YAYASAN BRATA BHAKTI DAERAH JAWA TIMUR
UNIVERSITAS BHAYANGKARA SURABAYA
LEMBAGA PENELITIAN DAN PENGABDIAN PADA MASYARAKAT
(LPPM)
Kampus : Jl. A. Yani 114 Surabaya Telp. 031 - 8285602, 8291055, Fax. 031 - 8285601

SURAT KETERANGAN

Nomor: Sket/ 23 /I/2023/LPPM/UBHARA

Kepala Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Universitas Bhayangkara Surabaya menerangkan bahwa:

Nama : Dr. Amirullah, ST, MT.
NIP : 197705202005011001
NIDN : 0020057701
Unit Kerja : Universitas Bhayangkara Surabaya

Benar telah melakukan kegiatan:

1. Menulis proseding berjudul Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network (Amirullah, Ontoseno Penangsang, Adi Soeprijanto), yang telah dipublikasikan pada Proseding International Seminar on Intelligent Technology and Its Applications (ISITIA), Date of Conference: 20-21 May 2015, pp. 193-200, Electrical Engineering Department, Kampus ITS Sukolilo Surabaya, Surabaya, Indonesia, Publisher IEEE. **Terindeks Ieeexplorer.**
2. Telah melakukan korespondensi melalui email dalam proses penerbitan jurnal tersebut. Bukti korespondensi email dan bukti pendukung adalah benar sudah dilakukan oleh yang bersangkutan serta sudah dilampirkan bersama surat ini.

Demikian surat keterangan ini dibuat untuk kepentingan kelengkapan pengusulan Guru Besar.

Surabaya, 20 Januari 2023
Kepala LPPM

Drs. Heru Irianto, M.Si.
NIP. 9000028

Lampiran 1

Bukti Korespondensi Email dengan Editor Seminar

Preliminary Decision of The Submitted Paper to ISITIA 2015

From: ISITIA 2015 Comittee (isitia2015@gmail.com)

To: am9520012003@yahoo.com

Date: Tuesday, 31 March 2015 at 10:12 pm GMT+7

Dear Authors,

Hereby, after reviewing the submitted papers to ISITIA 2015, we would like cordially to inform you that our preliminary decision for the submitted papers have been announced at our conference web site (http://isitia.its.ac.id). For detail information of the decision, you can access the information by logging in to our system with your account (http://isitia.its.ac.id/base/login.php)

Please consider the recommendations related to your submitted paper for further steps within the duration given for your submission.

Best Regards, Dr. Ronny Mardiyanto, ST, MT Chairman of ISITIA 2015 http://isitia.its.ac.id

ISITIA Friendly Reminder for Revised Paper Submission

From: ISITIA 2015 Comittee (isitia2015@gmail.com)

To: am9520012003@yahoo.com

Date: Monday, 6 April 2015 at 10:09 am GMT+7

Dear Authors,

Refering to our announcement of paper acceptance notification, we would like to congratulate you that your paper is conditionally accepted in our conference. In order for your paper to be fully accepted in our conference, we encourage you to revise your paper based on the reviewer comments. Detail informations on the revision and comments, you can access ISITIA website with your account.

If your revised paper has been submitted through ISITIA website, please ignore this reminder.

Thank you for your attention. We are looking forward to receiving your revised paper.

Best Regards, Dr. Ronny Mardiyanto Chairman of ISITIA 2015. http://isitia.its.ac.id

Final Decision of The Submitted Paper to ISITIA 2015

From: ISITIA 2015 Comittee (isitia2015@gmail.com)

To: am9520012003@yahoo.com

Date: Tuesday, 14 April 2015 at 10:01 am GMT+7

Dear Amirullah -,

The Technical Program Committee of the ISITIA 2015 has completed the evaluation on the following paper submission:

ID : 589

Title : Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network

---

On behalf of the committee, I am pleased to inform you that the paper mentioned above has successfully implemented the reviewer comments to your paper and therefore the paper are accepted and will be considered for the presentation at The 2015 International Seminar on Intelligent Technology and Its Applications (ISITIA 2015). The session title and time of presentation will appear in the conference program, that will be available on the ISITIA 2015 website http://isitia.its.ac.id

At least one of the authors listed in your paper must pay a non-refundable registration fee by the early-bird deadline of April 17, 2015 in order that the paper be scheduled for presentation. Each registrant is allowed to claim more than one submission with an applicable discount of normal registration fee for the other paper submissions. After the early-bird deadline, all unclaimed papers will be deleted from the program. Register can be conducted via your ISITIA Account.

During the registration process you will be given the opportunity to request a "visa assistance" letter which can help you to obtain a visa to enter Indonesia. Once you have finished the registration process, a "visa assistance" letter will automatically be mailed to you, together with the confirmation of your registration.

We can only issue these "visa invitation" letters after completion of your registration.

Should you need further assistance on the â€œvisa invitationâ€, please do not hesitate to contact us via sitia@its.ac.id.

Congratulations on your successful submission! We look forward to seeing you at Surabaya.

Best Regards, Dr. Ronny Mardiyanto, ST, MT Chairman of ISITIA 2015 http://isitia.its.ac.id

Nominal (IDR) payment for PhD Student Author Participant in Isitia 2015

Yahoo/Inbox

5

amir rullah <am9520012003@yahoo.com> Thu, 16 Apr 2015 at 7:35 am

To: sitia@its.ac.id
Cc: sitia@its.ac.id, ronny@ee.its.ac.id

Dear Isitia 2015 Commitee,

I am Amirullah, my paper title below accepted to present in Isitia 2015 conference on May 20, 2015. My status is Doctorate (S3) Student in Electrical Engineering ITS Surabaya (Power System) and lecturer in same department at University Bhayangkara Surabaya. Next I would process the payment of registration fee. Depend on the guideline in Isitia 2015 website I have to pay IDR 950.000 and IDR 200.000, for hardcopy or book - (total IDR 1.150.000) related with my status as PhD student in ITS Surabaya based time limit on April 17, 2015.

Is the nominal (IDR) payment corrent? If yes I would like to pay the registration fee today.

This is my question and thanks a lots for your anwer.

Title: Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network

Best Regards,

Amirullah
Student ID: 2214301012

amir rullah <am9520012003@yahoo.com> Thu, 16 Apr 2015 at 7:36 am

To: sitia@its.ac.id
Cc: sitia@its.ac.id, ronny@ee.its.ac.id

Dear Isitia 2015 Commitee,

I am Amirullah, my paper title below accepted to present in Isitia 2015 conference on May 20, 2015. My status is Doctorate (S3) Student in Electrical Engineering ITS Surabaya (Power System) and lecturer in same department at University Bhayangkara Surabaya. Next I would process the payment of registration fee. Depend on the guideline in Isitia 2015 website I have to pay IDR 950.000 and IDR 200.000, for hardcopy or book - (total IDR 1.150.000) related with my status as PhD student in ITS Surabaya based time limit on April 17, 2015.

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Best Regards,

Amirullah
Student ID: 2214301012

ISITIA 2015 <isitia2015@gmail.com>
To: am9520012003@yahoo.com
Cc: ronny@ee.its.ac.id

Thu, 16 Apr 2015 at 8:53 am

Dear Mr. Amirullah,

Thank you for your email.
Regarding the registration fee of your paper, please proceed the registration related to your student status. Please also show your Student ID as a proof of your status.

Thank you and see you in the conference.

Regards,
Technical Committee.

Hide original message

> On Apr 16, 2015 7:35 AM, "amir rullah" <am9520012003@yahoo.com> wrote:
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> Amirullah
> Student ID: 2214301012

amir rullah <am9520012003@yahoo.com>
To: isitia2015@gmail.com
Cc: ronny@ee.its.ac.id, am9520012003@yahoo.com

Thu, 16 Apr 2015 at 9:24 am

Dear Dr. Ronny Mardiato,

Thanks a lot of for your answer.

Best Regards: Amirullah

Hide original message

> On Thursday, 16 April 2015, 8:53, ISITIA 2015 <isitia2015@gmail.com> wrote:
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> Dear Mr. Amirullah,
> Thank you for your email.
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>
> Best Regards,
>
> Amirullah
> Student ID: 2214301012

amir rullah <am9520012003@yahoo.com> Thu, 16 Apr 2015 at 9:25 am
To: isitia2015@gmail.com
Cc: ronny@ee.its.ac.id, am9520012003@yahoo.com

Dear Dr. Ronny Mardiato,

Thanks a lot of for your answer.

Best Regards: Amirullah

Hide original message

> On Thursday, 16 April 2015, 8:53, ISITIA 2015 <isitia2015@gmail.com> wrote:
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Title: Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network

Best Regards,

Amirullah
Student ID: 2214301012

Validation of Isitia 2015 Registration Status 2

Yahoo/Inbox ☆ 29

amir rullah <am9520012003@yahoo.com> Thu, 16 Apr 2015 at 7:45 pm ☆
To: isitia2015@gmail.com, sitia@its.ac.id
Cc: ronny@ee.its.ac.id

Dear Dr. Ronny Mardiyanto,

Today I already have paid registration and order of hardcopy proceeding fees of Isitia 2015 as PhD ITS student (IDR 950.000 + IDR 200.000 = IDR 1.150.000), follow some steps of registration process (upload proof of payment and student ID), and finally click submit toolbox.

But in that registration process menu, there is no proof or validation to make sure what Isitia 2015 oral presenter or another participant has finished or submitted this process.

How could I know that I have finished or submitted of Isitia 2015 registration (number 9 process).

This is my answer and thank you very much for your respon.

Best Regards: Amirullah
Student ID: 2214301012

amir rullah <am9520012003@yahoo.com> Thu, 16 Apr 2015 at 7:45 pm ☆
To: isitia2015@gmail.com, sitia@its.ac.id
Cc: ronny@ee.its.ac.id

Dear Dr. Ronny Mardiyanto,

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But in that registration process menu, there is no proof or validation to make sure what Isitia 2015 oral presenter or another participant has finished or submitted this

Re: Nominal (IDR) payment for PhD Student Author Participant in Isitia 2015

From: amir rullah (am9520012003@yahoo.com)

To: isitia2015@gmail.com

Cc: ronny@ee.its.ac.id; am9520012003@yahoo.com

Date: Thursday, 16 April 2015 at 09:25 am GMT+7

Dear Dr. Ronny Mardiato,

Thanks a lot of for your answer.

Best Regards: Amirullah

> On Thursday, 16 April 2015, 8:53, ISITIA 2015 <isitia2015@gmail.com> wrote:
>
> Dear Mr. Amirullah,
> Thank you for your email.
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> >
> > Best Regards,
> >
> > Amirullah
> > Student ID: 2214301012

Registration Confirmation of ISITIA 2015 3

Yahoo/Inbox ☆

ISITIA 2015 Comittee <isitia2015@gmail.com> Wed, 22 Apr 2015 at 11:09 am ☆
To: am9520012003@yahoo.com

Dear Amirullah -,

The Technical Program Committee of the ISITIA 2015 would like to thanks for your registration of ISITIA 2015. We have received your payment and the payment receipt from the committee will be given on the seminar day.

The submission of camera ready paper and IEEE copyright transfer will be announced shortly. Thank you for your patiency. We look forward to seeing you at Surabaya.

Best Regards,
Dr. Ronny Mardiyanto, ST, MT
Chairman of ISITIA 2015
http://isitia.its.ac.id

amir rullah <am9520012003@yahoo.com> Wed, 22 Apr 2015 at 11:29 am ☆
To: isitia2015@gmail.com
Cc: isitia2015@gmail.com,
zenno_379@yahoo.com

Dear Dr. Ronny Mardianto,
Thanks you very much for your information. I would like to wait information when ISITIA 2015 camera ready submission opened.

Best Regards,

Amirullah
Electrical Engineering-Power System
PhD Student ITS Surabaya
Student ID: 2214301012

Hide original message

> On Wednesday, 22 April 2015, 11:23, ISITIA 2015 Comittee <isitia2015@gmail.com> wrote:
>
> Dear Amirullah -,
>
> The Technical Program Committee of the ISITIA 2015 would like to thanks

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To: isitia2015@gmail.com
Cc: isitia2015@gmail.com, zenno_379@yahoo.com

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Best Regards,

Amirullah
Electrical Engineering-Power System
PhD Student ITS Surabaya
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Dr. Ronny Mardiyanto, ST, MT
Chairman of ISITIA 2015
http://isitia.its.ac.id

Camera Ready Submission of ISITIA 2015 has been opened

From: ISITIA 2015 Comittee (isitia2015@gmail.com)

To: am9520012003@yahoo.com

Date: Friday, 24 April 2015 at 02:05 pm GMT+7

Dear Amirullah -,

The Technical Program Committee of the ISITIA 2015 would like to inform you that the link for camera-ready submission has been available in your ISITIA Account. Please also submit the IEEE Copyright Transfer of your paper through the link in your account. The due date for submission of Camera-Ready Paper and IEEE Copyright transfer is May 1, 2015.

