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Fuzzy based SAPF for Hybrid Renewable sources for Grid-interconnection

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ABSTRACT

A Fuzzy logic controller based SAPF for Hybrid Renewable sources for Grid-interconnection has been proposed. SAPF is shunted at the PCC with the existing power system to have compensation among power quality issues. The proposed converter topology also feeding the Maximum Power from the PV-Arrays and Wind Energy System into the Grid. The advancement of the 4-leg VSI with the proposed controller is found to be more prominent & sufficiently mitigate power quality issues under all Non-Sinusoidal situations. SAPF current reference signals are obtained by SRF scheme. Matlab Simulink results showed that the proposed scheme can effectively compensate the harmonic currents and improve Power Quality.

Index Terms-*Shunt Active Power Filter (SAPF), Point of Common Coupling (PCC), Synchronous Reference Frame (SRF), Fuzzy Logic, and Power Quality.*

I. Introduction

Day-by-day exponentially rising of power demands & Growth of population has been leads to deficiency of power. Research & initiative measures of replenishable sources have been showing excellent potential as a form of contribution to Non-replenishable fuel resources. Exploration of Renewable energy sources, allow pollution free energy, Decentralization and plentiful energy congregate from natural alternatives- such as sun-shine, wind, Bio-mass sources and so on. The solar and the wind energy were more customary complimentary power origin as they are seasonal. As a single entity, they were able to feed the local loads in remote locations far away from national grid. A hybrid system containing solar and wind has been designed to overcome the shortcomings [4] associated with stand-alone ones.

The electric power generation system, which consists of Non-conventional energy sources connected to grid, has the ability to provide 24-hour electricity to the load. This system offers a better reliability, efficiency, flexibility of planning and environmental benefits compared to the stand-alone system. Recent enhancements in power electronics provide a broad & narrow control over flow and conversion of power, leads to Quality of power.

The application of Current controlled voltage source inverters can be effective with an appropriate control strategy to perform active filter operation. The electrical grid is not a single entity aggregates multiple power sources with multiple networks including self-renewing energy sources. One should concerns with the interface unit between the power sources and the grid as renewable energy systems can inject harmonic component that may detoriate the power quality of the electric grid [5], [6]. In addition, the rapid use of semi-conductor based devices and intermittent loads at PCC leads to generate Fundamental harmonics, which raise the power quality issues. This leads the electrical designers to elaborate energetic & adaptable way out to the power quality issues. Such equipment, known to be Active power conditioner allowed to answering the power quality related issues.

II. Grid-connected pv-wind plants

The integration of RES, such as Solar or Wind energy systems incorporate with storage system, is hardly proven as a best solution to remotely operated conventional sources. The integrated systems are generally known to be Hybrid PV-Wind systems. The advancement of power electronic era makes the wind and photovoltaic power systems to have a successful transition from few KW stand-alone sites to MW grid-connected systems. This improves the firm capacity of an electrical power system aiding with overall economy.

With this implementation the RES can serve the local/remote area loads alternatively supply the surplus power into the grid to power-up the site loads.

Hybrid power systems (fig.1) integrate the local site solar energy with conventional wind driven generator. With aiding the Voltage source converter for inverter and rectifier operation, the system size can be reduced. The proper coordination of HES connected to a common Grid system leads to improve the Reliability, Flexibility of power system & reduce capital cost per KW as compared with stand-alone systems.

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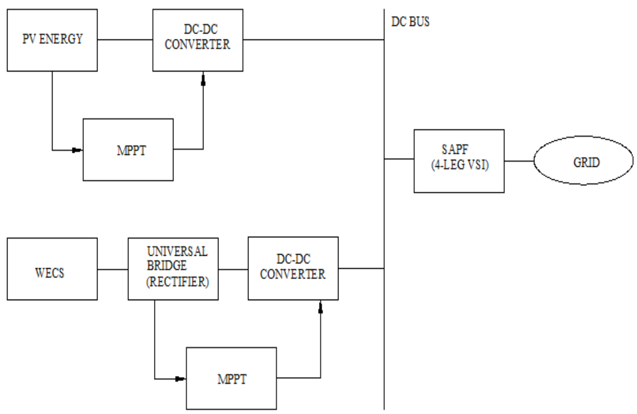

Figure 1. Generalized Block Diagram of Grid-Connected PV-Wind Systems

III. Control of grid inter-connected systems

The proper coordination & satisfactory operation of Grid-interconnected Hybrid systems involves the selection of the most suitable & alternative combination of power resources, power conversion, control, monitoring, units and battery back-up system together with adequate control methodology.

