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Spread of Harmonics in Power Systems

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Abstract

Simulation investigations have been carried out for studying the spread of harmonics in a Ward Hale 6 Bus System and a standard IEEE 14 Bus System. The Investigations have shown that a single load consisting of 15%, 5^{th} Harmonic and 7.5%, 7^{th} Harmonic in a Ward Hale 6 bus system can cause a maximum Total Harmonic Distortion (THD) of 9.88% in any of the interconnected Buses. Further two loads consisting of 15%, 5^{th} harmonic and 7.5%, 7^{th} harmonic can cause a maximum THD of 15.4% in any of the interconnected buses. Similar investigations carried out for studying the spread of harmonics in a standard IEEE 14 Bus System has indicated a maximum Total Harmonic Distortion (THD) of 38.98% for the case of single harmonic distortion load. For the case of two loads consisting of same type of harmonics the maximum THD obtained are 41.42% respectively.

Keywords: Harmonics, Spread, Ward Hale 6 Bus, IEEE 14 bus, THD.

Introduction

Present day power systems invariably have nonlinear loads, which inject harmonics into the system and give rise to nonsinusoidal voltages and currents. Power Quality issues are a prime concern of the power generation organizations as well as of customers. Power System harmonics are known to be generated by a number of sources in the power network [1]. Harmonics generated by large synchronous machines are within limitation as specified by existing standards [2]. There are many methods developed in past for analyzing harmonic distribution in power systems [3].Increase in demand for electrical energy has necessitated optimum utilization of generated electrical energy. Therefore present day power transmission and distribution consists of large interconnected systems. Due to increasing use of power electronic equipments and other harmonic generating equipments or devices, the identification and estimation of harmonic loads are of great concern for electric power generation and utilizing organizations [4]. Harmonic distortion causes financial expenses for customers and electric power companies. Companies are required to take necessary action to keep the harmonic distortion at levels defined by standards [2]. There have been many algorithms developed for linear and nonlinear model representation of power systems in order to estimate the harmonics [5-7].The present day load requirements can be of many different types. They can also introduce distortions of power system main parameters which are voltages and currents [8]. Some of the potentially harsh loads such as steel mills can cause an impact on generating units [9]. The use of non linear (electronic) loads in power system has increased the awareness of the potential reduction of life of transformers due to increased losses that arise due to presence of harmonics [10]. Recent research investigations report real time detection and extraction of individual harmonic and interharmonic components in a power signal with potentially time varying characteristics [11]. Wide spread use of sensitive loads, such as computers and microprocessors based industrial controllers, signify the increasing need for efficient harmonic measurement and compensating systems [12]. Load flow is the procedure used for obtaining the steady state voltages and currents of electric power systems at fundamental frequency. In the last few years, there has been a growing interest in obtaining steady state network voltages at harmonic frequencies due to nonlinear devices in electric power networks. The procedure for analyzing the harmonic problem could be classified into frequency domain [13-14] and time domain [15]. Frequency domain methods are the most widely used for the harmonic problem formulation. The present investigations have been aimed to study the spread of harmonics due to few harmonic generating loads in a standard Ward Hale 6 Bus system and a standard IEEE 14 Bus system. Investigations have been carried out by simulating presence of harmonic loads at a single bus and at two different busses of a standard Ward Hale 6 Bus system. Similar investigations have also been carried out for a standard IEEE 14 Bus system. The results of these investigations have been reported in this paper. Mipower software version 6.0 has been used for simulations [16].

Power Systems Selected for Investigations

There are two systems taken for our investigations. First system is the Ward Hale 6 Bus system and the second system is IEEE 14 Bus system. Each one is described below with their models.

A total of three loads have been considered in the present investigations which are supplied by two generators, generating the total required power demand of the system and the entire Power System forms a Ward-Hale 6 Bus System as shown in Fig.1.We have chosen Gen.1 as reference generator.

For the IEEE 14 Bus system [17], a total of eleven loads have been selected which are supplied by two generators, which generate the total required power demand of the system as shown in Fig.2. We have chosen generator Gen.1 as reference generator. The entire model has been taken from ref [17] which consists of three buses at Bus-1, Bus-2 and Bus-3. This is due to the fact that in India generation can be at 33KV and Transmission is at 132KV. Hence we have added three Busses to account for generation at 33KV. The Power generated at the added Buses was stepped up to 132KV by use of two winding Transformers, connected to Buses 1, 2 and 3. This makes the System more realistic and practical with the system operating at a voltage profile of 33/132/33KV. A one is to one Transformer is used between bus 7 and bus 8, as specified in the IEEE 14 BUS Test System.

