10th Eco-Energy and Materials Science and Engineering Symposium


On December 5-8, 2012
Sunee grand hotel,
Ubon-ratchathani

Organized by

Co-organized by
PREFACE:
Message from the President of Rajamangala University of Technology Thanyaburi

Rajamangala University of Technology Thanyaburi (RMUTT), in conjunction with Kyoto University, is pleased to host the 10th Eco-Energy and Materials Science and Engineering Symposium (10th EMSES). This international conference is not only giving an opportunity for Thai and foreign researchers to present and discuss their research works and update their expertise but also to initially stimulate the development of research works on eco-energy and materials science and engineering. Our program consists of six research tasks: (1) Energy Technology, (2) Environmental and Social Impact, (3) Nanotechnology and Materials Science, (4) Energy Economics and Management, (5) New Energy technology and (6) Nuclear Technology.

I would like to take this opportunity to express our sincere gratitude to our two distinguished Plenary Speakers for kindly accepting our invitation. I deeply appreciate of the very strong support given by Kyoto University. Thanks to the tireless works of the Organizing Committee, the Technical Program Committee, the invited speakers and paper and poster contributors, and excellent program been assembled to cover a broad spectrum of interesting topic. We warmly welcome you to the 10th EMSES on December 5-8, 2012, Ubon Ratchathani, Thailand.

Numyoot SONGTHANAPITAK, Ph.D.
President of Rajamangala University of Technology Thanyaburi
and Conference Chairman of 10th EMSES 2012
PREFACE:
Message from the Director of
Institute of Advanced Energy, Kyoto University

It is my great pleasure to have the 10th Eco-Energy and Materials Science and Engineering Symposium (EMSES) with Rajamangala University of Technology Thanyaburi (RMUTT) under the long-term collaboration between RMUTT and Kyoto University. The 1st EMSES was held in 2001 in Thailand and the symposium has been expanded in its scientific contents as well as the academic network. I believe that the 10th EMSES gives a good opportunity to all participants to exchange their knowledge and idea to realize eco-friendly energy system in society. I would like to express my welcome to all participants and sincere thanks to the 10th EMSES organizing committee and all supporting organizations to make us having this symposium.
I hope that the symposium will be successful and lead to further progress in energy science and technology and also in friendships of participants.

Professor Yukio Ogata, Ph.D.
Director of Institute of Advanced Energy, Kyoto University
I want to express my hearty welcome to all participants of Eco-Energy and Materials Science and Engineering Symposium (10th EMSES). This symposium is aiming the realization of importance of energy and materials technology through the academic, science and technology network among the world communities. The symposium gives an opportunity for researchers to discuss their research works and also to initially stimulate the development of research works on eco-energy and materials science and engineering. Once the cooperation among researchers has been created, the further cooperation work will be developed.

I would like also extend my sincere thanks to all who made the meeting possible, including the 10th EMSES organizers, the SEE forum committee members, and the Japanese Government, JSPS, for their kind support. I am looking forward to seeing you in Ubon Ratchathani, Thailand.

Professor Takeshi YAO, Ph.D.
Former Dean of Graduate School of Energy Science, Kyoto University
and Program Leader, Global COE “Energy Science in the Age of Global Warming”
Message from the Chairperson of 10th EMSES Organizing Committee

Rajamangala University of Technology Thanyaburi (RMUTT), in conjunction with Kyoto University, is pleased to host the 10th Eco-Energy and Materials Science and Engineering Symposium (10thEMSES).

RMUTT has a major mission on encouraging and supporting all areas of research. One of the key reasons is to assist in developing capability in science and technology in order to cope with recent rapid change in this field. We have jointly set up an academic symposium on the 10thEMSES with the perception on the significance of exchanging knowledge and research experiences between researcher in the field of energy, materials technology and environmental science. This symposium is not only giving an opportunity for Thai and foreign researcher to present and discussion their research works and update their expertise but also to initially stimulate the development of research works on eco-energy and materials science and engineering. Once the cooperation among researchers has been created, the closer future cooperation incorporate with joint-research works will be developed. Thus, to support the aforesaid role, the symposium working committee would like to invite you to participate in this academic symposium.

I would like to express our sincere thanks to the organizing committee, participants and contributors for your kind corporation to this symposium. I wish this symposium proceeding will be a useful reference for future scientific research development.