1. Four-Leg PWM Converter Model

Self-renewing resources, such as solar & wind, are basically intermittent in nature and complementary ones. Both types of power generation can utilize static PWM based voltage/current controlled converter topologies for conversion, controlling, conditioning and battery banks for reliable power.

The early thyristor based inverters are undesirable on the power system. Modern era of active filters utilize IGBTs as switching devices, designed with PWM technique. It consists of a source capacitor, a 4-eg voltage source converter, and a low-pass filter (Fig.2). The four-leg PWM converter topology is shown in Fig.3. The switching levels of the converter topology can be enhanced from 8 to 16 with fourth leg connected to neutral line of the Grid system, also improving control flexibility and output voltage quality [10] of the power system.

Converter topology consist 2-pairs of IGBT switches in each leg, controlled in complementary fashion (Fig.3).

In terms of switching levels, the voltage in any arm 'x' of the converter topology, refer to neutral point (n) can be obtained from equation (1).

$$V_{xn} = S_x - S_n V_{dc}; \quad x = R, Y, B, n \qquad (1)$$

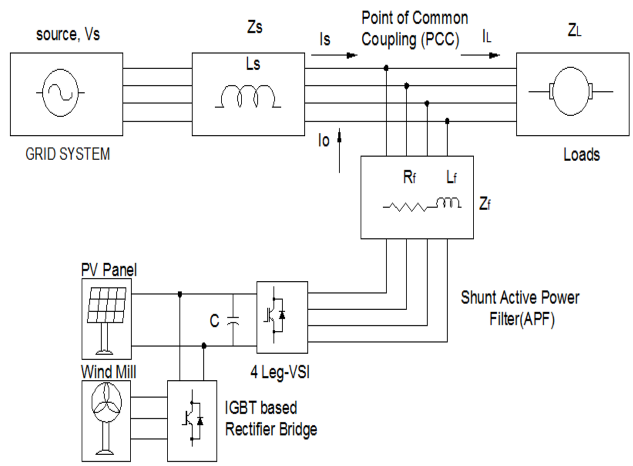

Figure 2. Equivalent model of the proposed scheme

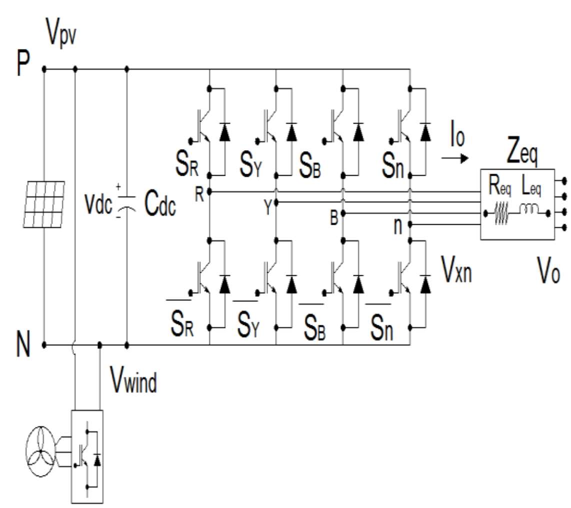

Figure 3. Four-Leg PWM Converter Topology

The mathematical expression of the low pass filter derived from the equivalent model shown in fig.3 is

$$V_O = V_{xn} - R_{eq} I_O - L_{eq} \frac{di_o}{dt} \qquad (2)$$

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The 4-leg converter output parameters R_{eq} & L_{eq} can be expressed as Thevenin's impedance Z_{eq} at the converter output terminals. Therefore, the series and parallel arrangement of the Filter impedance Z_f and System equivalent impedance Z_s & Load impedance Z_L respectively forms the Thevenin's impedance Z_{eq}

$$Z_{eq} = \frac{Z_S Z_L}{Z_S + Z_L} + Z_f \approx Z_S + Z_L \qquad (3)$$

For this system, it is assumed that $Z_L \ggg Z_S$, allowing the acceptable approx. of reactance in the series is in the range of 3 to 7% p.u & negligible system resistance for real system. Such that, in (2) $R_{eq} = R_f$ and $L_{eq} = L_s + L_f$.

