YAYASAN BRATA BHAKTI JAWA-TIMUR
UNIVERSITAS BHAYANGKARA SURABAYA
LEMBAGA PENELITIAN DAN PENGABDIAN KEPADA MASYARAKAT
(LPPM)
Jalan Ahmad Yani 114 Surabaya, Telp. 031-8285602, 8291055, Fax. 031-8285601

SURAT KETERANGAN

Nomor : Sket/69/II/2023/LPPM/UBHARA

Yang bertanda tangan dibawah ini :

Nama	:	Drs. Heru Irianto, M.Si
NIP	:	9000028
NIDN	:	0714056102
Jabatan	:	Kepala Lembaga Penelitian dan Pengabdian Kepada Masyarakat (LPPM) Universitas bhayangkara Surabaya

Dengan ini menerangkan bahwa dosen prodi Teknik elektro Universitas Bhayangkara Surabaya atas nama **Dr. Ir. Saidah, MT** benar telah melakukan kegiatan :

1. **Penelitian Kerjasama Luar Negeri (PKLN)** pada Penelitian Kompetitif Nasional berjudul **Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique** (Tahun Pertama) dengan nilai hibah sebesar **Rp. 90.500.000 (Sembilan Puluh Juta Lima Ratus Ribu Rupiah)** dari Direktorat Riset dan Pengabdian kepada Masyarakat (DRPM)-Kementrian Riset, Teknologi, dan Pendidikan Tinggi **Tahun Pendanaan 2018**.
2. Terlampir dalam surat keterangan berkas pendukung antara-lain: dokumen kontrak, laporan akhir 100% penelitian dan undangan monev external.

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

Surabaya, 31 Januari 2023
Kepala LPPM

UNIVERSITAS ★ BHAYANGKARA SURABAYA LPPM

Drs. Heru Irianto, M.Si.

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

KONTRAK PENELITIAN TAHUN TUNGGAL

Antara
Lembaga Penelitian dan Pengabdian Pada Masyarakat (LPPM)
Universitas Bhayangkara Surabaya
Dengan
Dr. Saidah, M.T..

TAHUN ANGGARAN 2018
Nomor : /LPPM/IV/2018/UB

Pada hari ini Selasa tanggal dua pulu empat bulan Maret tahun dua ribu dua puluh, kami yang bertandatangan dibawah ini :

1. **Drs.Heru Irianto, M.Si.** : Kepala Lembaga Penelitian dan Pengabdian Pada Masyarakat Universitas Bhayangkara Surabaya yang berkedudukan di Jl A.Yani 114, dalam hal ini bertindak untuk dan atas nama Lembaga Penelitian dan Pengabdian Pada Masyarakat Universitas Bhayangkara Surabaya **Nomor : /LPPM/IV/2018/UB** tanggal 24 Maret 2020, untuk selanjutnya disebut **PIHAK PERTAMA**;

2. **Dr. Saidah, M.T.** : Dosen Universitas Bhayangkara Surabaya yang berkedudukan di Jl. A.Yani 114 Surabaya, dalam hal ini bertindak untuk dan atas nama peneliti di Universitas Bhayangkara Surabaya untuk selanjutnya disebut **PIHAK KEDUA**.

PIHAK PERTAMA dan **PIHAK KEDUA** secara bersama-sama bersepakat mengikatkan diri dalam suatu Perjanjian Pelaksanaan Kegiatan Penelitian Tahun Tunggal dengan ketentuan dan syarat sebagai berikut:

PASAL 1
DASAR HUKUM

Kontrak Penelitian ini berdasarkan kepada:

1. Undang-Undang Republik Indonesia Nomor 17 Tahun 2003 tentang Keuangan Negara;
2. Undang-Undang Republik Indonesia Nomor 20 Tahun 2003 tentang Sistem Pendidikan Nasional;
3. Undang-Undang Republik Indonesia Nomor 01 Tahun 2004 tentang Perbendaharaan Negara;
4. Undang-Undang Republik Indonesia Nomor 15 Tahun 2004 tentang Pemeriksaan Pengelolaan dan Tanggung Jawab Keuangan Negara;
5. Undang-Undang Republik Indonesia Nomor 12 Tahun 2012 tentang Pendidikan Tinggi;
6. Peraturan Pemerintah Nomor 26 Tahun 2015 tentang Bentuk dan Mekanisme Perguruan Tinggi Negeri Badan Hukum:
7. Peraturan Presiden Nomor 13 Tahun 2015 tentang Kementerian Riset, Teknologi, dan Pendidikan Tinggi;
8. Peraturan Presiden Nomor 16 tahun 2018 tentang Pengadaan Barang dan Jasa Pemerintah;
9. Peraturan Menteri Keuangan Nomor 139/PMK.02/2015 tentang Tata Cara Penyediaan, Pencairan, dan Pertanggungjawaban Pemberian Bantuan Pendanaan Perguruan Tinggi Negeri Badan Hukum;

10. Peraturan Menteri Keuangan Nomor 32/PMK.02/2018 tentang Standar Biaya Masukan Tahun 2019;
11. Peraturan Menteri Keuangan Nomor 60/PMK.02/2018 tentang Persetujuan Kontrak Tahun Jamak oleh Menteri Keuangan;
12. Peraturan Menteri Keuangan Nomor 69/PMK.02/2018 tentang Standar Biaya Keluaran Tahun 2019;
13. Peraturan Menteri Riset,Tekologi dan Pendidikan tinggi Republik Indonesia Nomor 15 Tahun 2015, tentang Organisasi dan Tata Cara Kerja Kemenenterian Riset,Tekologi dan Pendidikan tinggi;
14. Peraturan Menteri Riset,Tekologi dan Pendidikan tinggi Republik Indonesia Nomor 695 Tahun 2016, tentang Organisasi dan Tata Cara Pembentukan Komite Penilaian dan/atau Reviewer Penelitian;
15. Peraturan Menteri Riset,Tekologi dan Pendidikan tinggi Republik Indonesia Nomor 6 Tahun 2018, tentang Bantuan Organisasi Perguruan tinggi Negeri;
16. Peraturan Menteri Riset,Tekologi dan Pendidikan tinggi Republik Indonesia Nomor 20 Tahun 2018, tentang Penelitian;
17. Peraturan Menteri Riset,Tekologi dan Pendidikan tinggi Republik Indonesia Nomor 15/PB/2017 tentang Petunjuk Pelaksanaan Pembayaran Anggaran Penelitian Berbasis Standar Biaya Keluaran Sub Keluaran Penelitian;
18. Peraturan Menteri Riset,Tekologi dan Pendidikan tinggi Republik Indonesia Nomor 209/M/KPT/2018 tentang Panduan Pelaksanaan Penelitian dan Pengabdian Masyarakat Edisi XII;
19. Keputusan Direktur Jenderal Penguatan Riset dan Pendidikan Tinggi Nomor 7/E/KPT/2018 18 Februari 2018 tentang Penerimaan Pendanaan Penelitian dan Pengabdian Masyarakat di Perguruan Tinggi Negeri Badan Hukum Tahun Anggaran 2018;
20. Kontrak Penelitian Tahun Anggaran 2018 antara Direktorat Riset dan Pengabdian Masyarakat dengan Lembaga Layanan Pendidikan Tinggi Wilayah VII Nomor;

PASAL 2
RUANG LINGKUP

(1) Ruang lingkup **Kontrak Penelitian** ini meliputi Pelaksanaan Penelitian sebanyak **satu** judul penelitian dibebankan pada DIPA (Daftar Isian Pelaksanaan Anggaran) Debuti Bidang Penguatan Riset dan Pengembangan Kementerian Riset, Teknologi/ Badan Riset dan Inovasi Nasional;

(2) Daftar nama Ketua Pelaksana, judul penelitian, luaran tambahan, jangka waktu penelitian, dan besarnya biaya setiap tahun masing-masing judul penelitian tercantum dalam Lampiran yang merupakan bagian yang tidak terpisahkan dari **Kontrak Penelitian** ini.

PASAL 3
JANGKA WAKTU

(1) **Kontrak Penelitian** ini dilaksanakan dalam jangka waktu 1 (satu) tahun.

(2) **Kontrak Penelitian** sebagaimana dimaksud pada ayat (1) dilaksanakan untuk penelitian sebagaimana tercantum dalam Lampiran yang merupakan bagian yang tidak terpisahkan dari **Kontrak Penelitian** ini.

PASAL 4
HAK DAN KEWAJIBAN

(1) **PIHAK PERTAMA** mempunyai kewajiban:
a. memberikan pendanaan penelitian kepada PIHAK KEDUA dan;
b. melakukan pemantauan dan evaluasi.
c. Melaksanakan penilaian luaran penelitian; dan
d. Melakukan validasi luaran tambahan.

(2) **PIHAK KEDUA** mempunyai kewajiban:

a. membuat sub Kontrak Penelitian antara Pimpinan Perguruan Tinggi dengan Ketua Pelaksana Penelitian di Perguruan Tingginya untuk pengaturan hak dan kewajiban setiap pelaksana yang memuat antara lain:
   1. nama pelaksana;
   2. judul penelitian;
   3. jumlah dana penelitian;
   4. tata cara dan termin pembayaran;
   5. waktu pelaksanaan;
   6. batas akhir pelaporan;
   7. pencantuman pemberi dana penelitian dalam publikasi ilmiah;
   8. luaran penelitian; dan
   9. sanksi.

b. mengkoordinir dan bertanggung jawab atas terlaksananya Kontrak Penelitian yang dilakukan oleh para peneliti di Perguruan Tinggi di Lingkungan LLDIKTI Wilayah VII.

c. memantau pengunggahan ke laman **SIMLITABMAS** dokumen sebagai berikut:
   1. revisi proposal penelitian
   2. catatan harian pelaksanaan penelitian
   3. laporan kemajuan pelaksanaan penelitian
   4. Surat Pernyataan Tanggungjawab Belanja (SPTB) atas dana penelitian yang telah ditetapkan
   5. laporan akhir penelitian
   6. luaran penelitian

   paling lambat tanggal 16 November 2018 iap tahun Anggaran berjalan.

(3) **PIHAK PERTAMA** mempunyai hak menerima dokumen hasil unggahan di laman SIMLITABMAS sebagai berikut:
   1. revisi proposal penelitian
   2. catatan harian pelaksanaan penelitian
   3. laporan kemajuan pelaksanaan penelitian
   4. Surat Pernyataan Tanggungjawab Belanja (SPTB) atas dana penelitian yang telah ditetapkan
   5. laporan akhir penelitian
   6. luaran penelitian

(4) **PIHAK KEDUA** mempunyai hak mendapatkan dana penelitian dari **PIHAK PERTAMA.**

PASAL 5
CARA PEMBAYARAN

(1) **PIHAK PERTAMA** memberikan pendanaan penelitian Rp. **90.500.000 ,-** (sembilan belas juta sembilan ratus tiga belas ribu rupiah) yang dibebankan kepada DIPA Direktorat Jenderal Penguatan Riset dan Pengembangan Kementerian Riset, Teknologi, dan Pendidikan Tinggi.

(2) Pendanaan penelitian sebagaimana dimaksud pada ayat (1) dibayarkan oleh **PIHAK PERTAMA** kepada **PIHAK KEDUA** secara bertahap:

a. Pembayaran Tahap Pertama sebesar Rp. ***Rp 63.350.000,- (enam puluh tiga juta tiga ratus lima puluh ribu rupiah)***

b. Pembayaran Tahap Kedua sebesar Rp. ***Rp 27.150.000,- (dua puluh tujuh juta seratus lima puluh ribu rupiah)*** dari Bendahara Pengaluaran LLDIKTI Wilayah VII kepada rekening Institusi melalui mekanisme transfer antar rekening.

(3) Pembayaran pada Skema Penelitian Dasar, Penelitian Dasar Unggulan Perguruan Tinggi, Penelitian Terapan, Penelitian Terapan Unggulan Perguruan Tinggi, Penelitian Pengembangan, Penelitian Pengembangan Perguruan Tinggi, Penelitian Kerjasama antar Perguruan Tinggi, dan Penelitian Pasca Sarjana – Pasca Doktor dibayarkan secara bertahap sebesar 70% dan 30%.

(4) Pembayaran pada Skema Penelitian Dosen Pemula, Penelitian Pasca Sarjana – Tesis Magister, dan Penelitian Pasca Sarjana – Disertasi Doktor dilaksanakan secara sekaligus (100%) diawal bersamaan dengan Pembayaran Tahap Pertama skema yang lainnya.

(5) Pendanaan penelitian sebagaimana dimaksud pada ayat (2) huruf a, diberikan dengan ketentuan apabila revisi proposal penelitian telah diunggah ke laman SIMLITABMAS.

(6) Pendanaan penelitian sebagaimana dimaksud pada ayat (2) huruf b, dengan ketentuan apabila **PIHAK PERTAMA** telah menerima dokumen sebagai berikut:
a. laporan kemajuan pelaksanaan penelitian
b. Surat Pernyataan Tanggungjawab Belanja (SPTB) atas dana penelitian yang telah ditetapkan

(7) Dana luaran tambahan sebagaimana dimaksud pada ayat (2) huruf c dibayarkan kepada **PIHAK KEDUA** bersamaan dengan pembayaran Tahap Kedua.

(8) Apabila luaran tambahan dinyatakan tidak valid oleh **PIHAK PERTAMA** sebagaimana dimaksud Pasal 4 ayat (1), maka dana luaran tambahan yang sudah diterima harus disetorkan kembali ke kas negara.

(9) Pendanaan **Kontrak Penelitian** sebagaimana dimaksud pada ayat (2) dibayarkan kepada Institusi sebagai berikut :

Nama Peneliti	**: Dr. Saidah. M.T.**
Nomor Rekening	**: 0177729292**
Nama penerima pada rekening	**: Dr. Saidah. M.T.**
Nama Bank	**: B N I**
Alamat Bank	**: Jl. A.Yani**
Kota	**: Surabaya**
NPWP Peneliti	

(10) **PIHAK PERTAMA** tidak bertanggungjawab atas keterlambatan dan/atau tidak terbayarnya sejumlah dana, yang disebabkan oleh kesalahan **PIHAK KEDUA** dalam menyampaikan informasi sebagaimana dimaksud pada ayat (7).

PASAL 6
PENGGANTIAN KEANGGOTAAN

(1) Perubahan terhadap susunan tim pelaksana dan substansi penelitian dapat dibenarkan apabila telah mendapat persetujuan dari Direktur Riset dan Pengabdian Masyarakat Direktorat Jenderal Penguatan Riset dan Pengembangan.

(2) Apabila Ketua tim pelaksana penelitian tidak dapat menyelesaikan penelitian atau mengundurkan diri, maka **PIHAK KEDUA** wajib menunjuk pengganti Ketua Tim Pelaksana penelitian yang merupakan salah satu anggota tim setelah mendapat persetujuan tertulis dari Direktur Riset dan Pengabdian Masyarakat Direktorat Jenderal Penguatan Riset dan Pengembangan.

(3) Dalam hal tidak adanya pengganti ketua tim pelaksana penelitian sesuai dengan syarat ketentuan yang ada, maka penelitian dibatalkan dan dana dikembalikan ke Kas Negara.

PASAL 7
PAJAK

PIHAK KEDUA berkewajiban memungut dan menyetor pajak ke kantor pelayanan pajak setempat yang berkenaan dengan kewajiban pajak berupa:

1. pembelian barang dan jasa dikenai PPN sebesar 10% dan PPh 22 sebesar 1,5%;
2. pajak–pajak lain sesuai ketentuan.

PASAL 8
KEKAYAAN INTELEKTUAL

(1) Hak Kekayaan Intelektual yang dihasilkan dari pelaksanaan penelitian diatur dan dikelola sesuai dengan peraturan dan perundang-undangan.
(2) Setiap publikasi, makalah, dan/atau ekspos dalam bentuk apapun yang berkaitan dengan hasil penelitian ini wajib mencantumkan **PIHAK PERTAMA** sebagai pemberi dana.

(3) Hasil penelitian berupa peralatan adalah milik negara dan dapat dihibahkan kepada institusi/lembaga melalui Berita Acara Serah Terima (BAST).

PASAL 9
KEADAAN KAHAR

(1) **PARA PIHAK** dibebaskan dari tanggung jawab atas keterlambatan atau kegagalan dalam memenuhi kewajiban yang dimaksud dalam **Kontrak Penelitian** disebabkan atau diakibatkan oleh peristiwa atau kejadian diluar kekuasaan **PARA PIHAK** yang dapat digolongkan sebagai keadaan memaksa (*force majeure*).

(2) Peristiwa atau kejadian yang dapat digolongkan keadaan memaksa (*force majeure*) dalam Kontrak Penelitian ini adalah bencana alam, wabah penyakit, kebakaran, perang, blokade, peledakan, sabotase, revolusi, pemberontakan, huru-hara, serta adanya tindakan pemerintah dalam bidang ekonomi dan moneter yang secara nyata berpengaruh terhadap pelaksanaan Kontrak Penelitian ini.

(3) Apabila terjadi keadaan memaksa (*force majeure*) maka pihak yang mengalami wajib memberitahukan kepada pihak lainnya secara tertulis, selambat-lambatnya dalam waktu 7 (tujuh) hari kerja sejak terjadinya keadaan memaksa (*force majeure*), disertai dengan bukti-bukti yang sah dari pihak yang berwajib, dan **PARA PIHAK** dengan itikad baik akan segera membicarakan penyelesaiannya.

PASAL 10
PENYELESAIAN PERSELISIHAN

(1) Apabila terjadi perselisihan antara **PIHAK PERTAMA** dan **PIHAK KEDUA** dalam pelaksanaan Kontrak Penelitian ini akan dilakukan penyelesaian secara musyawarah dan mufakat

(2) Dalam hal tidak tercapai penyelesaian secara musyawarah dan mufakat sebagaimana dimaksud pada ayat (1) maka penyelesaian dilakukan melalui proses hukum yang berlaku dengan memilih domisili hukum di Pengadilan Negeri Surabaya.

Pasal 11
AMANDEMEN KONTRAK

Apabila terdapat hal lain yang belum diatur atau terjadi perubahan dalam Kontrak Penelitian ini, maka akan dilakukan amandemen Kontrak Penelitian.

PASAL 12
SANKSI

(1) Apabila sampai dengan batas waktu yang telah ditetapkan untuk melaksanakan kegiatan Penelitian Multi Tahun telah berakhir, **PIHAK KEDUA** tidak melaksanakan kewajiban sebagaimana dimaksud dalam Pasal 4 ayat (2), maka **PIHAK KEDUA** dikenai sanksi administratif.

(2) Sanksi administratif sebagaimana dimaksud pada ayat (1) dapat berupa penghentian pembayaran dan tidak dapat mengajukan proposal penelitian dalam kurun waktu dua tahun berturut-turut.

PASAL 13
LAIN-LAIN

Dalam hal **PIHAK KEDUA** berhenti dari jabatannya sebelum Kontrak Penelitian ini selesai, maka **PIHAK KEDUA** wajib melakukan serah terima tanggung jawabnya kepada pejabat baru yang menggantikannya.

PASAL 14
PENUTUP

Surat Perjanjian Penelitian Multi Tahun ini dibuat rangkap 2 (dua) bermeterai cukup sesuai dengan ketentuan yang berlaku, dan biaya meterai dibebankan kepada **PIHAK KEDUA**.

