Prosiding Nasional Rekayasa Teknologi Industri dan Informasi XVI Tahun 2021 (ReTII)
November 2021, pp. 098 - 107
ISSN: 1907-5995

Virtual Laboratory for Power Quality Study

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ABSTRAK

Makalah ini memperlihatkan laboratorium virtual untuk mempelajari peristiwa kualitas daya, yaitu *voltage swell* dan *voltage sag*, harmonik, dan *flicker*, yang digunakan oleh siswa untuk belajar dan menguji pengetahuan mereka tentang subjek terkait. Laboratorium virtual diperlukan karena dalam kehidupan nyata, dalam ranah kualitas daya, merupakan sesuatu yang rumit untuk menghasilkan peristiwa kualitas daya dalam memahami efek atau menganalisis fitur-fiturnya. Laboratorium virtual dianggap memberikan kesempatan kepada siswa untuk mempelajari terlebih dahulu aspek teoritis dari suatu mata pelajaran, kemudian menerapkan pengetahuan yang mereka kumpulkan ke berbagai bentuk isyarat, untuk mendapatkan karakteristik peristiwa dan pada akhirnya untuk menguji hasil yang mereka capai. dengan karakteristik isyarat tersebut. Terdapat dua manfaat utama pada penggunaan laboratorium virtual: pertama adalah siswa dapat melihat peristiwa yang berbeda, dengan karakteristik yang berbeda dan dengan cara ini, mereka lebih memahami fenomena tersebut; dan yang kedua adalah laboratorium konvensional untuk pembelajaran peristiwa kualitas daya sangatlah mahal, komponen utamanya memiliki biaya yang sangat tinggi.
Kata kunci: kualitas daya, *voltage swell* dan *voltage sag*, harmonik, *flicker*

ABSTRACT

The paper shows a virtual laboratory for learning power quality events like voltage swell and sag, harmonic, and flicker, which is used by students to learn and test their knowledge about the subject. The virtual laboratory is required because in real life, in power quality domain, it is very problematic to generate power quality events in order to understand the effects or to analyse their features. The virtual laboratory is considered to give the students the opportunity to learn first the theoretical aspects of the subject, then to apply the knowledge they collect to several signals, in demand to get the characteristics of the event and in the end to test their attained results with signals characteristics. There are two major benefits of employing the virtual laboratory: first is that the students can see different events, with different characteristics, and in this way, they understand better the phenomenon; and the second is that a classical laboratory for learning power quality events is very expensive, the main components having a very high cost.
***Keyword**: power quality, voltage sag and swell, harmonic, flicker*

1. INTRODUCTION

It is identified that in some domains it is not always possible to work out on real circumstances because of the cost or more important due to safety and security. This is also the situation in the power quality domain where is problematic to generate power quality events with the intention of showing the effects and analyse them, so power quality laboratories are handling various virtual laboratories or simulation tools. As realized in the literature from the electrical domain, such virtual laboratories are used more often and become even more important in the modern teaching methods [1], and power systems [2-3].

Power quality is an electrical concept stated to the ability of a power system to distribute accurate voltage, current, and frequency signals [4]. Power quality degradation can be produced by using of non-linear loads in industrial sectors such as inverters, variable speed drives, transformers, power supplies [5]. Non-linear loads distort electrical signals in such a way that they change from perfect sinusoidal waves, since they include harmonic components of much lower amplitude at higher frequencies. This has a degrading effect on the power quality received by the industrial loads that can lead to several problems, such as manufacturing interruptions, loss of production, and competitiveness, malfunction of electrical devices, and inappropriate tripping of circuit breakers. Based on this growing trend, the undergraduate electrical engineering curricula have started to incorporate the study of power quality events. In this context, engineering curricula emphasis on both a deeper understanding on the phenomenon and its practical experimentation. In this regard, a possible approach to teach and learn power quality is the use of modelling and simulation tools. A model can be defined as a quantitative description of power quality event, while simulation is the experimentation on a computer with the model in order to see how the power quality progresses through time, for the purpose of better understanding. By examining simulation results, students could identify power quality disturbances, assess their effects on electrical grids, understand how these disturbances propagate in a grid, identify the sources of disturbances and know preventive and mitigation strategies. Several authors have developed and assessed education modelling and simulation tools for teaching power quality, most of them in the areas such as power systems [6] or converters [7].

This paper aims to present a virtual laboratory developed for students to understand and learn the power quality characteristics and to analyse. In this paper, MATLAB/Simulink with SimPowerSystems is chosen as the simulation platform. A comprehensive set of basic models developed to simulate voltage sag, swell, transient, harmonic, and flicker power quality disturbance are presented in this paper.

