Power Quality Improvement of Dispersed Generation Systems Using Hybrid Filter

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ABSTRACT

A hybrid filter constructed of a shunt active filter and distributed passive filters used for power quality improvement in dispersed generation system is presented. The distribution system consists of two wind turbines using induction generators for producing the required active power and several dynamic nonlinear loads. The power quality problems of dispersed generation LV or MV systems are introduced and the necessity of using hybrid filters instead of active or passive filters alone are discussed. The simulation is done with PSCAD/EMTDC software for a distribution system with dynamic nonlinear loads and wind turbines without any filters, with usage of just shunt active filter or passive filters and the hybrid filter structure, introduced in the paper. Studying and comparing the waveforms, frequency spectrums, harmonic contents and THD of the system current with different filter structures mentioned, proves power quality improvement by the applied hybrid filter.

Keywords: Distributed Generation, Power Quality, Hybrid Filter, Harmonics

1. INTRODUCTION

In recent years, there has been a considerable interest in installation of dispersed generation systems such as wind farms or photovoltaic cells in medium or low voltage distribution systems. Because of installation of wind turbines and PV's, low power quality issues such as harmonics and voltage flicker and fluctuation are imposed to the distribution system [1-2]. The circumstance becomes more serious because of harmonics and high THD of the current waveform of nonlinear and dynamic loads in the distribution system. Therefore, it is necessary to use effective power quality improvement facilities for improving the power quality of the distribution system and reducing harmonics in the system current. Usage of passive or active filters can be a successful procedure in limitation and removal of harmonics and improving THD of the system current. But because of dynamic loads, using passive filters alone cannot compensate the harmonics greatly; also it might cause resonances in the system, so they cannot be effective regardless of their low costs. On the other hand, using active filters alone with the ability for removing system current harmonics of dynamic loads can increase the costs of the project for high rating of active filters. Therefore, usage of hybrid filters would be the best solution for power quality improvement because the problems of using passive and active filters alone will not be any problem in such a structure, also the advantages of both of these filters can be gained together [3-4].

In this paper, power quality problems of dispersed generation LV or MV systems are introduced and the necessity of using hybrid filters instead of active or passive filters alone are discussed. A hybrid filter constructed of a shunt active filter and distributed passive filters used for power quality improvement in dispersed generation systems is presented and the parameters of the passive filters and the control system of the active filter are discussed. A distribution system with dynamic nonlinear loads and wind turbines as dispersed generation is simulated with PSCAD/EMTDC software [5]. The simulation is done for the distribution system without any filters, with usage of just shunt active filter or passive filters and the hybrid filter structure introduced in the paper. Studying and comparing the waveforms of the system current in time and frequency domains, harmonic contents and THD of the system current with different filter structures mentioned, proves the effective power quality improvement of the distribution system by the applied hybrid filter [6-8].

2. POWER QUALITY ISSUES OF DG

Technical studies of dispersed generation systems prove low power quality issues of these systems such as voltage fluctuation and flicker or high harmonic contents of the system current.

In the case of installation of DG units to distribution systems, voltage fluctuation is remarkable especially at connection points resulting of DG units switching or sudden fluctuations in their output power. So, load flow analysis of these systems should consider the voltage fluctuation not to exceed the standards for preventing power instruments and costumers from damage. According to the distribution systems standards, voltage fluctuation of MV systems should be less than 2%-3% for limiting LV fluctuations less than 10%.

Another problem of dispersed distribution systems is an increase in the fault level of the distribution system. This is caused when a ground fault is occurred in the system because DG units still feed the fault although the power system feeders are disconnected.

The most important power quality problem of dispersed generation systems is the existence of high contents of harmonics and interharmonics in the waveforms of the system current. For limiting the harmonics level of the system less than the standards, it is required to limit maximum output power of DG units in the system or use effective power quality improvement or harmonic removal facilities in the power system to be able to gain more power form DG unites. In this paper, an effective solution for this problem is proposed and presented.

3. FILTER STRUCTURE

3.1 Passive Filters

Passive filters as classic methods for power quality improvement of distribution systems consist of series LC tuned for removing a specific harmonic or blocking a bandwich of severe harmonics of nonlinear loads current. These filters have low impedances for the tuned frequencies such as 5^{th} and 7^{th} and for these frequencies, the lower impedance of the filter in comparison with system impedance, the better filtering characteristics of the passive filter. Low cost is a great benefit of these filters but because of their LC constant parameters, they cannot be efficient power quality improvement facilities for dynamic nonlinear loads. Another problem of installation of passive filters is probable resonances between the impedance of passive filter and the system resulting in increasing the harmonics of system current.