Please be noted that the compliance of your paper to IEEE Regulations is on your side, therefore please kindly ensure the format and English proficiency of your paper before submitted to ISITIA web site.

The paper which is not submitted the camera-ready version will not be included in the proceeding and there is no refund may be made.

We look forward to seeing you at Surabaya.

Best Regards,
Dr. Ronny Mardiyanto, ST, MT
Chairman of ISITIA 2015
http://isitia.its.ac.id

ISITIA 2015 Announcement â€“ Presentation File Uploading

From: ISITIA 2015 Comittee (isitia2015@gmail.com)

To: am9520012003@yahoo.com

Date: Monday, 11 May 2015 at 06:36 pm GMT+7

Dear Amirullah -,

Herewith, the committee of ISITIA 2015 announces that the link for uploading presentation file is already opened. Please login to ISITIA conference system with your account to upload your presentation file. The submission of presentation file no later than May 15, 2015.

In order to avoid file conflicting with another author and to simplify the classification of your file, please add your paper ID at the beginning of your file name.

Example: 312_filename.ppt

We look forward to seeing you at Surabaya.

Best Regards,
Dr. Ronny Mardiyanto, ST, MT
Chairman of ISITIA 2015
http://isitia.its.ac.id

Lampiran 2

Bukti Pendukung

Lampiran 2.1

Naskah makalah submitted

Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network

Amirullah[1,2)],
[1)]Electrical Engineering Study Program,
Engineering Faculty,
University of Bhayangkara Surabaya
Jl. Ahmad Yani 114 Surabaya Indonesia
am9520012003@yahoo.com[1)]

Ontoseno Penangsang[1)], Adi Soeprijanto[3)]
[2,3)]Electrical Engineering Department,
Industrial Engineering Faculty,
Kampus ITS Sukolilo Surabaya
Jl. Arief Rahman Hakim Surabaya Indonesia 60111
Zenno_379@yahoo.com[2)], adisup@ee.its.ac.id[3)]

***Abstract*-Objective of research is to analyze the influence of the photovoltaic (PV) generator installation to power quality on distribution network. There are two models of load distribution network, namely industrial and residential costumers distribution network. Simulation results show that the value of bus voltage THD on distribution network of industrial and residential customers are still under of voltage THD limit recomended by IEEE 519-1992 equal as 5%. The majority of the value of TDD conductor in two models of the distribution network is under the limit conductor current TDD recommended by IEEE 519-1992. In network industries and residential customers, the more number of PV plants installed, then the value of current harmonics (TDD) at PCC bus will be even greater. The using of single tuned passive filter able to improve THD Bus and TDD conductor still does not meet the standart requirements.**

Keywords: Photovoltaic Generator, Harmonics, Total Harmonic Distortion, Total Demand Distortion

I. INTRODUCTION

Utility customers are becoming more and more demanding in energy consumption and they need good supply to operate reliably. At the same time they tend to disrupt the utility supply with the equipment used for their main daily activities. Such kind of equipment may include variable speed drives, computers, electronic ballasts, and power electronic devices. This is imposing of higher burden on utilities to supply good quality electrical energy. Consequently, renewable energy sources and distributed generator (DG) will play a significant role in the energy mix in the future and a number of further research is require to optimize the number of grid development strategies and improve of power quality [1]. Microgrid is a group of loads and generators that operate as a controlled system that provides electricity to a particular region with relatively limited power. The concept provides a new view to define the operation of distributed generator [2], [3]. In microgrid technology, which is commonly used plant is a plant with renewable energy sources. One source of renewable energy is photovoltaic (PV) generator. The use of PV as an energy source requires an inverter to convert DC into AC voltage. In addition to function as a kind of change of voltage, inverter also cause damage to existing fundamental wave and commonly called harmonics. If it can not be controlled, then the harmonics will cause damage to equipment such as transformers, cables, and other electrical devices. One way to reduce the harmonics is using a filter [4].

The purpose of research is to analyze the influence of the photovoltaic (PV) generator installation to power quality on distribution network. There are two models of load distribution network, namely industrial and residential costumers distribution network. The research method begins by determining network modeling is connected to PV system, PV array circuit model, PV inverter circuit topology model, and network topology model of industrial and residential costumers. The next step is to determine a mathematical model of current control circuit PV inverter. The next process is to determine the strategy of the PV generator installation in the distribution network of industrial and residential customers. The next stage is to determine the value of bus voltage THD, conductor current TDD, and conductor power factor in the distribution network of industrial and residential customers on a different strategies PV generator installation.Futhermore is comparing value of bus voltage THD and conductor current TDD refers to IEEE Standard 519-1992 and conductor power factor refers on to the standard Indonesian Electricity Company (PLN) as a basis for determining level of power quality in industrial and residential costumer distribution network. Single tuned passive filter are selected to improve THD bus and TDD conductor value still does not meet the standart requirements.

II. THEORY

A. Power Quality Standart

Power quality has become a major concern in electrical world for recent decades. One issue that arises is the emergence of the current and voltage waveform is not sinusoidal or defects caused by the emergence of harmonics generated by the power system [5]. Figure 1 shows distorted waveform signal due to harmonics.

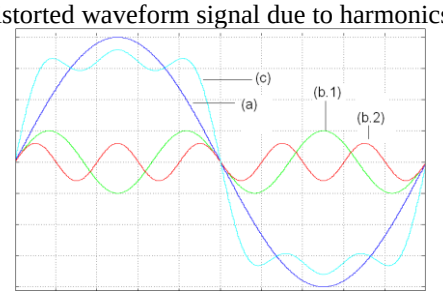


Figure 1. Distorted Wave Cause Harmonics. Where: a = Fundamental Frequency Wave, b.1 = 3rd Harmonics Wave, b.2 = 5th Harmonics Wave, c. = Distorted Harmonics.

The first parameter is the Total Harmonic Distortion (THD). THD is the ratio of the rms value of the harmonic components to rms value of fundamental component and is commonly expressed in percent (%). This index is used to measure periodic waveform deviations contains harmonics of a perfect sine wave [6]. In a perfect sine wave THD value is zero percent. THD value is expressed in Equation 1 as follows:

$$THD = \frac{\sqrt{\sum_{n=2}^{k} U_n^2}}{U_1} \times 100\ \% \qquad (1)$$

Where: U_n = Harmonic Component; U_1 = Fundamental Component; K = Maximum Harmonic Component

The second parameter is Individual Harmonic Distortion (IHD) is ratio of the rms value of individual harmonics to the rms value of fundamental component. The third parameter is Total Demand Distortion (TDD) is amount of current harmonic distortion and defined in the following Equation 2 [7]:

$$TDD = \frac{\sqrt{\sum_{n=2}^{k} I_n^2}}{I_L} \times 100\ \% \qquad (2)$$

Where I_L is maximum load current (for 15 or 30 minutes) at fundamental frequency at the Point of Common Coupling (PCC), is calculated from current average of maximum load of 12 months before.

Maximum THD value which allowable for each country is different depending on the standard used. THD standards is most often used in the electric power system is the IEEE Standard 519-1992. There are two criteria that are used in the analysis of harmonic distortion is the limit voltage distortion and current distortion limits. Table I shows voltage distortion limit (THD) on power distribution system. Table II shows current distortion limit is based on the IEEE Standard 519-1992 [5].

B. Single Tuned Shunt Passive Filter

Shunt passive filters always considered as agood solution to solve harmonic current problems [8], shunt passive filters can be classified into three basic catagories as follows:

1. Band pass filters (of single or double tuned).
2. High pass filters (of first, second, third-order or C-type).
3. Composite filters as shown in figure 4.

The single tuned filter (Figure 2) consisting of inductor L_f, capacitor C_f and small damping resistor R_f are connected in parallel with non linear loads to provide low-impedance paths for specific harmonic frequencies, thus resulting in absorbing the dominant harmonic currents flowing out of the load. Furthermore it also compensates reactive power at system operating frequency.

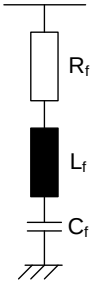


Figure 2. Single Tuned Shunt Passive Filter

The impedance versus frequency of this filter is shown [9]:

$$Z_f(S) = \frac{1 + R_f C_f S + L_f C_f S^2}{C_f S} \qquad (3)$$

Where S = j2πf

Generally the filter capasitor is sized for known reactive power compensation Q_c required to improve power factor, C_f can be expressed as:

$$C_f = \frac{1}{2\pi f_1 U^2}\left(1 - \frac{1}{n^2}\right) \qquad (4)$$

Where U is the supply voltage, n is the harmonic order and f_1 is a fundamental frequency.

At the harmonic frequency f_n = n f_1 the filter reactor provides a series resonance.

$$L_f\, 2\pi f_n = \frac{1}{C_f\, 2\pi f_n} \qquad (5)$$

The inductive value of filter can be obtained from equation 6 as:

$$L_f = \frac{1}{(2\pi f_n)^2 C_f} \qquad (6)$$

The value of the low-impedance R_f for each single tuned filter is affected by the quality factor of filter Q.

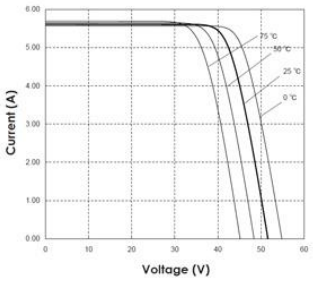
$$R_f = 2\pi f_1 n \frac{L_f}{Q} \qquad (7)$$

The quality factor Q determines the sharpness of tuning. Usually, a value of Q ranges between 20 and 100. High Q-value filter give the best reduction in harmonic distortion. The interaction of the filter with the source reactance L_s, creates a parallel resonance condition addition to the series resonance frequency of the filter.

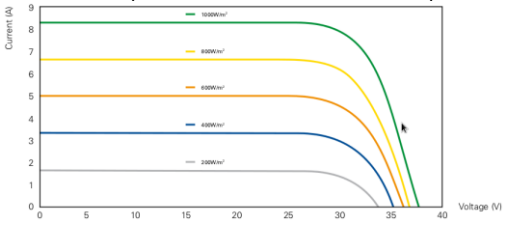
$$f_p = \frac{1}{2\pi(\sqrt{(L_f + L_s)C_f}} \qquad (8)$$

C. Photovoltaic System

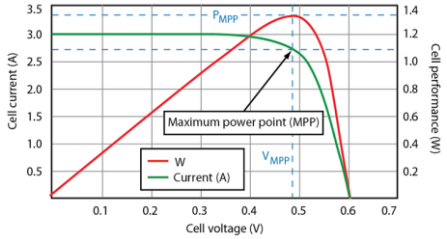
Photovoltaic systems (PV) or solar panels is one of renewable energy power generator that utilize sun as main source and then converted into electrical energy. In general, solar power has to be accepted as an alternative energy source. The issue now is the price is still expensive compared to electricity generated by other energy sources, so its use is now limited to a limited scale such as in electrical devices and are also used as power generator in areas that are still inaccessible by electrical network [10]. Figure 3 shows PV characteristic curve.



(a) I-V curve for PV panel PV for fix radiation and temperature change



(b) I-V curve for PV panel for radiation level change and fix temperature



(c) Curve of current versus voltage and power

Figure 3. Curve of PV panel characteristic

METHODOLOGY

A. Research Method

Research method begins by determining network model (grid) is connected to the PV system, PV array circuit model, PV inverter circuit topology models, as well as the distribution network topology model of industrial and residential customers. The next step is to determine a mathematical model of current control circuit of PV inverter. The next process is to determine the strategy of PV power generator installation in the distribution network of industrial and residential customers. PV system model which has been subsequently simulated in two distribution network topology. The first network representing industrial area measurements made before and after the installation of 150 kW PV system and the residential area. In the industrial customer case studies, three 150 kW PV system connected to the distribution network and subsequent evaluation of response of distribution network. A residential customer distribution topology then proposed with a 150 kW PV system. The next stage is to determine value of bus voltage THD, current TDD, and power factor (power factor) conductor in the distribution network of industrial and residential customers on a number of strategies installation of PV generator. Futhermore, comparing value of bus voltage THD and current conductor TDD refers to IEEE Standard 519-1992 and conductor power factor refers to the standard PLN. Single tuned passive filters are installed to improve THD bus and TDD conductor value still does not meet the standart requirements. Simulation and analysis of research using ETAP 7.0 software.