As it follows, Section II presents some theoretical aspects of power quality. Section III presents the implementation of the developed virtual laboratory, and finally Section IV presents the final conclusions.

2. RESEARCH METHOD

The simulation models were established using MATLAB/Simulink with SimPowerSystems. It is then used to simulate various power quality disturbances and perceive how these disturbances distort the power system sinusoidal waveform. The models were developed with minimum number of blocks in mind and use their default settings whenever possible to store their simplicity and reproducibility. The established models present in paper also serve as basic building blocks to a larger power system. Simulation models including line fault, induction motor starting, transformer saturation and hysteresis, harmonic, flicker, compensated networks, electric arc furnace, and electric motor starting models used to simulate various power quality disturbances are described in [8-9].

2.1. Transmission-Distribution Line Fault Model

The line fault model created in Simulink is shown in Figure 1. The model is used to simulate voltage sag produced by line fault. The line fault model consists of 150 kV, 100 MVA, 50 Hz three-phase source block feeding through 150 kV/20 kV, 1 MVA delta/wye transformers to a 10-kW resistive and 100VAR inductive load. There are instantaneous waveform and RMS measurement scopes located at 150 kV and 20 kV buses. There are two fault blocks located at the 150 kV bus to simulate line fault and multistage fault.

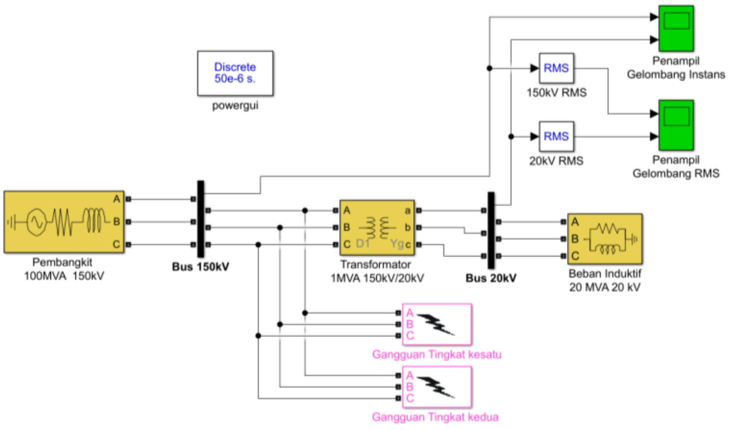


Figure 1. Transmission-distribution line fault model

2.2. Three-Phase Saturable Transformer Model

A three-phase transformer is energized on a 500 kV grid, shown in Fig. 2. A transformer rated at 450 MVA, 500 kV/230 kV/60 kV comprises of three windings connected Wye/Wye/Delta. The power system is simulated with an equivalence circuit consisting of an inductive source and a parallel RC load. The reactive power of the capacitor is designated to produce resonance at 240 Hz (4th harmonic). The saturation characteristic of the transformer is approached by a single slope *Xsat* of 0.32 pu, conforming to the air core reactance *Xac* = 0.40 pu (*Xac* = *Xsat*+*Xh* = 0.32+0.08 = 0.40 pu.) viewed from the primary. Three residual fluxes (-0.8 - 0.4 0.4 pu) were determined for phases A B and C. The Multimeter blocks were used to monitor additional signals without the use of measuring blocks. The output signal of the multimeter is three currents in the circuit breaker and three fluxes in the saturation transformer core. The flux in phase A is obtained by integrating the phase A voltage at the no-load output of winding two. The voltage and flux are converted to pu. with the gain block using proper scaling.

