MATEC Web of Conferences **225**, 03015 (2018) https://doi.org/10.1051/matecconf/201822503015
UTP-UMP-VIT SES 2018

Enhancement of Power Quality in Multi Feeder Three Phase System with Photovoltaic fed ANFIS-Unified Multi Converter Controller

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Abstract. Substantial growth in modern innovations demands more power from utility. To cope with drastic power demand on grid renewable sources have been integrated. This makes more complex power system as these integrated sources more dynamic in nature. Intelligent usage of renewable sources leads to optimal and reliable power structure. This paper provides an optimal usage of renewable source for unified controlling action to compensate power quality issues on multi distribution feeders. Proposed Unified Multi Converter Controller (UMCC) effectively alleviates power quality issues like harmonics, imperfections in current and voltage on multi feeder. ANFIS based harmonics alleviation is studied and compared with traditional control error tuning. Here, Photovoltaic source is considered. Proposed three phase system is analyzed in MATLAB\SIMULINK platform with variable load and supply voltage conditions.

1 Introduction

Growing modern technology in industries and living standards of human life demands renewable source integration to the grid [1-3]. Dynamic renewable source integration has considerable affect on power quality of the system. Increasing modern power demand and aging of networks requires a fast and reliable control of power in the power system. To achieve desired power quality limits, active filters play a vital role. The emerging FACTS devices specifically unified controllers are best suited to compensate the PQ disturbances [4-5].

Generalized Unified power flow controllers (GUPFC) [6] and Interline Power flow Controllers (IPFC) [7] are introduced for power flow control in Multi bus/line systems. GUPFC pre-dominates capabilities of Unified Power Flow Controller (UPFC), which provides voltage control, control of real & reactive power on multi lines. This technique is further extended as unified PQ controller in distribution level for multi-line/bus control.

This paper presents Unified Multi Converter Controller for power quality enhancement. Model considers a three phase two line system where the controller effectively works to compensate harmonics, and power flow control. The model also utilizes photovoltaic source in effective manner [8-9]. Harmonics alleviation in current and voltage, voltage

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swell/sag/interruption compensation, unbalanced and distorted source voltage compensation, effective integration of PV system are the objectives of proposed control technique.

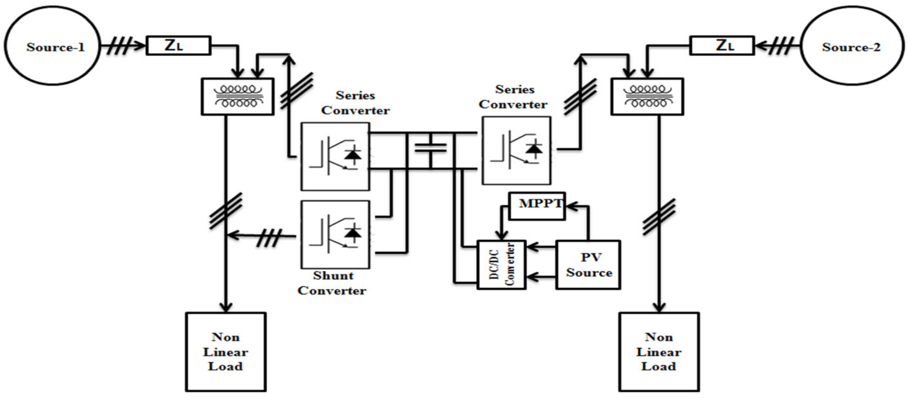


Fig. 1. Proposed System

2 Proposed System Description

Proposed UMCC is connected between two Lines of 2 bus system. Fig. 1 demonstrates Single line diagram of proposed 2 bus system. Two lines connected to two loads L_1 and L_2 served by two separate sources S_1 and S_2 respectively. Source-1 connected with Non Linear loads and Source-2 connected with sensitive load. V_{S1} and V_{S2} are source voltages, I_{S1} and I_{S2} are the source currents, I_{L1} and I_{L2} are load currents. Proposed UMCC consists of three 3 leg voltage source converters. Two converters are used as Series Converters ($VSCs_{e1}$ & VSC_{se2}). The third one is used as Shunt Converter (VSC_{sh}) connected to Line-1. All the 3 converters share the common DC link. The Photovoltaic Unit is fed at DC link to provide additional power to the system [4-5]. The DC link propagates the power from Photovoltaic Unit to the interconnected line.