B. PV Model Description

The PV system model proposed for the simulation consists of PV array, diode, inverters and a power grid interface as shown in Figure 4. The PV array is modeled according to its equivalent circuit shown in Figure 5, by using the equation deriving from aforemention circuit representation.

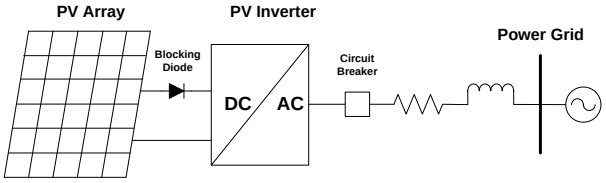


Figure 4. Proposed model for grid-connected photovoltaic system

In particular, the behavior of the PV array model is affected by the solar irradiance, the temperature and the specific characteristics of the chosen PV module technology. The PV inverter circuit is composed of a DC to DC converters which is necessary to determine maximum power point tracking of PV arrays, a DC to AC converter to transform DC power into AC, means of energy transfer to absorb fast voltage variations and filters to eleminate undesirable harmonic components. The modular circuit of the PV inverter is shown in Figure 6.

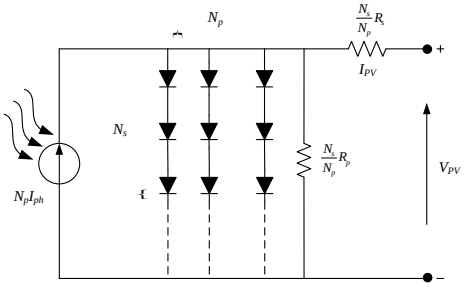


Figure 5. Equivalent circuit of PV array

A maximum power point tracking mechanism to extract the maximum power available from the PV array is also considered. The maximum power point tracking adopted is the incremental conductance method with integral regulator to minimize the errors in tracking MPP. More information about the specific algorithm is found in reference [1]. Distribution network model of industrial and residential customers is shown in Figure 6 and 7.

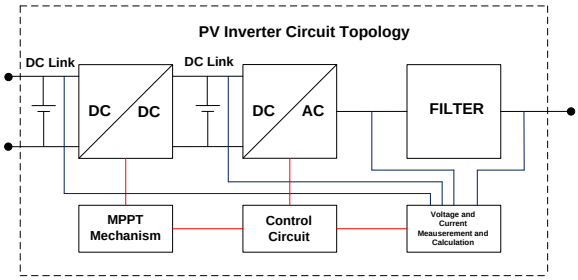
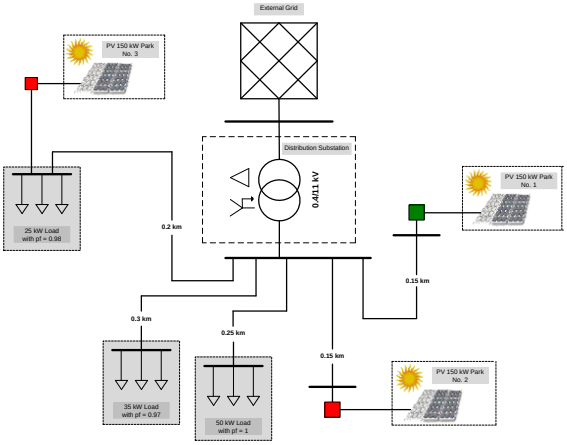
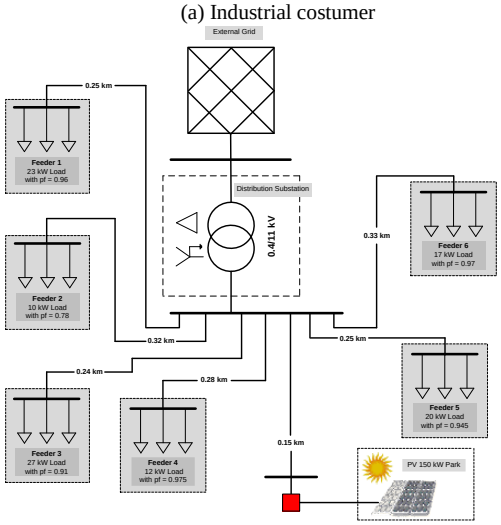


Figure 6. PV inverter circuit topology

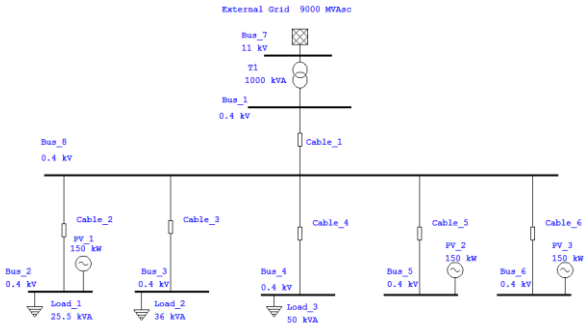


(a) Industrial costumer

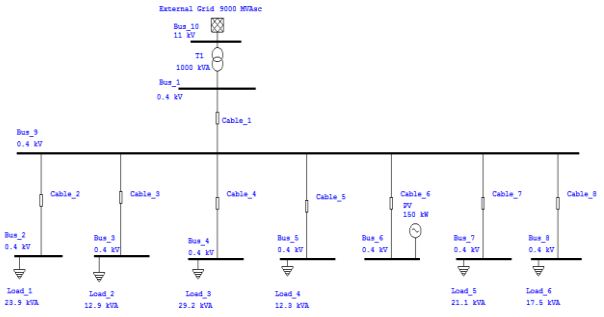


(a) Residential costumer

Figure 7. Two model of distribution network for industrial and residential customer



(a) Industrial costumer



(b) Residential costumer

Figure 8. Two model of distribution network for industrial and residential customer using ETAP

RESULT AND DISCUSSION

Research was conducted on the condition of system is connected to microgrid. There are two models of network topology, namely distribution network of industrial and residential customers. Both grid distribution network supplied by a power transformer 1000 kVA, 11/0.4 kV Δ /Y connection, which is connected to the external grid MVA_{sc} 9000. The first distribution network connected to 5 buses, respectively 2 load buses, connected to the PV plant, as well as one other bus connected to the PV generator and also serves as a bus load. The second distribution networks connected to 7 buses, each 6 load buses and 1 bus is connected to PV generator. Data load, transformer, conductor, and PV generator on the distribution network of industrial and residential costumer are shown in Table III. PV generator in addition to functioning supplying power to the distribution network, is also a source of harmonics due to the presence of inverter as a medium to transform the DC voltage into AC voltage. Data of harmonic current generated by the PV generaton is shown in Table IV [10]. Harmonic order are generated according to the ability of ETAP 7.0 software.

TABLE IV. HARMONIC CURRENT GENERATE BY PV

Order	Mag (%)	Order	Mag (%)
2	0.71	11	0.24
3	1.85	12	0.08
4	0.57	13	0.16
5	0.52	14	0.25
7	0.61	15	0.05
8	0.07	17	0.06
9	0.08	19	0.05
10	1.12	23	0.07

Based on the above data, then analyzed using ETAP 7.0 software help to determine the value of the bus voltage THD, current TDD current, and conductor power factor in the distribution network of industrial and residential customers on a number of installation strategies of PV generator. Analysis of three parameters shown in Table V, VI, and VII.

Table V. COMPARATION OF VOLTAGE QUALITY USING DIFFERENT STRATEGY OF PV INSTALATION ON INDUSTRIAL COSTUMER

Strategies	Bus	V(pu)	V_{THD} (%)	V_{THD} Std (%)
Without PV	1	0.998	0.01	5
	2	0.988	0.01	5
	3	0.985	0.00	5
	4	0.985	0.00	5
	5	0.989	0.01	5
	6	0.989	0.01	5
	7	1.000	0.00	5
	8	0.989	0.01	5
PV1	1	0.998	0.07	5
	2	0.981	0.18	5
	3	0.986	0.13	5
	4	0.986	0.13	5
	5	0.991	0.13	5
	6	0.991	0.13	5
	7	1.000	0.00	5
	8	0.998	0.13	5
PV1 + PV2	1	0.999	0.15	5
	2	0.989	0.32	5
	3	0.987	0.27	5

	4	0.986	0.27	5
	5	0.991	0.31	5
	6	0.991	0.27	5
	7	1.000	1.00	5
	8	0.991	0.27	5
PV1 + PV2+ PV3	1	0.999	0.22	5
	2	0.991	0.45	5
	3	0.988	0.40	5
	4	0.987	0.40	5
	5	0.992	0.44	5
	6	0.993	0.44	5
	7	1.000	0.00	5
	8	0.998	0.40	5

Table VI. COMPARATION OF VOLTAGE QUALITY USING DIFFERENT STRATEGY OF PV INSTALATION ON RESIDENTIAL COSTUMER

Strategies	Bus	V(pu)	V_{THD} (%)	V_{THD} Std (%)
Without PV	1	0.997	0.01	5
	2	0.986	0.00	5
	3	0.987	0.00	5
	4	0.986	0.01	5
	5	0.997	0.00	5
	6	0.998	0.00	5
	7	0.986	0.02	5
	8	0.986	0.01	5
	9	0.988	0.00	5
	10	1.000	0.00	5
PV	1	0.998	0.07	5
	2	0.987	0.13	5
	3	0.988	0.13	5
	4	0.987	0.13	5
	5	0.998	0.13	5
	6	0.990	0.17	5
	7	0.987	0.13	5
	8	0.987	0.13	5
	9	0.989	0.13	5
	10	1.000	0.00	5

Table V dan VI shows that bus voltage THD value on distribution network of industrial and residential customers ranged between 0 through 0.45%. This value is still below limit of voltage THD recommended by IEEE 519-1992 by 5%. The addition of PV generator in both distribution network generates increasing of voltage THD value. On industrial customer network without PV, maximum bus voltage THD value is 0.01%, while network using three PV maximum bus voltage THD value increased to 0.45%. The maximum bus voltage THD value on residential customer networks without PV of 0.02% and if using PV maximum bus voltage THD value increased to 0.17%.

Figure 8 and 9 show that on industrial and residential customers network, the more the number of PV generator installed then value of current harmonics (TDD) at PCC bus will be even greater. This is because in addition to functioning PV generator supplying power to the distribution network, is also generating harmonics due to presence of inverter as a media to convert DC to AC voltage.

Table VI shows that the value of conductor currents TDD in the industrial customers distribution network ranging from 0 through 224.9%. The value of conductor currents TDD in the residential distribution network ranges between 0 trough 39.44%. The majority of the value of TDD channel in two models of the distribution network is under the limit conductor currents TDD recommeded by IEEE 519-1992. The addition of PV generator in two models distribution network produce conductor current TDD value is increasing. The most value of conductor current TDD average generated by conductor that is connected directly to the PV generator bus. The value of the power factor in the distribution network of industrial and residential customers on average already meet the minimum requirements PLN limit by 85%, except for the bus that is not connected to the PV generator.

CONCLUSION

The simulation results show that the THD value on the bus voltage distribution network of industrial and residential customers are still under voltage THD limit recommended by the IEEE 519-1992 by 5%. The majority of the value of TDD conductor in two models of the distribution network is under the limit conductor current TDD recommeded by IEEE 519-1992. In industrial and residential customer networks, the more the number of PV generator installed, then the value of current TDD at PCC bus will be even greater. This is because in addition to functioning PV plants supplying power to the distribution network, is also generates harmonics due to the presence of the inverter as a medium to transform DC into AC voltage. The value of power factor in the distribution network of industrial and residential customers on average already meet minimum requirements set PLN limits by 85%.

