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Evaluation of available power quality disturbance generators for testing of power quality mitigation devices

A. Teke, M.E. Meral and M. Tümay

Department of Electrical and Electronics Engineering,
Çukurova University, Adana, TURKEY

ahmetteke@cu.edu.tr, emeral@cu.edu.tr, mtumay@cu.edu.tr

Abstract – *The devices used for testing Power Quality Mitigation Devices are called Power Quality Disturbance Generators. Three or single phase voltage sags, swells, outages, harmonics, transients, phase shifts and flickers can be generated using power quality disturbance generators having different circuit topologies. In this paper, the available disturbance generators are compared and discussed with a focus on the usefulness and economical aspects. The guide for optimum selection of the generators is also clearly highlighted.*

Index terms – *Disturbance Generator, Sag, Swell, Outage, Power Quality Mitigation*

1. Introduction

Power Quality Disturbances are defined as "any power problem manifested in voltage, current or frequency deviations that results in failure or misoperation of customer equipment. To reduce the effect of power quality disturbances, Power Quality Mitigation devices (may be called also Custom Power devices) can be applied to the systems [1-5]. However, to test the performance of Power Quality Mitigation devices (such as Dynamic Voltage Restorer, Static Transfer Switch, Distribution Static Compensator, Uninterruptible Power Supply, etc) power quality disturbance generators are necessary. Recently, new methods and circuit topologies for disturbance generators have been applied. The high level power sag, swell and

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harmonics can be generated in [6]. The thyristor controlled reactor (TCR) based topology is preferred in [6]. This system is composed of reactor, TCR system and step up transformer. The high level power sag, swell and flicker can be generated in [7]. This inverter based topology in [7] is too expensive to use in general purpose because many components such as rectifier unit, inverter unit, harmonic filter, series transformer, parallel transformer and switch gear are used. In [1] series transformer, backup SCR thyristor switches and auto transformer are used for disturbance generator. Sag, swell, outage, flicker and harmonics can be generated in [1]. The auto transformer based topology with thyristors has limitations to get different output voltage values in [1]. [8] uses transformer, solid state relay switch and PC for disturbance generator. The disturbance generator has limitations to get flexible output voltage values due the limited and constant value secondary outputs.

In this paper, the available latest disturbance generators are compared with a focus on the usefulness, economical aspects and simplicity.

2. Methods for Generation of Power Quality Disturbances

The power quality disturbance generators (PQDGs) can be grouped into three types namely power converter type [7], auto transformer switch types (using thyristors or using solid state relays) [1, 8] and TCR system type [6]. The overview of the available methods is clearly summarized in the subsections.

2.1. PQDG-A: Auto Transformer Switch Type Disturbance Generator Using Thyristors

A different sag-swell generator for the test of Power Quality Mitigation Devices is described in [1]. The voltage sag, swell, outage, harmonic distortion, notches and voltage unbalance can be generated. Figure 1 shows the single phase power quality disturbance generator using auto transformer, series transformer and SCR thyristors in [1].

In Figure 1 the source voltage V_s is constant. To produce a disturbed voltage V_o, a series transformer T_d is inserted between the negative grids of source voltage and output terminal. The secondary voltage of the transformer is determined by the turn-ratio of the transformer and voltage V_t, which is the secondary voltage of the auto transformer. If the moving contact point is in I-region, the voltage V_d is positive, which is added to the source voltage, resulting in voltage swell of output voltage V_o. Similarly, the voltage sag can be obtained by moving the contact point to the II-region of the auto transformer. The outage also generated by adjusting the magnitude of the voltage sag to the 100% of the some voltage.

The controller triggers S_1 and S_2 to connect or disconnect one of the tap winding sections into the circuit. The anti-parallel thyristors S_{B1} and S_{B2} are used as the bypass switch that connects the auto transformer output to the load unless the fault condition is presented.