3.2 Active Filters

Active filters as modern applications of power electronic inverters are used to fulfill the necessity of compensating the harmonics of power systems for dynamic conditions such as switching on and off loads and DG units. Shunt active filters are used at main bus of distribution systems for reducing the amount of current harmonics of the system being inserted to HV network. These filters are controlled as current sources for producing non sinusoidal currents according to non sinusoidal current of loads or system for removing the harmonics and making system current sinusoidal. These filters suffer from high ratings that increase the cost of project.

3.3 Hybrid Filters

Hybrid filters constructed of active and passive filters with different structures are used for removing the disadvantages of passive filters such as probability of resonances and non dynamic responses and also high costs of active filters, while using the advantage of both of the filters with lower costs. Different structures of hybrid filters can be utilized in power systems such as shunt passive filter and series active power filter with nonlinear loads, shunt active and passive filter with nonlinear load, series active and passive filter parallel with nonlinear load, etc. shown in Fig. 1.

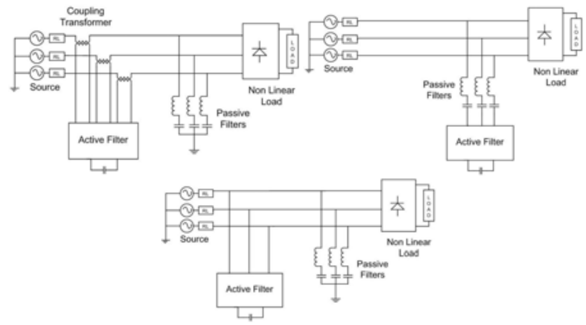

Fig. 1: *Different Structures of Hybrid Filters*

4. STUDY CASE AND SIMULATION RESULTS

Fig. 2 shows a 66 kV, 60 Hz power distribution system with two wind turbines connected to the main bus and four dynamic nonlinear loads, a shunt active power filter at the main bus of the power system and four distributed passive filters connected to the main buses of nonlinear loads, simulated with PSCAD/EMTDC.

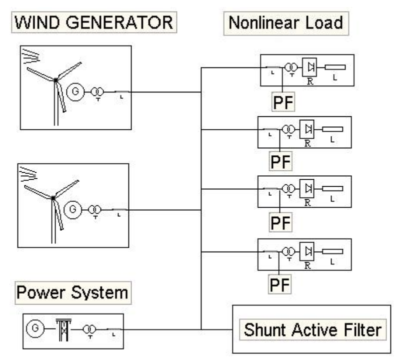

Fig. 2: *Simulated Power Distribution System with DG Units and Hybrid Filter Structure*

The wind turbines convey the mechanical output torque of wind speed to induction generators which produce the required active power of the distribution system. Synchronous machines can also be used instead of induction generator for inserting the required reactive power for the distribution system, if needed. The induction generator starts in constant velocity control but changes to torque constant at 2 seconds. The simulated DG unit of the system is shown in Fig. 3.

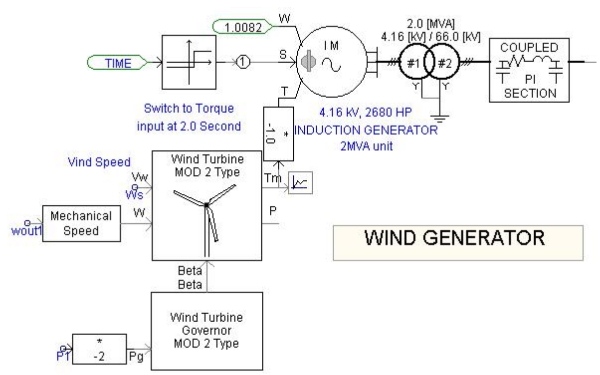

Fig. 3: *Simulated Wind Turbine Model of DG Units*

The properties of the wind turbines and induction generators of DG unit are shown in Tables 1 and 2 respectively.