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APPENDIXS:

Tabel I. IEEE 519-1992 HARMONIC VOLTAGE LIMIT

Bus Voltage on PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3,0	5,0
69,001 kV through 161 kV	1,5	2,5
161,001 kV and above	1,0	1,5

Tabel II. IEEE 519-1992 HARMONIC CURRENT LIMIT

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	**<11**	**11≤h<17**	**17≤h<23**	**23≤h<35**	**35≤h**	**TDD**
<20*	4	2	1,5	0,6	0,3	5
20 s/d 50	7	3,5	2,5	1	0,5	8
50 s/d 100	10	4,5	4	1,5	0,7	12
100 s/d 1000	12	5,5	5	2	1	15
>1000	15	7	6	2,5	1,4	20

Table III. Distribution network data of industrial and residential customer

Network models	Generator and Transformers	Conductors	Loads
Industrial costumer	External grid 9000 MVAsc (Swing) Transformer 1000 kVA, 11/0.4 kV, Δ/Y PV 1 (Bus 2) 150 kW (Mvar Control) PV 2 (Bus 5) 150 kW (Mvar Control) PV 3 (Bus 6) 150 kW (Mvar Control) Frekuensi 50 Hz	Bus 1-8, Al 3/C 120 mm^2 Bus 8-2, CU 3/C 35 mm^2 Bus 8-3, CU 3/C 35 mm^2 Bus 8-4, CU 3/C 35 mm^2 Bus 8-5, CU 3/C 35 mm^2 Bus 8-6, CU 3/C 35 mm^2	Bus 2, 25 kW cos φ = 0.980 Bus 3, 35 kW cos φ = 0.970 Bus 4, 35 kW cos φ = 1.000
Residential costumer	External grid 9000 MVAsc (Swing) Transformer 400 kVA, 11/0.4 kV, Δ/Y PV (Bus 6) 150 kW (Mvar Control) Frekuensi 60 Hz	Bus 1-9, Al 3/C 120 mm^2 Bus 9-2, CU 3/C 35 mm^2 Bus 9-3, CU 3/C 35 mm^2 Bus 9-4, CU 3/C 35 mm^2 Bus 9-5, CU 3/C 35 mm^2 Bus 9-6, CU 3/C 35 mm^2 Bus 9-7, CU 3/C 35 mm^2 Bus 9-8, CU 3/C 35 mm^2	Bus 2, 23 kW cos φ = 0.960 Bus 3, 10 kW cos φ = 0.780 Bus 4, 27 kW cos φ = 0.910 Bus 5, 25 kW cos φ = 0.975 Bus 7, 20 kW cos φ = 0.945 Bus 8, 35 kW cos φ = 0.970

Table VII. Comparison of current quality on a number PV installation strategy

Network Models	Strategies	Conductors	PF (%)	Isc (A)	IL (A)	Isc/IL	TDD (%)	TDD Standart (%)
Industrial Costumer	Without PV	1	99.2	13900	157.7	88.1420	0.000	12
		2	98.1	8100	36.30	223.141	0.000	15
		3	97.1	6700	51.20	130.860	0.000	15
		4	100.0	7300	71.10	102.673	0.000	15
		5	0.0	8960	0.000	N/A	0.000	20
		6	0.0	9040	0.000	N/A	0.000	20
	PV1	1	99.6	13860	145.5	95.2580	3.920	12
		2	100.0	8083	24.00	336.792	23.87	15
		3	97.2	6900	51.30	134.503	0.090	15
		4	100.0	7600	71.10	106.892	0.000	15
		5	0.0	9390	0.000	N/A	0.000	20
		6	0.0	9480	0.000	N/A	0.000	20
	PV1 + PV2	1	99.7	13860	143.3	96.7200	7.970	12
		2	100	8441	24.00	351.709	23.83	15
		3	97.2	7150	51.30	100.422	0.180	15
		4	100	7890	71.20	110.815	0.180	15
		5	85.7	9390	6.300	1490.48	224.5	20
		6	0.0	9930	0.000	N/A	0.000	20
	PV 1 + PV2 + PV3	1	100.0	13860	130.7	106.045	13.10	15
		2	100.0	8800	24.10	365.146	23.74	15
		3	97.2	7400	51.40	143.968	0.260	15
		4	100.0	8190	71.20	115.029	0.270	15
		5	85.8	9840	6.300	1561.91	224.9	20
		6	85.1	9930	15.60	636.539	39.54	20
Residential costumer	Without PV	1	93.6	13860	165.0	84.0000	0.000	12
		2	96.1	7300	34.00	214.710	0.000	15
		3	77.3	6430	18.40	349.460	0.000	15

		4	91.0	7450	41.60	179.090	0.000	15
		5	97.5	6810	17.50	389.143	0.000	15
		6	0.0	9040	0.000	N/A	0.000	20
		7	94.5	7210	30.00	240.334	0.000	20
		8	97.0	6230	24.90	250.201	0.000	20
	PV	1	94.3	13860	150.9	91.8900	3.780	12
		2	96.1	7590	34.10	222.581	0.090	15
		3	77.3	6600	18.50	356.757	0.070	15
		4	91.3	7750	41.60	186.298	0.080	15
		5	97.5	7070	17.50	404.000	0.090	15
		6	85.0	9040	14.60	619.178	39.44	15
		7	94.5	7500	30.00	250.000	0.130	15
		8	97.0	6450	24.90	259.036	0.130	15

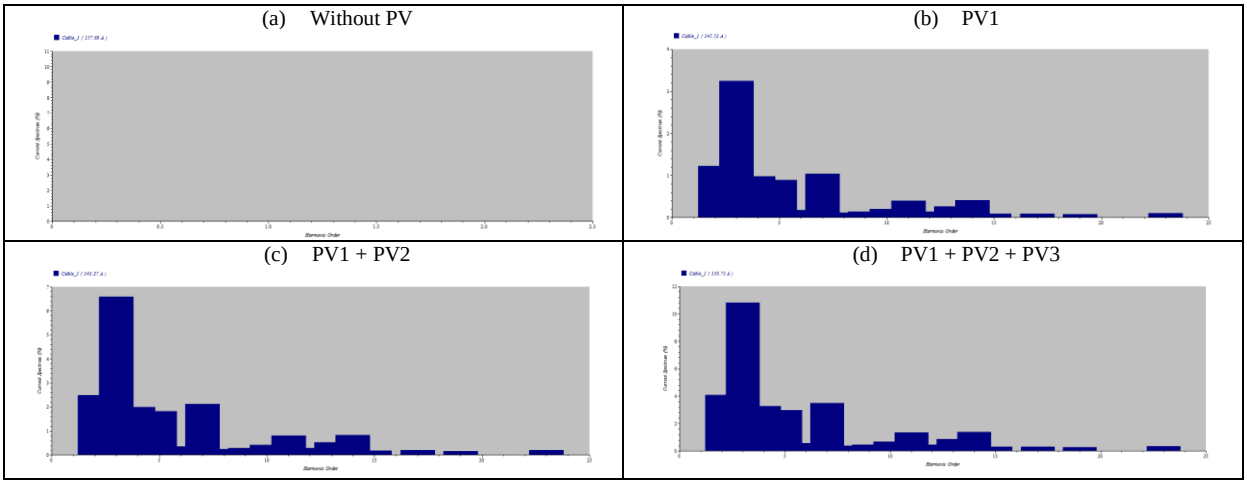

Figure 8. Harmonic current spectrum in the number of PV installation strategies on industrial costumer network at PCC

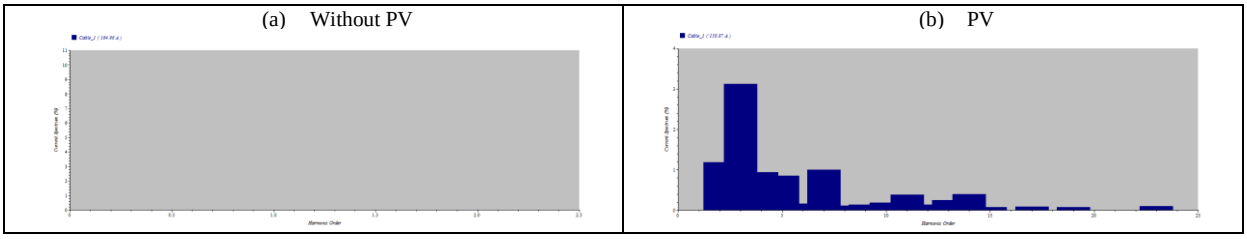

Figure 9. Harmonic current spectrum in the number of PV installation strategies on residential costumer network at PCC

Table VI. Designed Single Tuned Passive Filters and Total Demand Distortion

Strategies	Conductors	Tuned Filter	C (μF)	L (mH)	R (Ω)	TDD	
						Without Filter	With Filter
Industrial Costomer							
PV 1 + PV2	5	3rd	17.4690	44.7459	0.5062	224.50	154.65
		5th	17.4690	16.1113	0.3037	224.50	157.08
		7th	17.4690	8.22000	0.2167	224.50	156.65
		11th	17.4690	3.3288	0.1381	224.50	160.06
		14th	17.4690	2.0055	0.1059	224.50	163.06
PV 1 + PV2 + PV3	5	3rd	17.4690	44.746	0.5062	224.90	154.68
		5th	17.4690	16.111	0.3037	224.90	156.97
		7th	17.4690	8.2200	0.2167	224.90	156.47
		11th	17.4690	3.3288	0.1381	224.90	159.91
		14th	17.4690	5.0055	0.1059	224.90	161.10
	6	3rd	87.3713	8.9480	0.1012	39.540	28.260
		5th	87.3713	3.2213	0.0608	39.540	28.540
		7th	87.3713	1.6435	0.0434	39.540	28.880
		11th	87.3713	0.6656	0.0276	39.540	29.490
		14th	87.3713	0.4109	0.0217	39.540	30.190
Residential Costumer							
PV	6	3rd	87.3713	8.9480	0.1012	39.440	28.270

		5^{th}	87.3713	3.2213	0.0608	39.440	28.480
		7^{th}	87.3713	1.6435	0.0434	39.440	28.280
		11^{th}	87.3713	0.6656	0.0276	39.440	29.160
		14^{th}	87.3713	0.4109	0.0217	39.440	29.280

Lampiran 2.2

Revisi makalah final

(Camera ready)

Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network

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***Abstract*-Objective of research is to analyze the influence of the photovoltaic (PV) generator installation to power quality on distribution network. There are two models of load distribution network, namely industrial and residential costumers distribution network. Reseach show that the value of bus voltage THD on distribution network of industrial and residential customers are still under of voltage THD limit recomended by IEEE 519-1992 equal as 5%. The majority of the value of TDD conductor in two models of the distribution network is under the limit conductor current TDD recommended by IEEE 519-1992. In network industries and residential customers, the more number of PV plants installed, then the value of current harmonic (TDD) at PCC bus will be even greater. The most value of conductor current TDD average generated by conductor that is connected directly to the PV generator bus The using of single tuned passive filter able to improve THD Bus and TDD conductor which still does not meet the standart requirements.**

Keywords: Photovoltaic Generator, Harmonics, Total Harmonic Distortion, Total Demand Distortion

I. INTRODUCTION

Utility customers are becoming more and more demanding in energy consumption and they need good supply to operate reliably. At the same time they tend to disrupt the utility supply with the equipment used for their main daily activities. Such kind of equipment may include variable speed drives, computers, electronic ballasts, and power electronic devices. This is imposing of higher burden on utilities to supply good quality electrical energy. Consequently, renewable energy sources and distributed generator (DG) will play a significant role in the energy mix in the future and a number of further research is require to optimize the number of grid development strategies and improve of power quality [1]. Microgrid is a group of loads and generators that operate as a controlled system that provides electricity to a particular region with relatively limited power. The concept provides a new view to define the operation of distributed generator [2], [3]. In microgrid technology, which is commonly used plant is a plant with renewable energy sources. One source of renewable energy is photovoltaic (PV) generator. The use of PV as an energy source requires an inverter to convert DC into AC voltage. In addition to function as a kind of change of voltage, inverter also cause damage to existing fundamental wave and commonly called harmonics. If it can not be controlled, then the harmonics will cause damage to equipment such as transformers, cables, and other electrical devices. One way to reduce the harmonics is using a filter [4].

The purpose of research is to analyze the influence of the photovoltaic (PV) generator installation to power quality on distribution network. There are two models of load distribution network, namely industrial and residential costumers distribution network. The research method begins by determining network modeling is connected to PV system, PV array circuit model, PV inverter circuit topology model, and network topology model of industrial and residential costumers. The next step is to determine a mathematical model of current control circuit PV inverter. The next process is to determine the strategy of the PV generator installation in the distribution network of industrial and residential customers. The next stage is to determine the value of bus voltage THD, conductor current TDD, and conductor power factor in the distribution network of industrial and residential customers on a different strategies PV generator installation.Futhermore is comparing value of bus voltage THD and conductor current TDD refers to IEEE Standard 519-1992 and conductor power factor refers on to the standard Indonesian Electricity Company (PLN) as a basis for determining level of power quality in industrial and residential costumer distribution network. Single tuned passive filter are selected to improve THD bus and TDD conductor value which still does not meet the standart requirements.