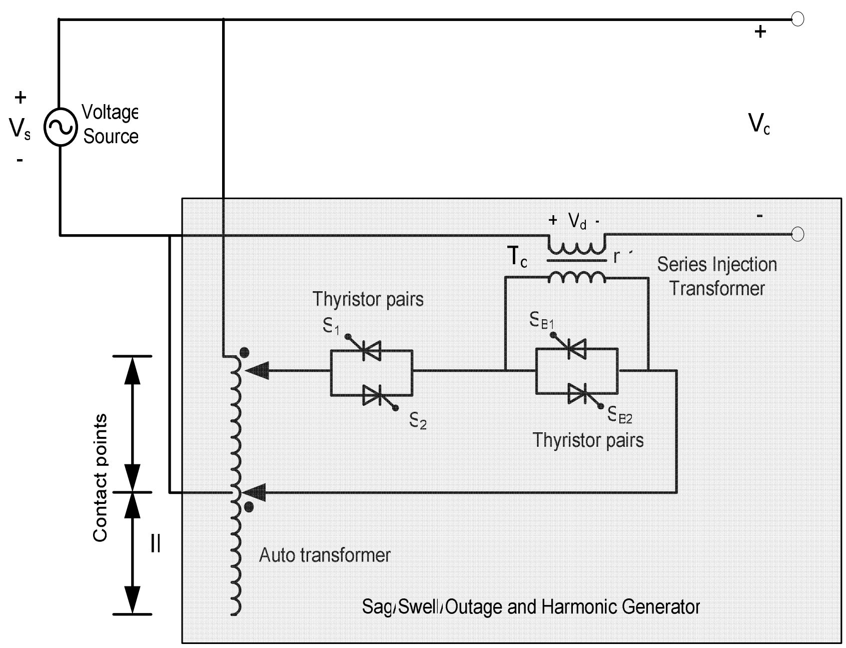

Figure 1. Auto transformer switch type using thyristors disturbance generator

2.2. PQDG-B: Auto Transformer Switch Type Disturbance Generator Using Solid-State Relays

The voltage sag and swell can be generated in [8]. Figure 2 shows the single phase power quality disturbance generator used in [8].

A transformer was used with two output voltages. The first output was set to 100% rated voltage. The second output was set to the required sag magnitude value. It has taps that can be set from 40 V to 400 V in steps of 40 V. A TMS320F240 DSP was used to log data and switch solid state relays very fast between the two outputs to obtain the desired sag magnitude and duration. When testing the performance for rate of change, a cascaded configuration was used.

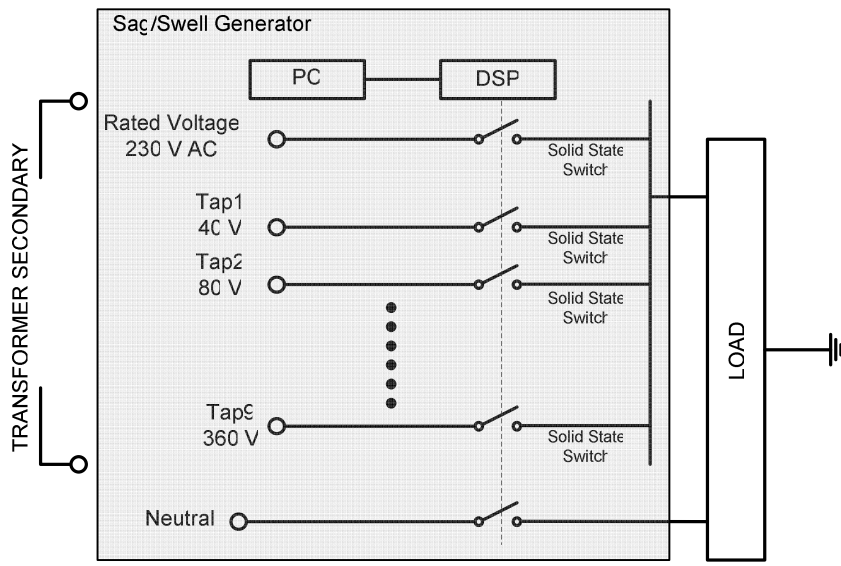

Figure 2. Auto transformer switch type disturbance generator using solid-state relays

2.3. PQDG-C:TCR System Type Disturbance Generator

The typical power disturbances such as sag, swell, under voltage, over voltage and harmonic distortion can be generated by using the disturbance generator composed of reactor, TCR system, harmonic filter and step up transformer in [6]. Figure 3 shows the sag swell generator with TCR used in [6].

The sag and the under voltage can be generated using the voltage drop across a reactor X_n when thyristors in TCRs are turned on after switch SW_1 is closed, while its magnitude and durations can be controlled by the firing angle of two TCRs. In the case of the swell and the over voltage generation, output of step-up transformer is connected to TCRs through switch SW_2 and step-up voltage is regulated by two TCRs to obtain nominal voltage level.

At any given instant, if the firing angle of two TCRs is retarded, then the swell voltage or the over voltage disturbance can be obtained.