Sommai PIVSA-ART, Ph.D.
Dean of Faculty of Engineering, RMUTT
Director of CoE on Sustainable Energy System (Thai-Japan)
Organizing Chairman of 10th EMSES 2012
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30 x 100 = 3330
### Conference Program of 10th Eco-Energy and Materials Science and Engineering

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<td>09:45-10:45 am</td>
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<td>Chair</td>
<td>Prof. Dr. Padungsak Ratthanachai</td>
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<td>Dr. Wirachai Ryonarin</td>
<td>Dr. Sorapong Pavaupreec</td>
<td>Asst. Prof. Dr. Warunee Intayawiriyanan</td>
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<td>Prof. Dr. Hideaki Ohgaki</td>
<td>Prof. Dr. Susumu Yoshikawa</td>
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<td>Dr. Supakij Suittuengwong</td>
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| Chair      | Asst. Prof. Dr. Krischosme Blumkittipich |
| Co-Chair   | Dr. Sorapong Pavaupreec and Dr. Sumonman Niamlang |
### 10th EMSES 2012

**Conference Program of 10th Eco-Energy and Materials Science and Engineering**

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<td>Dr. Seichi Aiba</td>
<td>Prof. Dr. Takeshi Yao</td>
<td>Asst. Prof. Dr. Somchai Hiranvarodom</td>
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<td>Dr. Leong Yew Wei</td>
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<td>Assoc. Prof. Dr. Kawee Srikulkit</td>
<td>Prof. Dr. Jun Li</td>
<td>Prof. Dr. Hiroyuki Hamada</td>
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<td>Assoc. Prof. Dr. Yuji Aso</td>
<td>Dr.Sarocha Charoenvai</td>
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<td>Prof. Dr. Keiji N. Ishihara</td>
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<td>Dr. Winai Chanpeng</td>
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*Prof. Dr. Takeshi Yao, Leader of GCOE Program/Professor, Graduate School of Energy Science, Kyoto University*
Application of Three-level Diode-clamped Converter on 10 kW Distribution Voltage Restorer

W. Chankhamrian, K. Bhumkittipich and N. Mithulananthan
Power and Energy System Research Centre, Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi, Klong 6, Thanyaburi, Pathumthani 12110
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Abstract—This paper presents development distribution voltage restorer (DVR) using three-level diode-clamped converter for create voltage to compensate with switching device is IGBT. Converter controls injection voltage by using voltage regulations, low-pass filter for filter harmonics signal and reduce signal distortion from the DVR. It is considered output voltage waveform of the converter. Simulation results show the effectiveness of the DVR to present. The output voltage waveform of three-level diode-clamped converter has a signal distortion less than output voltage waveform of original two-level converter. Moreover, three-level diode-clamped converter can also get a higher voltage range as well. The experimental results show that the proposed DVR has increased the efficiency and also it is able to compensation more than 0.1 second.

Keywords—Distribution Voltage Restorer, Three-level Diode-clamped Converter, Voltage Sag

1. INTRODUCTION

Transmission power system is an important factor and have essential for economic development and the stability of Thailand, especially the development of industries that require large amounts of electrical energy. Transmission power system to supply the electric power to the load must have high reliability. If fault occurs in the power system will cause voltage sag, voltage swell, interruption or disturbances that cause rapid changes in voltage [1]. From the events above that causes the voltage difference of the normally wave form, these affect to consumers. Most of the electrical load currently is sensitive to the failure of the voltage, cause damage to the equipment and information systems, including the loss of time and business opportunities affected hugely damage. Considering the causes and effects of power quality problems to prepare to cope with this problem and create equipment in order to optimize system efficiency is improved.

The power quality problems that may affect the electrical equipment such as small electronic devices or other equipment contained in appliances, make device is damage or cannot use it, depending on the severity or type of problem. Short duration variation is phenomenon that is changing the voltage or current only a short time. Most caused by fault in power system. Which phenomenon of power quality in this group are voltage sag, voltage swell and voltage interruption [2].

Therefore equipment will be used to solve the problem this is Distribution Voltage Restorer (DVR) which is connected for the generate voltage to compensate make load voltage is normal. DVR control is required to detection the voltage sag to calculation the voltage magnitude and frequency to compensate correct. Present the various technologies used to provide the features and performance the best. The important power system requirements are operation rapid of the DVR, for sensitive load not damaged or has been damaged the least.

In the recent past, there are many researches on the DVR, such as design using a single loop control. Which can control the peak of voltage but sensitivity of control is bad. It also does not display details of control [2]. Then, proposed a new method to the system. However, there is no clear comparison to the past research [3]. Later has tried to demonstrate the investment analysis of complex systems clearly, but also lack of basic information in order to understand easy [4]. Although, results of various researches can be compensate for voltage sag. Also has unclear in the control of the DVR. Therefore has tried to simplify the algorithm in terms of control. However, the converter is operating to make noise and disturb the measurement signal [5].