II. THEORY

A. Power Quality Standart

Power quality has become a major concern in electrical world for recent decades. One issue that arises is the emergence of the current and voltage waveform is not sinusoidal or defects caused by the emergence of harmonics generated by the power system [5]. Figure 1 shows distorted waveform signal due to harmonics.

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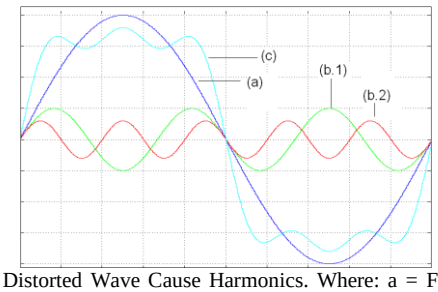


Figure 1. Distorted Wave Cause Harmonics. Where: a = Fundamental Frequency Wave, b.1 = 3rd Harmonics Wave, b.2 = 5th Harmonics Wave, c. = Distorted Harmonics.

The first parameter is the Total Harmonic Distortion (THD). THD is the ratio of the rms value of the harmonic components to rms value of fundamental component and is commonly expressed in percent (%). This index is used to measure periodic waveform deviations contains harmonics of a perfect sine wave [6]. In a perfect sine wave THD value is zero percent. THD value is expressed in Equation 1 as follows:

$$THD = \frac{\sqrt{\sum_{n=2}^{k} U_n^2}}{U_1} \times 100\ \% \qquad (1)$$

Where: U_n = Harmonic Component; U_1 = Fundamental Component; K = Maximum Harmonic Component

The second parameter is Individual Harmonic Distortion (IHD) is ratio of the rms value of individual harmonics to the rms value of fundamental component. The third parameter is Total Demand Distortion (TDD) is amount of current harmonic distortion and defined in the following Equation 2 [7]:

$$TDD = \frac{\sqrt{\sum_{n=2}^{k} I_n^2}}{I_L} \times 100\ \% \qquad (2)$$

Where I_L is maximum load current (for 15 or 30 minutes) at fundamental frequency at the Point of Common Coupling (PCC), is calculated from current average of maximum load of 12 months before.

Maximum THD value which allowable for each country is different depending on the standard used. THD standards is most often used in the electric power system is the IEEE Standard 519-1992. There are two criteria that are used in the analysis of harmonic distortion is the limit voltage distortion and current distortion limits. Table I shows voltage distortion limit (THD) on power distribution system. Table II shows current distortion limit is based on the IEEE Standard 519-1992 [5].

B. Single Tuned Shunt Passive Filter

Shunt passive filters always considered as agood solution to solve harmonic current problems [8], shunt passive filters can be classified into three basic catagories as follows:

1. Band pass filters (of single or double tuned).
2. High pass filters (of first, second, third-order or C-type).
3. Composite filters.

The single tuned filter (Figure 2) consisting of inductor L_f, capacitor C_f and small damping resistor R_f are connected in parallel with non linear loads to provide low-impedance paths for specific harmonic frequencies, thus resulting in absorbing the dominant harmonic currents flowing out of the load. Furthermore it also compensates reactive power at system operating frequency.

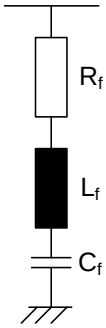


Figure 2. Single Tuned Shunt Passive Filter

The impedance versus frequency of this filter is shown [9]:

$$Z_f(S) = \frac{1 + R_f C_f S + L_f C_f S^2}{C_f S} \qquad (3)$$

Where S = j2πf

Generally the filter capasitor is sized for known reactive power compensation Q_c required to improve power factor, C_f can be expressed as:

$$C_f = \frac{1}{2\pi f_1 U^2}\left(1 - \frac{1}{n^2}\right) \qquad (4)$$

Where U is the supply voltage, n is the harmonic order and f_1 is a fundamental frequency.

At the harmonic frequency $f_n = n\ f_1$ the filter reactor provides a series resonance.

$$L_f\, 2\pi f_n = \frac{1}{C_f\, 2\pi f_n} \qquad (5)$$

The inductive value of filter can be obtained from equation 6 as:

$$L_f = \frac{1}{(2\pi f_n)^2 C_f} \qquad (6)$$

The value of the low-impedance R_f for each single tuned filter is affected by the quality factor of filter Q.

$$R_f = 2\pi f_1 n \frac{L_f}{Q} \qquad (7)$$

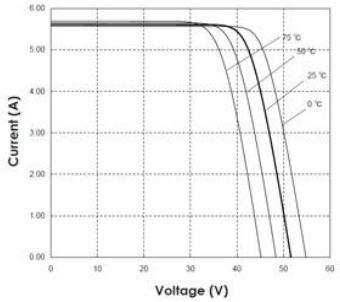
The quality factor Q determines the sharpness of tuning. Usually, a value of Q ranges between 20 and 100. High Q-value filter give the best reduction in harmonic distortion. The interaction of the filter with the source reactance L_s, creates a parallel resonance condition addition to the series resonance frequency of the filter.

$$f_p = \frac{1}{2\pi\left(\sqrt{(L_f + L_s)C_f}\right)} \qquad (8)$$

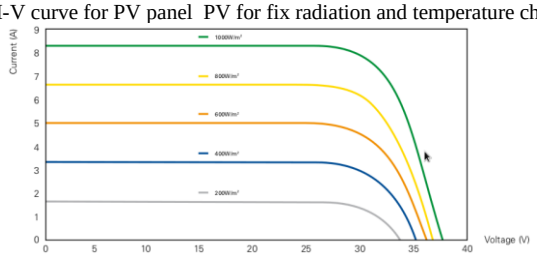
C. Photovoltaic System

Photovoltaic systems (PV) or solar panels is one of renewable energy power generator that utilize sun as main source and then converted into electrical energy. In general, solar power has to be accepted as an alternative energy source. The issue now is the price is still

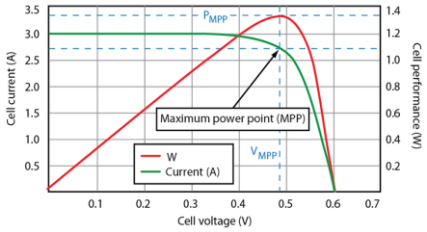
expensive compared to electricity generated by other energy sources, so its use is now limited to a limited scale such as in electrical devices and are also used as power generator in areas that are still inaccessible by electrical network [10]. Figure 3 shows PV characteristic curve.



(a) I-V curve for PV panel PV for fix radiation and temperature change



(b) I-V curve for PV panel for radiation level change and fix temperature



(c) Curve of current versus voltage and power

Figure 3. Curve of PV panel characteristic

III. METHODOLOGY

A. *Research Method*

Research method begins by determining network model (grid) is connected to the PV system, PV array circuit model, PV inverter circuit topology models, as well as the distribution network topology model of industrial and residential customers. The next step is to determine a mathematical model of current control circuit of PV inverter. The next process is to determine the strategy of PV power generator installation in the distribution network of industrial and residential customers. PV system model which has been subsequently simulated in two distribution network topology. The first network representing industrial area measurements made before and after the installation of 150 kW PV system and the residential area. In the industrial customer case studies, three 150 kW PV system connected to the distribution network and subsequent evaluation of response of distribution network. A residential customer distribution topology then proposed with a 150 kW PV system. The next stage is to determine value of bus voltage THD, current TDD, and power factor (power factor) conductor in the distribution network of industrial and residential customers on a number of strategies installation of PV generator. Futhermore, comparing value of bus voltage THD and current conductor TDD refers to IEEE Standard 519-1992 and conductor power factor refers to the standard PLN. Single tuned passive filters are installed to improve THD bus and TDD conductor value still does not meet the standart requirements. Simulation and analysis of research using ETAP 7.0 software.

B. *PV Model Description*

The PV system model proposed for the simulation consists of PV array, diode, inverters and a power grid interface as shown in Figure 4. The PV array is modeled according to its equivalent circuit shown in Figure 5, by using the equation deriving from aforemention circuit representation.

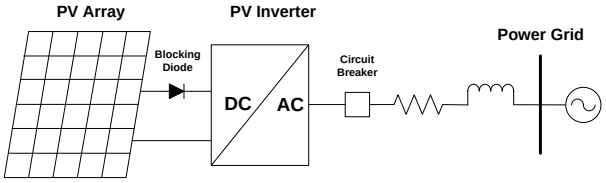


Figure 4. Proposed model for grid-connected photovoltaic system

In particular, the behavior of the PV array model is affected by the solar irradiance, the temperature and the specific characteristics of the chosen PV module technology. The PV inverter circuit is composed of a DC to DC converters which is necessary to determine maximum power point tracking of PV arrays, a DC to AC converter to transform DC power into AC, means of energy transfer to absorb fast voltage variations and filters to eleminate undesirable harmonic components. The modular circuit of the PV inverter is shown in Figure 6.

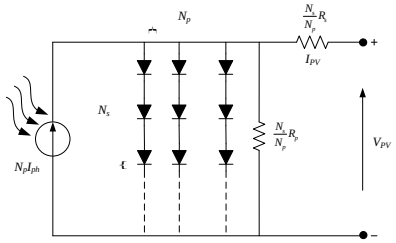


Figure 5. Equivalent circuit of PV array

A maximum power point tracking mechanism to extract the maximum power available from the PV array is also considered. The maximum power point tracking adopted is the incremental conductance method with integral regulator to minimize the errors in tracking MPP. More information about the specific algorithm is found in reference [1]. Distribution network model of industrial and residential customers is shown in Figure 7 and 8.

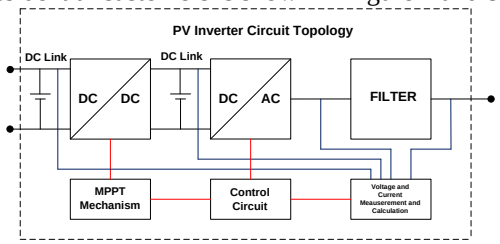
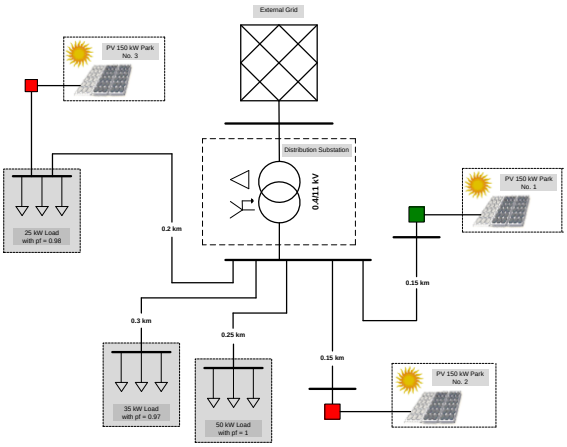
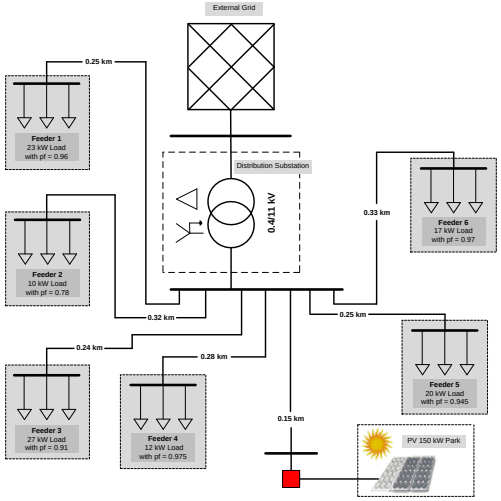


Figure 6. PV inverter circuit topology

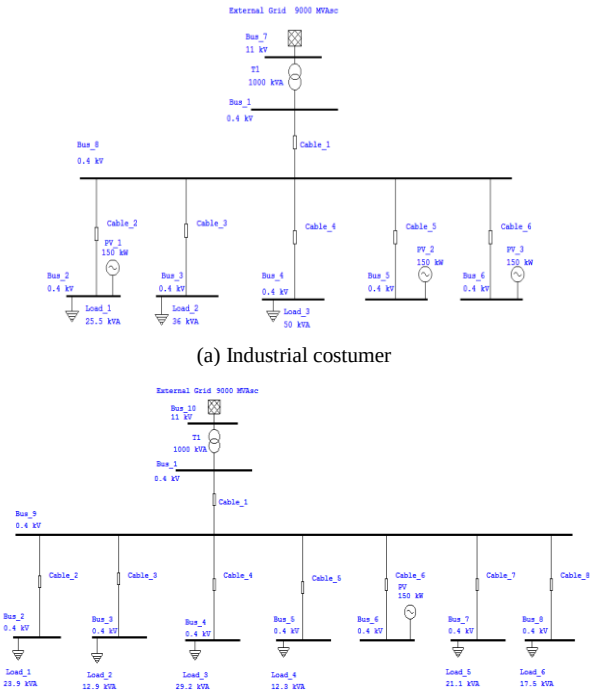


(a) Industrial costumer



(b) Residential costumer

Figure 7. Two model of distribution network



(a) Industrial costumer

(b) Residential costumer

Figure 8. Two model of distribution network for industrial and residential customer using ETAP

IV. RESULT AND DISCUSSION

Research was conducted on the condition of system is connected to microgrid. There are two models of network topology, namely distribution network of industrial and residential customers. Both grid distribution network supplied by a power transformer 1000 kVA, 11/0.4 kV Δ /Y connection, which is connected to the external grid MVA_{sc} 9000. The first distribution network connected to 5 buses, respectively 2 load buses, connected to the PV plant, as well as one other bus connected to the PV generator and also serves as a bus load. The second distribution networks connected to 7 buses, each 6 load buses and 1 bus is connected to PV generator. Data load, transformer, conductor, and PV generator on the distribution network of industrial and residential costumer are shown in Table III. PV generator in addition to functioning supplying power to the distribution network, is also a source of harmonics due to the presence of inverter as a medium to transform the DC voltage into AC voltage. Data of harmonic current generated by the PV generaton is shown in Table IV [11]. Harmonic order are generated according to the ability of ETAP 7.0 software.