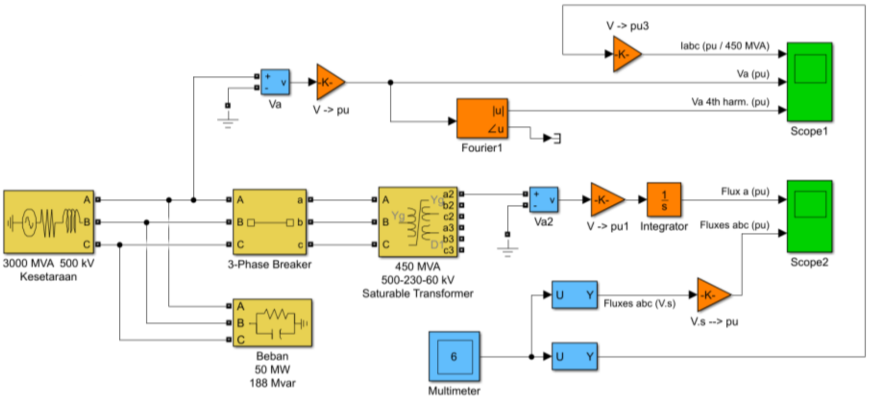


Figure 2. Three-phase saturable transformer model

2.3. Three-Phase Hysteresis Transformer Model

One phase of a three-phase transformer is connected to a 500 kV, 5000 MVA network, shown in Fig. 3. The transformer is rated at 500 kV/230 kV, 450 MVA (150 MVA per phase). The saturation characteristics of the transformer flux currents are modeled by simple piecewise nonlinear characteristics. A Three phase voltage source is used to vary the internal voltage of an equivalent 500 kV network. During the first 3 cycles the source voltage is programmed at 0.8 pu. Then, at t = 3 cycles (0.05 s) the voltage increases by 37.5% (up to 1.10 pu). To demonstrate the residual flux and inrush current in the energized transformer, the circuit breaker which was initially closed was opened first at t = 6 cycles (0.1 s), then closed again at t = 9 cycles (0.15 s). The initial flux phi0 in the transformer is set at zero and the source phase angle is set at 90 degrees so that the flux remains symmetrical around zero when the simulation starts. The Multimeter block are used to monitor flux waveforms, magnetizing currents excitation currents, and voltage and current flowing to the primary winding.

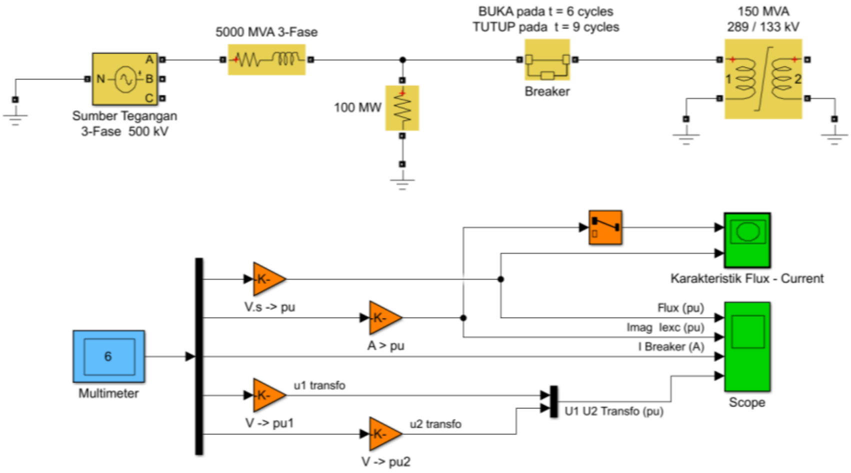


Figure 3. Three-phase hysteresis transformer model

2.4. Three-Phase Harmonic Filter Model

In HVDC connections, AC harmonic shunt filters are used to lowering the voltage and current harmonics in the electric power system, and supplies the reactive power consumed by the converter. To demonstrate this concept, a 1000-MW HVDC rectifier is simulated, shown in Fig. 4. The HVDC rectifier is built from two 6-pulse thyristor bridges connected in series. The converter is coupled to the system with a 1200-MVA Three-Phase (three winding) transformer. A 1000-MW resistive load is connected to the DC side via a 0.5 H smoothing reactor. The filter set is made up of the following four components from the Powerlib/Element's library: one capacitor bank 150 MVAR modeled by three phase series RLC load, three filters modeled using three phase harmonic filter, one type-C high-pass filter set to 3 of 150 MVAR, one dual adjustment filter 13/11 of 150 MVAR, and one high-pass filter set to 24 from 150 MVAR. The total MVAR value of the quantified filter is 600 MVAR. A three-phase circuit breaker is used to connect filters mounted on the AC bus.