PIHAK PERTAMA	**PIHAK KEDUA**
Drs.Heru irianto, M.Si.	**Dr. Saidah. M.T.**
NIP. 9000028	

Kode/Nama Rumpun Ilmu : 451/Teknik Elektro
Bidang Fokus : Energi-EBT

ANNUAL REPORT
INTERNASIONAL RESEARCH COLLABORATION
AND SCIENTIFIC PUBLICATION

Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique

RESEARCH TIM

Dr. Ir. Saidah, MT (NIDN : 0712066101) (Chief)
Dr. Ir. Hari Sutiksno, MT. (NIDN : 0015085501) (Member 1)
Dr. Bambang Purwahyudi, ST., MT (NIDN :0025057001) (Member 2)

UNIVERSITAS BHAYANGKARA SURABAYA
NOVEMBER 2018

HALAMAN PENGESAHAN

Judul	: Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique
Peneliti/Pelaksana	
Nama Lengkap	: Dr. Ir SAIDAH, M.T
Perguruan Tinggi	: Universitas Bhayangkara Surabaya
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Anggota (1)	
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NIDN	: 0025057001
Perguruan Tinggi	: Universitas Bhayangkara Surabaya
Institusi Mitra (jika ada)	
Nama Institusi Mitra	: California Polytechnic State University
Alamat	: San Luis Obispo, California 93407, Amerika Serikat
Penanggung Jawab	: Prof. Taufik
Tahun Pelaksanaan	: Tahun ke 1 dari rencana 2 tahun
Biaya Tahun Berjalan	: Rp 90,500,000
Biaya Keseluruhan	: Rp 209,000,000

Mengetahui,
Dekan fakultas Teknik

UNIVERSITAS BHAYANGKARA SURABAYA FAK. TEKNIK

(Dr. Bambang Purwahyudi, ST., MT)
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Kota Surabaya, 6 - 11 - 2018
Ketua,

(Dr. Ir SAIDAH, M.T)
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Menyetujui,
Kepala LPPM

UNIVERSITAS BHAYANGKARA

(Drs. Heru Irianto, M.Si.)
NIP/NIK 9000028

SUMMARY

This research has a background in the widespread use of power electronics circuits, especially three-phase AC-AC converters for various applications in the industry. Three-phase AC-AC converter as a device to convert voltage 220 Volt, 50 Hz into variable voltage and variable frequency. AC-AC converter is often found widely for various applications in the industry ie in wind power plants (PLTB) with great power and speed variable; industries which use big power induction motor and slower speed such as cement processing industries; PT. PLN that implements DC transmission on the island of Sumatra. The importance of using a three-phase AC-AC to generate variable AC voltages and variable frequencies has driven this research to discuss the AC-AC converter. In general, three-phase AC-AC converters have a topology consisting of a three-phase AC-DC converter (rectifier) and a three-phase DC-AC converter (Inverter) based on the IGBT switch and using PWM technology to set the ON-OFF switches. The use of a switch on a three-phase AC-AC converter will have an impact both on the input side and on the output side. On the input side power factor and THD still have problems while on the output side AC voltage is not regulated. At this time AC-AC converter can not overcome the impact caused. Therefore, to solve the problem, in this research is proposed AC-AC converter which can change the voltage from 100 - 265 Volt and frequency 20 Hz - 60 Hz. AC-AC converter is used to drive the asynchron motor (Motor Induction) with varying load according to the desired speed, so that the required frequency and voltage variables. AC-AC converters with variable voltages and frequencies are equipped with a power factor controller that can keep the power factor close to one, sinusoidal network current and applicable to different types of loads according to the desired voltage. This AC-AC converter has a high efficiency because it uses Space Vector PWM (SVPWM) in adjusting the pulse width of modulation on the IGBT switch component used. This type of AC-AC converter is indispensable in the industrial world and not yet on the market, so the opportunity for research teams to conduct research to produce appropriate technology that can be utilized in this industry. The first year of research produced an AC-AC converter model with Space Vector PWM (SVPWM) technique and equipped with Unity Power factor on input side and AC voltage with Proportional Integrator (PI) controller on output side. The AC-AC converter is used to drive the asynchronous motor and is applied to various types of loads according to the desired voltage. Then it is done a simulation test with Matlab. The simulation result shows unity power factor, low THD, high efficiency with SVPWM and regulated AC voltage on output side. The research was conducted in Indonesia and California that produced publications in international seminars and international journals. While the second year research focused on laboratory test of AC-AC converter model which started with inverter laboratory test to run asynchronous motor with variable load, then tested rectifier laboratories then rectifier and inverter merger, so as to produce AC-AC converter accordingly. This research was conducted in Indonesia and invited colleagues from california polythecnic to bhayangkara university. The results of the second year's research produced publications in international seminars, international journals and teaching materials.

Keywords : AC-AC Converter, SVPWM (Space Vector Pulse Width Modulation), Unity Power Factor Control, PI Controller.

CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Background

AC power sources are frequently needed in industry to operate devices, with different amplitude and frequency provided by the grid. The AC voltage of the grid provided by PT. PLN, in this case, is 220/380 AC 50Hz.

An power electronic circuit, a Three-phase AC-AC converter is used to convert the AC voltage 220 V 50 Hz. This converter is also used in industries which use big power induction motor and slower speed such as cement processing industries; applications in rolling ball mill, scherbius drive, mine-winders which have capacity more than 20 MW. A conventional AC-AC converter generally designed by combining 2 or more types of converter. This converter already has a topology in the shape of AC-DC converter (rectifier) – DC-AC converter (inverter) based on IGBT switch and has used Pulse Width Modulation (PWM) technology, but there are still problems with power factor and Total Harmonic Distortion (THD) on the input side and also the unregulated AC voltage on the output side. The low power factor brings loss to PT. PLN while the low THD is causing interferences to communication and other devices.

This research project proposes an AC-AC converter to convert voltage from 100 to 265 Volt and frequency from 20 Hz – 60 Hz. This converter is used to operate asynchronous motor (induction motor) with various loads which suitable with the expected speed, so frequency and voltage variable are needed. This AC-AC converter are equipped with power factor controller to keep up the unity power factor and the current of the grid is sinusoidal, it also applicable to any kind of load corresponding the desired voltage and frequency. This converter has high efficiency because it use Space Vector PWM (SVPWM) to handle the width of modulation pulse in IGBT switch component. This kind of AC-AC converter is absolutely necessary in industrial and not available yet in the market, so this is an opportunity for the research team to produce appropriate technology which can be utilized in industrial. AC-AC converter proposed can be showed in figure 1.1

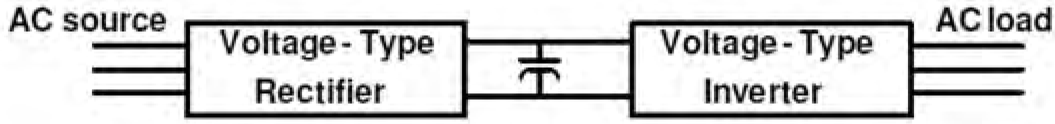


Fig 1.1 The topologi of proposed AC – AC converter

1.2 Research Objection

1. To create AC-AC converter model which can produce variable AC voltage and frequency.
2. To create AC-AC converter model equipped by power factor controller and high efficiency using SVPWM.
3. To produce AC-AC converter as a useful technology which can be used in industry.
4. To improve international collaboration so the quality of research and publication are also improved as the result.

1.3 Research Urgency and Potential

This research project is considered urgent because :

1. The available AC-AC converters can increase unity power factor, minimize THD and also have high efficiency.
2. This kind of AC-AC converter technology is not available yet in the market, so this is an opportunity for the research team to create a useful research which can be used in industrial.
3. Establishing cooperation with international college continuously, particularly with California Polytechnic which is accredited ABET.

1.4 Trace of Research Cooperation

California Polytechnic and Bhayangkara university have established collaboration since July 10th 2015, began with the acquaintance between Saidah and Prof. Taufik in Forum Teknik Elektro Indonesia (FORTEI). The collaboration started with the invitation from Ubhara to Prof. Taufik for attending a guest lecture event (Appendix) wherein Prof. Taufik explained about his previous and ongoing researches that actually had similarities of interest with Saidah, particularly in the field of power electronics. This similarity can be seen in the Curriculum Vitae of Prof. Taufik. Saidah has been focusing on the field of power electronics since her Master Degree and Doctoral Degree in ITS and has published 3 papers in international journal indexed by scopus. Saidah also did research in the field of power electronics in 2015 and 2016 which funded by DRPM Ristekdikti.

A Memorandum of Understanding (MoU) is created and signed between Ubhara and California Polytechnic in August 8th 2016, initiated by Prof. Taufik and Saidah (Appendix) and one of the activity was collaborative research. The research cooperation following the MoU need to be carried out in order to develop the relationship between both universities. Prof. Taufik from California Polytechnic has proposed a lot of collaborations with colleges in Indonesia. The Trace of Research Cooperation is showed by Fig. 1.2

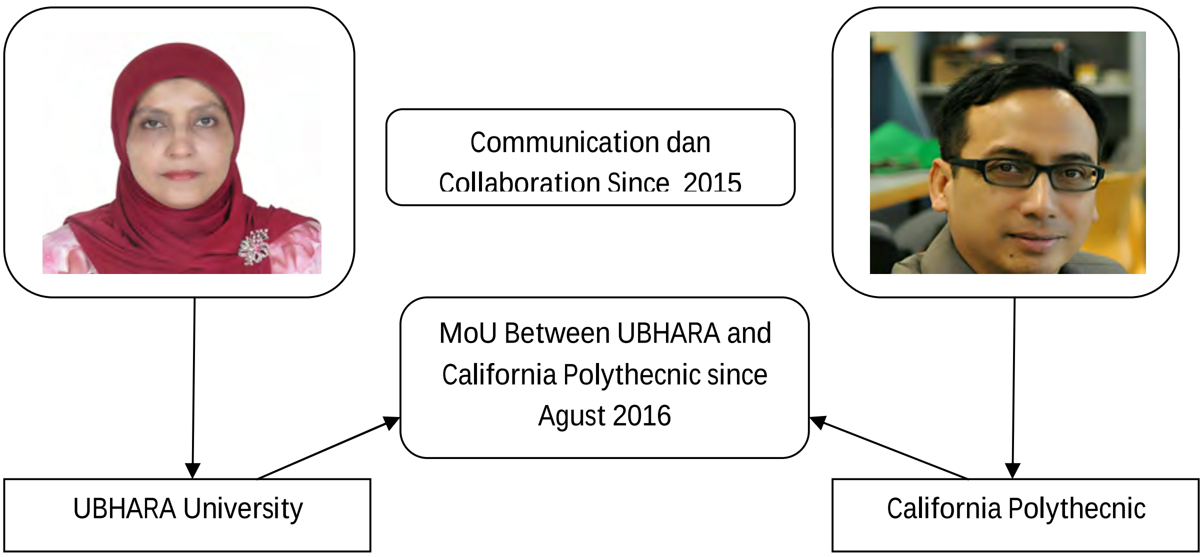


Figure 1.2. Trace of Research Collaboration

1.5 Justifikasi of the Importance of the research For The International Collaboration

It is difficult to find Indonesian researcher which has expertise in this field, and also it is difficult to find the components needed in its implementation. Prof. Taufik has lots of experience in cooperating with industries, so this research project could be supported by interactions with Prof. Taufik and also by support of components such as IGBT for high frequency switch component, sensors, and IC for DSP. Prof. Taufik's role as the Head of Power Electronics Laboratory in California Polytechnic which has been accredited ABET is also ready to help science and technology development in Bhayangkara University, while also help the supply of Power Electronics Laboratory in Ubhara. Due to this facts, a joint research or collaboration with the Professor in California Polytechnic is needed.

This research project will be carried out in Indonesia and California. The proposing team will discuss with Prof. Taufik through a video call and will also visit California associated with the AC-AC converter model development and component utilization. Prof. Taufik will be also expected to visit Indonesia. By the establishment of this collaboration, it is expected to improve equality between Indonesian researcher and international researcher.

1.6 Roadmap of the Research

An AC-AC converter is used to operate asynchronous motor (induction motor) with various loads which suitable with the expected speed, so frequency and voltage variable are needed. The AC-AC converter is equipped with power factor controller to keep up the unity power factor and the current in sinusoidal condition, it also applicable to any kind of load corresponding the desired voltage. This AC-AC converter has high efficiency because it use Space Vector PWM (SVPWM) to handle the width of modulation pulse in IGBT switch component. Research about converter have been done by team since 2009, both AC-DC (Rectifier) and DC-AC converters (Inverter), that published in some international journals. Figure 2.5 show the roadmap of the research.

1.7 Urgency and Potency of Research Results

The result of this research project will be an AC-AC converter as anappropriate technology product which can be used in industry as 3-phase induction motor drives with various loads which suitable with the expected speed. This kind of AC-AC converter is not available yet in the market, because it will be equipped by power factor controller, low THD and has high efficiency. This research project result can potensially to obtain a patent.

1.8 Outcome For International Collaboration

The expected outcome of this project mainly is an international publication and also an international seminar conference that could be achieved in the first and the second year. Appropriate technology and teaching materials will also be the outcome from this research project.

Tabel 1.1
Annual Achievement Target Plan

No.	Type of Outcome				Indikator	
	category	Sub category	Mandatory	Optional	Cy[1)]	Cy+1
1	Scientific Publication/Journal	International	√		accepted	accepted
		National-Accredited			nothing	nothing
2	Invited speaker in scientific forum	International		√	Has been conducted	Has been conducted
		National-Accredited		√	nothing	nothing
3	Keynote speaker in scientific forum[4)]	International		√	nothing	nothing
		National		√	nothing	nothing
4	Visiting Lecturer	International		√	nothing	nothing
5	Intellectual Property Right	Patent		√	nothing	nothing
		Simple Patent		√	nothing	nothing
		Copy Right		√	nothing	nothing
		Trade Mark		√	nothing	nothing
		Trade Secret		√	nothing	nothing
		Industrial Product Design		√	nothing	nothing
		Geographical Indication		√	nothing	nothing
		Plant Variety Conservation		√	nothing	nothing
		Integrated Circuit Topography Conservation		√	nothing	nothing
6	Intermediate Technology[7)]			√	nothing	nothing
7	Model/Prototype/Design/Art/ Social Engineering[8)]			√	product	application
8	Book (ISBN)[9)]			√	nothing	nothing
9	Technological Readiness Level (TRL)[10)]			√	2	3

CHAPTER 2

LITERATURE REVIEW

2.1 State of The Art

A three-phase AC-AC converter is an device used to increase and decrease three-phase AC voltage with different frequency. There are research about AC-AC Converter which use thyristor as the switch component (Atul Gupta and Amita Chandra, 2010) and many others which use IGBT as the switch component (SH Suresh Kumar Budi, 2013 ; S. Dhatchayani et al, 2014 ; Miroslav et al, 2012). Advantage of using IGBT components can minimize (THD) dan improve power factor. Use of proper controller could improve the performance of AC-AC converter for instance, the high power factor, lower THD which is shown by near sinusoidal current waveforms in the side of the grid. There are two control techniques used in AC-AC Converter, namely Direct Power Control (DPC) which based on the instantaneous active and reactive power directly. In DPC there are no internal current control loops and no PWM modulator block, because the converter switching states are selected by a switching table based on the instantaneous errors between the commanded and estimated values of active and reactive power. Therefore, the key point of the DPC implementation is a correct and fast estimation of the active and reactive line power (T. Ohnishi, 1991 ; T. Noguchi et al, 1998). The second control technique is Voltage Oriented Control (VOC), which guarantees high dynamics and static performance via an internal current control loops, has become very popular and has constantly been developed and improved. Consequently, the final configuration and performance of the VOC system largely depends on the quality of the grid current control strategy (S. Hansen et al, 2000 ; M.P. Kazmierkowski, 1998 ; B.H. Kwon et al, 1999 ; J.S. Prasad et al, 2008 ; B.K. Bose, 2002).

Related to VOC control technique strategy used in this research project, development of DC voltage control method and power factor which have been offered starting from simple and cheap control method that is PID (Kapikumar C. Dave and Dr. Utkrash Seetha, 2013) and intelligent control method Fuzzy (Padmanaban Sanjeevikumar et al, 2008) has been developed by researchers. However, research on AC-AC Converter has ignored the resistance in the grid and IGBT on the rectifier side, while on the inverter side is the resistance at IGBT. At the time of implementation, this resistance is very influential to obtain the accuracy of power factor (Kapikumar C. Dave, 2013; Padmanaban Sanjeevikumar et al, 2008; Pou Josep et al., 2002; Ojo Olorunfemi, 2005) Control pulse width modulation on IGBT Switch component needs to be done To ensure efficiency in both rectifier and inverter side, this technique is called Pulse Width Modulation (PWM). Initially, this technique introduced the Sinusoidal PWM technique with 78.5% efficiency (Ojo Olorunfemi, 2005) then developed into Space Vector PWM technique which improved efficiency by 90.7%, which means there is about 15% increase.

2.2 Topology of AC-AC Converter

This research project proposes an AC-AC Converter which consists of 2 converter units, a AC-DC converter (rectifier) and DC-AC converter (inverter), both are connected in series. Both converters are connected with DC link as shown in Figure 2.1

FVFF

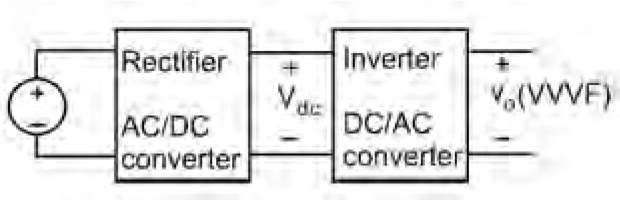


Fig. 2.1 FVFF (Fixed Voltage Fixed Frequency) to VVVF (Variable Voltage Variable Frequency) AC-AC Converter through a DC Link

Both converters use IGBT components as the switch component, both in AC-DC converter and DC-AC converter. The implementation of this converter with IGBTs is shown in Fig. 2.2.

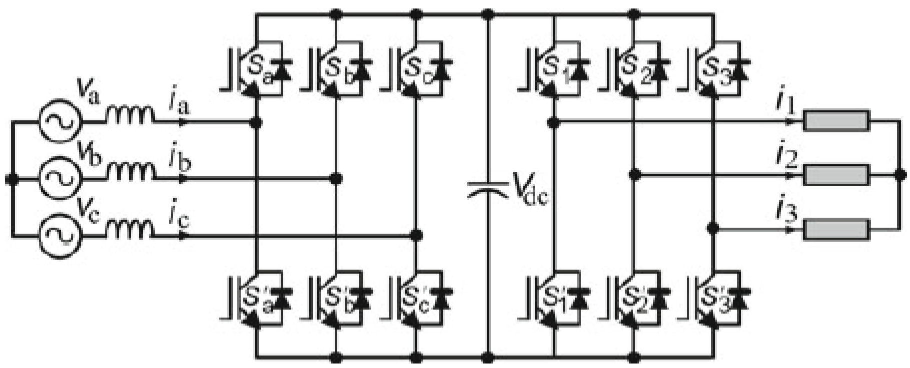


Fig. 2.2 Implementation of FVFF to VVVF AC-AC Converter Through a DC Link

This design allows two-way energy flow and four-quadrant operation and is usually applied to motor drives, electric power generation using asynchronous machines, energy storage systems (such as batteries, UPS, and flywheel energy systems), and the connection of two independent grids.

2.3 Space Vector Pulse Width Modulation (SVPWM)

The switch components in three phase rectifier and inverter are using 6 switches. These switches work in a way which require the corresponding signal to control ON and OFF the transistor. The method to code the analog signal to become the duration of those ON or OFF is PWM. The efficiency of the rectifier and the inverter are one of the important parameter in energy saving By using conventional method SPWM (Sinusoidal Pulse Width Modulation), the DC voltage produced is about 78,5% from the rectifier and the inverter maximum capacity. PWM method used in this research project is called Space Vector PWM (SVPWM) which is able to produce output DC voltage up to 90,7% from the capacity of the rectifier and the inverter, which means there is about 15% efficiency increment.

SVPWM is an easy method to be implemented digitally. The placement of the paired switches (Sa and Sa’, Sb and Sb’, Sc and Sc’) are set such that for each pair will never be ON or OFF simultaneously. This means if the Sa switch is ON, then Sa’ switch will be OFF or vice versa. Similarly, this situation is also applied to Sb and Sb’, Sc and Sc’. There are 8 ON-OFF placement combinations for the switches, which called as state, as shown in Figure 2.3. State 0 and state 7 express zero vector. State 1 – 6 are active vectors, so the six of them divide the sector of space vector into six sectors equally.

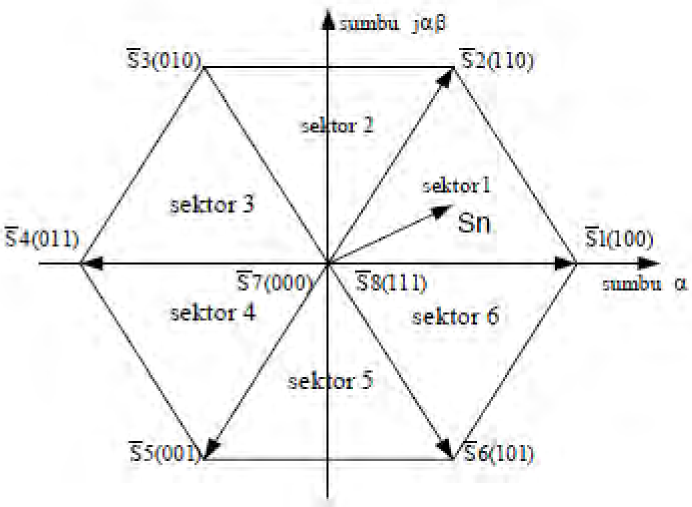


Fig. 2.3 Space Vector PWM

The algorithm of Space Vector PWM can be described in a flowchart as shown in Figure 2.4.

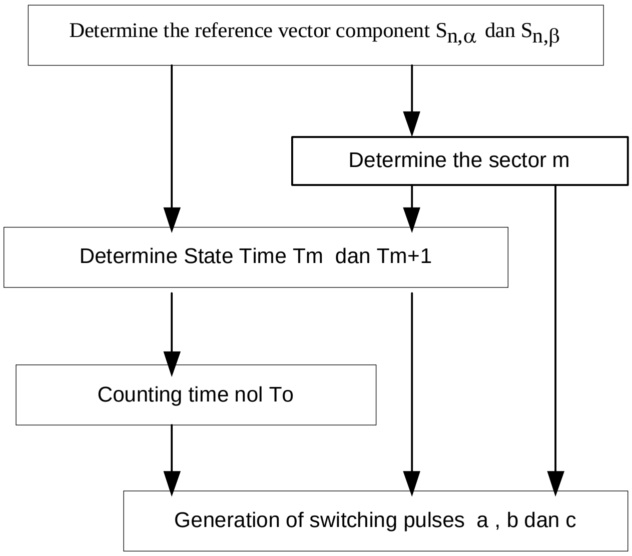


Fig 2.4. Space Vector PWM Algorithm

The research on AC-AC converter entitled "Power Factor Correction of A Variable Frequency Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique" has been conducted preliminary research by the proposing team. Preliminary study by the proposing team as shown **in Roadmap** Figure 2.5.

