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BULANIK MANTIK DENETLEYİCİ KULLANARAK ÇİFT AKTİF KÖPRÜ ÇEVİRİCİ TABANLI ELEKTRONİK GÜÇ TRANSFORMATÖRLERİNİN DENETİMİ (1)

CONTROL OF DUAL ACTIVE BRIDGE CONVERTER BASED SOLID-STATE TRANSFORMERS USING FUZZY LOGIC CONTROLLER

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Öz: Son zamanlarda, elektronik güç transformatörü (EGT) olarak adlandırılan güç elektroniği çeviricileri tabanlı yeni bir transformatör ortaya çıkmıştır ve birçok araştırmacı bu transformatörlerin tasarımı ve denetimi üzerine yoğunlaşmıştır. Bu çalışmadaki EGT yapısı giriş, izolasyon ve çıkış kısımlarından oluşmaktadır. Giriş kısmında, üç tane tek fazlı doğrultucu AC gerilimi DC gerilime dönüştürmek için tasarlanmıştır ve DC bara gerilimleri dayanıklı yapıya sahip olan bulanık mantık denetleyici ile denetlenmiştir. Giriş kısmından elde edilen DC gerilim izolasyon kısmına iletilmiştir. İzolasyon kısmında kullanılan çift aktif köprü çevirici de bulanık mantık denetleyici ile denetlenmiştir. Çıkış kısmında ise yükü beslemek için tek fazlı evirici kullanılmıştır. Ayrıca, önerilen denetim metotlu EGT yapısı için benzetim çalışmaları gerçekleştirilmiştir.

Anahtar Kelimeler: Çift Aktif Köprülü Çevirici, Bulanık Mantık Denetleyici, Güç Elektroniği Çeviricileri, Elektronik Transformatör

Abstract: Recently, a new type transformer based on power electronics converters, which are named as power electronic transformer (PET) or solid-state transformer (SST) has emerged and many researchers have focused on the control and design of these transformers. In this paper, SST structure includes three stages such as input, isolation and output stages. In the input stage, three single-phase rectifiers are designed for convert AC voltage into DC voltage and DC bus voltages are controlled by fuzzy logic contoller (FLC) which has robust structure. DC voltage obtained from input stage is transmitted to the isolation stage. Dual active bridge converter used in isolation stage is also controlled by using FLC. In the output stage, single-phase inverter is used in order to feed load. Moreover, simulation studies are realized for SST structure with proposed control method.

Key Words: Dual Active Bridge Converter, Fuzzy Logic Contoller, Power Electronics Converters, Solid-State Transformer

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INTRODUCTION

It is well-known that transformers (50Hz) are one of the most important parts in modern electrical distribution and transmission systems. Moreover, transformers are widely used in electrical power systems in order to perform many functions such as voltage-current transformation, galvanic isolation, energy transfer and noise decoupling, etc. However, Conventional transformers are one of the most bulky and expensive components in electrical power systems because of the composition consisting of iron cores and windings have undesirable properties such as heavy weight and large size, low performance under load unbalance, sensitivity to harmonics, larger loss (Chuanhong et al., 2014; Dujic et al., 2013; Falcones et al., 2010; Iman-Eini et al., 2008).

With improvements in power electronics, microprocessors and semiconductor materials, power electronics technology has become inevitable for many sectors and applications. Recently, a new type transformers concept which is based on power electronics converters, has been introduced. These new transformers are named as PET or SST which realizes voltage-current transformation, galvanic isolation, power quality improvement, reactive power compensation, power flow regulation and power factor correction in one circuit (Ling et al., 2011; Liu et al., 2009).

SSTs have first proposed by McMurray in 1970 (McMurray, 1970). Then, studies on SSTs have performed and many researchers have focused on the design and control of SSTs (Seon-Hwan et al., 2013; Wang et al., 2007; Xu, 2013; Xu, 2014; Zhao et al., 2013). There are generally two approaches such as with dc link and without dc link for SSTs. SSTs with dc-link have three stages such as input, isolation and output stages. Input stage has a rectifier which is used to convert AC voltage into DC voltage. Isolation stage which realizes the galvanic isolation between the primer and secondary side consists of DC-DC converter and high frequency transformer. Output stage consists of two level three-phase inverter which produces the desired output voltages and LC filter (Dujic et al., 2013; Falcones et al., 2010).