2. Reference Current Generator

In order to have compensation over the Non-Linear loads, there are many ways to determine the reference current signals. Generally, operating principle of the active filter is to generate either harmonic voltage/current in a fashion such that the grid voltage/current conserves the sinusoidal nature. With available solutions, the reference currents required by the SAPF, synchronous reference frame scheme is used to procurable required current components [11]. This scheme exhibits a fast and accurate signal tracking capability such that voltage fluctuations are minimized that detoriate the current reference signal affecting compensation performance [12].

The Synchronous reference frame scheme block diagram for current reference generator is shown in Fig.4. Here, the Synchronous reference frame can be obtained from the real currents allowing the application of Clarks and Parks transformation methods [11]. With PLL the reference frame is allowed to synchronize with the system voltage having same rotating Frequency. The equations defining Transformation are:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ \sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (4)$$

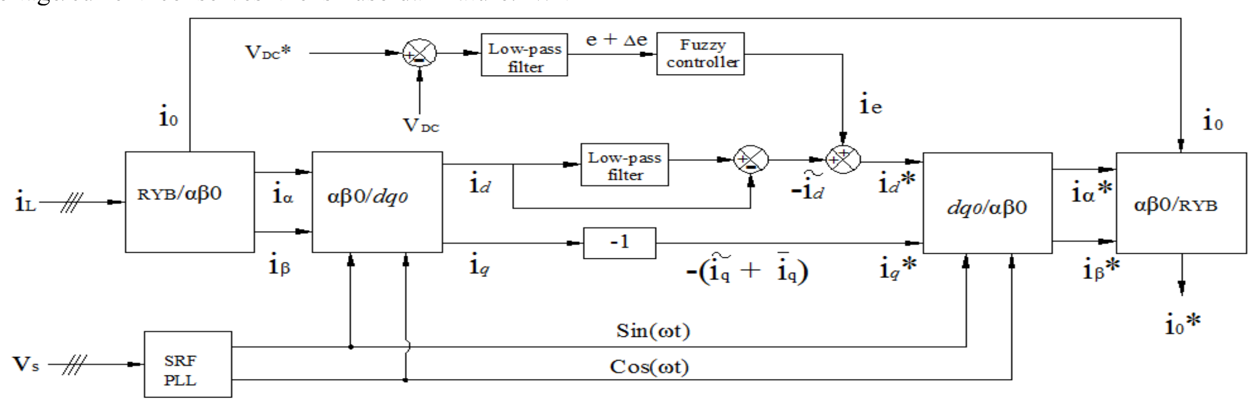

Figure 4. Current reference generator block diagram

Active filter compensation currents are obtained from eq. (5)

$$\begin{bmatrix} i_{Rref} \\ i_{Yref} \\ i_{Bref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$$

$$\begin{bmatrix} -1 & 0 & 0 \\ 0 & cos\cos(\omega t) & -\sin(\omega t) \\ 0 & \sin(\omega t) & \cos(\omega t) \end{bmatrix} \begin{bmatrix} i_o \\ i_{dref} \\ i_{qref} \end{bmatrix} \qquad (5)$$

Through this control algorithm, without considering the mains voltages the reference currents are directly generated with available load currents. However, in order to implement α-β to d-q frames simultaneousness w.r.t. phase-to-neutral voltages, the sine & cosine signals are required. Such operation can be implemented by using Phase-locked-loop in each phase (Fig.5)

The SRF-PLL can be employed as a control system for generating output signal which is having exact phase relation to the input signal phase. A low pass filter (LPF) extracts the ripple content of the phase current i_d to generate the harmonic reference components -$\tilde{i_d}$.

