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Power Harvesting System Using THSEAF with P+R Controller to Improve Grid Current Quality

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Abstract:
The main cause of inferior quality power supply involves the disturbance of power distribution to the consumers, who are prone to use low and high voltage current for their appliances, devices and gadgets. This perception of power quality has led to the advent of modern custom power devices for power quality improvement Unified Power quality Conditioner (UPQC) are a class of custom power devices for providing reliable distribution power quality. They employ voltage fed type of converters for both the active and reactive power compensation. There are many transformerless topologies available in literature such as H4, H5, H6, HERCC (Highly Efficient and Reliable Converters Concept) etc. Transformerless Hybrid Series Active Filter (THSeAF) is modelled and the control strategies for the THSeAF incorporating the renewable energy resources are designed in order to enhance the power quality. The THSeAF converter scheme has adopted a P+R topology in which the common mode leakage current is minimal. A prototype of THSeAF to validate the proposed control strategy is developed which validates the results with simulation.
Keywords*: point of common coupling, Series hybrid active filter, proportional resonant (P+R) regulator, Synchronous Reference Frame,voltage source Inverter*

I. INTRODUCTION

Electrical energy is the most efficient and popular form of energy andthe modern society is heavily dependent on the electric supply. At the same time, the quality andcontinuity of the electric power supplied is also very important for the efficientfunctioning of the end user equipment.Most of the commercial and industrialloads demand high quality uninterrupted power. Thus maintaining the qualitypower is of utmost important. The quality of the power is affected if there is anydeviation in the voltage and frequency values at which the power is beingsupplied. This affects the performance and life of the equipment whereas thecontinuity of the power supplied is affected by the faults which occur in thepower system.To maintain the continuity of the power being supplied, the faultsshould be clearedat a faster rate and for this, the power system switchgearshould be designed to operate without any time lag. Some of the power qualityproblems are harmonics, transients, sudden switching operations, voltagefluctuations, frequency variations etc. These problems are also responsible indeteriorating the consumer appliances. With the recentadvancements in power electronic devices, there are many possibilities to reducethese problems in the power systemvoltage levels. Yet, there are chances of leakage circulating currents flowingthrough ground and through the PV panels. To get rid of this hitch, the THSeAFconverters scheme has adopted a HERIC topology in which the common modeleakage current is minimal. In order to pump the power at unity powerfactor, an average current control scheme is adopted. Therefore, in this work, asan evolution, the THSeAFconverters extended with a control scheme is proposed.Thisscheme includes the P+Rconcept based maximum power reduction and the average current control scheme to pump power at unity power factorwith a sinusoidal current.Transformers being bulky, costly and

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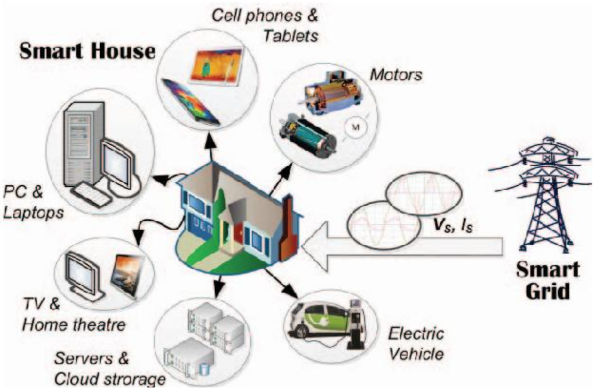
consume some power as thelosses, it is attempted to develop transformerless power conversion systems.

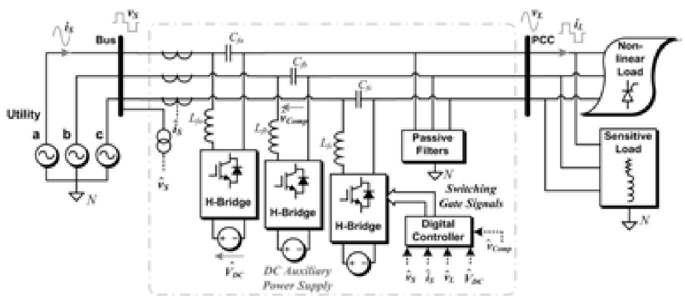
Fig.1. Smart residential consumer with non-linear electronic loads



Intransformerless power conversion systems, it is possible to develop the required.This paper is organized as follows. Section II, provides the description of the System overview and describes the Methodology in detail. Section III, presents the Experimental results and analysis. Conclusions and future work are given in Section IV. References are given in Section V.