Therefore, this paper proposes development of distribution voltage restorer (DVR) by using the topology of diode-clamped three-level converter to reduce signal distortion from the DVR. The proposed procedure is as follows.

2. VOLTAGE DIP OR SAG

Voltage Dip or Sag is the magnitude of the voltage lower than normally voltage during a short period and return to normal. Which that period is the duration of the voltage sag, mainly, cause by a fault in the power system as shown in Fig. 1 or the start-up of a large load. It has two important parameters, namely the magnitude and duration of the voltage sag.

The voltage sags in power system under IEEE 1159-1995 standard [6] is the reduction of the magnitude of voltage supply in a short time, since 0.5 cycles until a minute and return to normal conditions as shown in Fig. 2. The rms value of voltage between 0.1 p.u. and 0.9 p.u. compared with the voltage of the system is 1.0 p.u. Mainly, cause by a fault in the power system as shown in Fig. 3.

![Fig.1 voltage sag caused by the single-phase to ground fault](image-url)
3. DISTRIBUTION VOLTAGE RESTORER

The operation of DVR, initial will injected voltage into the power system to peak voltage, frequency and phase control at the grid points, to make the voltage at the load has been equal to the normal voltage. The structure of the DVR is show in Fig. 4. Generally consists of a converter, filter, transformers, energy storage and control systems.

Fig. 2 IEEE 1159-1995 standard

Fig. 3 fault in power system that causes voltage sag

Voltage sag drop across load line can be obtained from equation (1).

\[ V_{\text{sag}} = V_s \frac{Z_f}{Z_s + Z_f} \]  

(1)

When \( V_{\text{sag}} \) is peak value of voltage at PCC point when fault occurred

\( V_s \) is voltage source

\( Z_f \) is impedance between PCC point and Fault point

\( Z_s \) is impedance between source and PCC point

Fault in the power system are not only voltage levels reduced but also the main reason that causes the phase angle of the electrical equipment as well [7]. This can be obtained from equation (2).

\[ \phi = \tan^{-1} \left( \frac{X_s}{R_s} \right) - \tan^{-1} \left( \frac{X_s + X_f}{R_s + R_f} \right) \]  

(2)

When \( Z_s = R_s + jX_s \) is impedance between PCC point and Fault point

\( Z_f = R_f + jX_f \) is impedance between source point and PCC point

\( \phi \) is voltage angle at PCC point when fault occurred

Fig. 4 Components of the DVR

Fig. 5 DVR is like voltage source connected in series

Fig. 5 shows the DVR, which is like as a voltage source that can control the peak, frequency and phase of voltage. Injected voltage series to the power system, reference voltage injection of the DVR into the system will be converted to a PWM signal to inverter operation. The difference of the reference voltage, depending on the suitability of various control methods. Is there a way to compensate for the 3 methods [8] is

1. Pre-Sag Compensation
2. in-Phase Compensation
3. Energy Optimization Technique

Compared methods the 3 methods, it is obvious that the magnitude of the voltage injected into the system of pre-fault compensation and minimum energy optimization is larger than the in-phase compensation methods, but The minimum energy optimization method, DVR will use active power in very small quantities. The pre-fault compensation method is used active power larger than other method. However, it is the most accurate to compensate. To simplify, we can split the components into 3 main parts [5] is the converter, energy storage and controller parts.

3.1 Converter part

Fig. 6 Circuit of the 3-phase DVR

This part is used to generate a voltage compensate. The main component is the converter circuit. In addition transformer may be included, if the installation of power system has high and medium voltage. Fig. 6 shows the 3-phase DVR. However, for power system has low voltage. It was not appreciated used transformer connect to between converter circuit and power system. It is a direct converter to power system. Because of the disadvantages of the transformer causes a phase shift and voltage drop.
In addition important problem is the saturation of the transformer and Inrush current. This makes requires transformer size is 2 times of size of the DVR [10]. As a result, transformer has large size and expensive. In high and medium voltage power system that, when used transformer will have an impact on the transformer as well.

### 3.2 Diode-clamped three-level converter

Diode-clamped three-level converter 1-phase type shown in Fig. 7 will has use a three-level of DC voltage from the two capacitors connected in series for divide voltage of DC power supply. Three-level converter advantages over two-level converter is the voltage levels increases, making output current with low distortion and reduced Inrush current for the switching device. Compared to the two-level converter with a DC link voltage is same. Generate pulse width modulation (PWM) method for multi-level converter can divide to 3 types [11] is

1. **APOD**: Alternative Phase Opposition Disposition
   Triangle waveform adjacent to the phase difference 180°. Triangle waveform for three-level converter is similar to generate PWM method POD type as shown in Fig. 8.