TABLE IV. HARMONIC CURRENT GENERATE BY PV

Order	Mag (%)	Order	Mag (%)
2	0.71	11	0.24
3	1.85	12	0.08
4	0.57	13	0.16
5	0.52	14	0.25
7	0.61	15	0.05
8	0.07	17	0.06
9	0.08	19	0.05
10	1.12	23	0.07

Based on the above data, then analyzed using ETAP 7.0 software help to determine the value of the bus voltage THD, current TDD, and conductor power factor in the distribution network of industrial and residential customers on a number of installation strategies of PV generator. Analysis of three parameters shown in Table V, VI, and VII.

TABLE V. COMPARATION OF VOLTAGE QUALITY USING DIFFERENT STRATEGY OF PV INSTALATION ON INDUSTRIAL COSTUMER

Strategies	Bus	V(pu)	V_{THD} (%)	V_{THD} Std (%)
Without PV	1	0.998	0.01	5
	2	0.988	0.01	5
	3	0.985	0.00	5
	4	0.985	0.00	5
	5	0.989	0.01	5
	6	0.989	0.01	5
	7	1.000	0.00	5
	8	0.989	0.01	5
PV1	1	0.998	0.07	5
	2	0.981	0.18	5
	3	0.986	0.13	5
	4	0.986	0.13	5
	5	0.991	0.13	5
	6	0.991	0.13	5
	7	1.000	0.00	5
	8	0.998	0.13	5
PV1 + PV2	1	0.999	0.15	5
	2	0.989	0.32	5
	3	0.987	0.27	5

	4	0.986	0.27	5
	5	0.991	0.31	5
	6	0.991	0.27	5
	7	1.000	1.00	5
	8	0.991	0.27	5
PV1 + PV2+ PV3	1	0.999	0.22	5
	2	0.991	0.45	5
	3	0.988	0.40	5
	4	0.987	0.40	5
	5	0.992	0.44	5
	6	0.993	0.44	5
	7	1.000	0.00	5
	8	0.998	0.40	5

TABLE VI. COMPARATION OF VOLTAGE QUALITY USING DIFFERENT STRATEGY OF PV INSTALATION ON RESIDENTIAL COSTUMER

Strategies	Bus	V(pu)	V_{THD} (%)	V_{THD} Std (%)
Without PV	1	0.997	0.01	5
	2	0.986	0.00	5
	3	0.987	0.00	5
	4	0.986	0.01	5
	5	0.997	0.00	5
	6	0.998	0.00	5
	7	0.986	0.02	5
	8	0.986	0.01	5
	9	0.988	0.00	5
	10	1.000	0.00	5
PV	1	0.998	0.07	5
	2	0.987	0.13	5
	3	0.988	0.13	5
	4	0.987	0.13	5
	5	0.998	0.13	5
	6	0.990	0.17	5
	7	0.987	0.13	5
	8	0.987	0.13	5
	9	0.989	0.13	5
	10	1.000	0.00	5

Table V dan VI shows that bus voltage THD value on distribution network of industrial and residential customers ranged between 0 through 0.45%. This value is still below limit of voltage THD recommended by IEEE 519-1992 by 5%. The addition of PV generator in both distribution network generates increasing of voltage THD value. On industrial customer network without PV, maximum bus voltage THD value is 0.01%, while network using three PV maximum bus voltage THD value increased to 0.45%. The maximum bus voltage THD value on residential customer networks without PV of 0.02% and if using PV maximum bus voltage THD value increased to 0.17%.

Figure 9 and 10 show that on industrial and residential customers network, the more the number of PV generator installed then value of current harmonics (TDD) at PCC bus will be even greater. This is because in addition to functioning PV generator supplying power to the distribution network, is also generating harmonics due to presence of inverter as a media to convert DC to AC voltage.

Table VII shows that the value of conductor currents TDD in the industrial customers distribution network has already meet current TDD recommended by IEEE 519-1992 except on conductor 2, 5, and 6. Current TDD value on conductor 2 has a minimum because value of the power factor is 1.0. Improvement of TDD current only can be done on conductor 5 and 6 for the condition of P1 + PV1 and PV1+ PV2 + PV3 connected to the grid by increasing power factor of both conductor becomes 1.0. By using the power triangular method, we will obtain reactive power compensation value to get value of C, L, and R is based on the most dominant-order harmonics with a single passive filters tuned using Equation 4 to 7. The most dominant-order harmonics are 3^{rd}, 5^{th}, 7^{th}, 11^{th}, and 14^{th}. By using the same procedure, migitation of current TDD can be done on conductor 6 in the residential distribution network for PV installed to the grid. Table VIII shows designed single tuned passive filters, current TDD without and with filter. From Table VII, we can see that nominal current TDD on conductor 5 and 6 in the industrial costumer distribution network before using single tuned passive filters are 224.9 and 39.4. After using 3^{rd} order single tuned passive filter, as shown in Table VIII, the value of current TDD for both conductor has reduced to 154.68 and 28.26. Improvement of current TDD using filter also happens on conductor 6 in the residential distribution network for PV installed to the grid. Figure 11 and 12 show harmonic current spectrum of conductor 6 for PV1 + PV 2 + PV 3 connected to grid on industrial costumer network before and after installed single tuned passive filter.

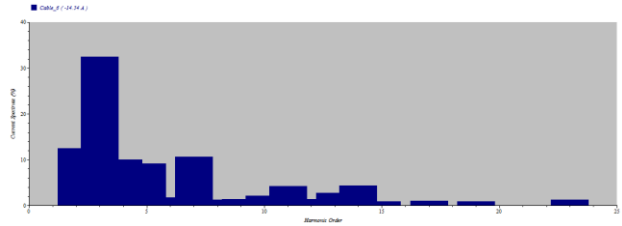


Figure 11. Harmonic current spectrum of conductor 6 for PV1 + PV 2 + PV 3 connected to grid on industrial costumer network without filter

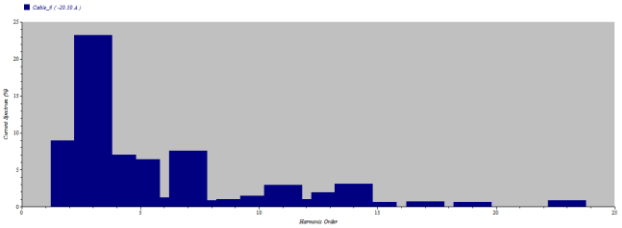


Figure 12. Harmonic current spectrum of conductor 6 for PV1 + PV 2 + PV 3 connected to grid on industrial costumer network with filter

Table VII also shows that the addition of PV generator in two models distribution network produce conductor current TDD value is increasing. The most value of conductor current TDD average generated by conductor that is connected directly to the PV generator bus.

V. CONCLUSION

The simulation results show that the THD value on the bus voltage distribution network of industrial and residential customers are still under voltage THD limit recommended by the IEEE 519-1992 by 5%. The majority of the value of TDD conductor in two models of the distribution network is under the limit conductor current TDD recommeded by IEEE 519-1992. In industrial and residential customer networks, the more the

number of PV generator installed, then the value of current TDD at PCC bus will be even greater. This is because in addition to functioning PV plants supplying power to the distribution network, is also generates harmonics due to the presence of the inverter as a medium to transform DC into AC voltage. Using of single tuned passive filter 3rd order give better solution to improve current TDD. The value of power factor in the distribution network of industrial and residential customers on average already meet minimum requirements set PLN limits by 85%.

VI. ACKNOWLEDGMENT

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APPENDIXS:

TABLE I. IEEE 519-1992 HARMONIC VOLTAGE LIMIT

Bus Voltage on PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3,0	5,0
69,001 kV through 161 kV	1,5	2,5
161,001 kV and above	1,0	1,5

Tabel II. IEEE 519-1992 HARMONIC CURRENT LIMIT

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4	2	1,5	0,6	0,3	5
20 s/d 50	7	3,5	2,5	1	0,5	8
50 s/d 100	10	4,5	4	1,5	0,7	12
100 s/d 1000	12	5,5	5	2	1	15
>1000	15	7	6	2,5	1,4	20

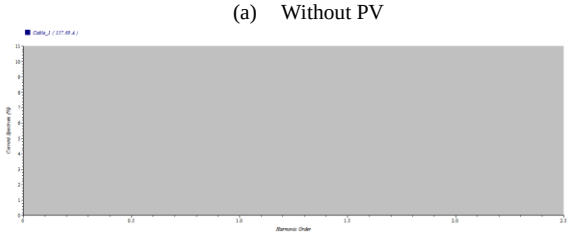
TABLE III. DISTRIBUTION NETWORK DATA OF INDUSTRIAL AND RESIDENTIAL COSTUMERS

Network models	Generator and Transformers	Conductors	Loads
Industrial costumer	External grid 9000 MVAsc (Swing) Transformer 1000 kVA, 11/0.4 kV, Δ/Y PV 1 (Bus 2) 150 kW (Mvar Control) PV 2 (Bus 5) 150 kW (Mvar Control) PV 3 (Bus 6) 150 kW (Mvar Control) Frekuensi 50 Hz	Bus 1-8, Al 3/C 120 mm^2 Bus 8-2, CU 3/C 35 mm^2 Bus 8-3, CU 3/C 35 mm^2 Bus 8-4, CU 3/C 35 mm^2 Bus 8-5, CU 3/C 35 mm^2 Bus 8-6, CU 3/C 35 mm^2	Bus 2, 25 kW cos φ = 0.980 Bus 3, 35 kW cos φ = 0.970 Bus 4, 35 kW cos φ = 1.000
Residential costumer	External grid 9000 MVAsc (Swing) Transformer 400 kVA, 11/0.4 kV, Δ/Y PV (Bus 6) 150 kW (Mvar Control) Frequency 60 Hz	Bus 1-9, Al 3/C 120 mm^2 Bus 9-2, CU 3/C 35 mm^2 Bus 9-3, CU 3/C 35 mm^2 Bus 9-4, CU 3/C 35 mm^2 Bus 9-5, CU 3/C 35 mm^2 Bus 9-6, CU 3/C 35 mm^2 Bus 9-7, CU 3/C 35 mm^2 Bus 9-8, CU 3/C 35 mm^2	Bus 2, 23 kW cos φ = 0.960 Bus 3, 10 kW cos φ = 0.780 Bus 4, 27 kW cos φ = 0.910 Bus 5, 25 kW cos φ = 0.975 Bus 7, 20 kW cos φ = 0.945 Bus 8, 35 kW cos φ = 0.970