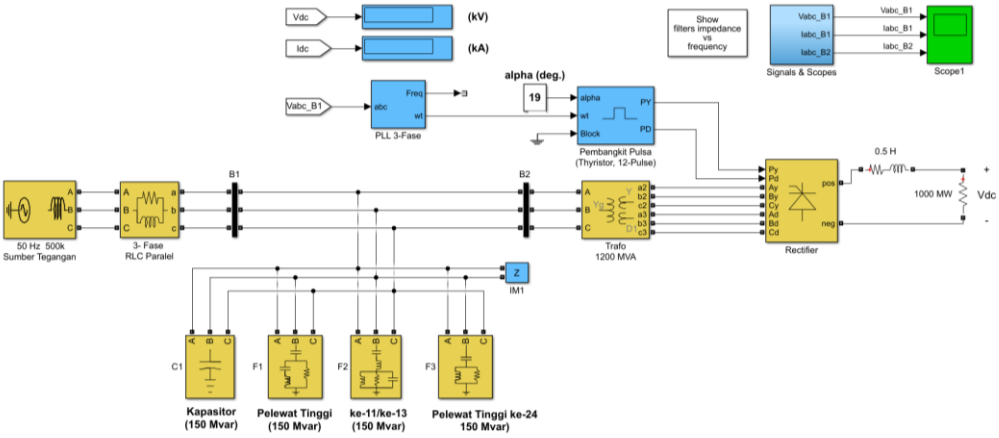


Figure 4. Three-phase harmonic filter model

2.5. Flicker Meter Model

The flicker meter device is used to measure the instantaneous flicker sensation at the terminal voltage of the STATCOM unit. Flicker meter is a standard instrument for measuring flicker obtained by simulation and statistical analysis of the link-light-brain chain response to input voltage fluctuations.

To minimize the initial transient response, initial conditions were defined for different transfer functions. A fixed initialization period (*Tini* = 0.3 sec) is required between when the model is activated (input ON = 1) and the result calculation. The initial state calculations are evaluated in the mask initialization section of the block. The model must be activated (input ON > 0) after the analyzed signal (input U) is stable, shown in Fig. 5. The internal flicker meter outputs of various modules are available in m outputs. In practice, output S (a momentary flickering sensation) stabilizes within 2 seconds after the initialization period starts (Init signal at output m) and Output_4 (One minute dose of instant perception signal at output m) stabilizes after 2 minutes.

Block 1 consists a signal generator for checking the flicker meter setting in the field and a circuit for normalizing (in pu) the RMS value of the input voltage at the network frequency (50 or 60 Hz). The generator adds a modulating voltage (a fluctuating sinusoidal or triangular signal) to the fundamental (120 Vrms/60 Hz or 230 Vrms /50 Hz). The different relative amplitudes (in %) and the frequency of fluctuations are defined in standards. Block 1 should produce on Output_5 an instant blinking sensation 1.

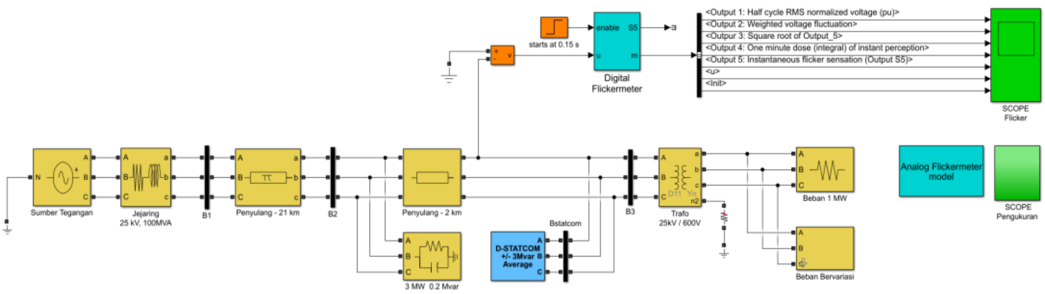


Figure 5. Flicker meter model

2.6. Single-Phase Series Compensated Network Model

A 735 kV, 300 km line is used to transmit power from bus B1 to bus B2, shown in Fig. 6. For easiness, only one phase of the system has been embodied. To rise the transmission capacity, the line is compensated in series at the center by a capacitor representing 40% of the line reactance. The line is also shunt compensated at both ends with a shunt reactance of 330 MVAR (110 MVAR/phase). Open the Series Compensation subsystem. Note that the series capacitor is MOV protected which is simulated by the surge arrester block. The 250 MVA, 735 kV / 315 kV transformer is a saturable transformer block that simulates a single phase of a 750

MVA three phase transformer. Multimeter blocks are used to monitor fault currents as well as transformer magnetizing fluxes and currents.