2. **POD**: Phase Opposition Disposition
   Triangle waveform above with below when compared to the reference zero point will have the phase difference 180° as shown in Fig. 9.

3. **PD**: Phase Disposition
   All triangle waveform must have the same phase as shown in Fig. 10.

Fig. 7 Diode-clamped three-level converter 1-phase type

From 3 techniques above, generate PWM method PD type will cause the least harmonics. So in this paper select of techniques PD to generate signal as shown in Fig. 11. The advantages of this technique is. Low frequency of the harmonics frequency was born the two times of the switching frequency. In addition the two times of harmonics frequency of the switching frequency will zero just remaining Sideband as shown in Fig. 12. Thus makes it easy to filter.

Fig. 8 Alternative Phase Opposition Disposition

Fig. 9 Phase Opposition Disposition

Fig. 10 Phase Disposition

### 3.3 Energy storage part

This part has important for capability to compensate for voltage sag in terms of load that can be received and the time to compensate. Generally use capacitors to be purchased easily and cheaply. Capacitor size can be obtained from equation (3).

\[
C_{bus} = \frac{2V_{\text{con(max)}}I_{\text{con(max)}}}{(V_{\text{bus(max)}} - V_{\text{bus(min)}})}
\]  

(3)

When
- \( C_{bus} \) is capacitor size
- \( V_{\text{con(max)}} \) is maximum voltage can be compensate
- \( I_{\text{con(max)}} \) is maximum current can be compensate
- \( t_{\text{con(max)}} \) is maximum duration can be compensate
- \( V_{\text{bus(max)}} \) is maximum DC bus voltage
- \( V_{\text{bus(min)}} \) is minimum DC bus voltage

### 3.4 Controller part

This part is the most important in the compensation voltage sag. Responsible for controlling the start or stop the system and calculate the compensate for voltage then send signal to the converter part to operation. Operation of control systems starting in occurred voltage sag. Detector will verify it. When there are signs it, the reference voltage generator part is created reference voltage for comparison with the actual voltage in the system. After, the voltage in this comparison will sent to PWM in the compensating voltage generator & voltage injection part for drive the converter, so it will inject voltage into the system. Block diagram of the control as shown in Fig. 13.
4. SIMULATION AND EXPERIMENTAL RESULT

4.1 Simulation result
The simulation program is MATLAB/SIMULINK. DVR will be connected to the secondary side of transformers in the distribution system as shown in Fig. 14. The defined as fault in the power system at a time 0.1 seconds until 0.04 seconds, three-phase voltage 380 V 50 Hz, Switching frequency 20 kHz, \( C_p = 8\mu F \), \( L_d = 2mH \), \( R_r = 32\Omega \), \( C_{aux} = 6,600 \mu F \), Criteria of the voltage sag \( |V_s| \leq 108V \), \( \Delta \theta > 1.85^\circ \) or \( \Delta \theta < 1.75^\circ \) and load is series RL, it has value 13 \( \Omega \) and 19 mH respectively.

From simulation compensation voltage sag the results in case of single line to ground fault at phase A to ground and double line fault between phase A and B as shown in Fig. 15 and 16 respectively. That compensation by three-level and two-level converters can compensate for voltage sag as well. However, in the circuit used three-level converter, it is obvious that the harmonics frequency \( f_0 \) 40 kHz and 80 kHz is less than used two-level converter. The total harmonics distortion of voltage (THDv) is equal to 1.91%. For the effect of a single line to ground fault, three-level converter is less than two-level converter to 2.05%. In the three-level converter circuit the THDv equal to 1.83%. This is less than a two-level converter to 1.90% for the effect from double line fault.

4.2 Experimental result
The experiment, DVR will be installed to power system as shown in Fig. 17 After that, simulate to have voltage sag in the power system by voltage sag generation. Control of DVR uses dSPACE board. Fig. 18 shows input and load before have voltage sag. Which, it has characteristic wave form as same.
5. CONCLUSION

This paper presents reduction of distortion signal from the DVR by using three-level diode-clamped converter. The simulation results show that the voltage sag compensation by using three-level converter proposed can solve the voltage sag problem as well. Load voltage while the voltage sag occurs has close to normal voltage (1.0 p.u.). When compared with the two-level converter that although the voltage sag compensation is the same. However, voltage waveform of the three-level converter has signal distortion is less than two-level converter. As a result, the harmonics in the power system has less as well. Moreover, the experimental result shows that the proposed DVR has increased the efficiency and also it is able to compensate more than 0.1 second.

REFERENCE


