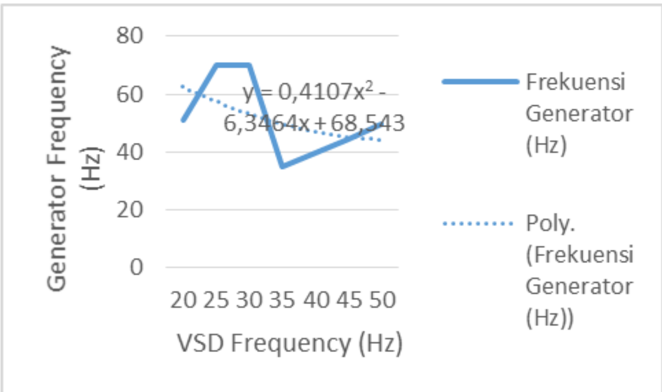

Figure 3. VSD test with varying frequencies.

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Using polynomial function plant equation is obtained:

$$Plant\ LFC = 0{,}4107t^2 - 6{,}3464t + 68{,}543 \quad (1)$$

Determination of PID for this prototype will be done with two methods, first with the Ziegler Nichols method, the second with the auto tuning method on the MATLAB.

3.2.1. Determination of PID with Ziegler Nichols method. From the known equation will be calculated with the Ziegler Nichols method to determine the parameters of Kp, Ti and Td in order to obtain step response by overshoot about 25%. The equation of the acquired plant is as follows:

$$f\ (t) = 0{,}4107t^2 - 6{,}3464t + 68{,}543 \quad (2)$$

The equation obtained is still in form (t) should be changed into Laplace (s) first. To change the equivalent of a plant that is known to be transformed into a function (s) then used MATLAB application with the following script:

```
syms s t
f3=0.4107*(t^2)-(6.3464*t)+68.543
%
disp('transformasi laplace fungsi f(t)')
L3=laplace(f3)
```

Figure 4. MATLAB application script.

Converting function into Laplace equation using MATLAB as follows:

$$f(s) = \frac{68543}{1000s} - \frac{7933}{1250s^2} + \frac{4107}{5000s^3}$$

$$f(s) = \frac{4107}{5000s^3} - \frac{7933}{1250s^2} + \frac{68543}{1000s}$$

$$f(s) = \frac{342715s^2 - 31732s + 4107}{5000s^3}$$

From the above equation, it will get the *close loop* equation, and then drawn in the Simulink as follows:

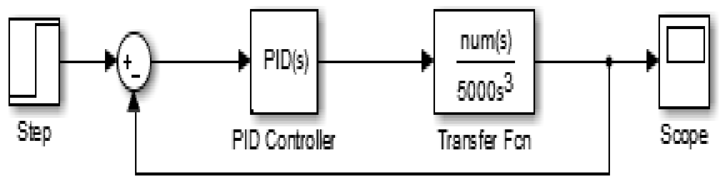

Figure 5. Blok diagram LFC Ziegler Nichols method.

The closed loop equation is as follows:

$$\frac{3427kps^2 - 31732kps + 4107kp}{5000s^3 + 3427kps - 31732kps + 4107kp} \quad (3)$$

The next step is to determine the value of Kcr. The equation of

$$5000s^3 + 3427kps - 31732kps + 4107kp \quad (4)$$

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Right hand side equation is:

$$\frac{(5000\,x\,4107kp)-(31732kp\,x\,3427kp)}{3427kp} > 0 \qquad (5)$$

$$kp < \frac{-20535000}{-10875032380}$$

$$kp < 0{,}0019$$

It is obtained that the value of Kp = 0,0019, therefore critical Gain is Kcr = 0,0019. The characteristic equation is:

$$5000s^3 + 3427kps^2 - 31732kps + 4107kp \qquad (6)$$

Frequency obtained during oscillation

$$5000\,(j\omega)^3 + 6{,}5113\,(j\omega)^2 - 60{,}2908\,(j\omega) + 7{,}8033$$
$$= (-0.1528 + 0.2063\omega)(-0.1528 - 0.2063\omega)$$
$$(0.1463 + 0.0478\omega)(0.1463 - 0.0478\omega)$$

$$\omega^2 = 0{,}1463 \rightarrow \omega = \sqrt{0{,}1463} \quad \text{rad/s} \qquad (7)$$