Table 1: *Properties of Wind Turbine of DG Units*

Turbine Rated MVA	2 MVA
Generator Rated MVA	2 MVA
Machine Rated Angular Speed	376.99 rad/s.
Rotor Radius	38 m
Rotor Area	4500 m^2
Air Density	1.229 kg/m^2
Gear Box Efficiency	0.97 pu

Table 2: *Properties of Induction Generator of DG Units*

Rated RMS Phase Voltage	2.4 kV
Rated RMS Phase Current	2.77 kA
Base Angular Frequency (rad/s)	376.99
Stator Resistance	0.066 pu
First Cage Resistance	0.298 pu
Second Cage Resistance	0.018 pu
Stator Unsaturated Leakage Current	0.046 pu
Rotor Unsaturated Mutual Reactance	3.86 pu
Unsaturated Magnetizing Reactance	0.122 pu
Second Cage Unsaturated Reactance	0.105 pu
Polar Moment of Inertia (J=2H)	1200.0
Mechanical Damping	0.008 pu

The average of output active power of both of the wind turbines is 1.8 MW for constant wind speed of 40 m/s. The waveforms of mechanical output torque of wind turbine and active and reactive power being inserted from DG unites to the distribution system are shown in Figures 4 and 5 respectively. The changes in these Figures happen at 2 seconds after the simulation start, when the induction generators of DG units are changed from constant speed to constant torque control mode.

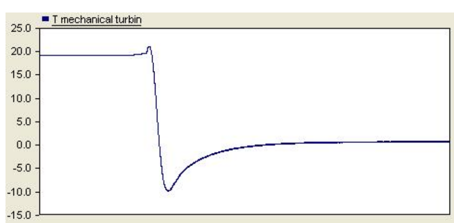

Fig. 4: *Output Mechanical Torque of Wind Turbine*

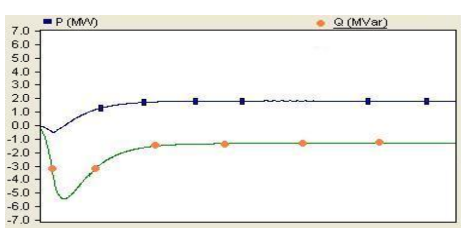

Fig. 5: *Output Active and Reactive Power of DG Units*

The nonlinear loads structure in the distribution system is shown in Fig. 6 constructed of RL thyristor controlled with low RL load in series.

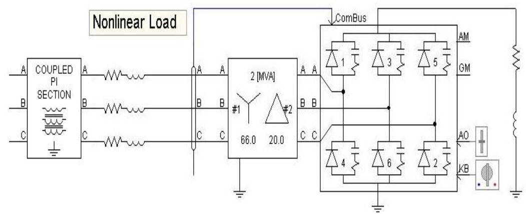

Fig. 6: *Nonlinear Load Structure of Distribution System*

The parameters of nonlinear loads including the magnitude of resistances and reactances, thyristor firing on degree, THD% and 5th and 7th harmonic levels of nonlinear load bus are shown in table 3. Their steady state waveforms in time domain are shown in Fig. 7.

Table 3: *Parameters of Nonlinear Loads*

R_{Load} Ω	L_{Load} mH	Thyr. deg	R_{series} Ω	L_{series} mH	THD%	h_5	h_7
100	100	38	0.265	0.635	17.10	0.149	0.052
25	400	85	0.525	1.3	30.91	0.276	0.759
132	250	75	0.35	2	32.04	0.174	0.116
20	300	50	0.3	10	23.38	0.296	0.052

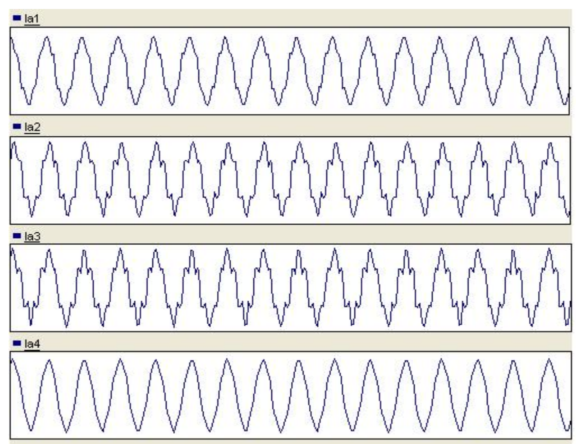

Fig. 7: *Steady State Waveforms of Nonlinear Loads in Time Domain*

For reducing the harmonic contents of the distribution system because of nonlinear loads, several passive filters are designed and used in nonlinear loads buses for removing or restricting the most severe harmonics such as 5th or 7th. A shunt active filter is located at the main bus of the distribution system and its control system consists of sampling from nonlinear loads and PWM control of its inverter with a triangular carrier waveform with 33 times system frequency. The block diagram of the control system of the active filter in the study case is shown in Fig. 8.