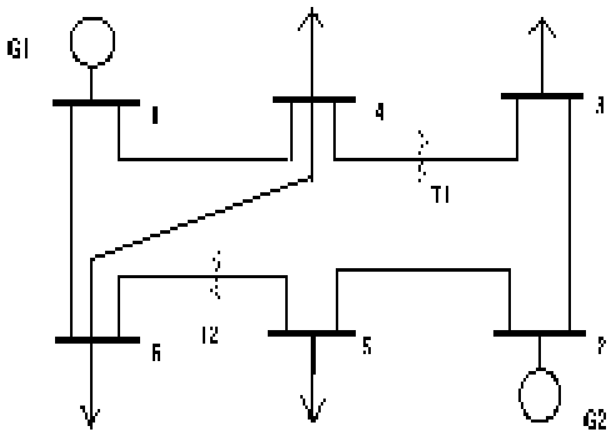

Figure.1. Ward Hale 6 Bus system

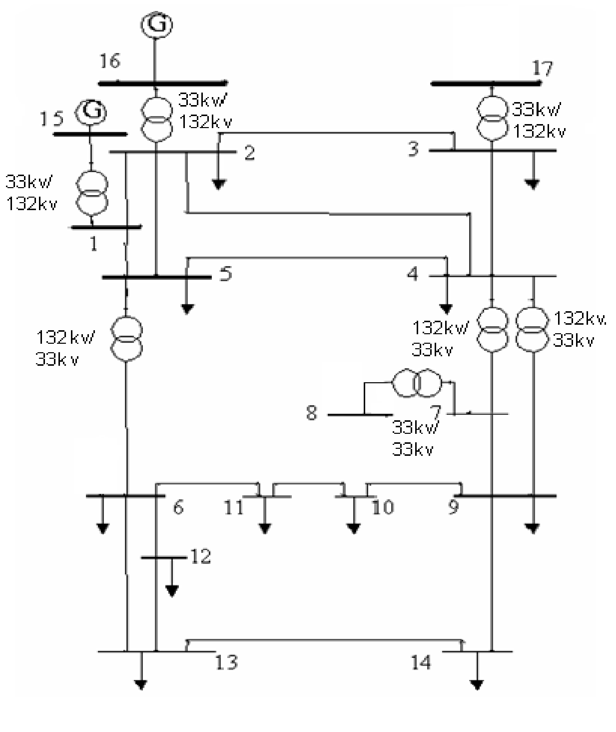

Figure. 2. IEEE 14 Bus System

Simulation Results

The investigations carried out are computer simulations using Mipower package version 6.0 [16]. Mipower package version 6.0 carries out the load flow Analysis using 'Fast Decoupled' method. The Mipower software has also program for carrying out the harmonic analysis of voltage and current parameters based on Fourier method. The Ward Hale 6 Bus system was first investigated for load flow analysis. This verifies that the load flow in all the busses is appropriate to the power generation and power demand as per connected loads. At the Buses where harmonics were considered to be present, the current at these buses were simulated to consist of 15%, 5th harmonic and 7.5%, 7th harmonic. All 3rd harmonic components get nullified because of the delta connections and therefore these are not considered in simulations. The investigations have been carried out by first considering presence of harmonics in any one load and calculating THD values for all other buses. The same is repeated for other two load positions. IEEE Standards require that the permissible limit of THD is 5%. Table 1 shows the number of busses affected because of presence of harmonics in any one load of a Ward Hale 6 Bus system. We observe from this table that the maximum THD is 9.88% which is large compared to maximum permissible value of 5% [2]. The Value of THD for voltage is calculated using the equation [18].

$$THD_V=\sqrt{(V_2^2+V_3^2+V_4^2+V_5^2+\ldots..)} / V1 \quad (1)$$

Table 1. THD Values for single harmonic load

Bus no with harmonic load	Buses with THD <or=5%	Buses with THD >5%	Min THD	Max THD
BUS 3	3	2	3.2	9.88
BUS 5	4	1	1.62	5.6
BUS 6	2	3	2.84	7.81

Similar investigations were carried out next by considering any two loads consisting of harmonics and calculating THD values for all other two busses. This procedure was repeated for all possible different load combinations with two buses having 15%, 5th harmonics and 7.5% 7th harmonics. The values of THD obtained in these investigations are shown in tables (Table 2 to Table 3). We observe from these results that large numbers of busses are affected in this case as compared to the case where in one of the loads is considered to be consisting of harmonics.

Table 2. THD Values for two harmonic loads 3rd Bus Combinations

Bus nos with harmonic load	Buses with THD <or = 5%	Buses with THD >5%	Min THD	Max THD
BUS 3,5	0	4	5.37	14.3
BUS 3,6	0	4	6.05	15.4

Table 3. THD Values for two harmonic loads 5th Bus Combinations

Bus no with harmonic load	**Buses with THD <or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 5,6	0	4	5.53	10.8

The similar investigations were carried out for a standard IEEE 14 Bus system. The results are recorded in the form of Tables (Table 4 to Table 15).The Table 4 shows that the max THD for a single harmonic distortion load can be 38.98 %. The Tables (Table 5 to Table 14) show that the max THD for two harmonic distorting loads can be 41.42 %.