So, the periods of oscillation becomes:

$$Pcr = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{0{,}1463}} = 17{,}50\ seconds \quad \text{rad/s} \qquad (8)$$

Using table of Ziegler Nichols method, variable obtained:

Kp = 0,6 x Kcr = 0,6 x 0,0019 = 0,00114
Ti = 0,5 x Pcr = 0,5 x 17,50 = 8,75
Td = 0,125Pcr = 0,125 x 17,50 = 2,18

Before being processed on MATLAB software, values Ti and Td should be converted to Ki and Kd with formulas using equations PID values then Kp = 0,00114; Ki = 0,00013; Kd = 0,00056 and System response is:

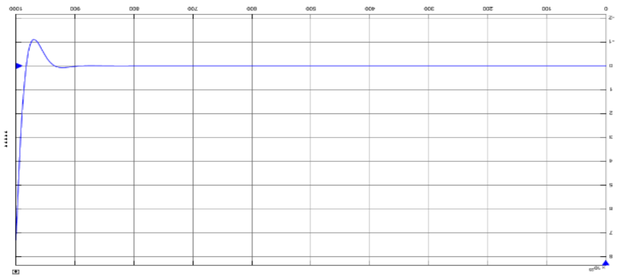

Figure 6. Response of Ziegler Nichols.

Figure 6 shows that system response becomes unstable due to the value of Kp is too low. So it needs to increase the Kp value to 1. Response system becomes:

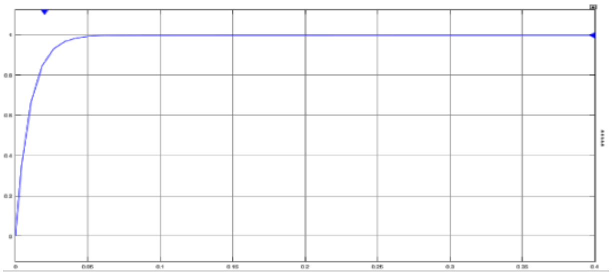

Figure 7. Response of Ziegler Nichols.

3.2.2. Determination of PID with auto tuning. PID with the Auto tuning method in MATLAB software is determined by creating a model of LFC prototype from known equations. As in the following figure 8.

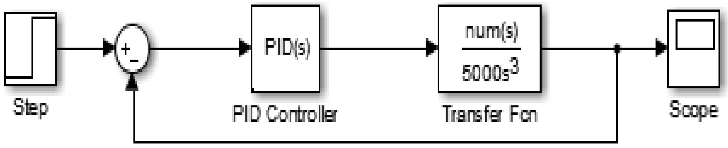

Figure 8. Sumulink of LFC with auto tuning.

The system response is:

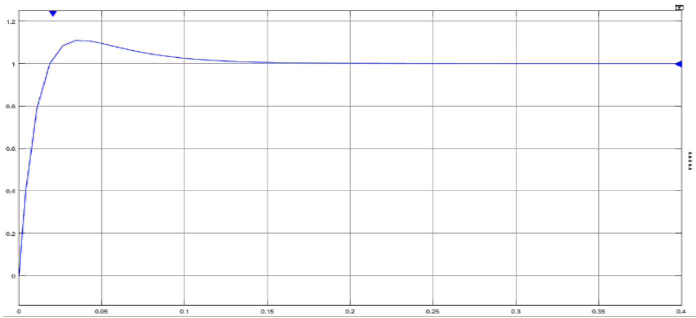

Figure 9. Response of LFC with auto tuning.

PID value of auto tuning in MATLAB are proportional value (P) of 1, Integral value (I) of 38 and derivative value (D) of 0. This Value then are inserted into the PLC but must be converted to Ti form first to see the response of frequency changes as load is added weather the value is better the system with PID or without added PID.