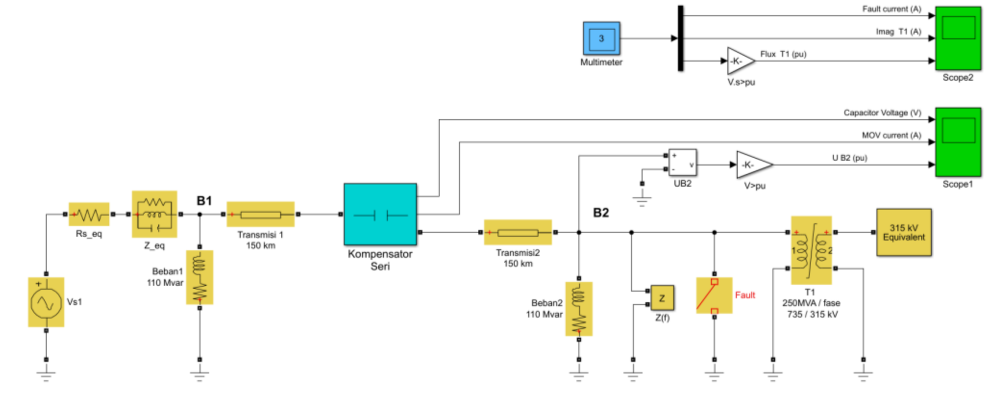


Figure 6. Single-phase series compensated network model

2.7. Three-Phase Series Compensated Network Model

The three-phase, 60 Hz, 735 kV power system transmits power from a generating plant consisting of six 350 MVA generators to the equivalent grid via a 600 km long transmission line, shown in Fig. 7. The transmission line is divided into two lines along the 300 km which are connected between buses B1, B2, and B3. To enlarge the transmission capacity, each line is compensated in series by a capacitor representing 40% of the line reactance. Both channels are also compensated by a 330 MVAR shunt reactance. Shunt and series compensation equipment is located at substation B2 where a 300 MVA 735/230 kV transformer with 25 kV tertiary winding supplies a 230 kV, 250 MW load. The series compensation system is identical for the two lines. Each phase of the series compensation module contains a series capacitor, a metal oxide varistor (MOV) protecting the capacitor and a parallel gap protecting the MOV. When the energy dissipated in the MOV exceeds the threshold level of 30 MJ, the gap is activated by the circuit breaker. CB1 and CB2 are two-line circuit breakers. The generator is simulated with a simple synchronous machine block. Universal transformer blocks (two winding and three winding) are used to model two transformers. Saturation is applied to the transformer connected to bus B2. Voltage and current are measured in blocks B1, B2, and B3.

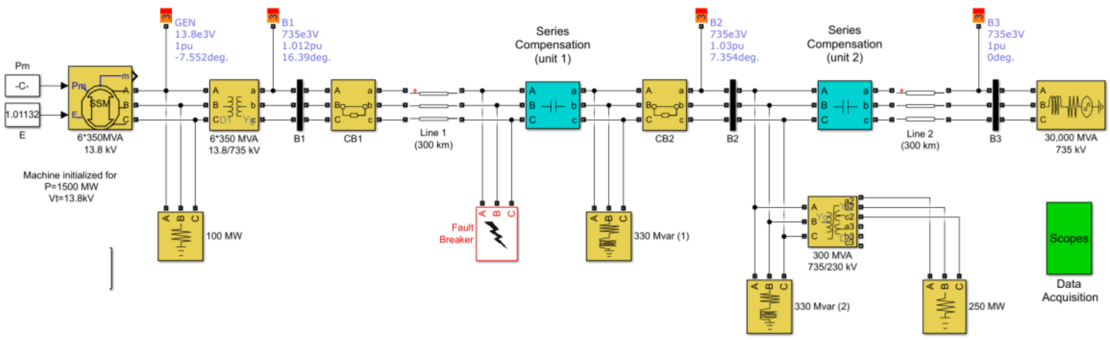


Figure 7. Three-phase series compensated network model

2.8. Electric Arc Furnace Model

Two parallel 735 kV lines, 200 km long, transmit 3000 MW of power from the generating plant an equivalent grid having a short circuit rating of 20 GVA, shown in Fig. 8. The generator is simulated with a simplified synchronous machine (0.22 pu sub-transient reactance). The machine is connected to the transmission network via a Wye/Delta 13.8 kV/735 kV transformer.