I. SYSTEM DESIGN

With the ongoing scenario of fast depleting fossil fuels, the power generation industry is constantly looking for alternative means of power generation systems using renewable sources. Global warming is another threat that the new alternatives tend to seek and recommend the usage of natural resources like wind and sun light which are somewhat harmless to global warming.In a typical PV farm, there are possibilities for existence of asignificant parasitic



capacitance between the ground of the grid and the PVpanels. This parasitic capacitance may lead to leakage currents that could, inturn, lead to electric shock hazards. Due to this leakage of current, there may beproblems associated with radiated interference.A number of methodologies have been suggested to bring down theleakage current within the limited range of tolerance. In the typical topologicalarrangement as given in Figure 2, the leakage current passes through theparasitic capacitances C1 and C2. Other components in the circuit with referenceto the Figure 1 are the bridgeelements, the filter elements, the grid and theground impedance. The filter inductances L1 and L2, along with the parasiticcapacitance, form a series resonant path, and the common mode voltage is given by the Equation.

$$I_{Sh} = \frac{+Z_L I_h - Z_L I_h}{Z_S + Z_L + G} = 0$$

The leakage currents can be minimized by keeping the common modevoltage near constantvalue. The Half bridge inverter topology can also helpreduce the common mode current. In this case, the centre point of the DC link. Capacitors is tied to the neutral point. This arrangement reduces the overalloutput voltage. With the half bridge arrangement, there is only a single inductor,and the common mode voltage is given by the following Equation,

$$v_{cm} = \frac{v_{AN} + v_{BN}}{2} + (v_{AN} - v_{BN})\frac{2(L_2 - L_1)}{L_1 + L_2}$$

With the full bridge arrangement based on two filter inductors ofequal values the common mode voltage is given by the following Equation,

$$v_{cm} = \frac{v_{AN} + v_{BN}}{2}$$

The block marked power calculation unit measures the present input voltage and the current supplied at the moment.The product of V and I gives the power being supplied by the at the moment. Presuming that this power is pumped into the grid, it is essential that the output voltage of the inverter matches the grid side voltage in amplitude, phase and frequency, and

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also the current entering into the grid must be calculatedaccording to the PV power available at the moment.

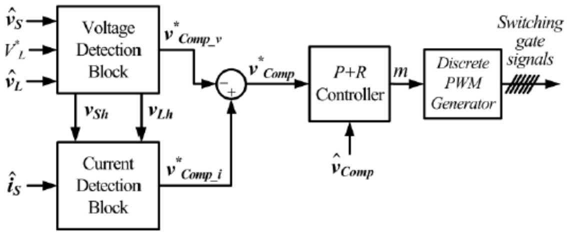

Fig.3. Controller architecture scheme.

The instantaneous value of estimated sinusoidal current is constantly compared against the actual current, and the error is fed into the error detector; the P+R controller, in turn, generates the control quantity to be used in the P+R section.

B. Average Current Control scheme:

The actual grid current, and the estimated grid current are used to findthe error and this error is fed into a P+R controller of large bandwidth fed into the PWM generator. Thebandwidth of the P+R controller should be large enough so that the time varyinggrid current and the sinusoidal reference current are compared very closely andthe controlsignal is generated. This control signal is used for sinusoidal P+R and the pwm pulses generated drive the power switches of the inverter.

C. A typical P+R controller

The objective of any controller in general is to make the errorbetweenthe expected value or set point and the actual value aszero. If, for themoment, there is a finite error, then the error is passed on through the P+R controller and the output of the P+R controller is used to alter the manipulatedvariable and with the negative feedback, in due course the errorwill becomezero.