3.2.3. Programming PID on PLC. General setting of PID in ladder diagram to be used is activation at PID 0. PID instruction block specifies the setpoint of the value to be stabilized. Setpoints are set on a PLC ladder with the address% MW11 and the value entered is a processed memory address that has been created in the PLC program which is% MW13. In the Corrector type is set at the PID position. To determine the address on the fill value of proportional parameters, integral, derivative and sampling period is set as desired. At the settings of the output PID instruction block selected% MW14 memory address is then sent to the output address% QW 0.1.0.

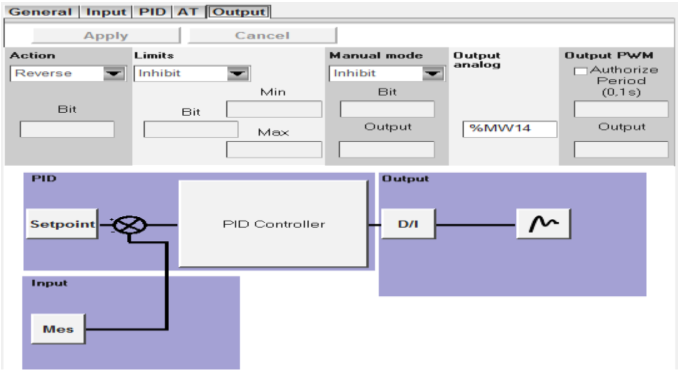

Figure 10. Output of PID Instruction.

4. Results and analysis

4.1. Results of SCADA monitoring

SCADA on the LFC prototype will be displayed parameter in the form of voltage and generator frequency displayed PC. To display these parameters used auxiliary equipment that is power mater, in power mater utilized register list so that the parameters can be displayed on SCADA. Used power Mater 810 and Movicon software to design and create SCADA.

So the results of frequency and voltage monitoring on the PC/laptop through generator using MOVICON software and at Power Mater the frequency and voltage values are the same. Designation frequency are 4958 Hz, 4880 Hz, 4835 Hz. The registers are in an integer-shaped power mater so that it can only Displays integers.

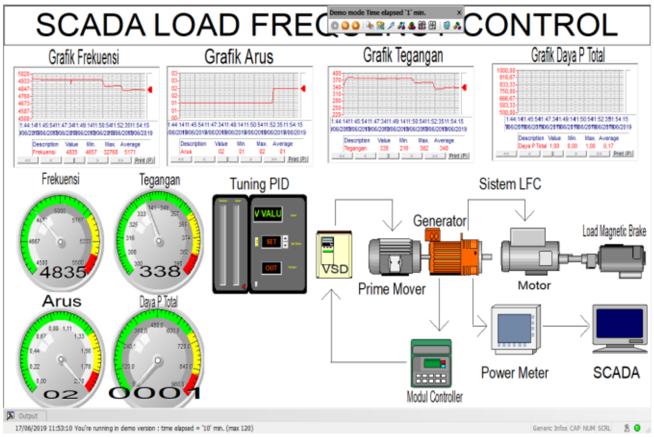

Figure 11. Frequency and Voltage as load of 3,5 Nm

The open loop test has the lowest frequency value compared to the close loop test without the PID and the close loop with the PID. Based on the close loop experiment data with PID it is known that adding the PID algorithm can improve the frequency of the system so that the gain when the low load is already able to produce a better frequency response than Open loop testing and close loop shown at figure 11.

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Table 2. Response of stability with Various PID.

Stability Parameters	Rise Time (ms)	Settlin g Time (s)	Overs hoot (%)	Error Steady State
Open loop	∞	∞	∞	∞
Close Loop	31,355	0,04	0,5	0,997
Auto Tuning KP=1 KI=38	12,3	0,105	10,56	1
Ziegler Nichols KP=1 I=0,115 D=0,49	21,09	0,03	0,492	0,996

4.2. Testing on close loop circuits with PID

In close loop testing with PID, the measurement of speed, voltage and frequency of the generators is also measured at the load torque and speed at the motor load. The frequency on load and torque of generators is known from calculation results. In close loop testing without PID also carried out monitoring through SCADA on the PC. The Data of the test results that you have taken can be viewed in the following table 3.