In this paper, we have been proposed a SST structure with dc-link. Rectifier at input stage and DAB converter at isolation stage are controlled by FLC in order to improve dynamic performance of proposed SST structure. Moreover, The rest of this paper is organized as follows. In section II, it has given information about proposed SST structure and design of proposed controller is shown in section III. The simulation results are given in Section IV. Conclusions are presented in section V.

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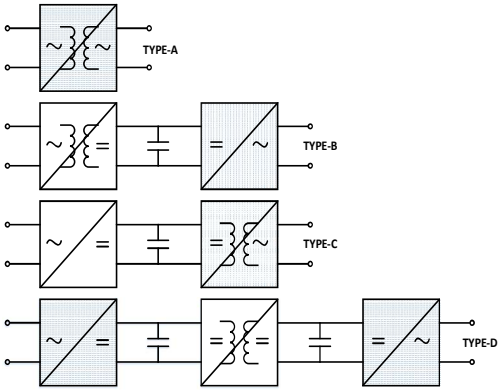


Fig. 1. Topology Classification of SST

CONTROL and ANALYSIS of SSTs

There are generally four basic topology configurations for SST structures as shown in Fig. 1, such as type A, B, C, and D. Type A has low cost and light weight solutions due to the simple configuration. However, the lack of DC-link makes them unsuitable for applications where reactive power compensation is required.

In type B consists of isolated AC-DC conversion stage and DC-AC conversion stage. Type C has the two-stage conversion, in which the galvanic isolation and voltage step-down are realized by the DC-AC stage, therefore low voltage DC link is not available. Type D has three-stages such as input (AC/DC conversion), isolation (DC/DC conversion) and output stages (DC/AC conversion) (Falcones et al., 2010).

This structure is the most preferred topology because it can reactive compensation. As shown in Fig. 2, Designed SST structure consists of an AC/DC rectifier, a DC/DC converter with a high frequency transformer and a DC/AC inverter. The SST is rated as single phase input voltage 50 Hz, 7.2kV, output voltage 50 Hz, 220V. The SST has high voltage high frequency AC/DC rectifier that converts 50Hz, 7.2kV AC to three cascaded 3800 V DC bus, three high voltage high frequency DC-DC converters that convert 3800V to 400V DC bus and a voltage source inverter that inverts 400V DC to 50 Hz, 220V. The isolation stage uses a high frequency transformer with 3.8kV/400V turns ratio to step down the voltage. d-q vector control is applied to input stage since all AC quantities can be expressed as DC in single-phase rectifier control. An imaginary m-axis that is 90° vertical to phase-a is formed (Dujic et al.,

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2013). The quantities of the d-q axis can be calculated with the following equation.

$$T = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \quad (1)$$

$$[x]_{dq} = T[x]_{am} \quad (2)$$

Control diagram of the single-phase rectifiers used in cells is given in Fig. 3.

According to the control diagram, the average of the output voltages of the cells (E1+E2+E3)/3) are compared with a reference voltage E_{ref}. Error of DC voltage is applied to FLC controller. Reference value of d-axis current is obtained from output of FLC controller. Also, the d_d and d_q are calculated according to the single phase d-q vector control (Zhao et al., 2013).