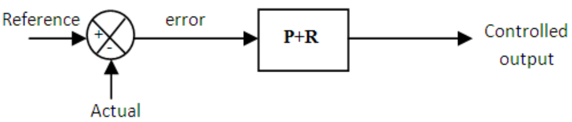

Fig.4. P+R Controller block

The controllers with slowly varying controlled variable will havelower bandwidth. Therefore, it is necessary to have higher bandwidthcontrollers for fast varying controlled parameters. With the sinusoidal signal asreference, it is required that the controlled parameter exactly tracks the referencesinusoidal signal as in the case of the current mode controller. After theestimation of the sinusoidal reference current for load the actual load, iscompared and the error is estimated. The error is fed into either the P+R controller. The performance of both the P+R controller Values are fed into the PWM generator.

$$v^*_{comp} = -v_{comp_v} + v_{comp\_i}$$

This above equation then analysed with the parameter output voltage of the compensator and by passing through the P+R controller; the duty cycle m is produced. The duty cycle is a matrix of three components, each for a phase of the system.

II. RESULT AND DISCUSSION

A simulation in the MATLAB / SIMULINK environment has been carried out. An experimental prototype has also beendevised to validate the proposed idea. The dynamic and steady state performance of the P+R are found to be better than the PI controller and the results are presented.The system parameters of theTHSeAF are given in Table 1. In order to validate the performance of the proposed THSeAF in mitigating the voltage sag,voltage swell, interruptionand harmonic compensation there are three case studies are performed. Thesimulation study described before andafter the installation of compensator.

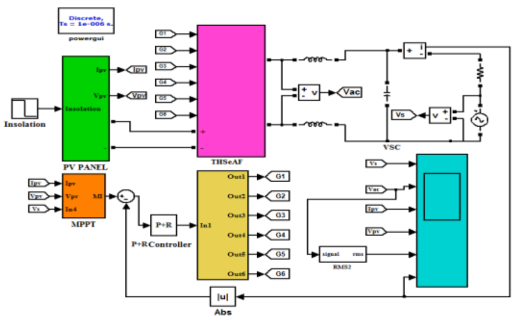

Fig.5. Simulink model of THSeAF transformerless configuration

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After estimating the reference voltage signal, which is comparedwith actual measured voltage and an error signal is given to the hysteresiscurrent controller. Hysteresis current controller scheme depends on a feedbackloop, usually with two-level comparators. The switching commands are givenwhen the error limit exceeds a specified tolerance band '± h1'.Unlike thepredictive controllers, the hysteresis controller has the main advantage of peakcurrent limiting capacity besides other meritssuch as good dynamicperformance, ease of implementationand not dependent on load parametervariations.

TABLE I
SIMULATION PARAMETERS

Symbol	Definition	Value
V_S	Line-to-Line voltage	190~208 Vrms
f	System frequency	60 Hz
R_1*, L_1*	Linear Load #1	12.5 Ω, 40mH
R*, L*	Non-linear CSC load	12.5 Ω, 20mH
Lf	Switching ripple filter inductance	5 mH
Cf	Switching ripple filter capacitance	0.5 μF
r_C	Switching ripple damping resistor	50 Ω
f_{PWM}	PWM frequency	8 kHz, 10 kHz*
V_{DC}	dc auxiliary power supply voltage	100~150 V
R	Non-linear load resistance	25 Ω
L	Non-linear load inductance	20 mH
S	Load power rating	2.6~3.1 kVA
K_P, K_r	Controller proportional and resonant gains	2.5, 10
ω_C	Cutoff frequency	5 rad/s
T_S	dSPACE, DS1103 Synchronous sampling time	42 μs

The balanced voltage sag with 76% (176V in RMS) of nominalvalue (230V) is applied during 0.025sec to 0.1sec and the balanced voltageswell (115% of the nominal value) is applied during the period 0.15 sec to0.2sec. The proposed PV-SHAPF detects the voltagesag and swell and injects suitable compensating voltage in series with the supply voltage at 0° and 180°phase angle jump to mitigate the voltage sag andswell.During this period, unbalanced loads are applied in the distributionsystem. Figure 6 shows the digital simulated waveform of distorted loadcurrent, compensation currents, the compensated source current and sourcevoltage overlaid with the source current.