Table 3. Close loop test with PID.

No	Im (A)	Vm (V)	Torsi (Nm)	Frekuensi (Hz)	
				Auto tuning P=1 I=38	Ziegler Nichols P=0,00114 I=8,75 D=2,18
1	0,5	100	0,2	49,62	49,6
2	0,5	100	1	49,35	49,42
3	0,5	100	2	49,01	49,05
4	0,5	100	2,5	48,84	48,80
5	0,5	100	3	48,64	48,66
6	0,5	100	3,2	48,52	48,56
7	0,5	100	3,5	48,39	48,41

Based on the table 3 can be seen that when the system is open loop condition then it does not respond to any system so that the response to the persistence cannot be known. Meanwhile, when the close loop condition without giving the system PID algorithm has been obtained stability response. In the Ziegler Nichols method, Auto Tuning and Try & Error when the same Kp value but with different Ki and KD values will provide different stability response. With a large Kp value it will enlarge the over shoot and slurries time values but will eliminate steady state errors and reduce the rise time. If the added value of Kd even if a small value on the system will reduce over shoot and slurries time but will give slight changes to steady state and rise time errors.

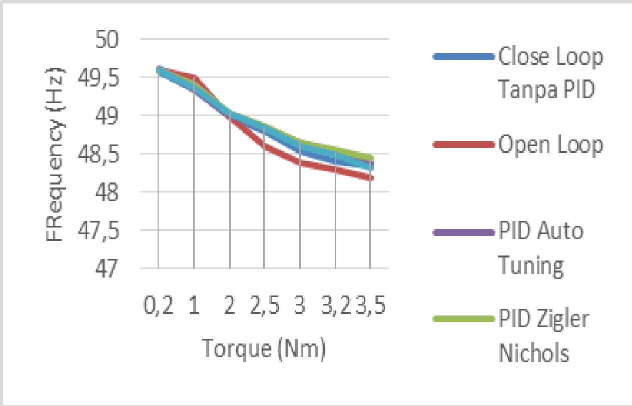

Figure 12. Frequency vs torque characteristics.

So it can be known the results of frequency and voltage monitoring on the PC through generator using MOVICON software and at Power Mater the frequency and voltage values are the same. But at the frequency measurement cannot show a comma so that on SCADA software MOVICON designation frequency to 4960 Hz, 4880 Hz, 4840 Hz. This is because the registers are in an integer-shaped power mater so that it can only Displays integers.

5. Conclusion

Conclusions that can be withdrawn from the calculations and analyses above are as follows:

- The SCADA design on the prototype Load Frequency Control is performed using the MOVICON software. In SCADA carried out monitoring the measurement of voltage and frequency on the generators that utilize the Register list on the Power meter 810.
- On the prototype Load Frequency Control when the open loop test with the highest loading of 3.5 Nm occurs a frequency decrease reaches 48.2 Hz. But by only providing feedback and controllers in the form of the data-processed frequency sensor With PLC can improve the frequency quality so that there is a frequency increase to 48.34 Hz. Frequency can still be fixed again by adding the PID algorithm on the controller in the form of PLC. By providing the calculation of PID algorithm, Ziegler Nichols method can improve the frequency to 48.41 Hz at the highest loading in the Load Frequency Control system. This is because adding a strengthening PID becomes larger so that load catics and higher load frequency response are better.
- SCADA monitoring results on the prototype Load Frequency Control using the software MOVICON shows the same measurement results if calibrated with other measuring instruments In the Form of Power Meter 810. However, Frequency Measurements in the MOVICON Software cannot display the measurements in the form of a fraction or comma because the Register list on the Power meter 810 has an integer that can display the measurement of integers only.

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