The single line diagram model is a distributed parameter line which is assumed to be transposed and the parameters R, L, C /km are specified in positive-sequence and zero-sequence components. Each line is compensated by two shunt reactors of 200 MVAR each, connected at the end of the line. Applying single pole reclosing at this voltage level is made possible by the use of neutral inductance for the two-line 2 shunt reactants. Otherwise, the secondary arc current induced into the fault, mainly because the capacitive coupling between the two noise phases and the fault phase would be too high to allow arc extinguishing after opening of the line breaker in the fault phase If the opening of the two shunt reactance blocks of line 2, the optimum neutral inductance can be calculated A phase-to-ground fault is applied in the center of channel 2. To apply the fault along the channel, this channel is simulated in two sections of 100 km. The breaker remains open for a certain 'dead time', usually about 0.5 seconds, during which the arc normally goes out, then both breakers are closed again. When two-line breakers are blocked in the fault phase, the fault current is cut off but a small current will continue to flow through the arc. If this secondary arc current is too large, the arc cannot be extinguished and the breaker will close again on fault. The electric arc is modeled by a fixed or nonlinear resistance. The arc goes out when its rms current drops below the threshold value (usually 50 A) specified in the arc *R=f (I_(arc-rms))* model block. The average arc resistance is programmed as an exponential function of the rms current and will increase as the rms arc current decreases so that the time for the arc current to decay below the threshold value.

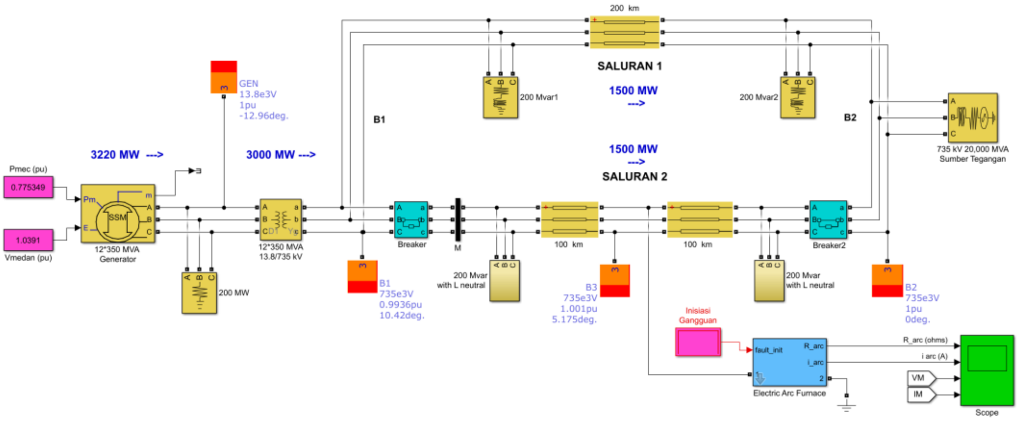


Figure 8. Electric arc furnace model

2.9. Induction Motor Wye-Delta Starting System Model

Figure 9 shows a wye-delta starting circuit for an induction machine. When the supply is linked to the machine via switch S1, switch S2 is initially off resulting in the machine being connected in a wye configuration. Once the machine is near to synchronous speed, switch S2 is operated so reconnecting the machine in a delta configuration. The higher impedance perceived by the supply when the motor is in wye configuration reduces the starting current, and causes less disturbance to other connected loads.

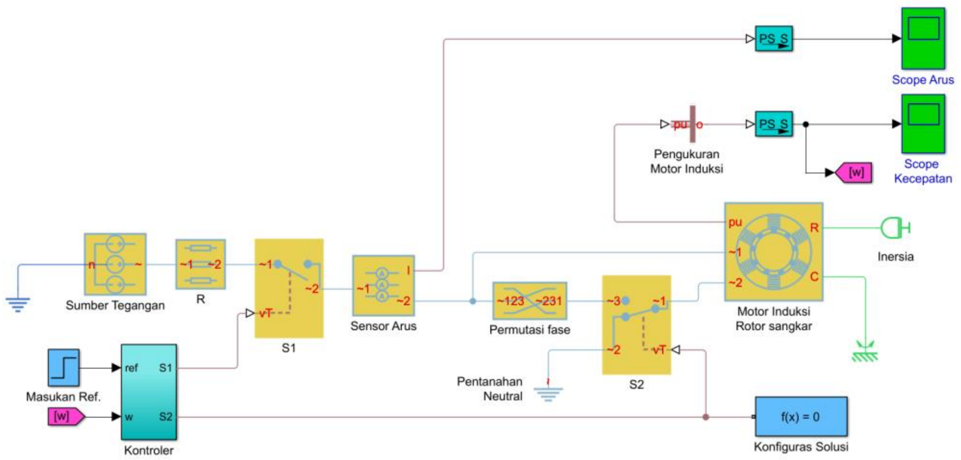


Figure 9. Induction motor wye-delta starting system model

2.10. Permanent Magnet DC Motor Starting System Model

Figure 10 shows model of the starting system for a DC motor. When a 240V supply is connected to the motor via an 'ideal switch' and a '3 step starter' (switch is in the '1' state) the motor rotates close to synchronous speed. If both switches are in '0' condition then the motor is connected to the ladder generator.