This research will differ from the previous research at least in the following ways :

1. Unity Power Factor with Taking into account the value of resistance on the network and on the IGBT
2. Low Total Harmonic Distortion
3. AC voltage in the output side is controlled from rectifier side

2009-2013

1. Research about rectifiers and inverters which have been done teams with various control methods have produced papers published in international Journals.

2. Research about Induction Motor has been done with applications on ships and in industry

International Journal :

(2011) Bambang, saidah, "RNN based Rotor Flux and Speed Estimation of Induction Motor ",(IJPEDS)

(2011) Bambang, "Feed-forward Neural Network for Direct Torque Control of Induction Motor" ,(IJICIC)

(2012) Saidah, "Advanced Control Of Active Rectifier Using Switch Function And Fuzzy Logic For Nonlinear Behaviour Compensation " ,(JATIT)

(2013) Saidah, "High Performance of Nonlinear Active Rectifier Voltage and Power Factor Control Using Feedback Linearization (International Review of Electrical Engineering ", (I.R.E.E.)

(2013) Hari Sutiksno, "Load Current Control Based on Luenberger Observer For Three Phase Power Converter SVPWM" (JATIT)

2014 - 2016

2014-2016

1. The HIBER Research for Induction Motor and its applications on board were funded by DRPM DIKTI for 2 years

2. Fundamental research about rectifiers was funded by DRPM DIKTI for 2 years and resulted in scopus indexed Journal

International Journal :

(2014) Bambang, Saidah, "Self Tuning Fuzzy-PI Controller in Volts/Hz Induction Motor Control For Electrically Driven Ship Propeller", (Academic Research Internasional)

(2015) Bambang, Saidah, "Self Tuning Fuzzy-PI Controller in Volts/Hz Induction Motor Control For Electrically Driven Ship Propeller ",(Academic Research Internasional)

2017

Proposal of Foreign Cooperation Research is proposed to Ristek Dikti

International Journal :

(2017) Saidah, Bambang , "Control Strategy For PWM Voltage Source Converter Using Fuzzy Logic For Adjustable Speed DC Motor", (IJPEDS)

2018 (First Year)

"Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique"

1. To make Three Phase AC-AC Converter model which consist of Three Phase Rectifier Model and Three Phase Inverter Model

2. Simulate Three Phase AC-AC Converter Model using Matlab software

3. Observe the simulation result by adding loads

Output Target:

1. Model of AC-AC Converter
2. International Publications
3. Internasional Journal

2019 (Second Year)

"Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique"

1. Design and implement the Three Phase Inverter by using loads
2. Design and implement the Three Phase Rectifier
3. Combine both the Rectifier and the inverter overall system by observing the power factor and THD values in the grid side and the loads variations

Output Target:

1. AC-AC Converter (Appropriate Technology)
2. International Publications
3. Internasional Journal
4. Draft Patent

Fig. 2.5 Research Roadmap

CHAPTER 3

RESEARCH METHOD

3.1 Research Plan

The research proposed in this proposal is entitled "Power Factor Correction Of A Variable Voltage Variable Frequency Ac-Ac Converter Via Appropriate SVPWM Technique". This research will produce three-phase AC-AC converter which has high efficiency, generating variable AC voltage, frequency variable, powerfactor close to one and low THD value. This AC-AC converter will be used to drive an induction motor with varying loads. This research project will be carried out in Indonesia and Calyfornia. it is planned as a two-year project which will be divided into two main parts.

In the first year, the model of AC-AC converter will be conducted in Indonesia and california, this activity will also be discussed with International Partners. The AC-AC converter has the characteristic that must be matched with industrial requirement in Indonesia.

In the second year, laboratory test of the AC-AC converter to become an appropriate technology which will be conducted in Indonesia with the help from the california Polythecnic. Stages of the research are shown in the form of flow diagrams that can be seen in Figure 3.1.

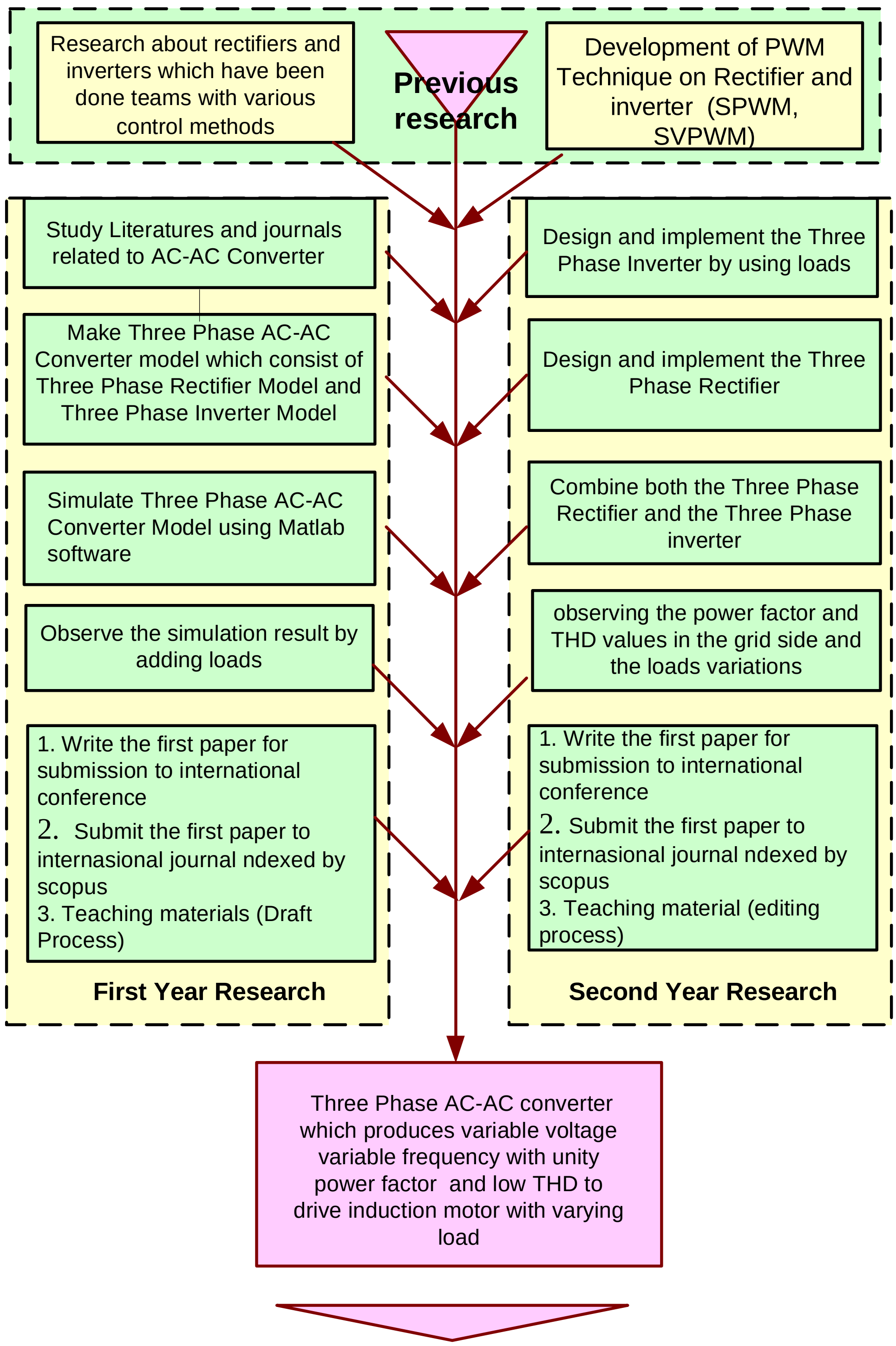


Figure 3.1 Scheme of The Planned Project Proposal

3.2 Research Stages

The details of the research stages is explained as follows :

3.2.1 First Year Project (Year 2018)

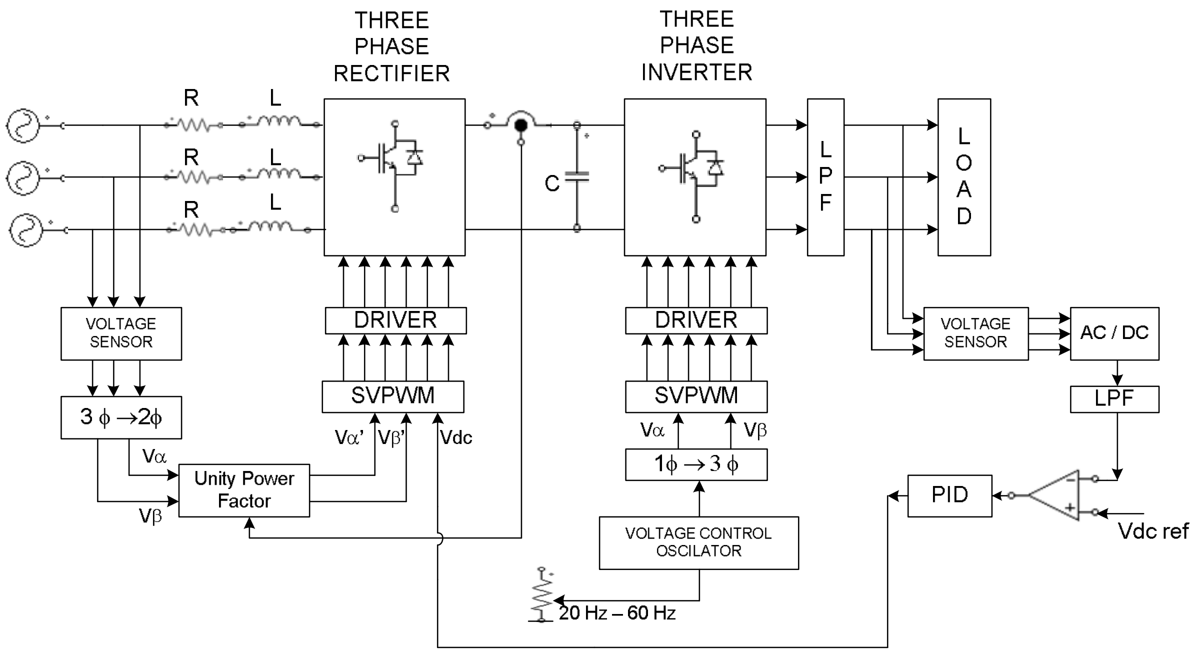


Fig. 3.2 AC-AC Converter System

a. Study Literatures and journals related to AC-AC Converter (Indonesia)
b. To make Three Phase AC-AC Converter model which consist of Three Phase Rectifier Model and Three Phase Inverter Model (Indonesia and California)
c. Simulate Three Phase AC-AC Converter Model using Matlab software (Indonesia and California)
d. Observe the simulation result by adding loads. (Indonesia)
e. Write the first paper for submission to international conference (Indonesia)
f. Submit the first paper to internasional journal indexed by scopus (Indonesia)

The expected research output in the first year is

1. The discovery of a three-phase AC-AC converter **model** that produces a variable voltage, variable frequency. AC-AC converter produces unity power factor and low

THD on the input side, while on the output side produces controlled AC voltage. This converter also has a high efficiency using SVPWM.

2. Publications at international seminars and international journals
3. Make teaching materials (Draft Process)

3.1.2 Second Year Project

a. Design and implement the Three Phase Inverter by using loads (Indonesia and California)
b. Design and implement the Three Phase Rectifier (Indonesia and California)
c. Combine both the Rectifier and the inverter overall system by observing the power factor and THD values in the grid side and the loads variations (Indonesia and California)
d. Write the first paper for submission to international conference (Indonesia)
e. Submit the first paper to internasional journal terindeks scopus (Indonesia)
f. Make teaching materials in editing process (Indonesia)

The expected research output in the second year is

1. Produce a three-phase AC-AC converter which is an appropriate technology and can be utilized in the industrial world
2. Publikasi pada seminar internasional dan jurnal internasional
3. Teaching materials in editing process

3.3 Place of Research

The research was conducted at the Electrical Engineering Laboratory of the Engineering Faculty of Engineering, Bhayangkara University of Surabaya and at the Power Electronics Laboratory of California Polytecnic. In the first year the research team will go to california and in the second year a partner from california (Prof Taufik) will come to Indonesia.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Model Of The Ac-Ac Converter

The converter model consists of a rectifier (VSR/AC-DC converter), DC-Link capacitor and an inverter (VSI/DC-AC converter) that implements the Space Vector Modulation (SVM) technique.The SVM control technique is used for both the rectifier and inverter feeding the induction motor.The SVM technique is chosen due to its more prevalent use than all other conventional techniques as the technique offers improved DC bus utilization, lower harmonics, less switching losses, and higher overall converter's efficiency. The main task of the SVM technique is to calculate the duty cycles and define the switching pattern. In the proposed converter and as illustrated in Figure 4.1, the novelty lies on the unity power factor control employed in the converter that will maintain the input power factor to the rectifier stage close to one. Consequently, the power factor control keeps the source current in the same phase as the voltage. There is PI controllers used in the proposed converter: the PI DC voltage control to maintain a stable DC voltage.

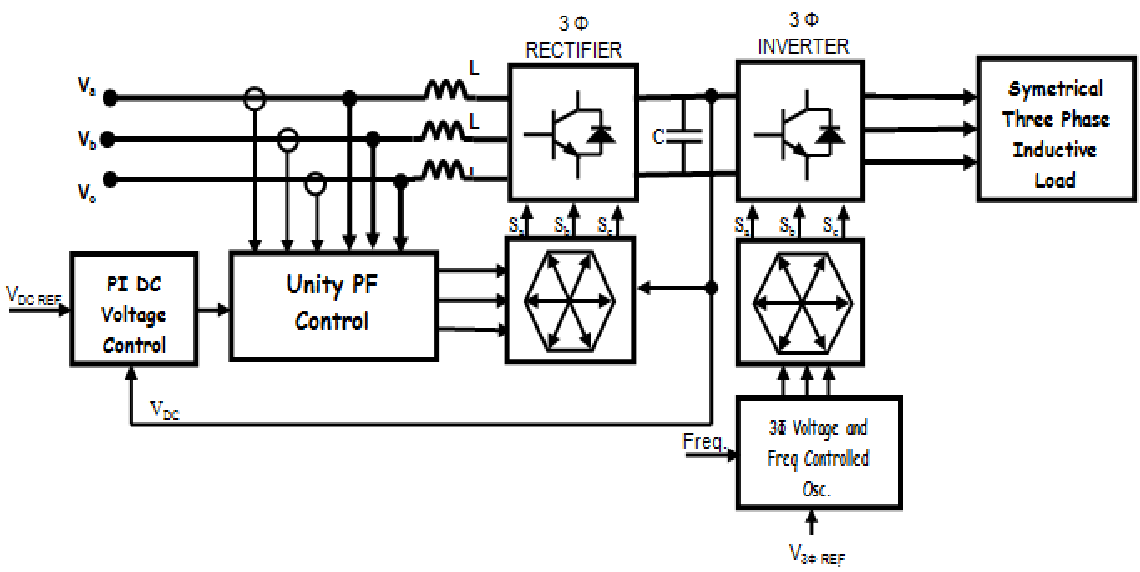


Fig. 4.1 Proposed of AC-AC Converter

PI DC Voltage Control

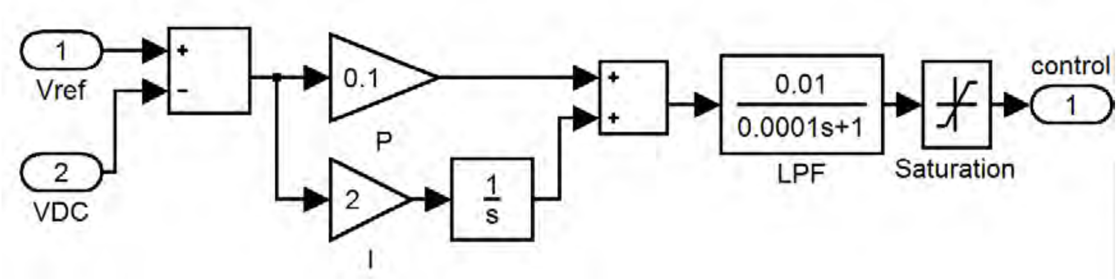


Fig 4.2. PI Control for DC voltage control

Unity Power Factor Control

Unity power factor occurs when the difference between voltage angle θ_V and current angle θ_I is zero degrees. In other words, it is established when voltage and current waveforms are in phase.

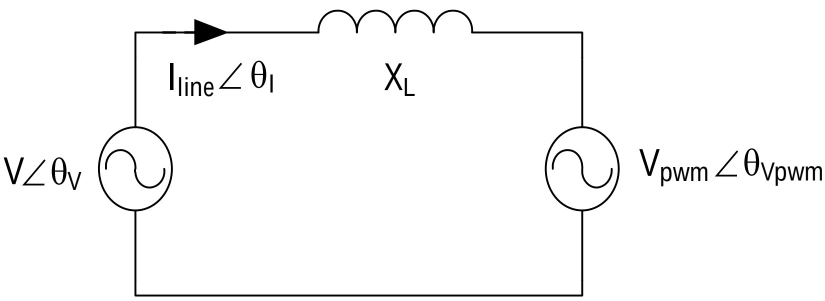


Fig. 4.3. Equivalent circuit of the converter from the AC source side

The current regulator can be realized by making a calculation process to generate the desired PWM voltage, so that the current flowing in the inductor can be determined, as shown in Figure 5. In a power converter, if it is assumed that the sampling period is Ts, the inductor resistance is negligible, and the source input voltage at the sampling interval is considered constant, then the current flowing in the inductor can be determined according to the equation as follows:

$$V(t_n) - V_{PWM}(t_n) = L\frac{\Delta i}{\Delta t} = L\frac{i(t_n + T_s) - i(t_n)}{T_s} \quad (1)$$

where: $V(t_n)$ is the source voltage at t = tn

$V_{PWM}(t_n)$ is the PWM voltage on the AC side of the converter

Equation (1) can be written as:

$$V_{PWM}(t_n) = V(t_n) - \frac{L}{T_s}[i(t_n + T_s) - i(t_n)] \quad (2)$$

Here it appears that the magnitude of the inductor current that will flow at time t = tn + Ts can be determined by giving the PWM voltage according to the instantaneous current equation proportional to the voltage. This current setting provides the possibility to obtain a sinusoidal current waveform with a power factor equal to one. If the current is a sinusodal and has a phase equal to its voltage, then the reference current may be defined as:

$$i(t_n + T_s) = kV(t_n + T_s) \quad (3)$$

where k is a constant whose magnitude depends on the current to be streamed. This reference current does not change rapidly compared to the sampling period. Therefore, the current can be predicted through the previous value approach, as shown in Figure 6, as:

$$i(t_n + T_s) \approx i(t) + \frac{i(t_n) - i(t_n - T_s)}{T_s}.T_s \quad (4)$$

or

$$i(t_n + T_s) \approx 2i(t_n) - i(t_n - T_s) \quad (5)$$

according to equation (3), the reference current of equation (5) can be expressed as follows:

$$i(t_n + T_s) \approx 2kV(t_n) - kV(t_n - T_s) \quad (6)$$

By combining equations (2) and (6), the reference voltage can be obtained as:

$$V^{'}(t_n) = (1 - \frac{2kL}{T_s})V(t_n) + \frac{kL}{T_s}V(t_n - T_s) + \frac{L}{T_s}i(t_n) \quad (7)$$

Equation (7) denotes the PWM voltage to be raised so that the current flowing in the inductor is k·V(t). Figure 7 shows the current regulator diagram of PWM converter with input voltage V(t), channel currenti(t), and k factor. This current regulator is realized in the calculation process by using a microprocessor, together with the PWM signal generation process. With the current regulator the current waveform will be the same as the voltage-shaped sinusoidal waveform and with the same phase. Figure 7 illustrates the vector diagram of the system.

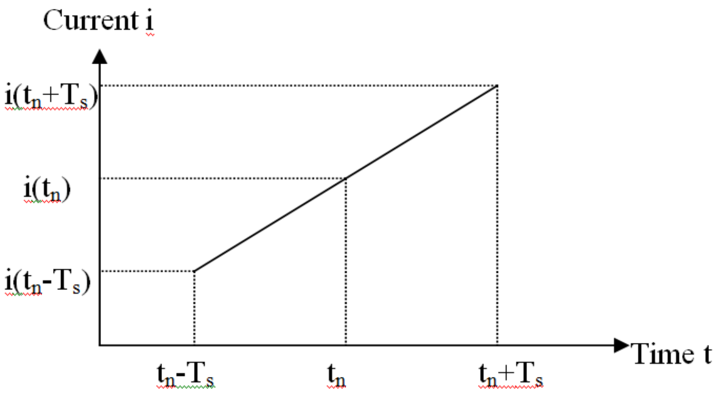


Fig. 4.4 The reference current at the end of each period

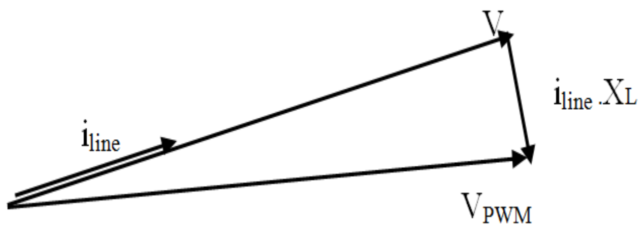


Fig. 4.5 Vector Diagram of the converter from the AC source side

4.2 Simulation Results

The proposed AC-AC converter performance is simulated with Matlab/Simulink software. In the simulation, the three-phase source voltage is set at 220 V/50 Hz, the DC voltage is 1000 Volts and the sampling frequency is 10 kHz. The desired AC output voltage varies with variable frequency and different load impedance. The simulation is done on the output voltage from 120 to 300 Voltswith output frequency being varied from 20 to 60 Hz, while observing the power factor, DC voltage and current, the output voltage and current waveforms. The rectifier in the simulation follows the requirements of three-phase voltage source 220 V/50 Hz with amplitude √2 x 220 = 311 Volts, DC Voltage of 1000 Volts, and the sampling frequency is 10 kHz. To evaluate the performance of the proposed converter, six different cases were simulated and analyzed. Table 1 list the inverter specifications for each of these cases.