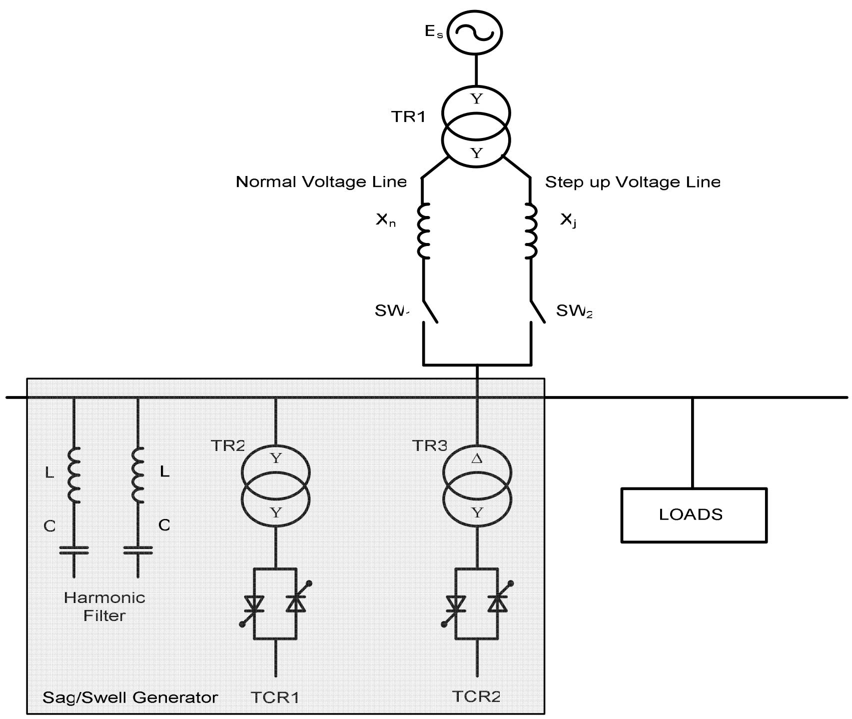

Figure 3. TCR system type disturbance generator

2.4. PQDG-D: Power Converter Type Disturbance Generator

The typical power disturbances such as sag, swell, over voltage, under voltage and voltage flicker can be generated by using the sag-swell generator (SSG) composed of energy storage DC capacitor, series inverter made of IGBT, rectifier and clamp circuit in [7]. Also it can generate the distorted voltage waveforms and the phase jumping by controlling the series inverter. Figure 4 shows the circuit diagram of the SSG used in [7].

Topology of SSG is similar to the Dynamic Voltage Restorer [9] except for the power ratings of parallel transformer and the rectifier. During voltage sag generation, energy is absorbed by the series inverter and dissipated through the voltage clamp circuit. On the other hand, during voltage swell generation, dc energy is supplied through the parallel transformer and rectifier. The bypass switch consisting of anti-parallel thyristors is used to connect the voltage source (V_A, V_B, V_C) to the load unless the fault condition is presented.

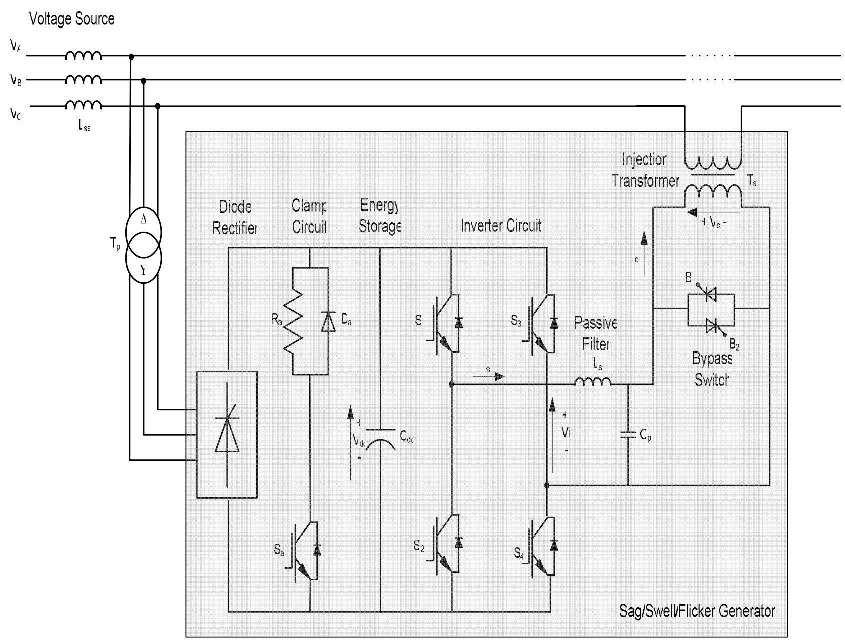

Figure 4. Power converter type disturbance generator

3. Comparison and Discussion of Presented Methods

The presented methods are compared on the basis of usefulness, simplicity and economical aspects and. The users should clearly specify which Power Quality Mitigation devices will be tested or power quality disturbances will be generated.

3.1. Comparison of Usefulness

In this section, the characteristics, advantages and drawbacks of auto transformer switch types, TCR system type and power converter type disturbance generators are discussed on usefulness and simplicity.

Auto transformer-switch types of the disturbance generator are usually realized as a combination of an auto transformers and appropriate switching devices. The different voltage outputs are generated by switching the outputs contacts from one step to another. This method has good features of generating harmonics by simply controlling the firing angles of the thyristor pairs. The main drawbacks of the method are that all of the non-conducting thyristor pairs connected to the unselected taps dissipate power due to their leakage current and the increased number of thyristor pairs connected to the taps. It has a complex structure and requires control of signal processors.