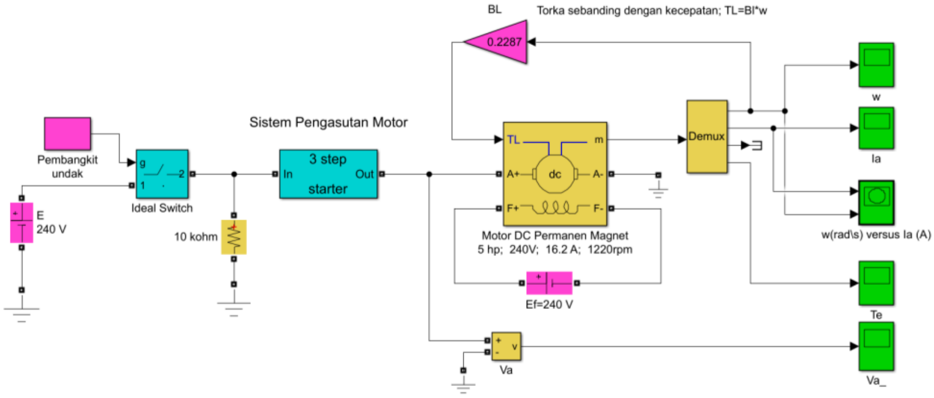


Figure 10. Permanent magnet DC motor Starting System Model

2.11. Virtual Laboratory for Power Quality Study

The Virtual Power Quality Laboratory was conceived as a means for offering a power quality laboratory experience using an interactive computer program, that is, a virtual laboratory course. It consists of a laboratory manual and software which based on MATLAB-Simulink stored on a Flash Disk. Presently, the Virtual Power Laboratory allows the user to “Mulai” a laboratory equipped to deliver 10 power quality experiments. The nature of these experiments and the features of the laboratory are described in this paper.

One can access MATLAB’s GUI facilities to construct a software package of virtual laboratory for studying power quality. As an example of using MATLAB’s GUI capabilities, menu and plotting commands are implemented in a script file to provide interactive windows, shown in Figure 11. The main menu, which is displayed after running the file, are shown in Figure 12 and Figure 13.

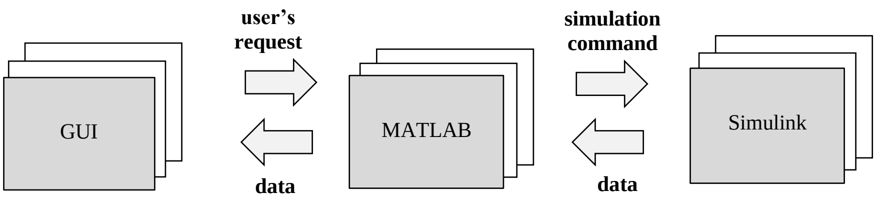


Figure 11. Architecture of power quality virtual laboratory

Figure 12. The main window of the developed virtual laboratory

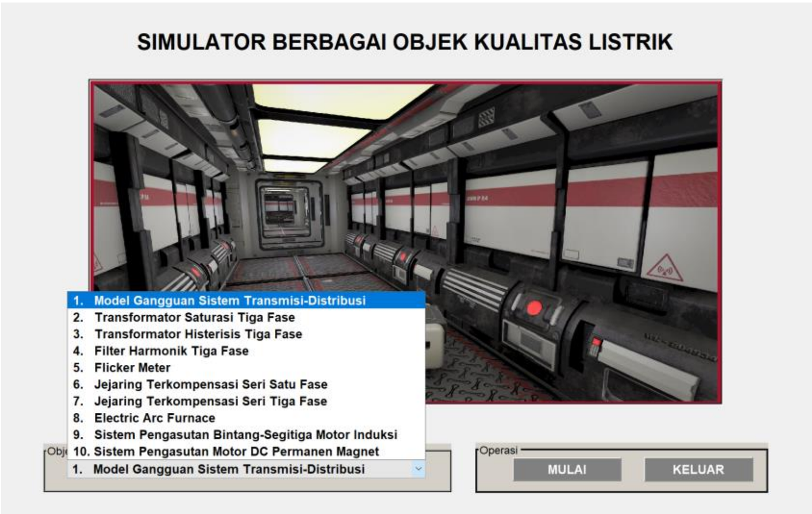
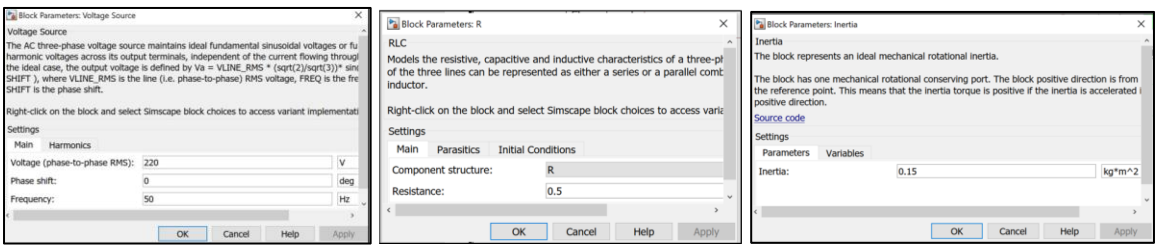