Table 1. Inverter Specifications

Case	Output Voltage	Amplitude Voltage	Output Frequency	Load
1	220 Volt	311 Volt	30 Hz	6 + j 8 ohm
2	250 Volt	353 Volt	50 Hz	10 + j 10 ohm
3	120 Volt	170 Volt	60 Hz	6 + j 8 ohm
4	120 Volt	170 Volt	50 Hz	10 + j 10 ohm
5	120 Volt	170 Volt	30 Hz	6 + j 8 ohm
6	300 Volt	424 Volt	30 Hz	10 + j 10 ohm

Case 1. DC voltage source 1000 Volts, voltage amplitude of inverter output 311 Volts, output frequency 30 Hz and load impedance 6 + j 8 ohm.

Simulation results are shown in Figures 4.6 – 4.9. Figures 4.6 and 4.7 show that DC Current and DC Voltage are both stable respectively with steady state DC voltage of 1000 Volts. The source current and voltage of the rectifier have the same phase as shown at Figure 4.8,which results in unity power factor. The rectifier source voltage amplitude of 311 Volts at frequency 50 Hz is successfully converted to 311Volts at 30 Hz frequency sinusoidal output waveform, as depicted in Figure 4.9.

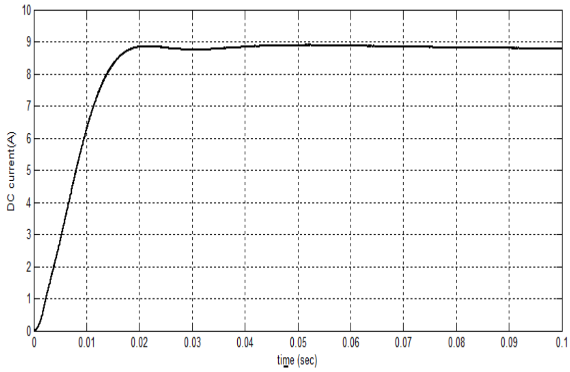


Figure. 4.6 DC Current, Case 1

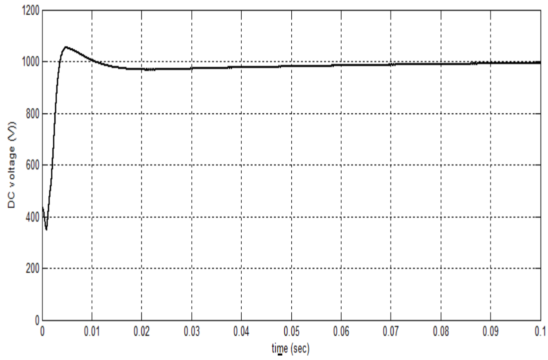


Figure 4.7. DC Voltage, Case 1

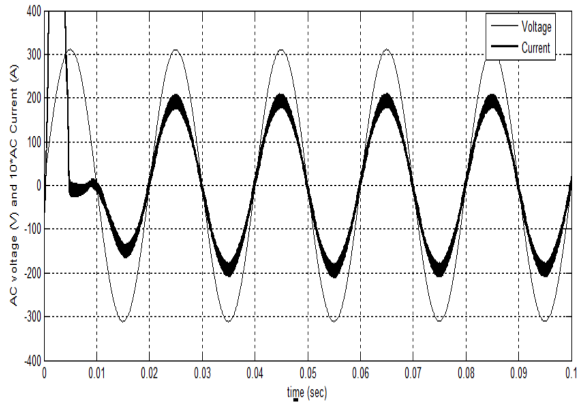


Figure 4.8. Amplitude of Voltage and Current at input of rectifier, Case 1

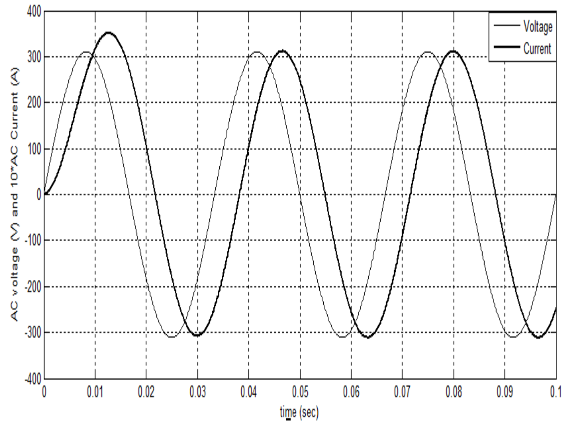


Figure 4.9. Amplitude of Voltage and Current at Output of inverter, Case 1

Case 2. DC voltage source 1000 Volts, voltage amplitude of inverter output 353 Volts, output frequency 50 Hz and load impedance 10 + j 10 ohm.

Simulation results are presented in Figures 4.10 – 4.13. As observed in the previous case, the result shows stable DC current and DC Voltage at 1000 Volt as illustrated in Figures 4.10 and 4.11 respectively. The source current and voltage of the rectifier have the same phase, which again proves the unity power factor, as shown in Figure 4.12. The rectifier source voltage amplitude of 311 Volts at frequency 50 Hz is again converted well to 353 Volts at the same frequency 50 Hz, as seen in Figure 4.13, while the output current waveform is sinusoidal as desired.

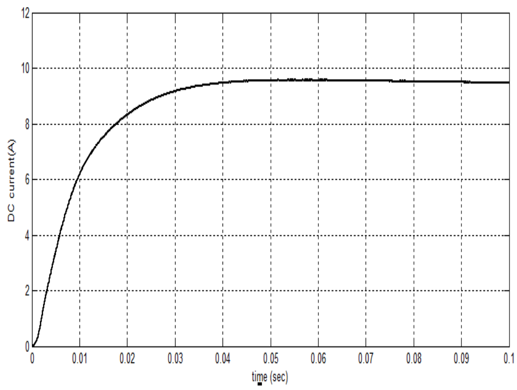


Figure. 4.10 DC Current, Case 2

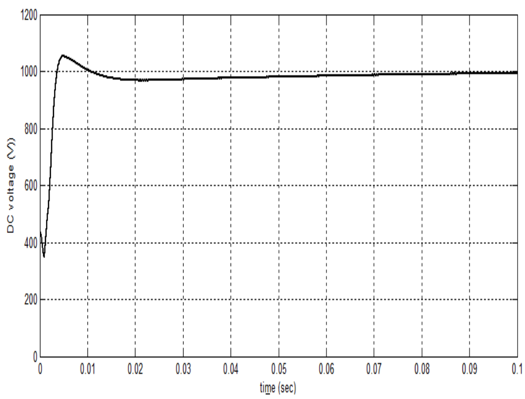
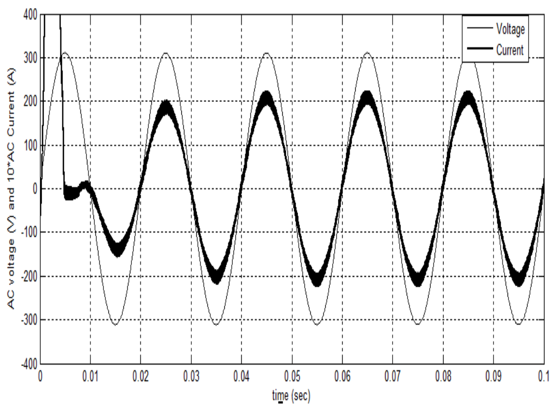


Figure 4.11. DC Voltage, Case 2



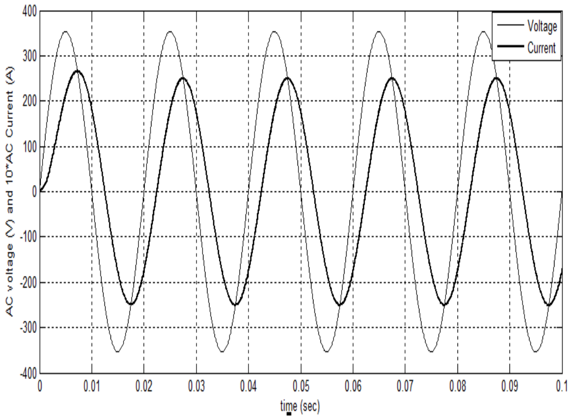
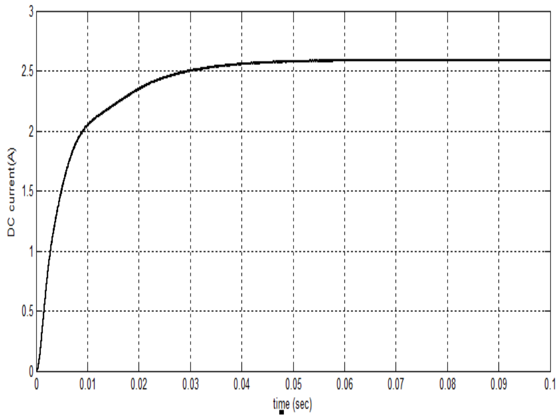


Figure 4.12. Amplitude of Voltage and Current at input of rectifier, Case 2

Figure 4.13 Amplitude of Voltage and Current at Output of inverter, Case 2

Case 3. DC voltage source 1000 Volts, voltage amplitude of inverter output 170 Volts, output frequency 60 Hz and load impedance 6 + j 8 ohm.

Simulation results as presented in Figures 4.14 – 4.17 again showstable DC current and DC Voltage at 1000 Volt as illustrated in Figures 4.14 and 4.15 respectively. The unity power factor has also been achieved between the source current and voltage of the rectifier as shown in Figure 4.16. The rectifier source voltage amplitude of 311 Volts at frequency 50 Hz is converted to 170 Volts at the same frequency 60 Hz, as depicted in Figure 4.17, while again achieving the desired sinusoidal output current waveform.



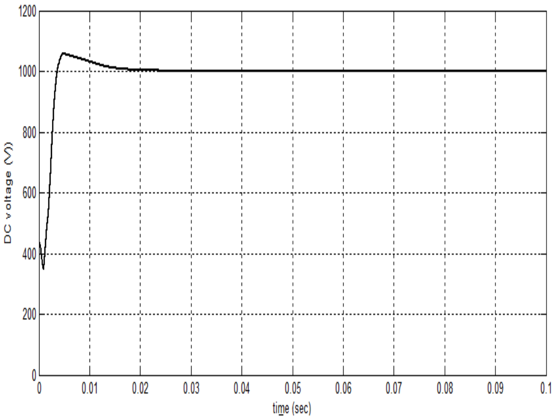
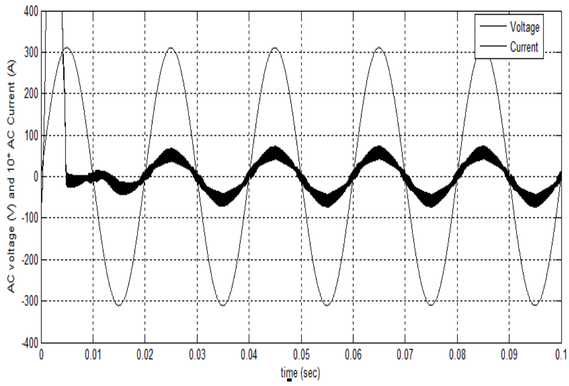


Figure 4.14. DC Current, Case 3

Figure 4.15. DC Voltage, Case 3



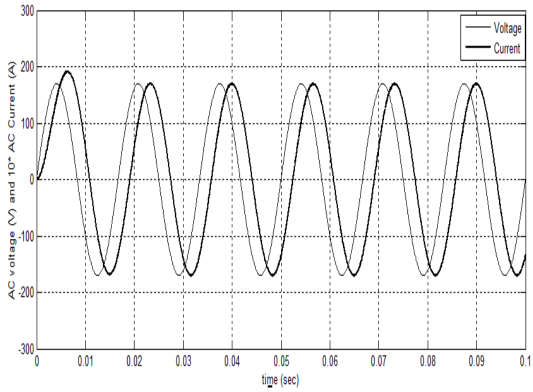
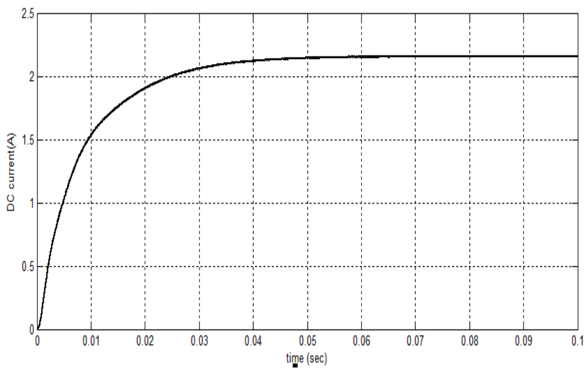


Figure 4.16 : Amplitudeof Voltage and Current at input of rectifier, Case 3

Figure 4.17. Amplitude of Voltage and Current at output of inverter, Case 3

Case 4. DC voltage source 1000 Volts, voltage amplitude of inverter output 170 Volts, output frequency 50 Hz and load impedance 10 + j 10 ohm.

Simulation results are shown in the Figure 4.18 – 4.21. Figure 4.18 shows stable DC current and Figure 4.19 shows DC voltage is stable at 1000 Volts. The source current and voltage of rectifier again shows that they are in phase as shown at Figure 4.20. The conversion of source voltage with amplitude of 311 Volts at 50 Hz takes place successfully to sinusoidal 170 Volts at 50 Hz as presented in Figure 4.21.



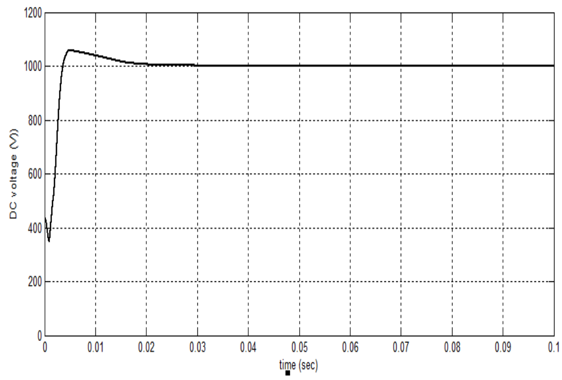
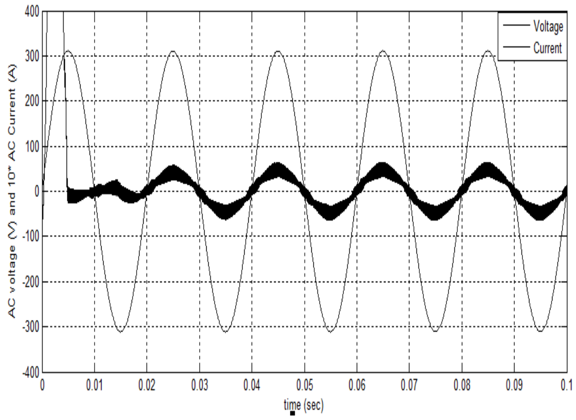


Figure 4.18. DC Current, Case 4

Figure 4.19. DC Voltage, Case 4



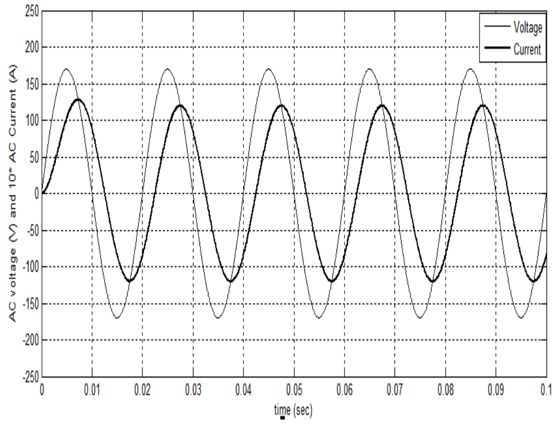
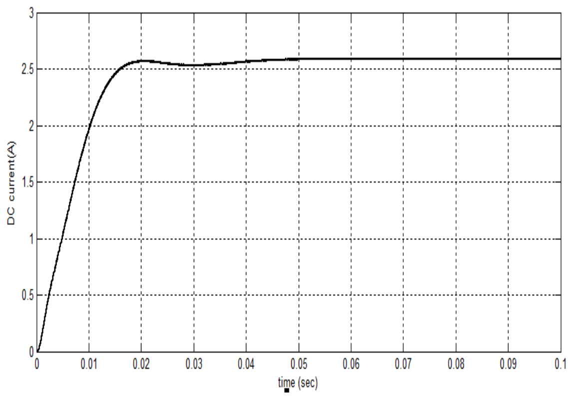


Figure 4.20. Amplitude of Voltage and Current at input of rectifier, Case 4

Figure 4.21. Amplitude of Voltage and Current at output of inverter, Case 4

Case 5. DC voltage source 1000 Volts, voltage amplitude of inverter output 170 Volts, output frequency 30 Hz and load impedance 6 + j 8 ohm.

Results of this case are in agreement with the previous ones. As illustrated in Figures 4.22 and 4.23, both DC current and DC voltage are stable. The source current is also in phase with the source voltage of rectifier, making the input power factor unity, see Figure 4.23. Sinusoidal output waveform is achieved after the conversion of source voltage amplitude of rectifier at 311 Voltsand 50 Hz to 170 Volts at 30 Hz took place, as depicted in Figure 4.25.



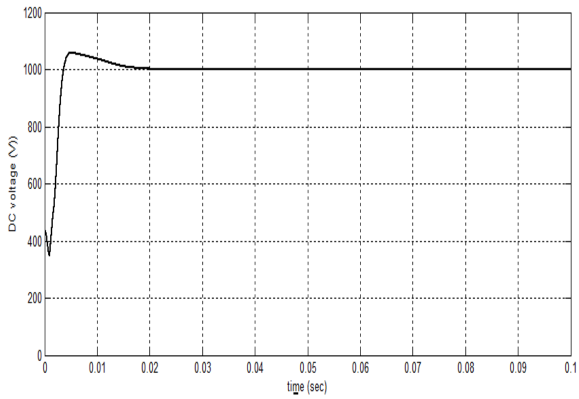


Figure 4.22. DC Current, Case 5

Figure 4.23. DC Voltage, Case 5

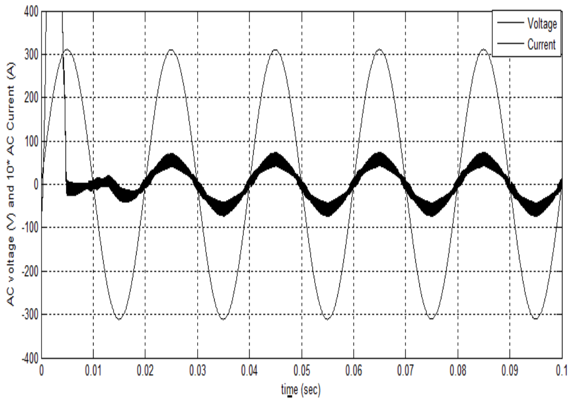


Figure 4.24. Amplitude Voltage and Current at input of rectifier, Case 5

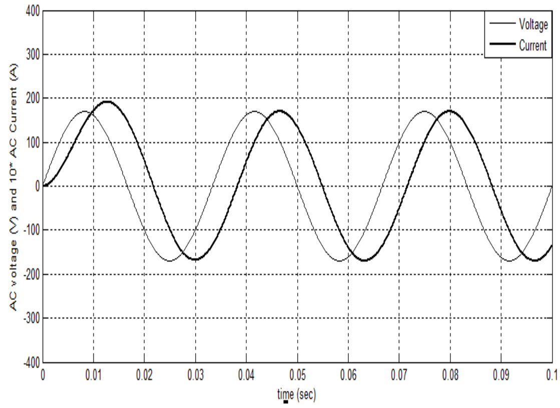


Figure 4.25. Amplitude Voltage and Current at output of inverter, Case 5

Case 6. DC voltage source 1000 Volts, voltage amplitude of inverter output 300 Volts, output frequency 30 Hz and load impedance 10 + j 10 ohm.

Simulation results for this case are consistent with those observed in the previous cases. Stable DC current and DC voltage are shown in Figure 4.26– 4.27, and unity power factor as the result of in phase behavior of source current and voltage can be observed in Figure 4.28. The converter is also able to convert successfully 311 Volts at 50 Hz at the rectifier to sinusoidal 300 Volts at 30 Hz at converter's output in Figure 4.29.