Phase current reactive reference currents were obtained by shifting the phase of corresponding dc and

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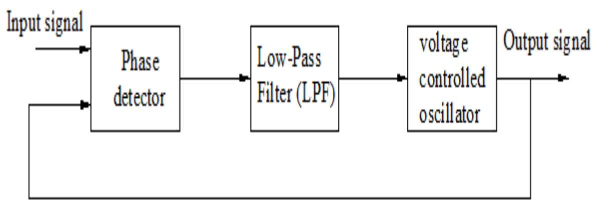

Figure 5. Block diagram of PLL

ac components of Quadrature current component by 180^0. With aiding the active power reference signal i_e with the d-axis component, current magnitude of the converter can be modified, allows the stiff dc-voltage. Applying inverse Park and Clark transformation, resulting i_d^* and i_q^* are transformed back to real system parameters given by (5). The Neutral current in the system bus can be mitigated by allowing the same instantaneous current derived from the phase current, Phase-shifted by 180^0 given by:

$$I^*_{on} = -(i_{Lr} + i_{Ly} + i_{Lb}) \quad (6)$$

3. DC-Voltage Control

The control algorithm for dc-voltage converter is accompanied with a predictive Fuzzy Controller. Fuzzy controllers are very effective and provide adequate solutions with Non-Linear systems. These controllers employs human like thinking in terms of IF-THEN rules to follow dynamics of the Non-Linear systems [14]. Fuzzy control structure built-up here (shown in Fig.6) is a Dual-Input-Single-Output (DISO) controller. The concerned inputs are the error, e (k) and the change in error Δe (k).Consequently, the Fuzzy Controller generates switching signals that would be given as input of power conversion converter (DC-DC converter).

Main blocks involved with the Fuzzy controller operational structure are Fuzzifier, inference engine and De-Fuzzifier. Fuzzy controller generates switching signals based on requirement for converter topology, followed by rules given in table-1.

TABLE-1 RULES FOR FUZZY LOGIC CONTROLLER:

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

The converter topology is provided with a feedback path that initiates the error value at the output. Utilization of active power by the converter which is in phase with phase-voltage can be controlled by controlling the magnitude of active power reference signal. From Fig.6, the dc-voltage V_{dc} is calculated and then compared with a constant reference value $V^*_{dc.}$ The error e (k) or changes in error Δe (k) are processed by a Fuzzy Controller, in order to provide switching signals to the shunt active filter (SAF) according to the dynamic response requirements in a real time situation as rules generated by Fuzzy controller.

IV. Simulated results

To examine the effectiveness of the proposed Fuzzy based grid inter-connected Solar-Wind system with 3-phase, 4-leg converter topology and the simulation model is developed, simulated and implemented using MATLAB-Simulink software. The model parameters are listed as shown in table-2.

In order to verify the proposed model results shown in Fig. (a) To (f), a 6-pulse rectifier bridge with RL-Load was used as a Non-Linear Load.

TABLE-2 MODEL PARAMETERS:

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Variable	Description	Value
Vs	Source Voltage	55[V]
fs	System Frequency	50[Hz]
Vdc	dc-Voltage	162[V]
Cdc	dc Capacitor	2200[μF]
Lf	Filter inductor	5.0[mH]
Rf	Internal resistance within Lf	0.6[Ω]
Ts	Samling time	20[μs]
Tc	Execution time	16[μs]

Note: V_{base} = 55v and S_{base} = 1 KVA

Now, allow step change applied at t = 0.2 s (say) to test the performance of the dc-voltage loop. Finally allow Non-linear load to switch-on, to confirm the neutral current compensation. As the load is unbalanced it draws a non-sinusoidal current, without active power filter compensation, the load current at t = 0 s to t = 0.2 s shown in Fig. (b). Now allowing another step load change at t = 0.3 s, proposed model can be examined by allowing another step load change. Now the active power filter starts compensate at t = 0.3 s. Active power filter injects compensation currents both in particular phase and into neutral bus simultaneously based on requirement.

Thus the simulation results proved that the proposed controlled scheme effectively compensates power quality issues, due to the unbalanced and nonlinear loads connected to PCC. Thus the load & grid side currents always conserve the sinusoidal nature. Additionally, for the whole operation of shunt active filter Fig. (f) Shows that the DC voltage remains stable and maintains constant.

