# The Impact of the Converter Modes on the Distribution of Harmonic Active Powers

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***Abstract*—The quality of electricity supply requires among other things the identification or localization of distortion sources. However, one of the major impediments to this task remains the non-existence of a unifying technique and the versatile characteristics of harmonic-polluting loads. In this paper, the distribution of active harmonic powers of the fifth, the seventh, the eleventh and the thirteenth harmonic frequency, between two controlled converters, connected to the same bus system, is analysed on the basis of the converter's modes of operation (Rectification or Inversion). The power network under investigation is simulated on the digsilent 14.1 computer program which favourably supports harmonic load flow studies. The harmonic active power trends produced, when converters are either switched in similar or different modes of operation, indicate that the distribution of harmonic active powers is randomly based and therefore irrespective of the converter operating modes.**

***Index Terms*—Harmonic active power, converter, firing angle, operating mode, load flow.**

## I. Introduction

Controlled converters are reputed to be traditional sources of harmonics in power systems [1]. When found to be more than one in the network, they tend to exchange distortion [2], while of course polluting other components connected to the system point of common coupling (PCC). In most applications, converters are required to operate either as rectifier or inverter at the expense of the control parameter, which for thyristor converters, happens to be the firing angle [3]. Therefore, this change of status is associated to specific regions of the firing angle: $0 < \alpha < 90°$ for rectification and $90° < \alpha < 180°$ for inversion [4]. The usefulness of thyristor converters has made these power electronics devices to become quite popular in power systems, and consequently significant distortion contributors [5]. It would therefore be interesting to investigate whether or not the distribution or exchange of active harmonic powers, between converters, could be influenced by their respective operating modes. To conduct this analysis, a power network consisting of two thyristor converters, operating either in similar or different states, are connected to the same PCC with a linear load. The supply to the network is from two identical power transformers connected to the external grid. This network is built and simulated on the digsilent 14.1 computer software which performs harmonic load flow at the following designated harmonic frequencies: $5^{th}$, $7^{th}$, $11^{th}$ and $13^{th}$. Harmonic load flow analysis is therefore based on the following operating cases: (1) both converters operate in rectifier mode, (2) both converters operate in inverter mode, and (3) one converter operates as a rectifier and the other as inverter. In each of these cases, the firing angle is adjusted in every step of ten.

Harmonic load flow analysis from the digsilent software under the above conditions suggests that harmonic active power is randomly exchanged or distributed, and is therefore irrespective of the converter operating states.

## II. System Technical Data

The supply system consists of two 5 MVA, 11/0.4 kV transformers connected in parallel and being fed from a 10 MVA external grid. Both harmonic loads in use consist of ac/dc thyristor converters externally controlled, and with the following power and dc voltage ratings: 3 MW, 0.5 kV for converter 1 and 6 MW, 0.5 kV for converter 2. The rectifier converter supplies two 1.5 MW dc loads whereas the inverter is connected to a 600 V dc generator, having an armature resistance of 2.5 Ω and field inductance of 200 mH, through a 1 km dc line with resistance of 0.034 Ω/km and inductance of 35.1 Ω/km. On the other end, the linear load consists of the following: a 1 MW, 0.4 kV at power factor of 0.85 lagging. The system technical data thus described is derived from the software library. Figure 1 shows the power network under investigation.

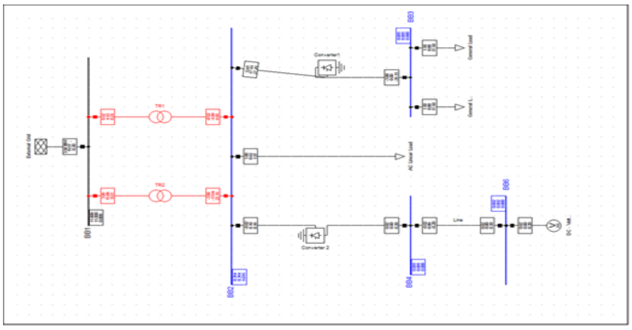

Fig.1. Digsilent Model of the Power Network

## III. Harmonic Load Flow

One of the methods used to identify the distortion sources in power systems, is the analysis of the direction of active power harmonics [6]. Harmonic load flow such as supported by the digsilent provides both the magnitude and direction of active harmonic powers [7]. It is worth noting that the direction of harmonic active power is revealed in terms of the positive or negative sign preceding the magnitude. Accordingly, the positive sign implies that power is consumed and such a load is a victim of harmonics, whereas the negative sign implies that power is released and such a load is obviously a harmonic source [8]. However, it is a requirement for the software in use that harmonic loads should be defined either as phase correct balanced or unbalanced current sources by the end user. For the purposes of this study, the balanced approach is adopted. Therefore, harmonic loads are defined to be injecting respective characteristic harmonic currents at the proportion indicated in table 1.