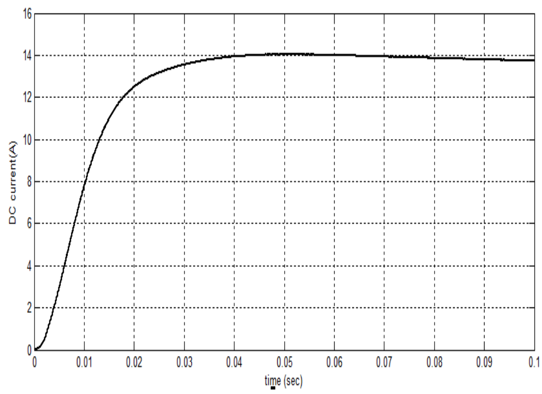


Figure 4.26. DC Current, Case 6

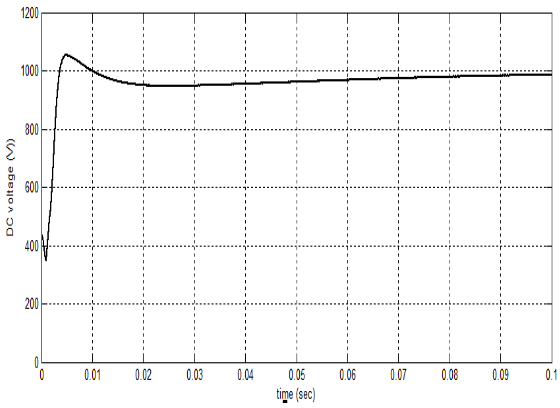
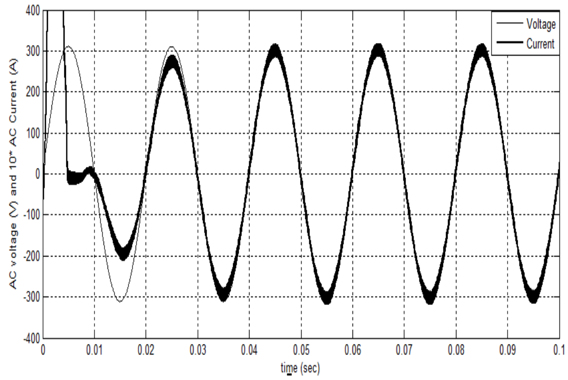


Figure 4.27. DC Voltage, Case 6



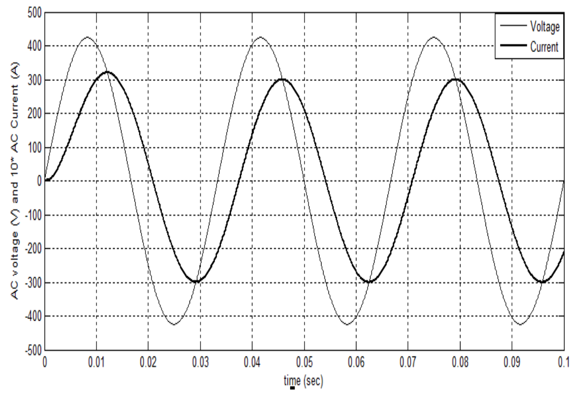


Figure 4.28. Amplitude Voltage and Current at input of rectifier, Case 6

Figure 4.29 Amplitude Voltage and Current at output of inverter, Case 6

CHAPTER 5

THE NEXT STAGE PLAN

Research results in this Annual report have reached 100%, namely

1. Has produced a model of Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique
2. Has conducted an international seminar at ICW September 2018 and was selected to be published in the Telkomnika (Scopus) journal in February 2019
3. Submit a journal that has been sent to an international journal indexed by Scopus (IJPEDS) in review process
4. finished making the third paper to be sent to the IREE Journal
5. Has finished making teaching materials (in draft form)

5.1 Second Year Project

In the second year, the laboratory test will be continued from the results in year I. This test is conducted to determine the performance of the Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique

a. Design and implement the Three Phase Inverter by using loads (Indonesia)
b. Design and implement the Three Phase Rectifier (Indonesia)
c. Combine both the Rectifier and the inverter overall system by observing the power factor and THD values in the grid side and the loads variations (Indonesia)
d. Write the first paper for submission to international conference (Indonesia)
e. Submit the first paper to internasional journal terindeks scopus (Indonesia)
f. Make teaching materials in editing process (Indonesia)

5.2 Research Budget

A summary of the proposed budget for the research can be shown in Table 4.1.

Table 4.1 Summary of Budget

No	Type of expenditure	The proposed cost	
		First Year	Second Year
1.	Honorarium research assistant	**21.450.000**	**14.700.000**
2.	Material and equipment	**47.203.110**	**53.649.400**
3.	Travel	**4.341.500**	**31.500.000**
4.	Others	**17.600.000**	**18.500.000**
	TOTAL	**90.594.610**	**118.349.400**

5.3 Research Schedule

Research activities will be undertaken for 10 (ten) months each year. The research will be started on February and finished on November. The schedule diagram was shown as follows :

Tabel 4.1
Research Plan Activities

NO	ACTIVITIES	YEAR 1										YEAR 2									
	First-year Schedule	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1.	Study literatures and journals																				
2.	Make AC-AC Converter model																				
3.	Simulate AC-AC Converter Model																				
4.	Analyze simulation result with induction motor loads.																				
5.	Write the first paper for submission to international conference																				
6.	Submit the first paper to international journal indexed by scopus.																				
7.	Make draft of teaching materials																				
	Second-year Schedule																				
1.	Design and implement Three Phase Rectifier with induction motor loads																				
2.	Design and implement Three Phase Inverter																				
3.	Combine Three Phase Rectifier with Three Phase Inverter																				
4.	Write the first paper for submission to international conference																				
5.	Submit the first paper to international journal indexed by scopus																				
6.	Teaching materials in editing process																				

CHAPTER 6

CONCLUTION

This research presents a proposed three-phase AC-AC converter using a capacitor as an energy storage element. A model of the proposed converter was developed which utilizes power factor control to ahieve close to unity power factor. The proposed converter model also includes PI controllers to keep the DC voltage stable and the inverter output voltage at the expected position. The proposed AC-AC converter was tested using simulation to produce inverter output voltages ranging from 120 Volts to 300 Volts with frequencies between 30 - 60 Hz. Simulation results of six different system scenarios further exhibit the ability of proposed converter in successfully changing the inverter output voltage at different frequencies and varying load. All of these were achieved by the proposed converter while maintaining unity power factor, stable DC voltage and DC current, and sinusoidal inverter output voltage waveform.

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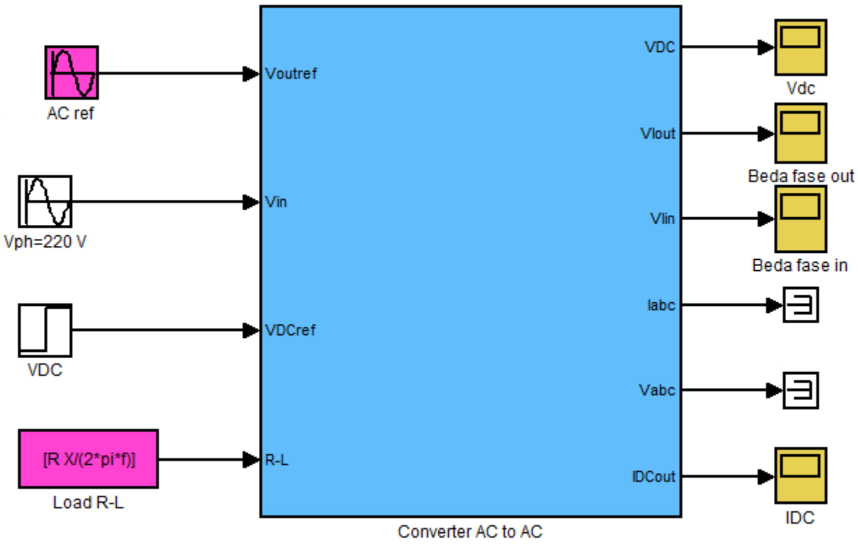
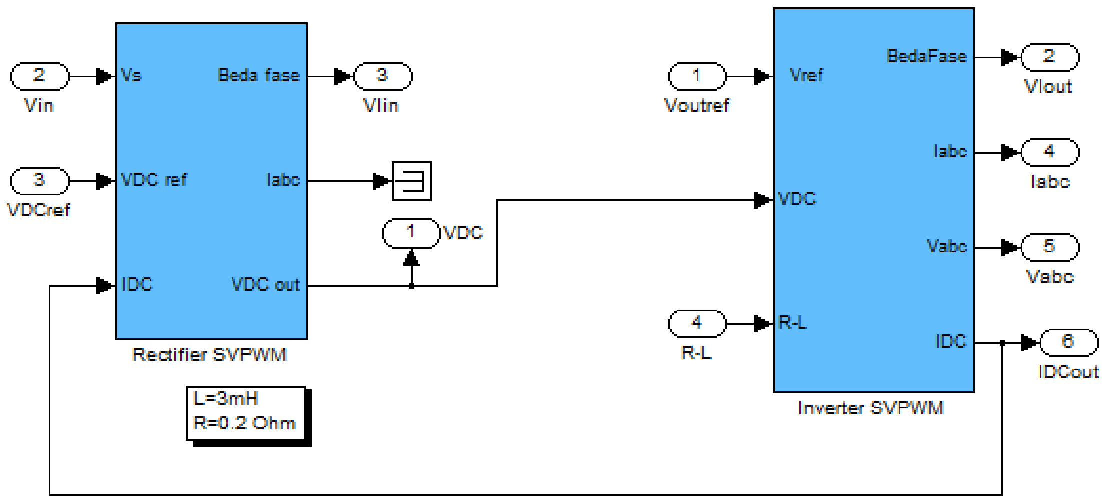
SIMULINK MODEL

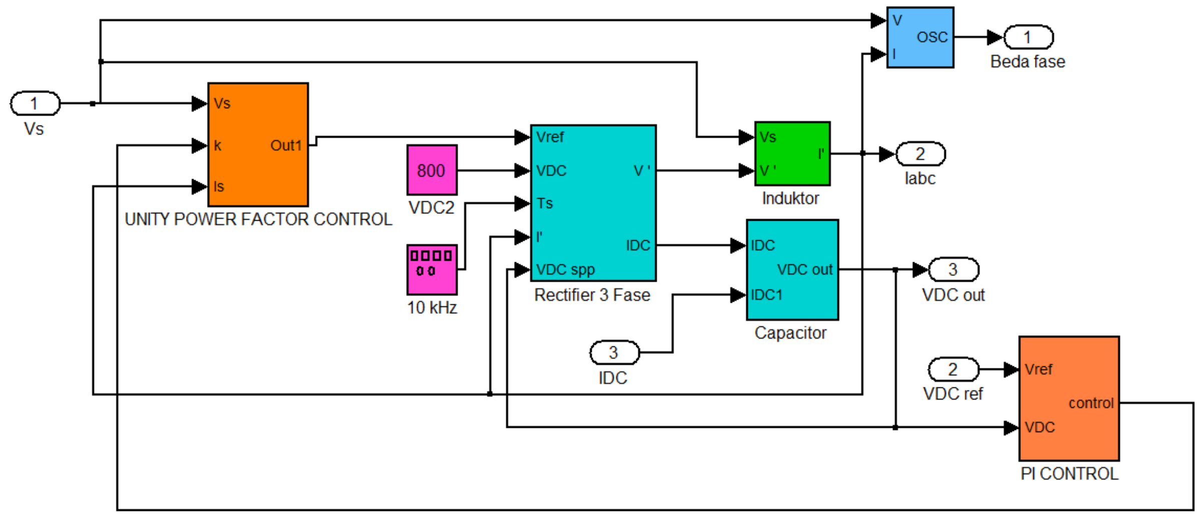
Power Factor Correction Of A Variable Voltage Variable Frequency AC-AC Converter Via Appropriate SVPWM Technique



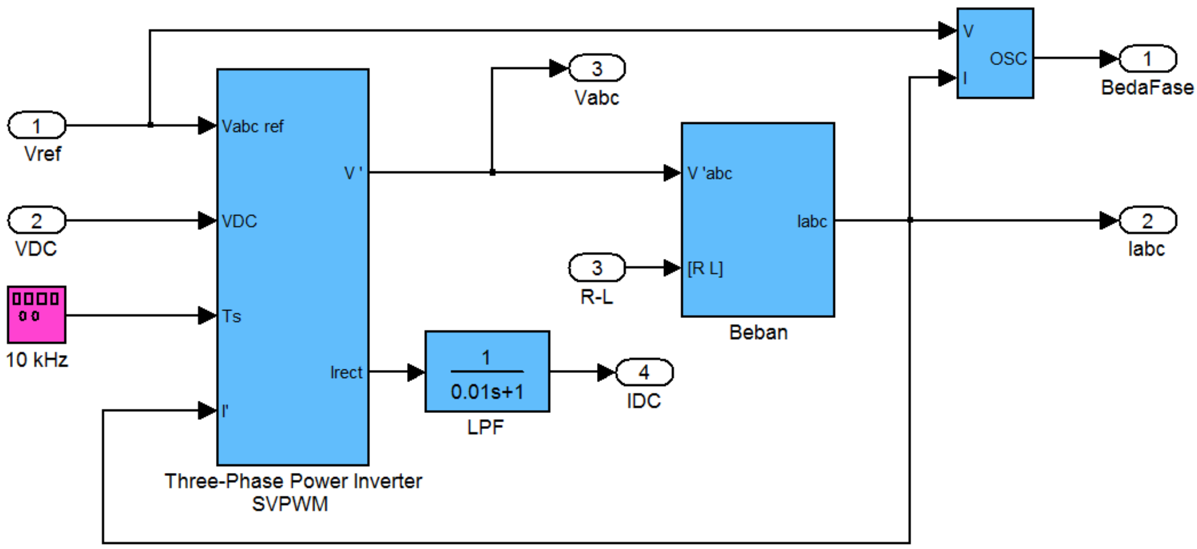
SIMULINK MODEL OF THREE PHASE POWER CONVERTER SPACE VECTOR PWM WITH UNITY POWER FACTOR AND PI CONTROL



SIMULINK MODEL OF THREE PHASE AC-AC CONVERTER (RECTIFIER AND INVERTER)

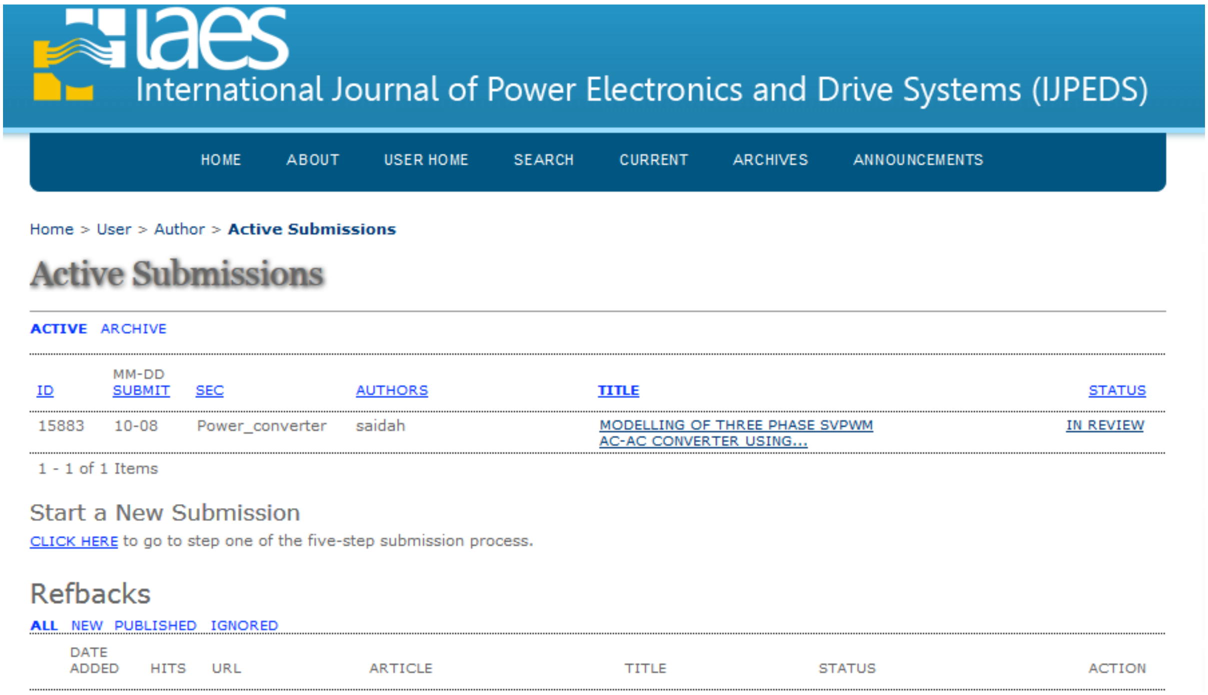


SIMULINK MODEL OF THREE PHASE RECTIFIER SVPWM



SIMULINK MODEL OF THREE PHASE INVERTER SVPWM

SUBMIT TO IJPEDS JOURNAL



Modelling of Three Phase SVPWM AC-AC Converter Using Unity Power Factor Control

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Article Info

Article history:

Received Sep 17, 2016
Revised Nov 22, 2015
Accepted Dec 3, 2016

Keyword:

AC-AC Converter
SVPWM
Power Factor Control
PI Controller

ABSTRACT

This paper introduces the modelling of a novel three phase AC-AC converter with indirect use of a capacitor as DC voltage link. The proposed converter has high efficiency because it uses Space Vector PWM (SVPWM) technique at both rectificier and inverter stages to operate the pulse width modulation in IGBT switches. The novel converter is equipped with a power factor control to shape the rectifier input current waveform to be sinusoidal and to be in phase with the input voltage. To keep the DC voltage stable, the converter utilizes PI controllers. Simulations are conducted for output voltage from 120 to 300 Volts with output frequency ranging from 30 Hz to 60 Hz. The simulation results show that the converter is able to maintain stable the DC voltage and current. Furthermore, the model demonstrates the benefits of proposed converter in terms of acquiring high input power factor and sinusoidal current waveform at the output side of the inverter.

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1. INTRODUCTION

AC power sources are frequently needed in industry to operate devices, with different amplitude and frequency from that provided by the grid. A power electronic circuit known as a three-phase AC-AC converter is used to convert a fixed AC voltage to a variable AC voltage with adjustable frequency. Some common applications of such converter that are widely used in industry include adjustable-speed drives, AC–AC transmission, uninterruptible power supplies (UPS) and renewable energy conversion systems [1]. However, the variable speed drive systems for induction motors constitute an important area of AC–AC conversion sue to the fact that it currently accounts for about 50% of electricity consumption [2]. To accomplish the most desirable operation, the AC-AC converters must be able to generate load voltages with arbitrary amplitude and frequency, produce sinusoidal source and load currents further implying the provision of unity power factor for any load, accommodate bidirectional power flow through the converters, and finally a simple and compact power circuit [3]. The most popular of approach for AC-AC converter involves the use of a DC-link component by employing either a capacitor (as a DC voltage source) or an inductor (as a DC current source). This type of converter is widely used in industry and is known as an indirect frequency converter with a DC energy storage element, and has been investigated extensively for many years [4]. This AC-AC converter has the main advantage that both rectification and inverter are largely separated for control process. On the other hand, the approach has inherent drawback of having DC link energy storage component that is relatively large in physical volume.

To address the aforementioned issue with the physical size of the DC link component, some researchers have developed other types of AC-AC converters without using the DC-link component. These converters are called a direct power-frequency converter. There are many direct power frequency converter topologies with the most common one is the Matrix Converter (MC). This converter has no DC energy storage elements and basically consists of an array of static power switches connected between the source and load terminals. For good performance direct frequency converters must have small capacitors and inductors, such as those used in their high frequency component filters or small regenerative AC energy storage. However MC has some disadvantages. The voltage transfer ratio is limited to 0.866 to obtain sinusoidal output waveforms [5]-[7]. It also requires more semiconductor devices compared to conventional AC–AC indirect converters. Moreover, MC is sensitive to disturbances at the input voltage to the system [8]. The MC has been observed to possess higher level of Total Harmonic Distortion (THD) compared to indirect converters [9].

This paper describes a proposed three phase AC-AC converter to convert 220 Volts, 50 Hz input into a variable voltage from 120 to 300 Volts with variable frequency from 20 Hz – 60 Hz. This converter belongs to the indirect converter type and it is suitable to operate asynchronous motors (induction motors) with various loads where expected speed, thus frequency, and variable voltage are needed. The proposed AC-AC converter is equipped with power factor controller to keep a unity power factor and obtain sinusoidal input current from the grid as well as sinusoidal ouput current. The converter offers high efficiency because it uses Space Vector PWM (SVPWM) to handle the pulse width modulation in its IGBT switch components.

2. MODEL OF AC-AC CONVERTER

2.1 Proposed AC-AC Converter Model

Figure 1 shows the proposed three Phase AC-AC converter model. The converter is an indirect converter with DC-Link capacitor as the energy storage element. The converter model consists of a rectifier, DC-Link capacitor and an inverter that implements the Space Vector Modulation (SVM) technique. The SVM control technique is used for both the rectifier and inverter feeding the induction motor. The SVM technique is chosen due to its more prevalent use than all other conventional techniques as the technique offers improved DC bus utilization, lower harmonics, less switching losses, and higher overall converter's efficiency [10]-[13]. The main task of the SVM technique is to calculate the duty cycles and define the switching pattern.

In the proposed converter and as illustrated in Figure 1, the novelty lies on the unity power factor control employed in the converter that will maintain the input power factor to the rectifier stage close to one. Consequently, the power factor control keeps the source current in the same phase as the voltage. The researchers previously used filters on the network side to obtain unity power factor [14],[15]. There are also researchers who use the technique of nonlinear backstepping control [16], PID Control [17] and voltage oriented controls with estimation of active power and reactive power [18]. There is PI controllers used in the proposed converter: the PI DC voltage control to maintain a stable DC voltage.