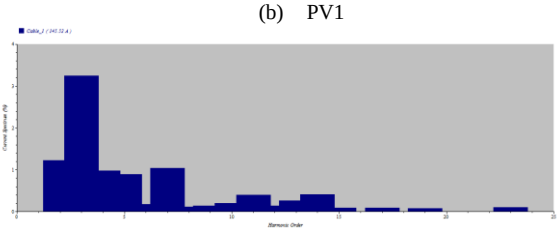
TABLE VII. COMPARATION OF CURRENT QUALITY ON A NUMBER PV INSTALLATION STRATEGY

Network Models	Strategies	Conductors	PF (%)	Isc (A)	IL (A)	Isc/IL	TDD (%)	TDD Std (%)
Industrial Costumer	Without PV	1	99.2	13900	157.7	88.1420	0.000	12
		2	98.1	8100	36.30	223.141	0.000	15
		3	97.1	6700	51.20	130.860	0.000	15
		4	100.0	7300	71.10	102.673	0.000	15
		5	0.0	8960	0.000	N/A	0.000	20
		6	0.0	9040	0.000	N/A	0.000	20
	PV1	1	99.6	13860	145.5	95.2580	3.920	12
		2	100.0	8083	24.00	336.792	23.87	15
		3	97.2	6900	51.30	134.503	0.090	15
		4	100.0	7600	71.10	106.892	0.000	15
		5	0.0	9390	0.000	N/A	0.000	20
		6	0.0	9480	0.000	N/A	0.000	20
	PV1 + PV2	1	99.7	13860	143.3	96.7200	7.970	12
		2	100	8441	24.00	351.709	23.83	15
		3	97.2	7150	51.30	100.422	0.180	15
		4	100	7890	71.20	110.815	0.180	15
		5	85.7	9390	6.300	1490.48	224.5	20
		6	0.0	9930	0.000	N/A	0.000	20
	PV 1 + PV2 + PV3	1	100.0	13860	130.7	106.045	13.10	15
		2	100.0	8800	24.10	365.146	23.74	15
		3	97.2	7400	51.40	143.968	0.260	15
		4	100.0	8190	71.20	115.029	0.270	15
		5	85.8	9840	6.300	1561.91	224.9	20
		6	85.1	9930	15.60	636.539	39.54	20
Residential costumer	Without PV	1	93.6	13860	165.0	84.0000	0.000	12
		2	96.1	7300	34.00	214.710	0.000	15
		3	77.3	6430	18.40	349.460	0.000	15
		4	91.0	7450	41.60	179.090	0.000	15
		5	97.5	6810	17.50	389.143	0.000	15
		6	0.0	9040	0.000	N/A	0.000	20
		7	94.5	7210	30.00	240.334	0.000	20
		8	97.0	6230	24.90	250.201	0.000	20
	PV	1	94.3	13860	150.9	91.8900	3.780	12
		2	96.1	7590	34.10	222.581	0.090	15
		3	77.3	6600	18.50	356.757	0.070	15
		4	91.3	7750	41.60	186.298	0.080	15
		5	97.5	7070	17.50	404.000	0.090	15
		6	85.0	9040	14.60	619.178	39.44	15
		7	94.5	7500	30.00	250.000	0.130	15
		8	97.0	6450	24.90	259.036	0.130	15

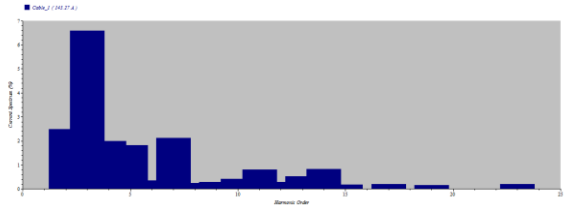
(a) Without PV



(b) PV1



(c) PV1 + PV2



(d) PV1 + PV2 + PV3

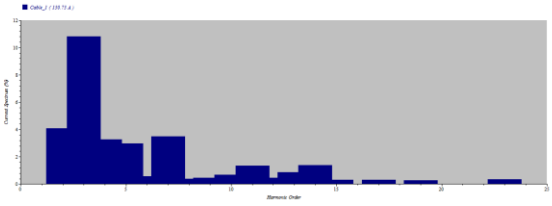


Figure 9. Harmonic current spectrum in the number of PV installation strategies on industrial costumer network at PCC

(a) Without PV (b) PV

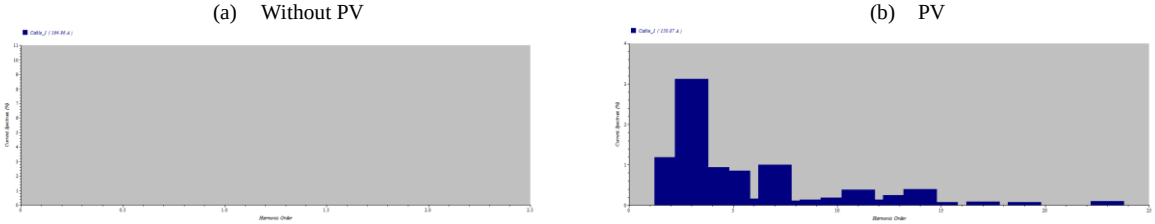


Figure 10. Harmonic current spectrum in the number of PV installation strategies on residential costumer network at PCC

TABLE VIII. DESIGN SINGLE TUNED PASSIVE FILTERS AND TOTAL DEMAND DISTORTION

Strategies	Conductors	Tuned Filter	C (µF)	L (mH)	R (Ω)	TDD	
						Without Filter	With Filter
Industrial Costomer							
PV 1 + PV2	5	3rd	17.4690	44.7459	0.5062	224.50	154.65
		5th	17.4690	16.1113	0.3037	224.50	157.08
		7th	17.4690	8.22000	0.2167	224.50	156.65
		11th	17.4690	3.3288	0.1381	224.50	160.06
		14th	17.4690	2.0055	0.1059	224.50	163.06
PV 1 + PV2 + PV3	5	3rd	17.4690	44.746	0.5062	224.90	154.68
		5th	17.4690	16.111	0.3037	224.90	156.97
		7th	17.4690	8.2200	0.2167	224.90	156.47
		11th	17.4690	3.3288	0.1381	224.90	159.91
		14th	17.4690	5.0055	0.1059	224.90	161.10
	6	3rd	87.3713	8.9480	0.1012	39.540	28.260
		5th	87.3713	3.2213	0.0608	39.540	28.540
		7th	87.3713	1.6435	0.0434	39.540	28.880
		11th	87.3713	0.6656	0.0276	39.540	29.490
		14th	87.3713	0.4109	0.0217	39.540	30.190
Residential Costumer							
PV	6	3rd	87.3713	8.9480	0.1012	39.440	28.270
		5th	87.3713	3.2213	0.0608	39.440	28.480
		7th	87.3713	1.6435	0.0434	39.440	28.280
		11th	87.3713	0.6656	0.0276	39.440	29.160
		14th	87.3713	0.4109	0.0217	39.440	29.280

Lampiran 2.3

Sampul proseding

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Lampiran 2.4

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Lampiran 2.5

Daftar isi proseding

Table of Contents

Title Page

Copyright

Greetings From The General Chair

Foreword from Head of Department of Electrical Engineering

2015 ISITIA Committee

Program Session

Table of Contents

Invited Speaker

Invited Speaker #1
Rescue system with sensor network forvital sign monitoring.
Tutorial: OpenCV - How it works for detecting forest pigs –
Kohei Arai

Invited Speaker #2
Towards Integration of Electronic Health in Dermatology and in Drug Delivery Systems
Soegijardjo Soegijoko

Invited Speaker #3
Ultrasound imaging for the unusual structure: see the unseed
I Ketut Eddy Purnama

Artificial Intelligent

PAPER ID: 421
A vibratory-based method for road damage classification 1
Fergyanto E. Gunawan, Yanfi, Benfano Soewito

PAPER ID: 435
Prediction of Significant Wave Height in The Java Sea Using Artificial Neural Network 5
Illa Rizianiza, Aulia Siti Aisjah

PAPER ID: 528
Traffic Light Signal Parameters Optimization Using Particle Swarm Optimization 11
I Gede Pasek Suta Wijaya, Keiichi Uchimura, Gou Koutaki

PAPER ID: 569
Multi Behavior NPC Coordination Using Fuzzy Coordinator And Gaussian Distribution 17
Muhammad Aminul Akbar, Wida Praponco, Mochamad Hariadi, Supeno Mardi S.N

PAPER ID: 586
Technical Data Analysis for Movement Prediction of Euro to USD Using Genetic Algorithm-Neural Network 23
Ary Sespajayadi, Indrabayu, Ingrid Nurtanio

PAPER ID: 592
An Automatic Text Summarization using Text Features and Singular Value Decomposition for Popular Articles in Indonesia Language 27
Fergyanto E. Gunawan, Adrian Victor Juandi, Benfano Soewito

PAPER ID: 631
The Perfomance of GM (1,1) and ARIMA for Forecasting of Foreign Tourists Visits to Indonesia 33
Anung Kharista, Adhistya Erna Permanasari, Indriana Hidayah

PAPER ID: 634
Performance Analysis of NaÃ¯ve Bayes, PART and SMO for Classification of Page Interest in Web Usage Mining 39
Saucha Diwandari,Adhistya Erna Permanasari,Indriana Hidayah

Control System and Robotics

PAPER ID: 422
Design And Implementation Of A Submerged Capacitive Sensor In PID Controller To Regulate The Concentration Of Non-Denaturated Ethyl Alcohol 45
Muhammad Rivai, Peter Chondro, Masaji Suwito, Shanq-Jang Ruan

PAPER ID: 480
Inverse Kinematic Implementation of Four-Wheels Mecanum Drive Mobile Robot Using Stepper Motors 51
Eka Maulana, M. Aziz Muslim, Veri Hendrayawan

PAPER ID: 511
Design of Decoupling and Nonlinear PD Controller for Cruise Control of a Quadrotor 57
Hanum Arrosida, Rusdhianto Effendy, Trihastuti Agustinah, Josaphat Pramudijanto

PAPER ID: 516
INI Framework : Indonesian Language Interpreter Software for Controlling Nao Robot Movement 63
Muhtadin,Eka Prasetya Herwidodo,Ahmad Zaini,

PAPER ID: 605
Implementation of Fuzzy Logic Control in Robot Arm for Searching Location of Gas Leak 69
Muhammad Rivai, Rendyansyah, Djoko Purwanto

PAPER ID: 611
A Design of Radio-controlled Submarine Modification for River Water Quality Monitoring 75
Sritrusta Sukaridhoto,, Dadet Pramadihanto, Taufiqurrahman, Muhammad Alif, Andrie Yuwono, Nobuo Funabiki

PAPER ID: 623
2D Map Creator for Robot Navigation by Utilizing Kinect and Rotary Encoder 81
Ronny Mardiyanto,Janu Anggoro,Fajar Budiman

Electronics and Biomedical Engineering

PAPER ID: 389
Performing High Accuracy of The System for Cataract Detection Using Statistical Texture Analysis and K-Nearest Neighbor 85
Yunendah Nur Fuadah,Agung W Setiawan,Tati Latifah Erawati Rajab

PAPER ID: 409
A Comparison of Classification Methods on Diagnosis of Thyroid Diseases 89
I Md. Dendi Maysanjaya, Hanung Adi Nugroho, Noor Akhmad Setiawan

PAPER ID: 427
Wireless Body Area Network for Monitoring Body Temperature, Heart Beat and Oxygen in Blood 93
M. Udin Harun Al Rasyid, Bih-Hwang Lee, Amang Sudarsono

PAPER ID: 446
Hardware Implementation of Montgomery Modular Multiplication Algorithm Using Iterative Architecture 97
Antonius P. Renardy, Nur Ahmadi, Ashbir A. Fadila, Naufal Shidqi, Trio Adiono

PAPER ID: 450
Skeletonization Using Thinning Method for Human Motion System 101
Wahyu Andhyka Kusuma, Lailatul Husniah

PAPER ID: 451
The Effect of Photoelectrode TiO2 Layer Thickness to The Output Power of Chlorophyll-Based Dye-Sensitized Solar Cell (DSSC) 105
Sholeh Hadi Pramono, Eka Maulana, M.A.R. Sembiring

PAPER ID: 514
FPGA Implementation of Modified Serial Montgomery Modular Multiplication for 2048-bit RSA Cryptosystems 111
Bagus Hanindhito, Nur Ahmadi, Hafez Hogantara, Annisa I. Arrahmah, Trio Adiono

PAPER ID: 533
TGS2611 Performance as Biogas Monitoring Instrument in Digester Model Application 117
Helmy Rahadian, Bambang Sutopo, Indah Soesanti