The waveforms of the distribution system current at the main bus for the system without any filters, with usage of just shunt active filter or passive filters and the hybrid filter structure introduced in the paper in the system structure in time and frequency domains are shown respectively in Figures 9a and 9b respectively. THD and 5th and 7th harmonic contents of the system current are also measured as shown in Table 4.

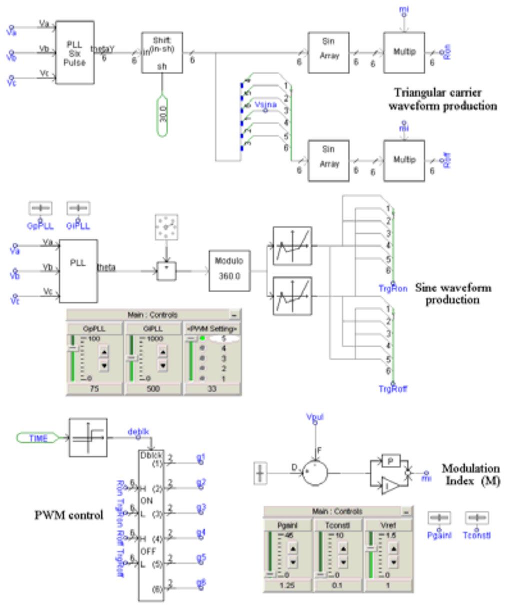

Fig. 8: *Control Block Diagram of Shunt Active Filter*

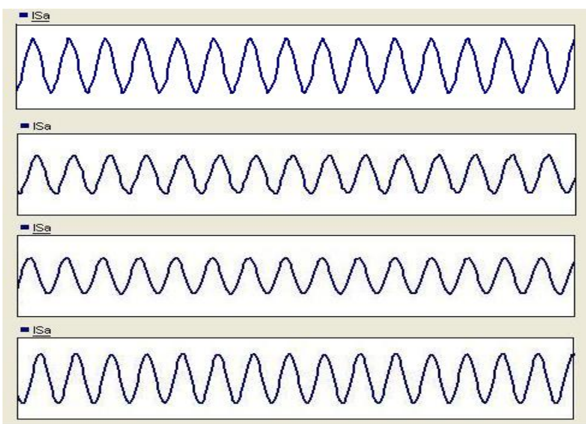

Fig. 9a: *System current waveforms in time domain for the system without any filters, just shunt active filter, just passive filters and the hybrid filter structure introduced in the paper (from top to bottom respectively)*

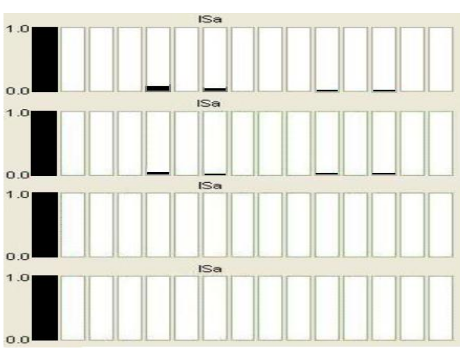

Fig. 9b: *System current waveforms in frequency domain for the system without any filters, just shunt active filter, just passive filters and the hybrid filter structure introduced in the paper (from top to bottom respectively)*

Table 4: *THD and Harmonic Contents of System Current*

	THD%	h_5	h_7
Without any filters	16.04	0.1531	0.031
With nonlinear load 1 PF	3.96	0.0371	0.0092
With nonlinear load 2 PF	1.12	0.0087	0.0041
With nonlinear load 3 PF	1.11	0.0082	0.0043
With nonlinear load 4 PF	1.89	0.0174	0.0045
With four passive filters	3.64	0.0343	0.0063
With shunt active filter	0.33	0.0007	0.0022
With hybrid filter	0.2	0.0005	0.0011

5. CONCLUSION

In this paper, a hybrid filter constructed of a shunt active filter at the main bus and distributed passive filters at the buses of nonlinear loads of a distribution system with DG units was used for power quality improvement and reduction in the system current harmonics. High harmonic contents of the distribution system because of nonlinear loads and DG units are removed and restricted by the use of active and passive filters. Studying and comparing the waveforms, frequency spectrums, harmonic contents and THD of the system current without any filters, with active filter, with passive filters and with the hybrid filter structure introduced in the paper proves the effectiveness of the proposed structure.

6. REFERENCES

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