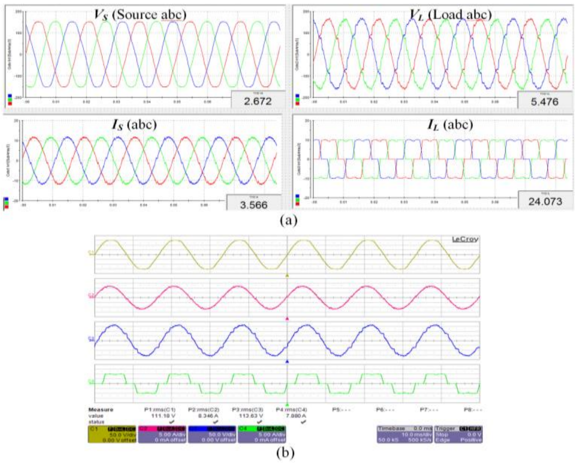

Fig.6. THSeAF compensating load current harmonics; (a) The dSPACE snapshot during operation of the real-time system; (b) Oscilloscope's measurement on phase-A.

Fig.6. shows the sourcevoltages during voltage sags and swell and interruption, series APFinjectedvoltage and compensated load voltage. The proposed THSeAF compensationability is tested for voltage sag, swell and voltage interruption under balancedvoltage with unbalancedloads. The effectiveness of the voltage sag/swell andvoltage interruption compensation was verified under the balanced voltageand unbalanced load condition is shown in the Figure 6 (a), (b) and (c).

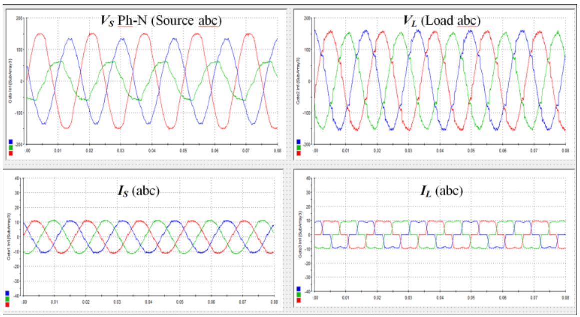

Fig.7. The dSPACE snapshot during a real-time operation of the THSeAF compensating current harmonics and performing voltage restoration.

The current harmonics THD level of the three phase currents beforeconnecting the active power filter is 25.13%, 26.10% and 27.60%, in thephase-A, B and

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C respectively is shown in Fig.7. After connecting theTHSeAF based power angle control scheme, THD level is reduced to3.32%, 2.92% and 2.84% in in the phase-A, B and C respectively is shown inFigure6. In addition, the source current is in phase with the source voltage,so that the power factor is equal to one as shown in Figure 6.

III. CONCLUSION

Proposed research, the THSeAF topology, presented APF, modes of operation of the APF and P+R based power angle control method are described.The simulation results of the APF for different load conditions are also described to show the recompense ability of the APF.The proposed transformerless Active power filter was simulated and experimentally validated.In this application of injecting power into the grid by using the THSeAF converter, the PWM outperforms the P+R based controller in terms of injectedpower quality. It can therefore be concluded that the PWM outperforms the PIcontroller in terms of efficiency improvement from 88% to 91.2%. Similarly, PWM causes the THD to decrease by 1.5% from 4.7% to 3.2%.Theresearch area has wide scope for future research and the variousresearch directions include the exploration of multi-level inverters withharmonic reduction techniques, such as selective harmonic elimination and spacevector PWM, can also be attempted in this application. Such multi-levelinverters arerecommended. The outcome of this study widens the research scopefor a single comprehensive control system to ensure maximum power harvestingwhile ensuring power quality.

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