The power converter based type of the disturbance generator usually uses power electronic converters and energy storage units. This configuration is more appropriate than auto transformer-switch type, because of producing more precise control of disturbances. The main disadvantage of the method is having a very large number of power electronic converters that requires high initial costs and complex control algorithm.

Thyristor Controlled Reactor based type is usually realized as a combination of a transformers, TCRs and reactors. The different voltage outputs are generated by firing the TCR with different angles. The principal disadvantages of this configuration are the generation of low frequency harmonic current components and higher losses when working in the inductive region [10]. This method also has a large number of input/output components. Table 1 summarizes the most common power quality disturbances and the ability of the generators to perform these disturbances. PQDG-D can generate more power quality disturbances. PQDG-B has the simple structure for disturbance generation.

Table 1: Usefulness of power quality disturbance generators

Types of Power Quality Disturbances	Available Methods			
	PQDG-A	PQDG-B	PQDG-C	PQDG-D
Sag	✓	✓	✓	✓
Swell	✓	✓	✓	✓
Harmonic	✓		✓	✓
Flicker				✓
Outage	✓	✓		
Notch	✓			
Voltage unbalance	✓			
Over voltage			✓	✓
Under voltage			✓	✓

3.2. Economical Comparison

This section presents the comparison of the cost of available disturbance generators. The cost information is obtained from a variety of sources including sales companies [11-13] and surveys.

The prices of required components to setup a 10 kVA disturbance generator which is enough to build a laboratory scale prototype is given in Table 2 for economical comparison of the presented methods.

PQDG-B is the cheapest solution to generate sag, swell and outage which are the most common power quality problems [14]. PQDG-C is the most expensive disturbance generator.

4. Conclusions

In this paper, the latest power quality disturbance generators are comprehensively discussed and compared with a focus on the usefulness and economical aspects.

In order to setup the cost effective disturbance generator type, the users should clearly specify which Power Quality Mitigation devices will be tested or power quality disturbances will be generated. Consequently, this study helps to users for optimum selection of disturbance generator type by deeply analyzing the economical and usefulness aspects of the methods.

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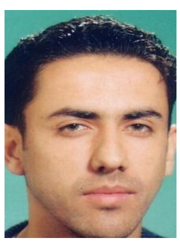
Table 2: Comparison of components prices

Components	**Approximate Cost ($)**	**Number of Components Used in Generators**			
		PQDG-A	**PQDG-B**	**PQDG-C**	**PQDG-D**
3-Phase Auto Transformer	625	1	1	-	-
3-Phase Variable Transformer	1400	-	-	-	-
3-Phase Rectifier	550	-	-	-	1
1-Phase Inverter	380	-	-	-	3
1-Phase Series Transformer	425	3	-	-	3
3-Phase Step Down Transformer	1950	-	-	2	1
SCR Thyristor Pairs	33	6	-	6	3
SCR Driver Circuit	250	6	-	6	3
Solid State Relay	9	-	9	-	-
DC Link Capacitor	75	-	-	-	1
LC Filter	240	-	-	6	3
Line Reactor	220	-	-	6	-
Current Transducer	28	-	-	-	3
Voltage Transducer	55	-	-	-	3
PC	800	-	1	1	1
DSP Controller	380	-	1	1	1
TOTAL		**3598**	**1886**	**9538**	**7988**

Biography

Ahmet Teke received the B. Sc. degree in Electrical and Electronics Engineering from Çukurova University, Adana, Turkey in 2002. After completion his B.S. training, he received M. Sc. degree in the department of Electrical and Electronics Engineering in Çukurova University. He has started Ph. D. degree in the department and has been working there as a research assistant since 2005. His areas of interest include power system analysis and modeling, power quality applications, energy management, PWM modulation techniques, power system harmonics and control of power converters. He is a member of Turkish Chamber of Electrical Engineers.



Mehmet Emin MERAL received the B.S. degree in Electrical and Electronics Engineering from İnonu University, Turkey in 2001. After completion his B.S. training, he has started MSc degree in the department of Electrical and Electronics Engineering in Yuzuncuyıl University. He has started Ph.D degree in the department of Electrical and Electronics Engineering in Çukurova University and he has been working there as a research assistant since 2005. His areas of interest include power system analysis and modeling, power quality applications, nonlinear power system elements, lightning strokes and analysis electrical faults.

Mehmet TUMAY received a Ph.D in Electrical Engineersing from The Strathclyde University in 1995, and is presently Professor of Electrical and Electronics Engineering Department of Cukurova University. His research interests include modeling of electrical machines, power flow controllers, power quality and custom power devices.