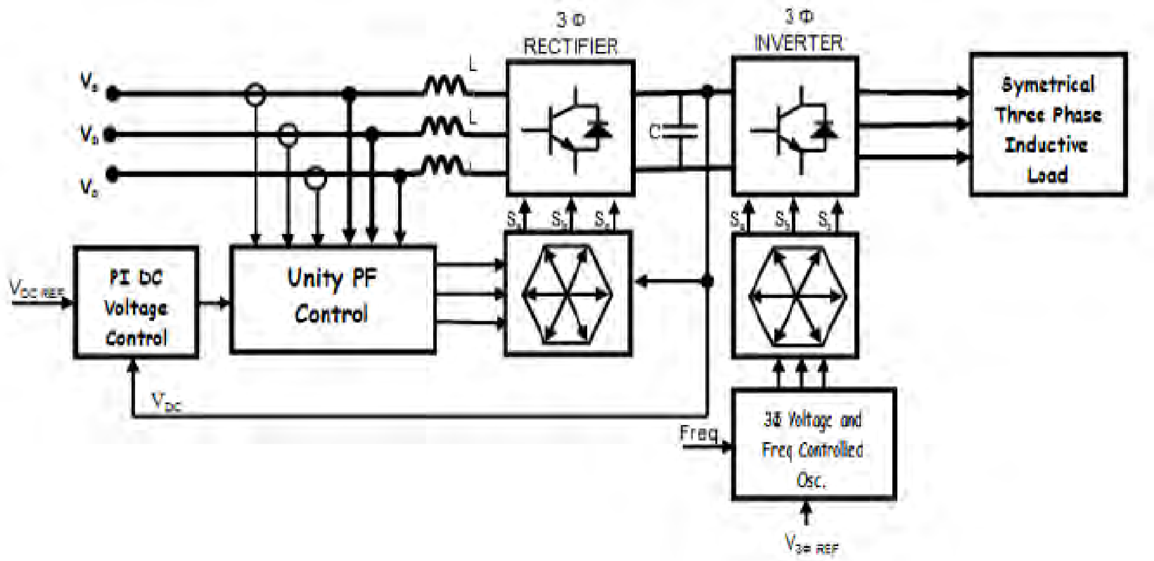

Figure 1. Proposed of AC-AC Converter

2.2 Unity Power Factor Control

Unity power factor occurs when the difference between voltage angle θ_V and current angle θ_I is zero degrees. In other words, it is established when voltage and current waveforms are in phase.

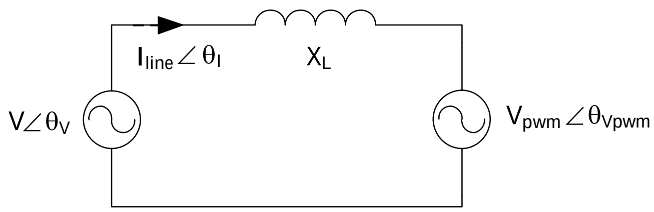

Figure 2. Equivalent circuit of the converter from the AC source side

The current regulator can be realized by making a calculation process to generate the desired PWM voltage, so that the current flowing in the inductor can be determined, as shown in Figure 2. In a power converter, if it is assumed that the sampling period is Ts, the inductor resistance is negligible, and the source input voltage at the sampling interval is considered constant, then the current flowing in the inductor can be determined according to the equation as follows:

$$V(t_n) - V_{PWM}(t_n) = L\frac{\Delta i}{\Delta t} = L\frac{i(t_n + T_s) - i(t_n)}{T_s} \quad (1)$$

where: $V(t_n)$ is the source voltage at t = tn

$V_{PWM}(t_n)$ is the PWM voltage on the AC side of the converter

Equation (1) can be written as:

$$V_{PWM}(t_n) = V(t_n) - \frac{L}{T_s}[i(t_n + T_s) - i(t_n)] \quad (2)$$

Here it appears that the magnitude of the inductor current that will flow at time t = tn + Ts can be determined by giving the PWM voltage according to the instantaneous current equation proportional to the voltage. This current setting provides the possibility to obtain a sinusoidal current waveform with a power factor equal to one. If the current is a sinusodal and has a phase equal to its voltage, then the reference current may be defined as:

$$i(t_n + T_s) = kV(t_n + T_s) \quad (3)$$

where k is a constant whose magnitude depends on the current to be streamed. This reference current does not change rapidly compared to the sampling period. Therefore, the current can be predicted through the previous value approach, as shown in Figure 3, as:

$$i(t_n + T_s) \approx i(t) + \frac{i(t_n) - i(t_n - T_s)}{T_s}.T_s \quad (4)$$

Or $$i(t_n + T_s) \approx 2i(t_n) - i(t_n - T_s) \quad (5)$$

according to equation (3), the reference current of equation (5) can be expressed as follows:

$$i(t_n + T_s) \approx 2kV(t_n) - kV(t_n - T_s) \quad (6)$$

By combining equations (2) and (6), the reference voltage can be obtained as:

$$V'(t_n) = (1 - \frac{2kL}{T_s})V(t_n) + \frac{kL}{T_s}V(t_n - T_s) + \frac{L}{T_s}i(t_n) \quad (7)$$

Equation (7) denotes the PWM voltage to be raised so that the current flowing in the inductor is k·V(t). Figure 4. shows the current regulator diagram of PWM converter with input voltage V(t), channel currenti(t), and k factor. This current regulator is realized in the calculation process by using a microprocessor, together with the PWM signal generation process. With the current regulator the current waveform will be the same as the voltage-shaped sinusoidal waveform and with the same phase. Figure 4. illustrates the vector diagram of the system.

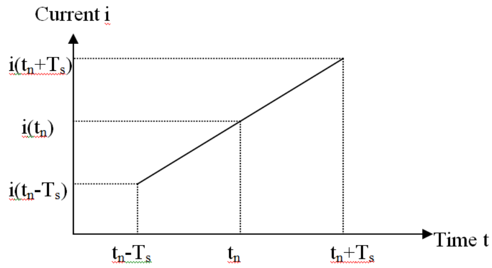

Figure 3. The reference current at the end of each period

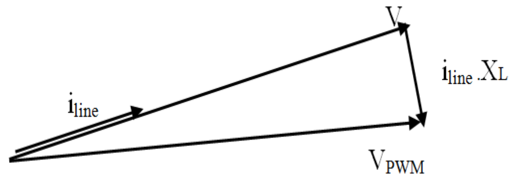

Figure 4. Vector Diagram of the converter from the AC source side

3. RESULTS AND DISCUSSION

The proposed AC-AC converter performance is simulated with Matlab/Simulink software. In the simulation, the three-phase source voltage is set at 220 V/50 Hz, the DC voltage is 1000 Volts and the sampling frequency is 10 kHz. The desired AC output voltage varies with variable frequency and different load impedance. The simulation is done on the output voltage from 120 to 300 Voltswith output frequency being varied from 20 to 60 Hz, while observing the power factor, DC voltage and current, the output voltage and current waveforms. The rectifier in the simulation follows the requirements of three-phase voltage source 220 V/50 Hz with amplitude √2 x 220 = 311 Volts, DC Voltage of 1000 Volts, and the sampling frequency is 10 kHz. To evaluate the performance of the proposed converter, six different cases were simulated and analyzed. Table 1 list the inverter specifications for each of these cases.

Table 1. Inverter Specifications

Case	Output Voltage	Amplitude Voltage	Output Frequency	Load
1	220 Volt	311 Volt	30 Hz	6 + j 8 ohm
2	250 Volt	353 Volt	50 Hz	10 + j 10 ohm
3	120 Volt	170 Volt	60 Hz	6 + j 8 ohm
4	120 Volt	170 Volt	50 Hz	10 + j 10 ohm
5	120 Volt	170 Volt	30 Hz	6 + j 8 ohm
6	300 Volt	424 Volt	30 Hz	10 + j 10 ohm

Case 1. DC voltage source 1000 Volts, voltage amplitude of inverter output 311 Volts, output frequency 30 Hz and load impedance 6 + j 8 ohm.

Simulation results are shown in Figures 5–8. Figures 5 and 6 show that DC Current and DC Voltage are both stable respectively with steady state DC voltage of 1000 Volts. The source current and voltage of the rectifier have the same phase as shown at Figure 7.,which results in unity power factor. The rectifier source voltage amplitude of 311 Volts at frequency 50 Hz is successfully converted to 311Volts at 30 Hz frequency sinusoidal output waveform, as depicted in Figure 8.

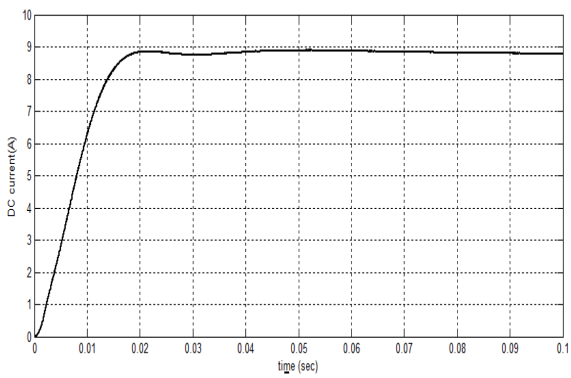

Figure 5. DC Current, Case 1

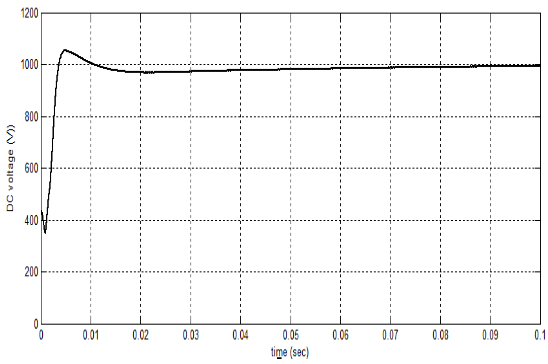

Figure 6. DC Voltage, Case 1

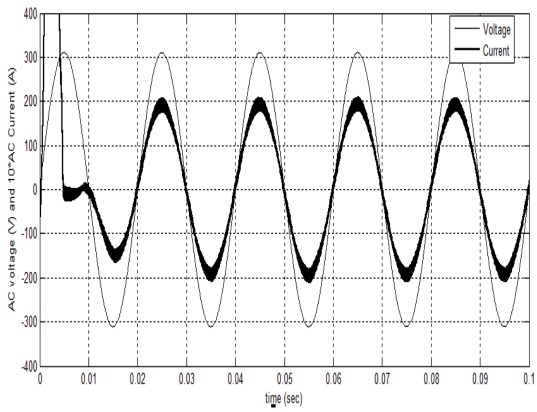

Figure 7. Amplitude of Voltage and Current at input of rectifier, Case 1

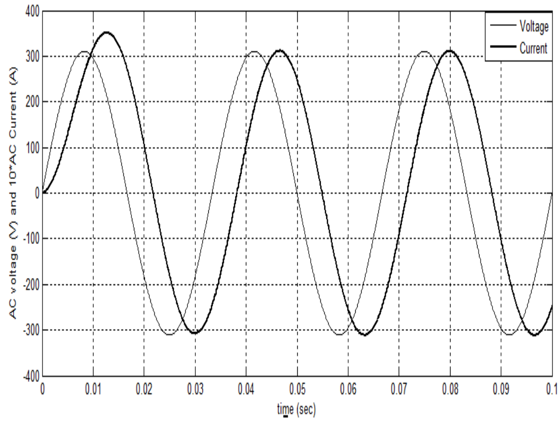

Figure 8. Amplitude of Voltage and Current at Output of inverter, Case 1

Case 2. DC voltage source 1000 Volts, voltage amplitude of inverter output 353 Volts, output frequency 50 Hz and load impedance 10 + j 10 ohm.

Simulation results are presented in Figures 9 – 12. As observed in the previous case, the result shows stable DC current and DC Voltage at 1000 Volt as illustrated in Figures 9 and 10 respectively. The source current and voltage of the rectifier have the same phase, which again proves the unity power factor, as shown in Figure 11. The rectifier source voltage amplitude of 311 Volts at frequency 50 Hz is again converted well to 353 Volts at the same frequency 50 Hz, as seen in Figure 12, while the output current waveform is sinusoidal as desired.

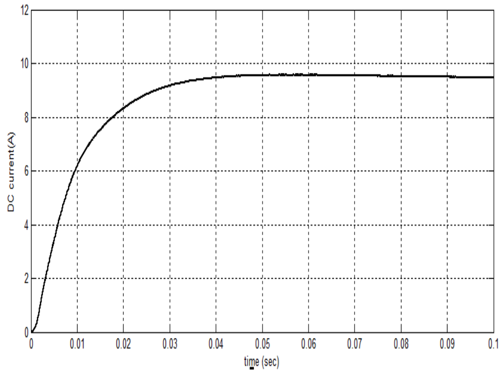

Figure 9. DC Current, Case 2

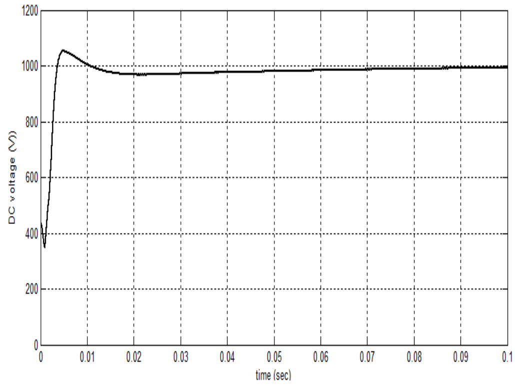

Figure 10. DC Voltage, Case 2

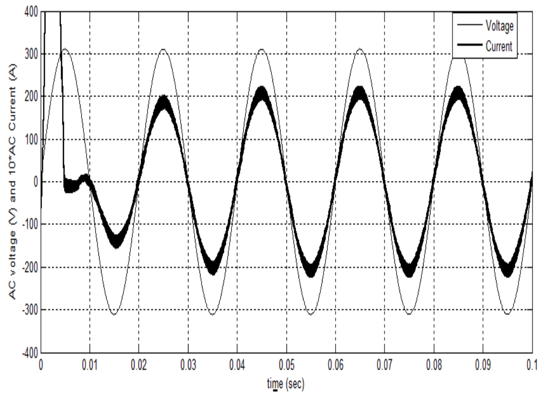

Figure 11. Amplitude of Voltage and Current at Iinput of rectifier, Case 2

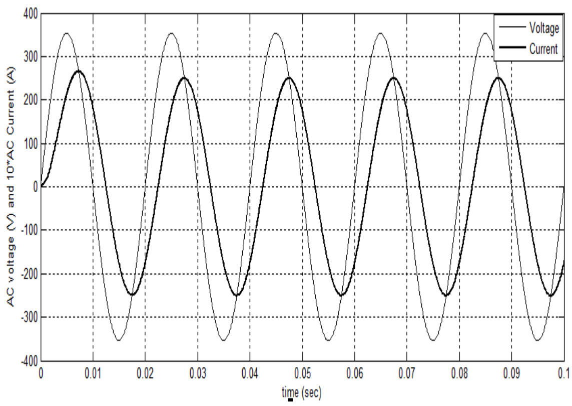

Figure 12. Amplitude of Voltage and Current at Output of inverter, Case 2

Case 3. DC voltage source 1000 Volts, voltage amplitude of inverter output 170 Volts, output frequency 60 Hz and load impedance 6 + j 8 ohm.

Simulation results as presented in Figures 13–16 again showstable DC current and DC Voltage at 1000 Volt as illustrated in Figures 13 and 14 respectively. The unity power factor has also been achieved between the source current and voltage of the rectifier as shown in Figure 15. The rectifier source voltage amplitude of 311 Volts at frequency 50 Hz is converted to 170 Volts at the same frequency 60 Hz, as depicted in Figure 16. , while again achieving the desired sinusoidal output current waveform.

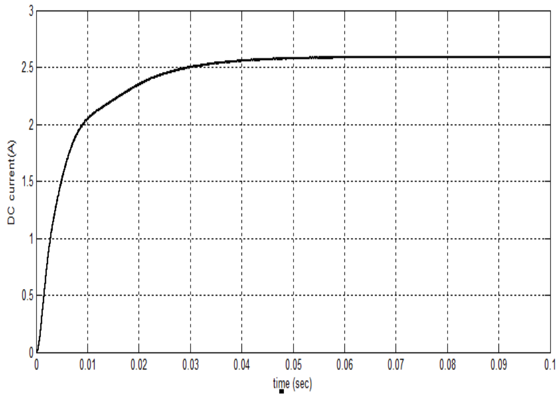

Figure 13. DC Current, Case 3

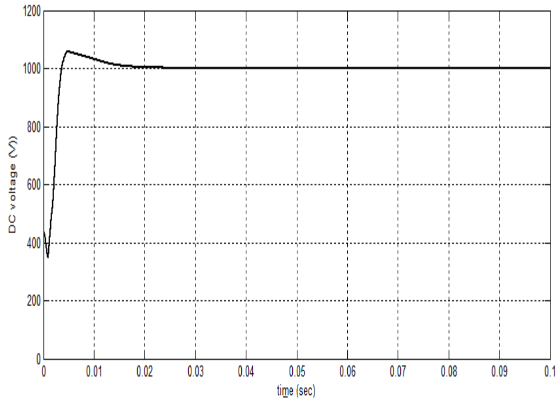

Figure 14. DC Voltage, Case 3

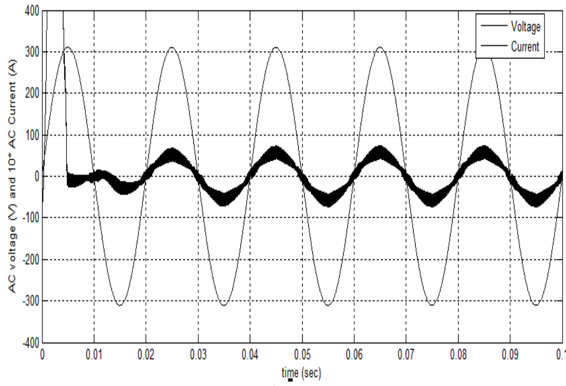

Figure 15 : Amplitudeof Voltage and Current at input of rectifier, Case 3

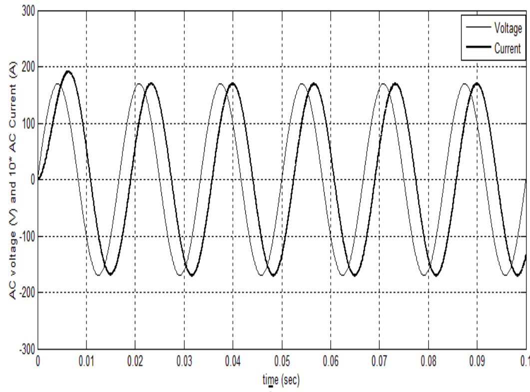

Figure 16. Amplitude of Voltage and Current at output of inverter, Case 3

Case 4. DC voltage source 1000 Volts, voltage amplitude of inverter output 170 Volts, output frequency 50 Hz and load impedance 10 + j 10 ohm.

Simulation results are shown in the Figure 17–20. Figure 17 shows stable DC current and Figure 18 shows DC voltage is stable at 1000 Volts. The source current and voltage of rectifier again shows that they are in phase as shown at Figure 19. The conversion of source voltage with amplitude of 311 Volts at 50 Hz takes place successfully to sinusoidal 170 Volts at 50 Hz as presented in Figure 20.

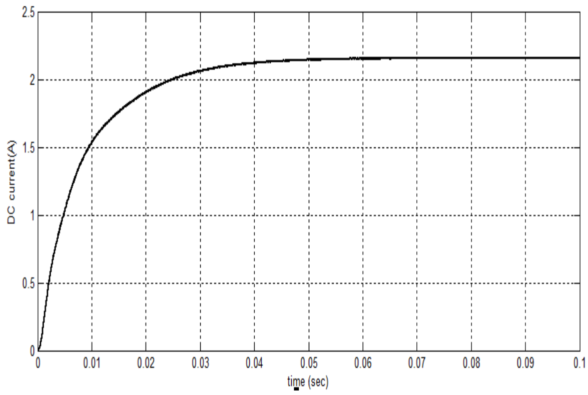

Figure 17. DC Current, Case 4

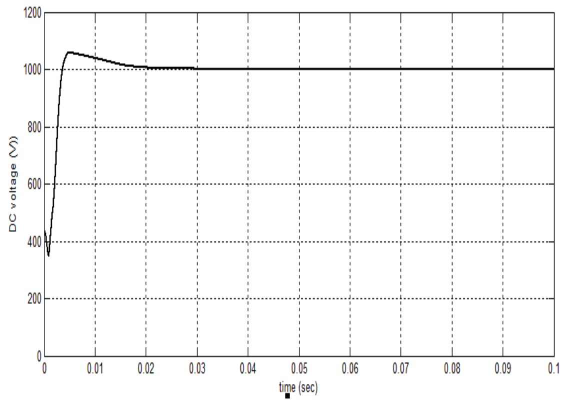

Figure 18. DC Voltage, Case 4

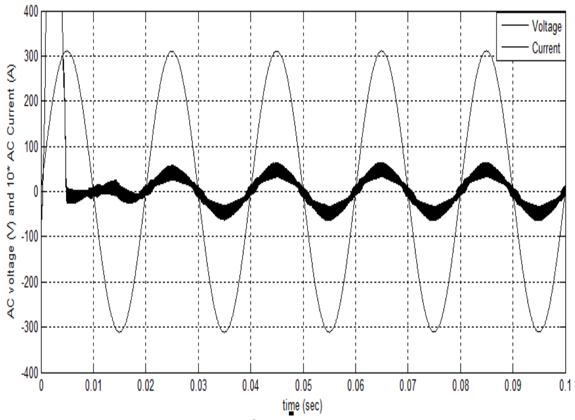

Figure 19. Amplitude of Voltage and Current at input of rectifier, Case 4

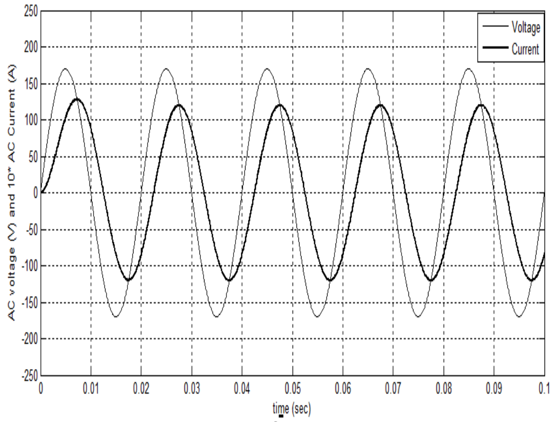

Figure 20. Amplitude of Voltage and Current at output of inverter, Case 4

Case 5. DC voltage source 1000 Volts, voltage amplitude of inverter output 170 Volts, output frequency 30 Hz and load impedance 6 + j 8 ohm.