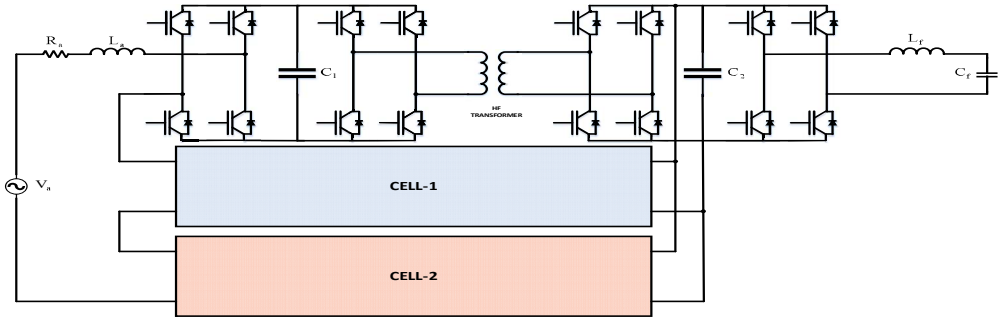


Fig. 2. Configuration of SST Structure

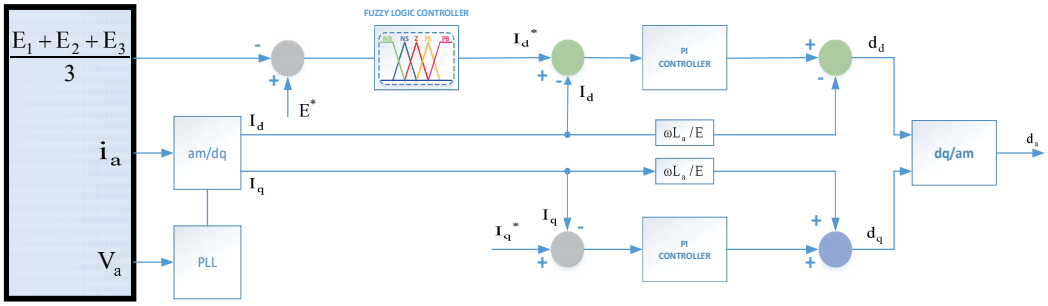


Fig. 3. d-q Decoupled Control of Rectifier

DAB converter which provides high performance/efficiency, galvanic isolation and soft-switching property is used at the isolation stage to step down the DC voltage obtained from input stage (Xu, 2014). The basic block diagram of the DAB converter is given in Fig. 4.

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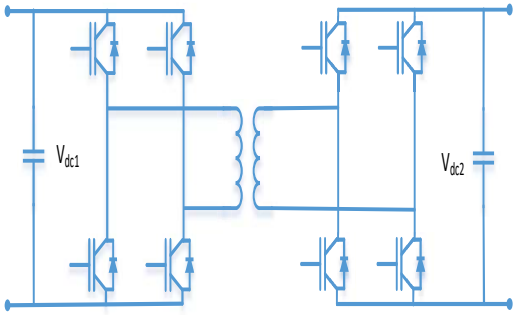


Fig. 4. Configuration of Isolation Stage

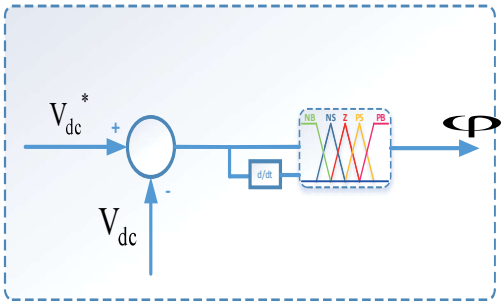


Fig. 5. Control of DAB converter with FLC

High frequency transformer provides the electrical isolation and voltage transformation. In order to regulate DC voltage obtained from output of DAB converter, FLC are used as phase shift controller. The difference between DC voltage at output of isolation stage and reference DC voltage is compared and FLC generates the phase shift angle required for DAB converterThe control of DAB converter based on FLC is as shown in Fig. 5.

DESIGN of FUZZY LOGIC CONTROLLER FOR SST STRUCTURE

FLC is an appropriate method for designing nonlinear controllers via the use of heuristic information. A FLC system allows changing the control laws in order to deal with parameter variations and disturbances. Especially, the inputs of FLC are error and change in the error for input and isolation stages (Zadeh, 1965). These inputs are normalized to obtain error e(k) and its change Δe(k) in the range of -1 to +1. The fuzzy membership functions consist of five fuzzy sets: NB, NS, Z, PS, PB as shown in Fig. 6. Also, internal structure of

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FLC is given Fig.7. In the FLC, the rule has the form of: IF e is F^k_e AND de is F^k_{de} THEN du is w^k:

k=1…M (3)

F^k_e and F^k_{de} are the interval fuzzy sets and w^k is singleton output membership functions (Zadeh, 1965).