TABLE I. Proportion of Injected Harmonics

| Harmonic Order n | Percentage Harmonic Distortion (%) | Phase Angle |
|---|---|---|
| $h_5$ | 20 | 0 |
| $h_7$ | 14.286 | 0 |
| $h_{11}$ | 9.091 | 0 |
| $h_{13}$ | 2.703 | 0 |

## IV. Harmonic Active Power Distribution

The dynamic behaviour of harmonic active powers, between the system's components connected to bus 2 (BB2) of the power network under scrutiny, is analysed on the basis of the firing angle variations. For the three operating conditions to be studied the thyristor control adjustment for the converters is either incrementally (from 10° to 90° or 90° to 180°) or decrementally (from 90° to 10° or 180° to 90°) varied, and the obtained harmonic active powers expressed in kilowatts are plotted in terms of both direction and magnitude.

### *A. Case 1: Both Converters Operate as Rectifier*

In this case, both converters are switched to be operating on the rectification mode where the firing angle of converter 1 ($\alpha_1$) is incrementally adjusted while that of converter 2 ($\alpha_2$) is decrementally controlled. The parameters of the system components are applicable just as defined above. However, it is worth noting that since in this case all converters are treated as rectifiers, converter 2 is consequently defined to be driving a 3 MW dc load. The percentage harmonic injections, as expected for each of the harmonic-polluting loads (converters), are in accordance to the proportion set in Table I.

### *B. Case 2: Both Converters operate as Inverter*

In this application, both converters are set to operate as inverters where $\alpha_1$ is incrementally controlled while $\alpha_2$ is decrementally adjusted. Each of the converter loads is connected on the dc side to a 600 V dc generator. The harmonic spectrum of the converters as well as the rest of the system components are defined in a similar manner to the first case of analysis.

### *C. Case 3: Rectifier versus Inverter*

In this case, converter 1 is set to operate as a rectifier while converter 2 is switched in inversion mode. Both $\alpha_1$ and $\alpha_2$ are incrementally adjusted within respective operating regions.

## V. Results and Discussion

The results obtained subsequent to harmonic load flow analysis based on each case are presented on Fig. 2, Fig.3 and Fig. 4 respectively.