Results of this case are in agreement with the previous ones. As illustrated in Figures 21 and 22, both DC current and DC voltage are stable. The source current is also in phase with the source voltage of rectifier, making the input power factor unity, see Figure 23. Sinusoidal output waveform is achieved after the conversion of source voltage amplitude of rectifier at 311 Voltsand 50 Hz to 170 Volts at 30 Hz took place, as depicted in Figure 24.

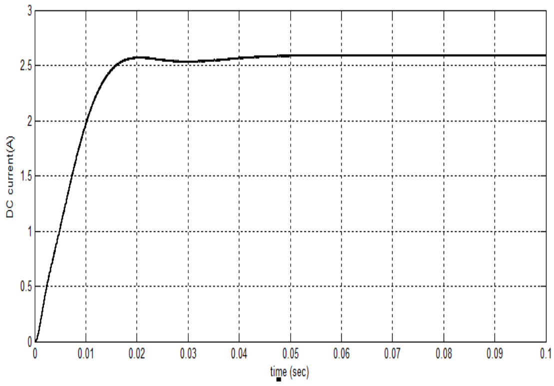

Figure 21. DC Current, Case 5

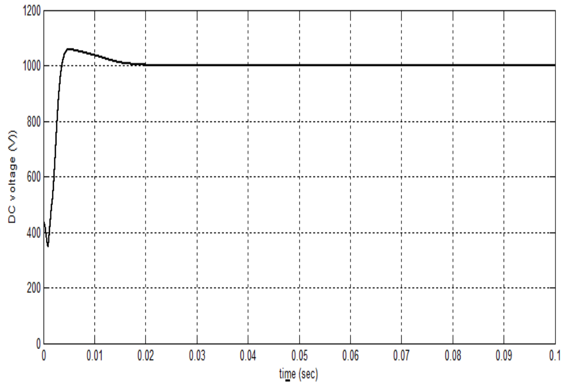

Figure 22. DC Voltage, Case 5

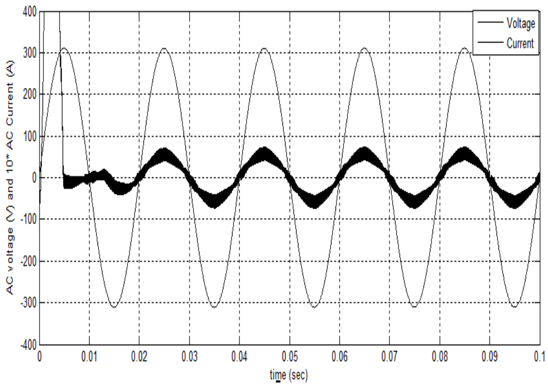

Figure 23. Amplitude Voltage and Current at input of rectifier, Case 5

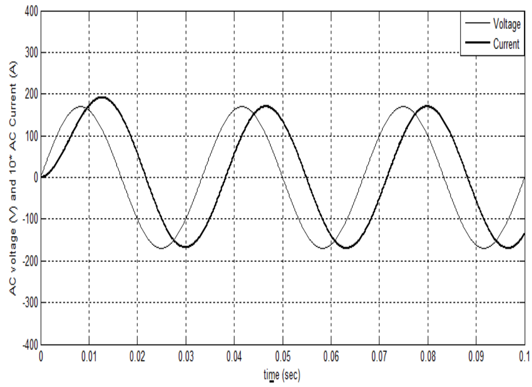

Figure 24. Amplitude Voltage and Current at output of inverter, Case 5

Case 6. DC voltage source 1000 Volts, voltage amplitude of inverter output 300 Volts, output frequency 30 Hz and load impedance 10 + j 10 ohm.

Simulation results for this case are consistent with those observed in the previous cases. Stable DC current and DC voltage are shown in Figure 25 and 26, and unity power factor as the result of in phase behavior of source current and voltage can be observed in Figure 27. The converter is also able to convert successfully

311 Volts at 50 Hz at the rectifier to sinusoidal 300 Volts at 30 Hz at converter's output in Figure 28.

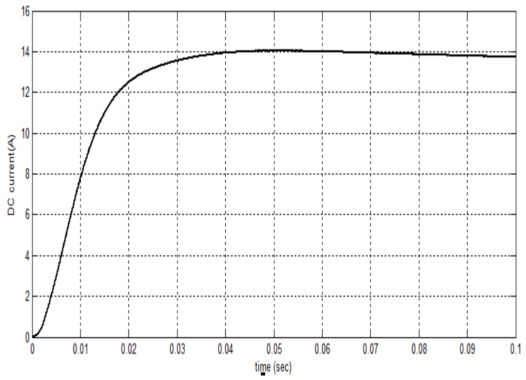

Figure 25. DC Current, Case 6

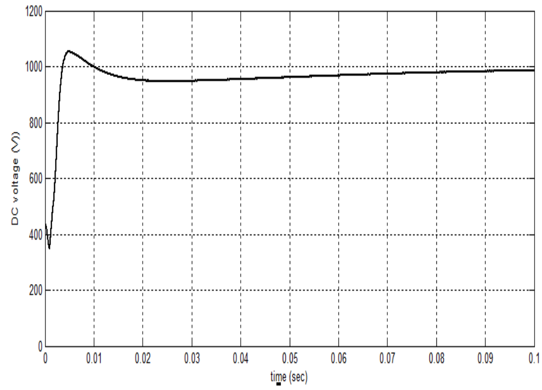

Figure 26. DC Voltage, Case 6

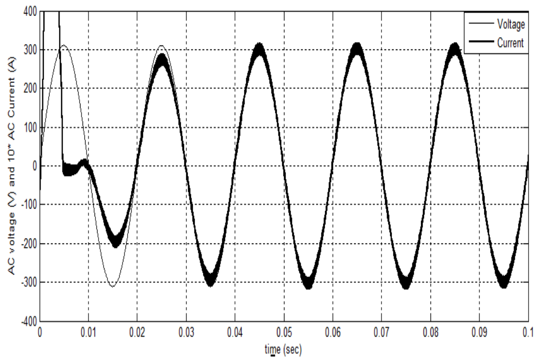

Figure 27. Amplitude Voltage and Current at input of rectifier, Case 6

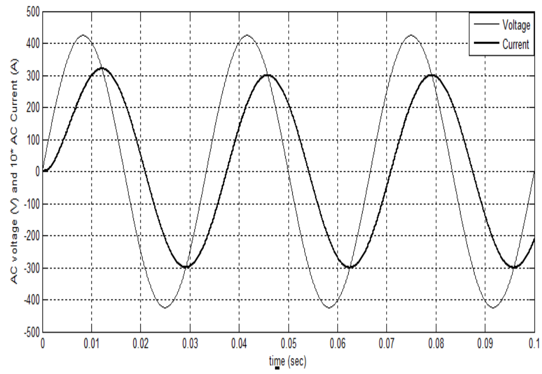

Figure 28. Amplitude Voltage and Current at output of inverter, Case 6

4. CONCLUSION

This paper presents a proposed three-phase AC-AC converter using a capacitor as an energy storage element. A model of the proposed converter was developed which utilizes power factor control to ahieve close to unity power factor. The proposed converter model also includes PI controllers to keep the DC voltage stable. The proposed AC-AC converter was tested using simulation to produce inverter output voltages ranging from 120 Volts to 300 Volts with frequencies between 30 - 60 Hz. Simulation results of six different system scenarios further exhibit the ability of proposed converter in successfully changing the inverter output voltage at different frequencies and varying load. All of these were achieved by the proposed converter while maintaining unity power factor, stable DC voltage and DC current, and sinusoidal inverter output voltage waveform.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to God, beloved family, and teachers. Special thanks are due to the Directorate General of Higher Education (Direktorat Jenderal Pendidikan Tinggi) that provided the funding for this research.

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TELKOMNIKA
Telecommunication, Computing, Electronics and Control
ISSN: 1693-6930, e-ISSN: 2302-9293
Accredited "A" by Directorate General of Higher Education (DIKTI)
Decree No: 58/DIKTI/Kep/2013
SCOPUS indexed

Vol 17, No 1

February 2019

DOI: http://dx.doi.org/10.12928/telkomnika.v17i1

List of accepted papers

Table of Contents

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TELKOMNIKA, Vol.13, No.2, June2015, pp. 125~132
ISSN: 1693-6930, accredited **A**by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI:10.12928/TELKOMNIKA.v13i2.xxxx

Ambient Light Adaptive LED Light Dimmer

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Abstract

This paper presents the design of an Adaptive Light Dimmer based on the method of sensingambient light content to adjust lamp's light intensity accordingly, and thus regulating the room's light content. The device is designed to work with renewable energy sources such as wind and solar energy. This would be useful in less developed countries where AC electricity is not well spread and renewable DC sources, such as solar, can be better utilized. It functions by using the TSL2561 light sensor, ATTiny85 microcontroller to output PWM to the LED driver, LT3795 LED driver to output current to an LED and LT3014 LDO to lower the input voltage and power the microcontroller and sensor. The dimmer is designed to work with a 48V input voltage and operate from an input light range of 20 to 100 Lux. Above 100 Lux the light is off and below 20 Lux the light is fully on.

Keywords*: light dimmer, LED driver, adaptive dimmer*

1. Introduction

With regard to efficiently using sustainable energy, there is a significant amount of data supporting the energy saving capabilities of light dimming technology. Some state that smart lighting, using sensors and controllers to control lighting, saves between 50% and 70% of energy compared to an uncontrolled lighting system [1-5]. These energy savings have huge impacts, considering that lighting accounts for about 19% of the electrical energy generated worldwide. In commercial buildings, lighting accounts for even more, 30-40% [6-11]. This being said, smart lighting seems to be the next logical step in saving electricity and tackling the problems of world-wide electrification in today’s world.

In order to improve smart lighting technology, it makes sense to utilize electrical devices, such as microcontrollers, to increase efficiency and usability of lighting systems. Microcontrollers would be a reasonable choice for controlling light dimmer due to their decreasing costs, versatility, and ease of use [12-14]. In addition to microcontrollers, DC-DC converters are also essential to improving smart lighting systems[15-17]. These converters are the most efficient ways of converting DC power and consequently are used in many stages of power conversion. Without them, electronics, such as lighting systems, would be much more inefficient. Any improvements to these DC-DC converters directly improve the efficiency and performance of smart lighting systems.

There are existing solutions for AC lighting in the form of smart lighting and socket to bulb interfaces [18-22]. Smart lighting uses “smart systems” to control lighting with applications in computers, tablet devices, or smart phones. On a larger scale, they can also be used to control the lighting system of a room, house, or building. They can wirelessly turn on and off lights, control their brightness, set the lights on a timer, and even integrate sensors. Existing socket to bulb interfaces use a sensor in an attempt to dim the bulb appropriately but they do not function very well. An example of an AC powered smart lighting device, called a home light control module (HLCM) and designed by Ying-Wen Bai and Yi-Te Ku, uses passive infrared (PIR) sensors, light sensors, a microprocessor, and an RF module to control light intensity in all the rooms of a house [23]. The system is illustrated in Figure 1. A single HLCM controls one set of luminaires. As a result, multiple microprocessors determine lighting levels, rather than a

Received February 23, 2014; Revised May 29, 2014; Accepted June12, 2014

single central controller. This device uses the PIR sensors to determine the presence of any people in a room, turning off the lights if no one occupies the room. The light sensors determine the room's brightness levels. If outside sources, like daylight, provide enough light, then the luminaires are turned off. Otherwise, the system activates the appropriate amount of luminaires to achieve the desired brightness levels. The device's RF module allows communication between different HLCMs. In the case that brightness levels are insufficient even when all luminaires are on, communication between HLCMs allows an adjacent HLCM to increase the number of lights to activate. This then affects the light intensity of the first device's room. While these components help this device operate with high efficiency, the design presented in this paper needs not contain any unnecessary modules if their inclusion greatly increases purchase costs. For example, there won't be any need to use the RF module if its use produces costs that outweigh its energy benefits. Additionally, the HLCM does not use light dimming technology while the proposed solution is based on light dimming.

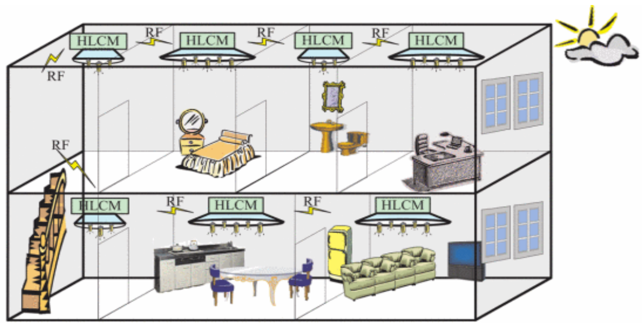

Figure 1. The configuration of an HLCM system for a 2 story house [20]

However, there are currently no existing DC dimmers that are inexpensive and entirely autonomous. The objective of the proposed solution is therefore to design and construct an adaptive DC light dimmer that autonomously dims a set of LEDs depending on the ambient light sensed in the room, providing the appropriate amount of light to the environment it is in. The end product of this project will save electricity usage; thus, reducing electrical costs and increasing the viability of renewable energy.

2. Design Methodology and Requirements

For the proposed design, the adaptive light dimmer must be able to produce the same or more light than a normal 60W incandescent light bulb at maximum brightness. This was determined to be roughly 800 lumens. If the adaptive light dimmer is incapable of producing the appropriate amount of light, a house may not be bright enough during darker hours of the day. Another important aspect is the efficiency of the device. Having better efficiency leads to less costs in terms of both energy and money. While both are definitely important, reduction in energy costs will likely have a greater impact on those rural areas depending on renewable energy sources, since these energy resources are much more limited. The adaptive light dimmer should have at least an efficiency of 70% at full load.

In addition, the device should consume a relatively low amount of power. Considering that the LED being used is a 5W rated LED, the maximum output power must be 5W. Derived from the efficiency requirement, the maximum input power must be 7.14W. The device must be able to operate from a 48V input, for example to match the DC bus used by the DC house project [24]. It should ideally be able to operate at other DC voltages as well for other applications. The device must also be quick to respond without causing abrupt changes. So, the device should be able to adjust its output at least once every two seconds. Each adjustment may need to be gradual for any sudden changes in the surrounding brightness levels.

The sensor should be sensitive enough that it can differentiate changes in daylight throughout the day. The sensor measures light intensity in lux, so the placement of the sensor can have a significant effect on measurement values. The best place to put the sensor is near the floor, as this minimizes the vertical movement of the sensor. Near the floor, the expected lux measurements range from 35 to 150 lux.The device will be connected to a lamp, so the entire system will be fairly large. Approximately, the height must be 4 to 5 feet, and the base should be about a foot in diameter. The height will also help to spread the light to the entire room.

Figure 2 depicts the block diagram of the design, consisting of specialized blocks each with their individual inputs and outputs (I/O). It specifies the types and connections of these I/Os and how it achieves the desired output to the level 0 block diagram. The system first takes the 48V DC and sends it through a Low-Dropout Regulator (LDO) to lower the voltage to 5V so that it may be used to power the microcontroller and photosensitive sensor. The photosensitive sensor communicates via i2c to the microcontroller to give a light intensity reading. The microcontroller then maps this reading to a corresponding pulse width modulated (PWM) control voltage that it outputs to the LED driver. Based on the PWM voltage it receives from the microcontroller, the LED driver outputs appropriate PWM current using the 48V DC from the bus. The LED is driven by the current output and produces the correct amount of light out.

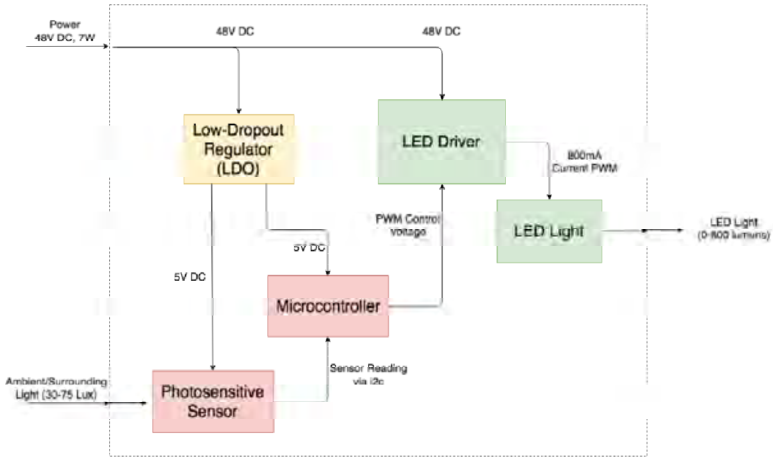

Figure 2. Block diagram of the adaptive light dimmer

The software flow diagram as illustrated in Figure 3 describes the process performed by the microcontroller. The microcontroller initializes the photosensitive sensor and then goes into an endless loop consisting of three stages. First it requests a reading from the sensor. Once it has received and stored this reading, it maps the reading to an appropriate PWM output value through a lookup table. The PWM is then written out to the appropriate pin.

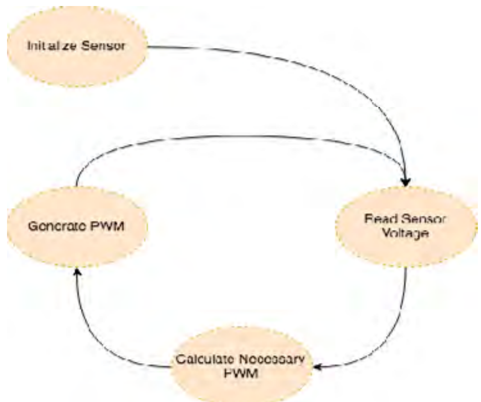

Figure 3. Software flow diagram of the adaptive light dimmer

3. Design and Simulation Results

The main purpose of the Adaptive Light Dimmer is to both minimize costs by using cheaper materials while maximizing efficiency and to operate from a DC voltage source, allowing renewables to be a direct source of power. Simplifying the design can also allow the device to operate without worry of installation. The Adaptive Light Dimmer has three main parts to design. First is the LED driver, which has to drive a 5V LED at a maximum current of 800mA.

The second is the LDO linear regulator, which had to step down the 48V input to 5V in order to power the microcontroller and the light sensor. The last portion of the design is the combination of the microcontroller and the light sensor, both of which have to operate at 5V.