Table 4. THD Values for single harmonic load

Bus no with harmonic load	**Buses with THD <or=5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 2	3	13	2.4	6.2
BUS 3	0	16	12	27.4
BUS 4	0	16	17.3	38.98
BUS 5	0	16	12.81	29.25
BUS 6	0	16	13.499	30.604
BUS 9	0	16	15.748	35.478
BUS 10	0	16	13.18	29.97
BUS 11	0	16	12.43	28.35
BUS 12	0	16	12.89	29.35
BUS 13	0	16	12.89	29.35
BUS 14	0	16	12.89	29.35

Table 5. THD Values for two harmonic loads 2nd Bus Combination

Bus nos with harmonic load	**Buses with THD <or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 2,3	0	15	14.94	34.44
BUS 2,4	0	15	8.90	22.17
BUS 2,5	3	12	1.639	11.14
BUS 2,6	1	14	4.98	12.7
BUS 2,9	0	15	7.28	18.27
BUS 2,10	1	14	4.72	12.01
BUS 2,11	2	13	3.97	10.17
BUS 2,12	2	13	4.24	10.82
BUS 2,13	0	15	5.17	13.16
BUS 2,14	0	15	5.31	13.47

Table 6. THD Values for two harmonic l loads 3rd Bus Combination

Bus nos with harmonic load	Buses with THD <or = 5%	Buses with THD >5%	Min THD	Max THD
BUS 3,4	0	15	18.52	41.42
BUS 3,5	0	15	13.96	31.73
BUS 3,6	0	15	14.59	33.11
BUS 3,9	0	15	16.89	37.99
BUS 3,10	0	15	14.33	32.49
BUS 3,11	0	15	14.33	32.49
BUS 3,12	0	15	13.85	31.45
BUS 3,13	0	15	14.78	33.52
BUS 3,14	0	15	16.54	37.34

Table 7. THD Values for two harmonic loads 4th Bus Combination

Bus nos with harmonic load	Buses with THD <or = 5%	Buses with THD >5%	Min THD	Max THD
BUS 4,5	0	15	6.15	15.09
BUS 4,6	0	15	6.78	16.65
BUS 4,9	0	15	9.09	22.22
BUS 4,10	0	15	6.53	15.97
BUS 4.11	0	15	5.77	14.12
BUS 4,12	0	15	6.04	14.78
BUS 4,13	0	15	6.97	17.11
BUS 4,14	0	15	7.11	17.42

Table 8. THD Values for two harmonic loads 5th Bus Combination

Bus nos with harmonic load	Buses with THD <or = 5%	Buses with THD >5%	Min THD	Max THD
BUS 5,6	12	3	2.23	5.62
BUS 5,9	1	14	4.53	11.19
BUS 5,10	15	0	1.97	4.93
BUS 5,11	15	0	1.22	3.08
BUS 5,12	15	0	1.249	3.74
BUS 5,13	8	7	2.41	6.08
BUS 5,14	5	10	2.56	6.38

Table 9. THD Values for two harmonic loads 6^{th} Bus Combination

Bus nos with harmonic load	**Buses with THD <or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 6,9	0	15	5.16	12.7
BUS 6,10	4	11	2.60	6.49
BUS 6,11	15	0	1.84	4.69
BUS 6,12	14	1	2.11	5.30
BUS 6,13	3	12	3.04	7.63
BUS 6,14	2	13	3.19	7.94

Table 10. THD Values for two harmonic loads 9^{th} Bus combination

Bus nos with harmonic load	**Buses with THD >or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 9,10	0	15	6.61	16.42
BUS 9,11	0	15	5.81	14.46
BUS 9,12	0	15	6.11	15.23
BUS 9,13	0	15	7.11	17.56
BUS 9,14	0	15	7.26	17.87

Table 11. THD Values for two harmonic loads 10^{th} Bus Combination

Bus nos with harmonic load	**Buses with THD >or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 10,11	5	10	0.89	8.325
BUS 10,12	2	13	3.627	8.979
BUS 10,13	1	14	4.556	11.314
BUS 10,14	1	14	4.704	11.622

Table 12. THD Values for two harmonic loads 11^{th} Bus Combination

Bus nos with harmonic load	**Buses with THD >or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 11,12	2	13	-	-
BUS 11,13	2	13	3.8	9.7
BUS 11,14	2	13	-	-

Table 13. THD Values for two harmonic loads 12th Bus Combination

Bus nos with harmonic load	**Buses with THD >or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 12,13	2	13	4	10.4
BUS 12,14	2	13	-	-

Table 14. THD Values for two harmonic loads 13th Bus combination

Bus nos with harmonic load	**Buses with THD >or = 5%**	**Buses with THD >5%**	**Min THD**	**Max THD**
BUS 13,14	0	15	5.1	12.7

Conclusions

Simulation investigations carried out on Ward Hale 6 Bus system and standard IEEE 14 Bus system using Mipower Package version 6.0 for harmonic analysis have shown that there are a number of busses affected by harmonics. The value of THD is more in the case of two harmonic generating loads as compared to single harmonic generating load for both Ward Hale 6 Bus system and standard IEEE 14 Bus system.

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