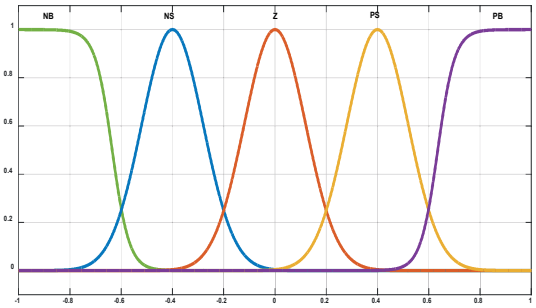


Fig. 6. Membership Function of Inputs And Outputs

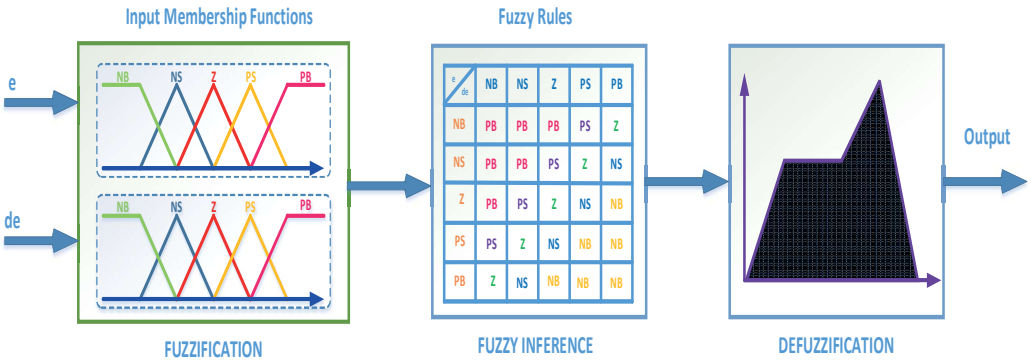


Fig. 7. Fuzzy Logic Controller Structure

Moreover, the rule base of the FLC system is given in Table 1.

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Table 1. Rule Base

e/de	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

SIMULATION STUDIES

In order to verify the SST model used in this paper, simulation studies in Matlab/Simulink are carried out under conditions of input voltage sag/swell and voltage harmonics. The SST parameters are given in Table 2.

Table 2. SST Parameters

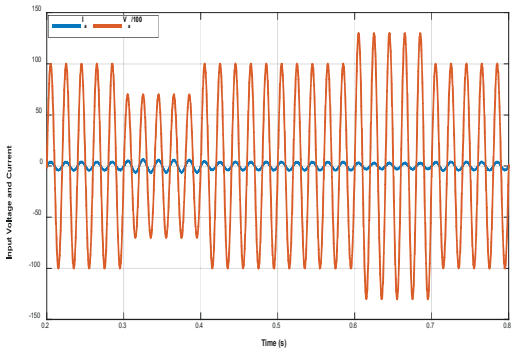
Parameters	Value
Input Voltage	7.2 kV
Ra, La	220mH, 2Ω
C_1, C_2	30µF, 3.3mF
High DC Bus Voltage	3800V
Low DC Bus Voltage	400V
K_p, K_i for rectifier	0.2, 10
L_f, C_f	1mH, 120µF

Fig. 8. demonstrates the responses of the SST under input AC voltage sag/swell condition. In this simulation, the magnitude of input voltage changes from 100% to 70% at 0.3 s and changes back from 70% to 100% at 0.4 s. In the voltage swell condition, as shown in Fig. 8, the magnitude of input voltage changes from 100% to 130 % at 0.6 s, and then changes back from 130% to 100% at 0.7 s.

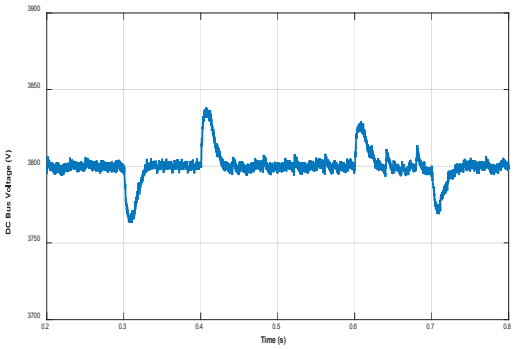
During the voltage sag and swell conditions, response of the DC bus voltage at input stage has a small overshoot and undershoot. Moreover, the DC bus voltage at isolation stage is regulated at 400V and the output voltages are not affected by the input voltage sag/

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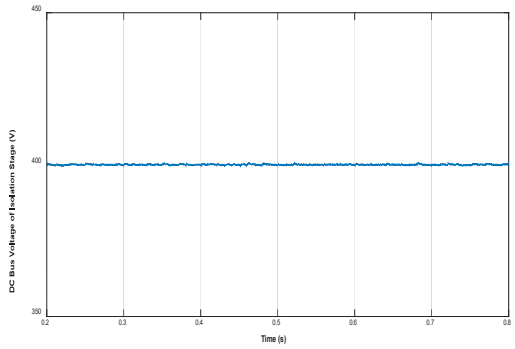
swell conditions, and the input current still maintains a unity power factor. The input currents given in Fig. 8 have clearly sinusoidal waveforms and in phase with grid voltage.