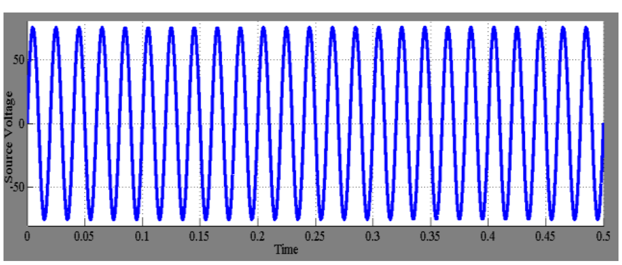

Figure a. System voltage

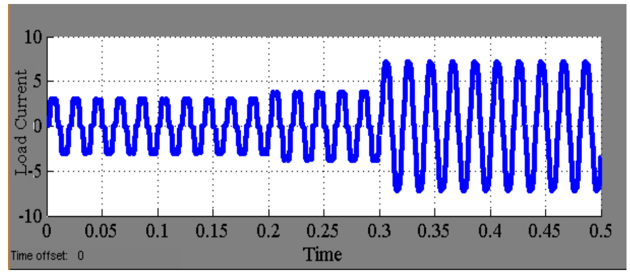

Figure b. Load side Current

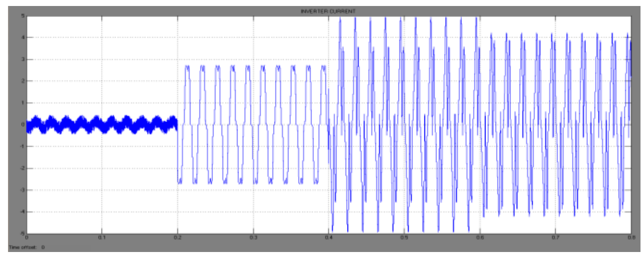

Figure c. Inverter Current

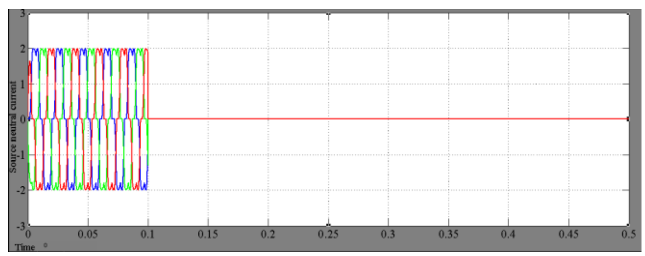

Figure d. Neutral Current (Source)

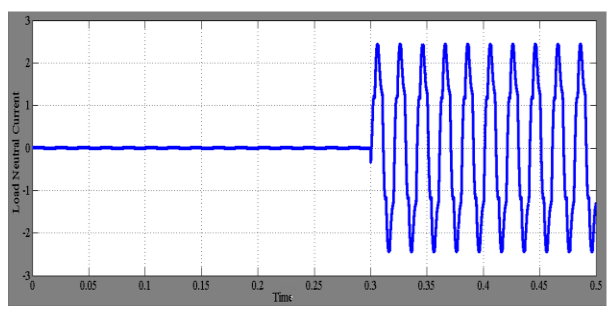

Figure e. Neutral Current (Load)

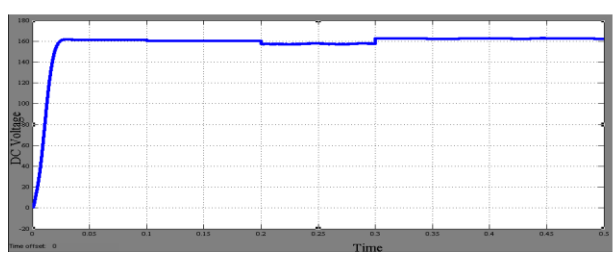

Figure f. DC Voltage

V. Conclusion

Proposed converter topology with fuzzy controller not only solves the power quality issues, but also feeds the peak power from the solar and wind power sources inter-connected with the Grid. Under all non-sinusoidal scenarios the modeled 4-leg VSI seems to be worth and adequate solution. The control strategy aiding with Fuzzy controller can be modeled and simulated using MATLAB for Integrated system interconnected to the Grid. Applied Fuzzy logic controller provides stable & robust solution to the proposed project. Simulink results shows that the proposed control methodology is best solution among alternative conventional solutions. Advantages of such a proposed scheme are related to its friendly interface to the electrical Grid.

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