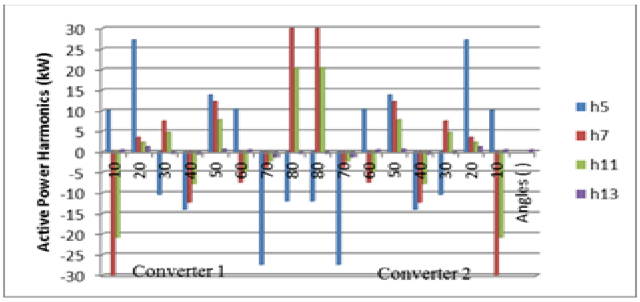


Fig.2. Harmonic Active Power versus Firing Angle. *(case 1)*

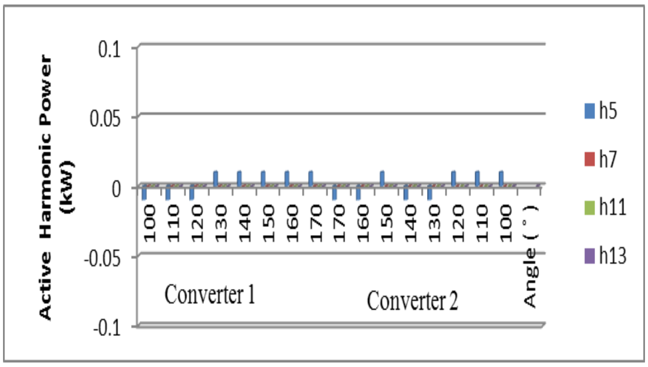


Fig.3. Harmonic Active Power versus Firing Angle. *(case 2)*

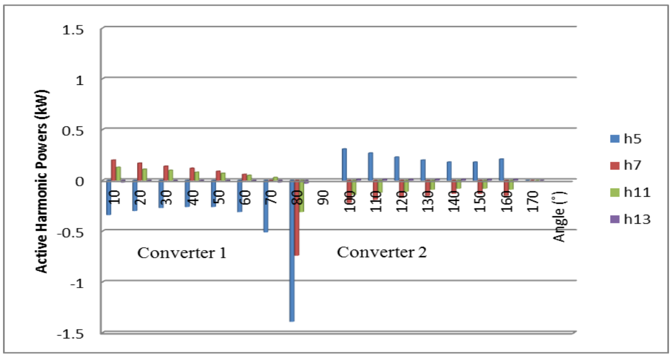


Fig.4. Harmonic Active Power versus Firing Angle. *(case 3)*

The results obtained in Fig. 2 show a non-uniform distribution of harmonic active powers neither in terms of magnitude nor direction. This applies in either direction of the firing angle adjustment. Converter 1 seems to be inheriting 10.09 kW, 27.20 kW, 13.87 kW and 10.41 kW of the fifth harmonic active power at firing angles of 10, 20, 50 and 60 degrees respectively. Yet, for the same harmonic component, the same converter appears to be generating 10.45 kW, 14.09 kW, 27.47 kW and 12.04 kW at 30, 40, 70 and 80 degrees respectively. This trend is also observed right across all harmonic components associated with converter 1. However, at the firing angle of 20 and 50 degrees, converter 1 imports all characteristic harmonics whereas at 40 and 70 degrees, it rather behaves as a generator of all harmonic components.

On the other end, converter 2 is no exception to the versatile behaviour of its counterpart, as it generates 12.04 kW, 27.47 kW, 14.09 kW and 10.45 kW of the fifth harmonic active power at 80, 70, 40 and 30 degrees respectively. For the same harmonic component, converter 2 consumes 10.41 kW, 13.87 kW, 27.20 kW and 10.09 kW at 60, 50, 20 and 10 degrees. Similarly, it generates the full spectrum of harmonics at 70 and 40 degrees, while importing all harmonic components at 20 degrees of the firing angle.

Although it is expected that the linear load and the supply transformer receive some proportion of distortion produced, a larger share of harmonics generated is rather interchanged between the two converters, whereby one is acting as a source and the other as the largest consumer. Interestingly, when the firing angle is the same both converters act as sources of harmonics. This could be clearly observed right across the entire rectification region by cross checking the results produced. For instance, when converter 1 is fired at 50 degrees, 13.87 kW, 12.20 kW, 7.78 kW and 0.66 kW are generated, which is exactly the same when converter 2 is operated at the same angle. It could also be shown that out of the total fifth harmonic active power generated by converter 2, given as 12.04 kW, 10.09 kW which represents 83.80 % is consumed by converter 1 while only 16.20 % is shared between the linear load and the supply transformer.

Harmonic load flow analysis applied to case 2 is not proven to yield significant results since no tangible figures could be obtained at each simulation run. Therefore, it was not possible to draw any correlation between the firing angle adjustments and the flow of harmonic active powers. This could be attributed to insignificantly low values of harmonic active power circulating in the system.

The results presented in Fig. 4 indicate a generally decay pattern of the magnitude of harmonic active powers over the regional firing angle involved. In terms of the direction, there seems to be a fairly consistent distribution of characteristic harmonics over the range of the firing angle. Thus, converter 1 is consistently generating the fifth and the thirteenth harmonic while consuming the seventh and the eleventh distortion components. However, at 70 and 80 degrees, it does act as a seventh harmonic generator and from 60 to 80 degrees, as a thirteenth harmonic producer.  Converter 2 consistently consumes the fifth and the thirteenth while producing the seventh and the eleventh all along its operation. This therefore suggests that at firing angles of 70 and 160 degrees for the rectifier and the inverter respectively, both converters behave as sources of the seventh harmonic active power. Subsequently, at 80 degrees, the rectifier is seen to be injecting the full harmonic spectrum. It should also be noted that the linear load as well as the supply system happen to be inherit harmonic powers at lower quantities compared to that is interchanged between the distortion sources. For instance, converter 2 receives 0.20 kW of the fifth harmonic active power out of 0.26 kW generated by converter 1 which is representative of 76.92 % while the rest of the system shares 23.08 % of the distortion produced.

The results produced based on the digsilent 14.1 software simulation seem to confirm that the distribution of harmonic active powers, in a power network involving thyristor converters, is random both in terms of direction and magnitude, and it is therefore irrespective of the operating modes of the converters.

Furthermore, controlled converters are able to interchange larger share of the distortion generated in the power system, and could therefore behave either as source of harmonics or as harmonic consuming load. However, it is observed in some cases that converters could both be acting as distortion sources, thus able to generate the full spectrum of harmonics. This versatile behavior of converters adds in as an impediment to the accurate identification or localisation of distortion sources in power networks.

## VI. Conclusion

This study makes use of the digsilent 14.1 computer software in a bid to analyse the impact of the converter's operating states on the distribution of harmonic active power components. Three case studies, which consider possible converter applications, are therefore investigated. The harmonic spectrum used in each of the converters is defined in accordance with the software requirements before simulation attempts. For every case study undertaken, simulation runs conducted produce the harmonic active spectrum variations on the basis the firing angle adjustments. The results obtained suggest that harmonic active powers are randomly distributed across the firing angle and consequently cannot be influenced by the operating modes of the thyristor converters.

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