PAPER ID: 563
A Signal Processing Framework for Multimodal Cardiac Analysis 123
*Nada Fitrieyatul Hikmah, Achmad Arifin, Tri Arief Sardjono, * Eko Agus Suprayitno*

PAPER ID: 591
Design of Wearable System for Closed-Loop Control of Gait Restoration System by Functional Electrical Stimulation 129
Fauzan Arrofiqi,Achmad Arifin,Benicditus Indrajaya

PAPER ID: 603
Automatic Segmentation of Malaria Parasites on Thick Blood Film using Blob Analysis 135
Dwi Harini Sulistyawati , Farah Zakiyah Rahmanti , I Ketut Eddy Purnama , Mauridhi Hery Purnomo

Power System

PAPER ID: 445
Conditions of PV-Diesel Hybrid Systems In Tagalaya Village, Tagalaya Island, North Halmahera, North Maluku 141
Leony Ariesta Wenno, F. Danang Wijaya

PAPER ID: 462
Optimal Placement And Tuning Power System Stabilizer Using Participation Factor And Imperialist Competitive Algorithm In 150 Kv South Of Sulawesi System 145
Muhammad Ruswandi Djalal, Andi Imran, Imam Robandi

PAPER ID: 465
Multi Objective Optimal Power Flow To Minimize Losses and Carbon Emission Using Wolf Algorithm 151
Yun Tonce Kusuma Priyanto, Lukman Hendarwin

PAPER ID: 466
Optimal Controller for Doubly Fed Induction Generator (DFIG) Using Differential Evolutionary Algorithm (DE) 157
H. Suryoatmojo, A. M. B. Zakariya,A. Musthofa, I. Robandi, S. Anam

PAPER ID: 472
Accelerated Ageing experiment for Induction motor Insulation Due to Humidity Effect 163
Dapis, Muhammad Wahyudi, Dimas Anton Asfani, Daniar Fahmi, I Made Yulistya Negara

PAPER ID: 475
Digital Overcurrent Relay with Conventional Curve Modeling Using Levenberg-Marquardt Backpropagation 169
Anang Tjahjono,Dimas Okky Anggriawan,Ardyono Priyadi,Margo Pujiantara,Mauridhi Hery Purnomo

PAPER ID: 501
Control Design of Photovoltaic BPSX-60 Using Fuzzy Logic Controller for Low Voltage Grid 175
Soedibyo, Feby Agung Pamuji, M.Ashari

PAPER ID: 509
Combining Simplified Firefly and Modified P&O Algorithm for Maximum Power Point Tracking of Photovoltaic System Under Partial Shaded Condition 179
Ardyono Priyadi, Yanuar Mahfudz Safarudin, Mauridhi Hery Purnomo, Margo Pujiantara

PAPER ID: 583
Dynamic Optimal Power Flow with Geothermal Power Plant under Take or Pay Energy Contract 185
Rony Seto Wibowo, Nani\' Lathifatun Nada, Sjamsjul Anam, Adi Soeprijanto, Ontoseno Penangsang

PAPER ID: 589
Effect of Installation of Photovoltaic (PV) Generation to Power Quality in Industrial and Residential Customers Distribution Network 191
Amirullah, Ontoseno Penangsang, Adi Soeprijanto

PAPER ID: 609
Design of Bidirectional Converter Using Fuzzy Logic Controller to Optimize Battery Performance in Electric Vehicle 199
Kharisma Bani Adam, Mochamad Ashari

PAPER ID: 639
Modeling and Simulation of MPPT-Bidirectional Using Adaptive Neuro Fuzzy Inference System (ANFIS) in Distributed Energy Generation System 205
Farid Dwi Murdianto, Ontoseno Penangsang, Ardyono Priyadi

Signal and Image Processing

PAPER ID: 403
A New Quantitative Evaluation Metric for Color Correction Algorithm 211
Mohd-Jain-Noordin Mohd Naim, Nor Ashidi Mat Isa, Wei Hong Lim

PAPER ID: 404
SADE: Android Spectral Reflectance Estimator Application Using Wiener Estimation to Estimate Sambiloto Leafâ€™s Age 217
Muhammad Rake Linggar Anggoro, Yeni Herdiyeni

PAPER ID: 426
A Chaos-based Fragile Watermarking Method in Spatial Domain for Image Authentication 225
Rinaldi Munir

PAPER ID: 443
3D Coordinate Extraction from Single 2D Indoor Image 231
Maulana Aziz Assuja, Iping Supriana Suwardi

PAPER ID: 471
Digital Camera Interface Mapping With Speech And Hand Gestures For Differently Abled 237
Arun Kumar, Anurag Pandey

PAPER ID: 473
Gaussian Mixture Models Optimization For Counting The Numbers Of Vehicle By Adjusting The Region Of Interest Under Heavy Traffic Condition 243
Basri, Indrabayu, Andani Achmad

PAPER ID: 479
Multimedia Adventure Game Folklore "Doyan Nada" For Improving The Cultural Understanding of Sasak (Lombok) to Children 249
Yana Hendriana, Renna Yanwastika Ariyana

PAPER ID: 488
Remodeling of Human Foot Using Chain Code For Designing Special Shoes 255
Cahyo Dwi Raharjo, Izzati Muhimmah

PAPER ID: 517
Six Key Points Lip's Feature Extraction Using Adaptive Threshold Segmentation 259
Hadid Tunas Bangsawan, Ronny Mardiyanto, Tri Arief Sardjono

PAPER ID: 600
Scattering on Mini Underwater Acoustic Tank 265
Rindy Trisna Wulandari, Dhany Arifianto

PAPER ID: 633
Synthesis of Virtual Character Poses Using Lagrange Polynomial Interpolation 271
Irwan Karim\', Surya Sumpeno, Mauridhi Hery Purnomo

PAPER ID: 636
Music Transcription of Javanese Gamelan Using Short Time Fourier Transform (STFT) 277
Liza Fitria, Yoyon Kusnendar Suprapto, Mauridhi Hery Purnomo

PAPER ID: 640
Separation of Gamelan Instruments Signal Using ICA Based on Projection Pursuit 283
Atik Wintarti, Yoyon K. Suprapto

Information System and Computer Science

PAPER ID: 383
Formal Verification of Integrated Modular Avionics (IMA) Health Monitoring using Timed Automata 289
Ida Bagus Budiyanto, Achmad Imam Kistijantoro, Bambang Riyanto Trilaksono

PAPER ID: 392
Design of Agent Framework Using Aspect Oriented Approach 295
Maman Somantri, Lukito Edi Nugroho, Widyawan, Ahmad Ashari

PAPER ID: 401
Data Transmission Strategy of Probe Vehicle in Floating Car Traffic Monitoring 301
Fergyanto E. Gunawan, Fajar Yoseph Chandra, Benfano Soewito

PAPER ID: 424
Workflow Common Fragments Extraction Based on WSDL Similarity and Graph Dependency 307
Riyanarto Sarno,Endang,Dwi Sunaryono,Sarwosri

PAPER ID: 425
Business Process Composition Based on Meta Models 313
Riyanarto Sarno,Endang,Dwi Sunaryono,Sarwosri

PAPER ID: 428
Application Search School Location Method Using Location Based Services (LBS) based on J2ME 317
Wasum, Andreas Setiyono, Raimundus Sedo, Sholeh Hadi Pramono

PAPER ID: 454
EVALUATION MATURITY INDEX AND RISK MANAGEMENT FOR IT GOVERNANCE USING FUZZY AHP AND FUZZY TOPSIS (CASE STUDY BANK XYZ) 321
Uky Yudatama, Riyanarto Sarno

PAPER ID: 457
Handling Of Internal Inconsistency OLAP - Based Lock Table Using Message Oriented Middleware In Near Real Time Data Warehousing 327
Ardianto Wibowo, Saiful Akbar

PAPER ID: 474
Development of Algorithmic-Based Estimation for Cost Estimation of In-House Software in Government Agencies. Case Study: Badan Pusat Statistik 333
Joko Widiarto, Arry Akhmad Arman

PAPER ID: 491
Evaluation of Edutainment e-Marketing Model Implemetation at Bank Mandiri Museum 339
Arta Moro Sundjaja, Evi Ekawati

PAPER ID: 500
Problems and Available Solutions On The Stage of Extract, Transform, and Loading In Near Real-Time Data Warehousing (A Literature Study) 343
Ardianto Wibowo

PAPER ID: 614
NAIVE RANDOM NEIGHBOR SELECTION FOR MEMORY BASED COLLBORATIVE FILTERING 349
Agung Toto Wibowo, Aulia Rahmawati

PAPER ID: 619
Implementation of Modified Probabilistic Caching Schema On Bittorrent Protocol for Video on Demand Content 355
Mahar Faiqurahman, Achmad Imam Kistijantoro

PAPER ID: 626
Usability Characteristic Evaluation On Administration Module of Academic Information System Using ISO/IEC 9126 Quality Model 361
Siti Rochimah, Hanifa I Rahmani, Umi Laili Yuhana

PAPER ID: 635
Genetic Algorithm in Solving the TSP on These Mineral Water Distribution 367
Richki Hardi

PAPER ID: 637
Noun Ontology Generation From Wikipedia Article Using Map Reduce with Pattern Based Approach 371
Joan Santoso,James Nakoda Nugraha,Eko Mulyanto Yuniarno,Mochamad Hariadi

Telecommunication System and Networking

PAPER ID: 386
Energy Efficiency in Cognitive Radio with Cooperative MME (Maximum to Minimum Eigenvalue) Spectrum Sensing Method 377
Syarifah Muthia Putri, Sugihortono

PAPER ID: 434
Design And Implementation Fast Response System Monitoring Server Using Simple Network Management Protocol (SNMP) 383
Achmad Affandi, Dhany Riyanto, Istas Pratomo, Gatot Kusrahardjo

PAPER ID: 436
Openvoice : Low-Cost Mobile Wireless Communication Project For Rural Area Based On OpenWRT 389
Asriadi, Istas Pratomo, Achmad Affandi, Djoko Suprajitno Rahardjo

PAPER ID: 453
Prototype Development of Monitoring System in Patient Infusion with Wireless Sensor Network 395
Fathur Zaini Rachman

PAPER ID: 503
Balanced-Delay Filterbank for Closed-Loop Spatial Audio Coding 401
Ikhwana Elfitri, Heru Dibyo Laksono, Al Kautsar Permana

PAPER ID: 529
16-Port Array Antenna Feeding Network with Programmable Phase Shifter Capability 407
Jane Litouw, Achmad Munir

PAPER ID: 556
Design of Microstrip Patch Antenna Based on Complementary Split Ring Resonator Metamaterial for WiMAX Applications 411
Nurul Khaerani Hamzidah, Eko Setijadi

PAPER ID: 557
Design and Simulation Wimax Networks 802.16d and 802.16e In Sleman 417
Firdaus, Isra Darmawan, Hendra Setiawan, Ferdyan Pradana

PAPER ID: 562
Pathloss and Shadowing Characteristics in Indoor Environment at 2.4 Ghz Band 421
Puji Handayani, Lina Mubarokah, Gamantyo Hendrantoro

PAPER ID: 566
Early Results from Adaptive Combination of LRU, LFU and FIFO to Improve Cache Server Performance in Telecommunication Network 427
Tanwir, Gamantyo Hendrantoro, Achmad Affandi

PAPER ID: 585
Scattering Parameters Extraction of Dielectric Loaded Circular Waveguide Using Cylindrical Coordinate System-based FDTD Method 431
Ershad Junus Amin, Achmad Munir

PAPER ID: 587
Performance Analysis of Cooperative Spectrum Sensing with Asymmetric Channel 435
Abdul Haris Junus Ontowirjo,Wirawan,Adi Soeprijanto

PAPER ID: 607
Printed Traveling Wave Antenna\Composed of Interdigital Capacitor Structure for Wireless Communication Application 439
Achmad Munir, Eka Kurnia Sari

PAPER ID: 617
Comparative Analysis of Routing Protocol on Wireless Sensor Network (WSN) with Gradient Based Approach and Geographic Based Approach Method 443
Miftahul Khairat Sukma, Indarini Dyah Irawati, Hafidudin

PAPER ID: 625
Implementation and Performance Evaluation of Orthogonal Frequency Division Multiplexing (OFDM) using WARP 449
Titiek Suryani, Suwadi, Hasan, Septriandi Wira Yoga

Lampiran 2.6

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