The LED driver used is Linear Technology's LT3795 since it can operate with an input voltage of 48V. The circuit is a buck mode LED driver meant to operate from 24V to 80V and output a controlled current to the LEDs. This current can be controlled directly by changing the control voltage or by sending a PWM signal into the PWM pin of the device.The components that has to be changed are the input capacitor C_{IN}, the inductor L, the input current sense resistor $R_{INSENSE}$, the LED current resistor R_{LED}, the PMOS, the NMOS, and the PNP BJT. These components directly affect the operation of the circuit, so they are changed in order to produce the correct maximum output current and to keep the circuit from damaging any components in the design.Because the input voltage was 48V, during transient operation, the voltage could reach upwards of 63V; thus, requiring careful consideration when designing the circuit. The equation used to find the appropriate value of C_{IN} in microfarads is:

$$C_{IN} = I_{LED} \cdot V_{LED} \cdot \frac{(V_{IN} - V_{LED})}{V_{IN}^2} \cdot T_{SW} \cdot \frac{10\mu F}{A \cdot \mu s}$$
$$C_{IN} = 0.8A \cdot 5V \cdot \frac{(48V - 5V)}{(48V)^2} \cdot \frac{1}{400000Hz} \cdot \frac{10\mu F}{A \cdot \mu s} = 1.87\mu F \quad (1)$$

The equation for sizing the inductor:

$$L = \frac{(T_{SW} \cdot R_{SENSE} \cdot V_{LED} \cdot [V_{IN} - V_{LED}])}{V_{IN} \cdot 0.02V} = \frac{\left(\frac{1}{400000Hz} \cdot 0.015\Omega \cdot 5V \cdot [48V - 5V]\right)}{48V \cdot 0.02V} = 8.4\mu H \quad (2)$$

The input current sense resistor is determined more loosely. Because the configuration is a buck LED driver, the input current should not be very high, so $R_{INSNS}$is chosen as 100 mΩ. By the equation below, the maximum input current can be determined.

$$I_{IN(MAX)} = \frac{0.06V}{R_{INSNS}} = \frac{0.06V}{0.1\Omega} = 600\ mA \quad (3)$$

The LED current resistor is chosen such that the maximum LED current is 800mA. Because the control pins are tied high, the equation used to determine the LED current resistor is simplified to:

$$R_{LED} = \frac{0.25V}{I_{LED(MAX)}} = \frac{0.25V}{0.8A} = 312.5\ m\Omega \quad (4)$$

The PMOS and PNP BJT transistors are chosen differently because the ones from the datasheet are not readily available for both simulation and hardware tests. The same is true for the NMOS transistor, but in addition, the NMOS transistor is chosen to minimize the gate charge. Higher gate charge values increases the current in the INTVCC pin and could disrupt the operation of the circuit by dropping the INTVCC pin below the threshold.

$$Q_{G(MAX)} = \frac{I_{INTVCC}}{f_{OSC}} = \frac{0.02A}{400000Hz} = 50nC \quad (5)$$

The timing resistor, which determines the switching frequency of the LED driver, is determined to yield 400kHz. This frequency is neither too low, which would increase component sizing, nor too high, which would increase losses. The feedback resistors, which set the maximum output voltage, are adequate because the LEDs operated at 5 V. The sense resistor R_{SNS} is used to measure the actual current through the LEDs. Its value must be less than $0.07V/I_{LED}$, which for 800mA, is calculated to be 87.5mΩ. The final design of the LED driver is shown in Figure 4.

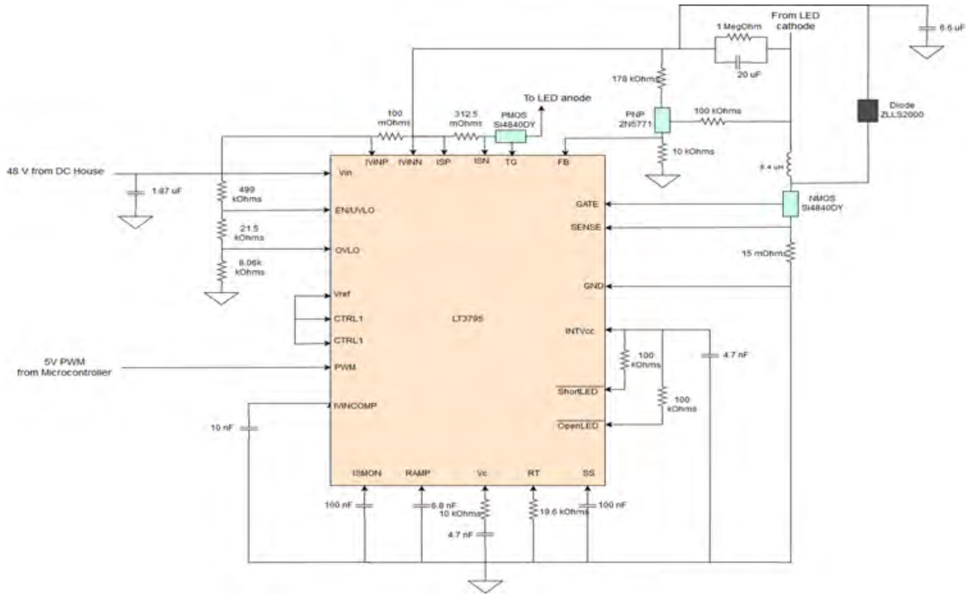

Figure 4. Final schematic of LED driver for the adaptive light dimmer

Simulations of the design were done using LTSpice. Results are shown in Figures 5 and 6 for the output voltage and the input current at 100% duty cycle, respectively.

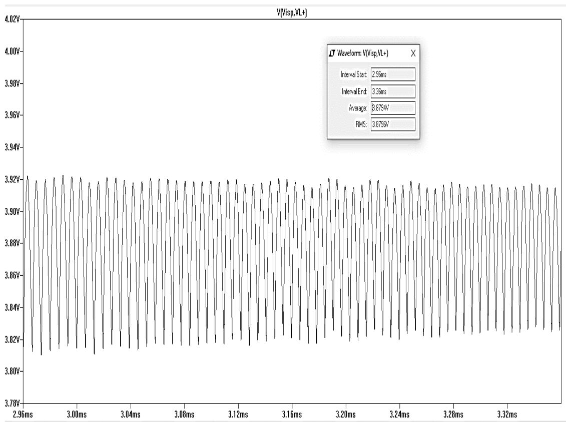

Figure 5. Simulation result for output voltage at 100% duty cycle

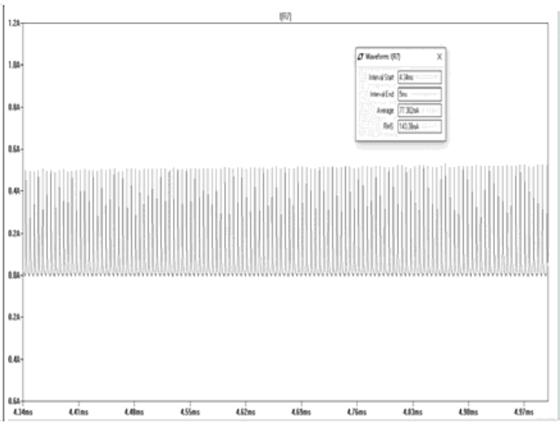

Figure 6. Simulation result for input current at 100% duty cycle

The second portion of the dimmer is the low drop-out regulator (LDO) circuit which lowers the 48V input to a usable 5V for the microcontroller and sensor. The LT3014 was chosen because it fits well into the design; it has the capability of dropping 48V to 5V, and it would incur little power loss since the microcontroller/sensor circuit would not pull a significant amount of current.Figure 7 shows the configuration of the LDO to be implemented taken from the LT3014 datasheet. This configuration is setup for “5V Supply with Shutdown” according to the datasheet and fits the needs of the light dimmer.The value of the capacitor on the output was specified to be at least 0.47μF to prevent oscillations.

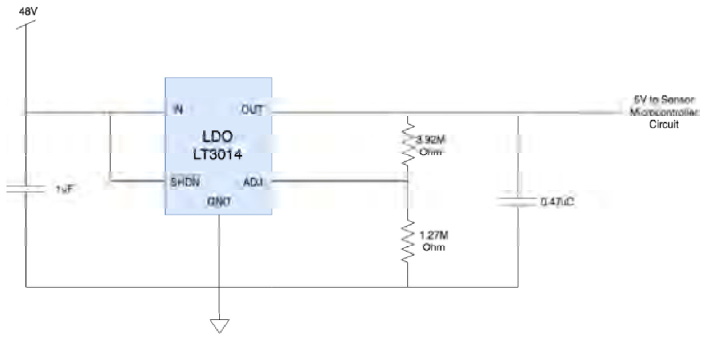

Figure 7. The LDO section of the adaptive light dimmer

The final portion of the dimmer consists of the sensor and microcontroller circuits. The VEML6070 is chosen due to its ability to communicate via I2C and to detect UV light, and because its operating voltage range that is the same as the ATTiny85. The ATTiny85 is chosen for its low cost, I2C capability and ability to produce a PWM output. In addition, it also can be programmed with the Arduino UNO using Sketch's built in "ArduinoISP" library.Since the VEML6070 communicates via I2C, the SDA (data line) and SCL (clock line) have 4.7kΩ pull up resistors to ensure proper logic levels. These are connected to the 5 V from the LDO, which supplies voltage to the microcontroller and UV light sensor. The output PWM on pin six on the microcontroller connects to the PWM input of the LED Driver. The ACK pin of the VEML6070 sends a signal if the UV light reading drops below a built in threshold and was not connected since the feature is not necessary for the function of the device. The ground is common to the LED driver and LDO circuits as well.The design of the circuit is shown in Figure 8.

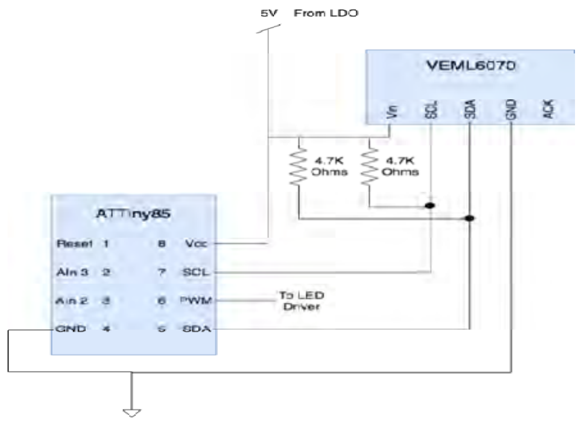

Figure 8. Sensor and Microcontroller Circuit Diagram of the adaptive light dimmer

3. Hardware Construction and Results

The hardware of the light dimmer was built and tested in separate stages. The LED driver, LDO, microcontroller, and sensor were tested individually and then combined to construct the entire system. After constructing the circuit on the PCB as shown in Figure 9, testing the individual components, and checking all possible connections, power was applied and the entire system to evaluate its functionality. Results from the test demonstrate that when dark below 10 Lux, the LED driver received 100% duty cycle and the lamp went to full brightness, and when bright above 100 Lux, the LED driver receives 0% duty cycle and the lamp outputs no light. Different duty cycles were assigned to different ambient light levels in between 0 and 100 Lux. This approach reduces the complexity in the operation of LED drive using the pulse density modulation [25-26].

The LED dimmed and grew brighter according to how much light reached the sensor, and the brightness changed smoothly without visible leaps in light output. The adaptive light dimmer worked as expected as ambient light levels increased and increased in brightness during low light.When dark, below 10 Lux, the LED driver received 100% duty cycle and the lamp went to full brightness and when bright, above 100 Lux, the LED driver receiver 0% duty cycle and the lamp outputs no light. Different duty cycles were assigned to different ambient light levels in between 0 and 100 Lux. The LED dimmed and grew brighter according to how much light reached the sensor, and the brightness changed smoothly without visible leaps in light output.Furthermore, the proposed design was quick to respond to changes in the environment, as the LED was able to change more quickly than once every two seconds and each change was gradual. This is important to prevent the LED's dimming from bothering users. Overall, the proposed adaptivelight dimmer is an improvement in functionality compared to the results presented in [2].

However, this achievement comes at the cost of efficiency because the microcontroller and sensor draw about 30 mA, increasing the input power needed while the output power of the LED stays constant. This current is relatively significant compared to 115 mA input current needed for the LED driver. Thus,the microcontroller and sensor increased the input current to yield input power by 26%. The high input voltage of 48 V meant that input power increased by about 1.44 W, about 1.29 W of which was dissipated through the LDO. Figures 10 through 12 detail the hardware test results of the adaptive light dimmer prototype. These results indicate the linear operation of the light dimmer as duty cycle is varied. The efficiency after connecting the microcontroller and LDO was 48.7%, which is well below that presented in [27]. Based on these results, the main function of sensing ambient light levels and dimming appropriately has been achieved by the proposed solution.

There are several ideas to improve the performance of the proposed adaptive light dimmer. One example involves the addition ofa 0.47 μF LDO output capacitor will be included on the PCB design to ensure that the microcontroller and sensor circuit were receiving a more stable voltage. This capacitor needs to be connected close to the supply of the microcontroller and sensor. The easiest way to do this would be to connect a 0.47 μF through-hole ceramic capacitor between the input voltage to the sensor on the PCB and the ground to the sensor on the PCB.

Figure 9. Adaptive light dimmer hardware prototype

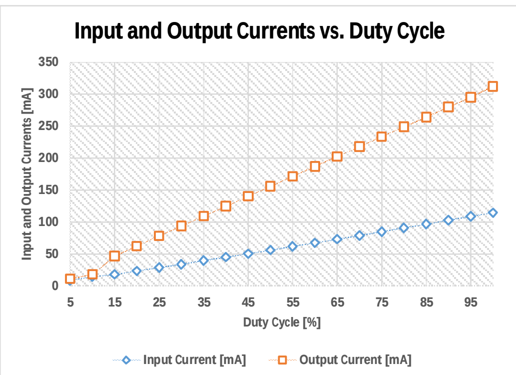

Figure 10. Hardware test results on input and output currents with varying duty cycle

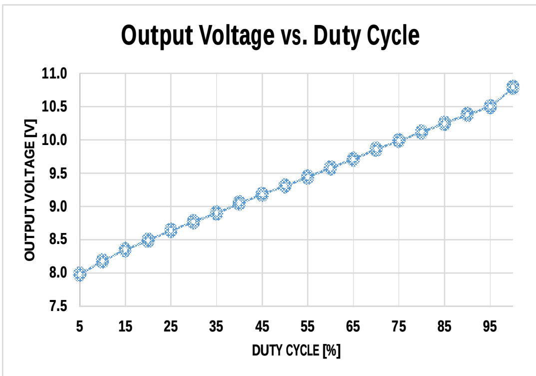

Figure 11. Hardware test results on output voltage with varying duty cycle

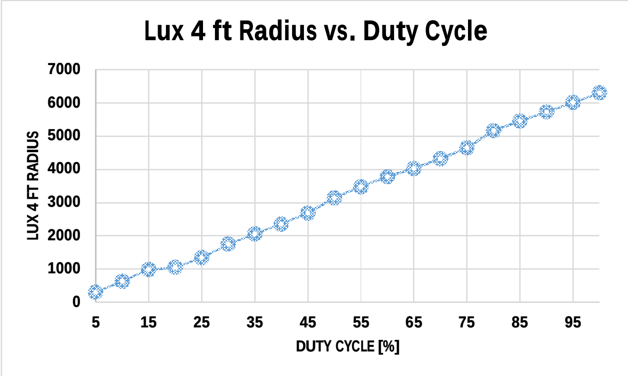

Figure 12. Hardware test results on Lux 4 ft radius with varying duty cycle

4. Conclusion

An adaptive LED light dimmerwhich operates automatically based on ambient light condition was presented in this paper. The design has been shown through computer simulation and hardware prototype tests to successfully perform the dimming function following the changing condition of the ambient light. Theproposed solution reduces the complexity of previous approaches and it can be adapted to any DC system operating at different DC voltage levels. Further improvements of the proposed solution involves increasing the overall system efficiency. This could be done by utilizing a snubber to the NMOS switch to reduce switching losses at 400 kHz. The PCB design could also be optimized for better signal integrity since many components are farther apart on the current PCB design. Additionally, an alternative to the LDO utilized in the proposed designmust be sought to further improve the overall efficiency.

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Nomor : Lemlit. 042 / B.1.06/ X/ 2018
Lampiran : 1 (satu) berkas
Perihal : Undangan
Kepada
Yth : Ketua Peneliti Riset Dasar (daftar nama terlampir)
Di –
Tempat

Menindaklanjuti surat dari Direktur Riset & Pengabdian Masyarakat Kemenristek Dikti nomor : 3321/E3.2/LT/2018, tanggal 19 Oktober 2018 perihal pelaksanaan Monev Eksternal Penelitian Perguruan Tinggi Tahun 2018, maka bersama ini kami selaku host mengundang bapak/ ibu untuk hadir pada :

Hari/tanggal : Rabu, 8 Nopember 2018
Jam : 08.00 WIB – 20.00 WIB
Tempat : Ruang RM. Soemantri Gedung A Lantai III & Ruang Proklamasi Gedung A Lantai II Universitas Dr. Soetomo
Rundown : Terlampir

Berkaitan dengan acara tersebut dimohon ketua peneliti wajib hadir dan mempersiapkan bahan paparan tentang pelaksanaan, capaian, hasil luaran penelitian dan kelengkapannya (foto, produk, artikel dan lain-lain) serta rencana penelitian tahun berikutnya.

Mengingat padatnya acara tersebut, maka kami mohon peserta hadir paling lambat 30 menit lebih awal dari jadwal yang kami sediakan.

Demikian kami sampaikan, atas perhatian dan kerjasamanya kami sampaikan terima kasih.

Surabaya, 29 Oktober 2018
Ketua Lembaga Penelitian

Dr. Sri Utami Ady, SE, MM
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Surabaya, 29 Oktober 2018

Ketua Lembaga Penelitian

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RUNDOWN PELAKSANAAN MONEV EKSTERNAL RISET DASAR
TANGGAL 8 NOPEMBER 2018, UNIVERSITAS DR SOETOMO

Ruang Proklamasi Gedung A Lantai 2 Universitas Dr. Soetomo

Ruang	Tanggal	Jam (WIB)	NAMA Ketua Peneliti	Institusi / Perguruan Tinggi	Reviewer
A	8 Nopember 2018	08.30 - 12.00	ACHMAD YANU ALIFFIANTO	Institut Bisnis dan Informatika STIKOM Surabaya	DURAN COREBIMA ALOYSIUS
			MOHAMMAD ABU JAMIIN	Politeknik Perkapalan Negeri Surabaya	DURAN COREBIMA ALOYSIUS
			FIDIANA	Sekolah Tinggi Ilmu Ekonomi Indonesia Surabaya	DURAN COREBIMA ALOYSIUS
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			DIDIK SETYO PURNOMO	Politeknik Elektronik Negeri Surabaya	DURAN COREBIMA ALOYSIUS
			DWI KURNIA BASUKI	Politeknik Elektronik Negeri Surabaya	DURAN COREBIMA ALOYSIUS
			PRIMA KRISTALINA	Politeknik Elektronik Negeri Surabaya	DURAN COREBIMA ALOYSIUS
			TRI HARSONO	Politeknik Elektronik Negeri Surabaya	DURAN COREBIMA ALOYSIUS
		12.30 - 16.30	AGUS SAMEKTO	Sekolah Tinggi Ilmu Ekonomi Perbanas Surabaya	DURAN COREBIMA ALOYSIUS
			BURHANUDIN	Sekolah Tinggi Ilmu Ekonomi Perbanas Surabaya	DURAN COREBIMA ALOYSIUS
			EMANUEL KRISTIJADI	Sekolah Tinggi Ilmu Ekonomi Perbanas Surabaya	DURAN COREBIMA ALOYSIUS
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			RATNA SETYARAHAJOE	Universitas Bhayangkara Surabaya	DURAN COREBIMA ALOYSIUS
			SAIDAH	Universitas Bhayangkara Surabaya	DURAN COREBIMA ALOYSIUS
		18.00 - 20.00	MUHAMMAD UDIN HARUN AL RASYID	Politeknik Elektronik Negeri Surabaya	DURAN COREBIMA ALOYSIUS
			YUGOWATI PRAHARSI	Politeknik Perkapalan Negeri Surabaya	DURAN COREBIMA ALOYSIUS
			WIWIEK HARWIKI	Universitas Dr Soetomo	DURAN COREBIMA ALOYSIUS
			NEVRETTA CHRISTANTYAWATI	Universitas Dr Soetomo	DURAN COREBIMA ALOYSIUS

RUNDOWN PELAKSANAAN MONEV EKSTERNAL RISET DASAR
TANGGAL 8 NOPEMBER 2018, UNIVERSITAS DR SOETOMO

Ruang RM. Soemantri Gedung A Lantai 3 Universitas Dr. Soetomo

Ruang	Tanggal	Jam (WIB)	NAMA Ketua Peneliti	Institusi / Perguruan Tinggi	Reviewer
B	8 Nopember 2018	08.30 - 12.00	TATANG SOPANDI	Universitas PGRI Adi Buana	SUTRISNO T
			NYOMAN PUSPA ASRI	Universitas W R Supratman	SUTRISNO T
			AGUS DWI SASONO	Universitas Narotama	SUTRISNO T
			FLORIANUS ROOSLAN EDY SANTOSO	Universitas Narotama	SUTRISNO T
			RUSDIANTO S	Universitas Narotama	SUTRISNO T
			WIDYAWATI BOEDININGSIH	Universitas Narotama	SUTRISNO T
			RONALD	Universitas Pelita Harapan Surabaya	SUTRISNO T
			VIERLY ANANTA UPA	Universitas Pelita Harapan Surabaya	SUTRISNO T
		12.30 - 16.30	SUNING	Universitas PGRI Adi Buana	SUTRISNO T
			ACHMADI SUSILO	Universitas Wijaya Kusuma Surabaya	SUTRISNO T
			MIARSONO SIGIT	Universitas Wijaya Kusuma Surabaya	SUTRISNO T
			ROESWANDONO	Universitas Wijaya Kusuma Surabaya	SUTRISNO T
			SRI ARIJANTI PRAKOESWA	Universitas Wijaya Kusuma Surabaya	SUTRISNO T
			SUKIAN WILUJENG	Universitas Wijaya Kusuma Surabaya	SUTRISNO T
			TJATURSARI WIDIARTIN	Universitas Wijaya Kusuma Surabaya	SUTRISNO T
			FARIDA	Universitas Dr Soetomo	SUTRISNO T
		18.00 - 20.00	IWAN JOKO PRASETYO	Universitas Dr Soetomo	SUTRISNO T
			NUR SAYIDAH	Universitas Dr Soetomo	SUTRISNO T
			REDI PANUJU	Universitas Dr Soetomo	SUTRISNO T
			SRI UTAMI ADY	Universitas Dr Soetomo	SUTRISNO T