Figure 13. The window of choosing the power quality object

3. RESULT AND ANALYSIS

With the purpose of exploring the characteristic of power quality on various objects of power systems, numeral simulations were carried out for several disturbances, such as voltage sag, harmonic, hysteresis and saturation, and flicker under different operating conditions. For example, wye-delta starting system is used to start an induction motor 15 KW and the values of voltage supply about armature current and rotor speed are subject to change in pu, as shown in Fig. 9. The parameters of wye-delta induction motor starting system are shown in Fig. 14.



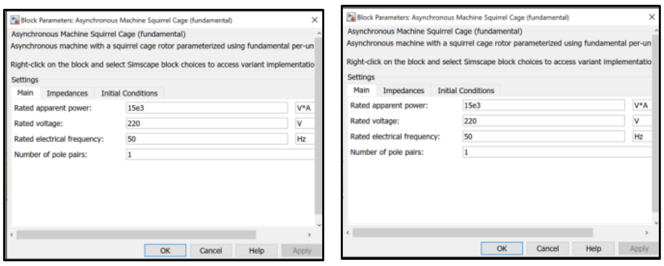


Figure 14. The parameters of wye-delta induction motor starting system

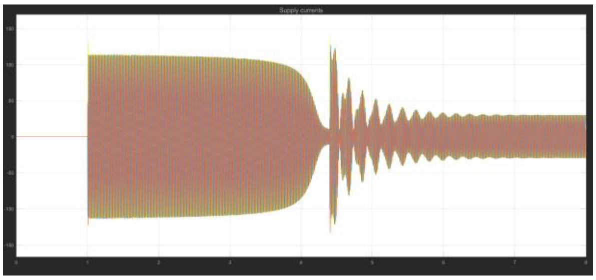


Figure 15. The curve of starting current at nominal loading

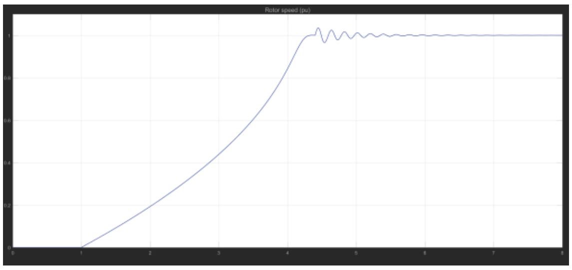


Figure 15. The curve of rotor speed at nominal loading

Figure 15 and 16 show the curves of starting current and rotor speed at nominal loading. It is clear the voltage sag in the wye-delta starting occurs during the transition from the wye connection to the delta connection. During the transition moment, the contactor switches and causes the voltage to breakdown for an approximately of 0.1 seconds and this is enough to cause the voltage sag to occur in the motor starting.

4. CONCLUSION

The experimental laboratory, as it has been shown in the paper, is a very helpful tool to improve the student's understanding of many basic and advanced concepts about power quality. This experimental simulator accompaniments the computer simulators based on MATLAB-Simulink engaged in theoretical courses because the parameters of the virtual laboratory system are available for computer simulations, and the students can verify their results experimentally.

ACKNOWLEDGEMENTS

The authors are thankful to Rector and Head of LPPMI, Institut Teknologi Nasional Yogyakarta for subsidy this project no. 11/ITNY/LPPMI/Pen.int/PD/II/2021. And also, to the Dean of Industrial Technology Faculty and the Head of Electrical Engineering Study Program, Institut Teknologi Nasional Yogyakarta for providing requirement services.

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