(a)

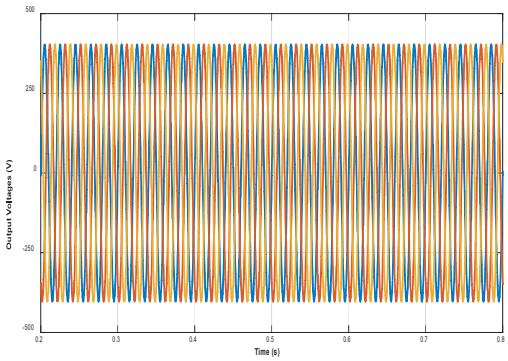


(b)



(c)

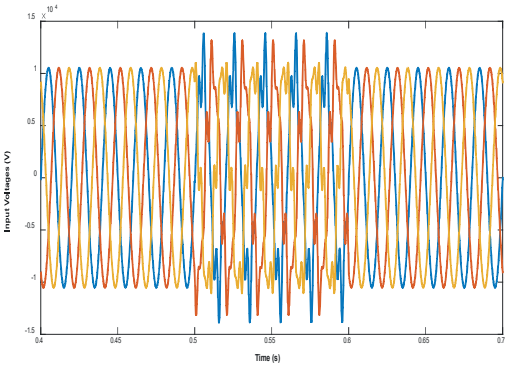
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(d)

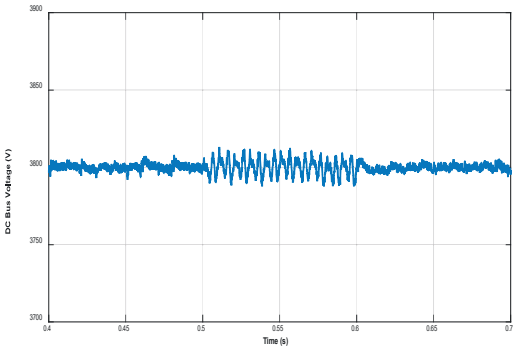
Fig. 8. Waveforms of SST Under Voltage Sag And Swell Conditions a) Grid Voltage-Current b) DC Voltage Responses of Input Stage c) DC Voltage Responses of Isolation Stage d) Output Voltages

Also, simulation studies are realized in order to indicate the effectiveness of SST against voltage harmonics. Voltage harmonics of the 5th and 7th orders with amplitudes of 20% and 15% are applied on the grid voltages between t= 0.5 and t=0.6 s. Response of the DC bus voltage at input stage has small oscillations as seen Fig. 9. Moreover, Fig. 9 shows clearly that the output voltages are not affected by the voltage harmonics in input voltages.

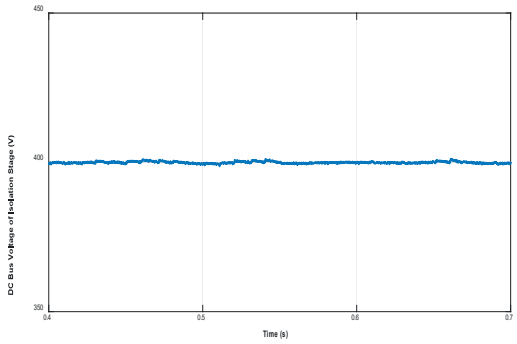


(a)

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(b)



(c)

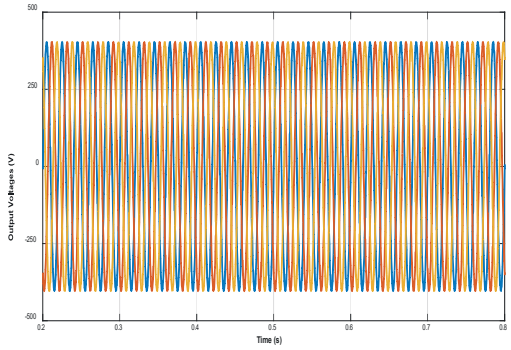


Fig. 9. Waveforms of SST Under Voltage Harmonic Condition a) Grid Voltages b) DC Voltage Responses of Input Stage c) DC Voltage Responses of Isolation Stage d) Output Voltages

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CONCLUSION

In this paper, control and simulation of SST structure with DC-link have carried out in Matlab/Simulink environment. Rectifiers at input stage is not only used in order to convert AC to the constant DC voltage, but also has reactive power compensation ability. FLC is preferred for input stage in this study in order to control DC bus voltage because of its robust nature. Dual active bridge converter at isolation stage is used for DC-DC conversion and single-phase inverter that provides the desired power and voltage to load is existed at output stage. A number of simulation studies have realized in order to verify performance of SST structure under voltage harmonics and voltage sag/swell conditions. The simulation results illustrate that SST structure with FLC has durable structure over these conditions and is capable of regulate output voltages and compensate disturbances in grid voltages.

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