Here, control strategy uses both series and shunt controllers which are based on Synchronous Reference Frame d-q method. Gating pulses for Shunt Controller and series controller are generated using pulse width modulation (PWM) technique.

Integrated PV source at DC link delivers required power to Shunt Converter for mitigating current abnormalities on Line-1 and power required to SEC_1 and SEC_2 during voltage sag/swell/interruption condition [1,5]. In general Lead Acid Batteries, Fly wheels, Super Capacitors are utilized for supplying required power at DC link. In current model battery is replaced by Photo Voltaic Source. This works as DC link voltage stabilizer and delivers the part of real power to load.

Several maximum power point tracking algorithms are available for tracking maximum solar energy [10]. Like Perturbation & Observation, Incremental Conductance, soft computing based MPPT methods. Ease of less parameters and uncomplicated feedback makes P&O as most preferred algorithm [11]. Considered Photovoltaic Source comprises PV cell, MPPT unit and DC/DC boost converter.

2.1 Shunt Control Strategy

Here, shunt controller compensates reactive component and harmonic content in (I_{S1}) source current. It also regulates dc link voltage (V_{dc}). Fig. 2, shows the shunt control strategy. Here, the load currents transformed into reference frame dq0 components given by

$$I_{Ldq0} = T_s * I_{Labc} \tag{1}$$

Where T_s is the transformation matrix given by,

$$T_s = \frac{2}{3}\begin{bmatrix} cos(wt) & cos(wt-120) & cos(wt+120) \\ -sin(wt) & -sin(wt-120) & -sin(wt+120) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \tag{2}$$

For regulating DC link voltage, response signal of PI controller given in (3) is added with d component of I_L. The d and q component of reference current are given in (4) & (5),

$$V_{e(t)} = K_p e(t) + K_i \int_0^t e(t)dt \tag{3}$$

Where $V_{e(t)}$ is output of PI controller, e(t) is input error signal and traditional controller gains are K_p & K_i .

$$I_{ref}^{d} = I_{Ld} + \Delta I_{dc} \tag{4}$$

$$I_{ref}^{q} = I_{Lq} \tag{5}$$

Above d & q components of reference currents are again transformed into 'abc' component frame using (6),

$$I_{ref}^{abc} = T_s^{-1} * I_{ref}^{dq0} \tag{6}$$

Later, using PWM controller gate pulses are generated to cancel the harmonics and reactive component in Source current. In this model, ANFIS & Fuzzy logic are utilized to tune the DC link voltage error for effective harmonic compensation. This method pre-dominates commonly traditional PI controller technique. Fuzzy controller has three stages to develop desired response. At beginning, fuzzification phase converts crisp variables into linguistic fuzzy variables. Both input and output spaces are mapped using triangular membership functions. The selected linguistics variables are PH, PM, PS, ZE, NS, NM and NH [12]. At inference stage, input variables are processed based on knowledge base. At defuzzification stage, response variables of inference stage coalesced by centroid method for producing targeted final control signals.

ANFIS controller utilizes both Neural Network's adaptive learning features & Fuzzy inference mechanism. Neuro-Fuzzy combination has proven its fine tuning of error signal ability in [13]. Five layer ANFIS structure is used in current model for tuning DC link error [8] and sugeno rules are used for ANFIS controller.

2.2 Series Control Strategy

Here, series controller mitigates voltage swell, sag and interruption. It also compensates voltage harmonics. ANFIS based series voltage controller is show in Fig.3. Initially, source voltages are transformed into dq0 components using (7),

$$V_{s1}^{dq0} = T_s * V_{s1}^{abc} = V_{s1p} + V_{s1n} + V_{s10} + V_{s1h} \tag{7}$$

where V_{s1p}, V_{s1n}, V_{s10}, and V_{s1h} are positive, negative, zero sequence and harmonic component respectively.

Objective is to get sinusoidal voltage, so the dq0 reference frame of load voltage is given by (8),

$$V_{L1}^{dq0} = T_s * V_{s1}^{abc} = \begin{bmatrix} U_m \\ 0 \\ 0 \end{bmatrix} \tag{8}$$

Required compensating dq0 reference frame voltage is given by (9),

$$V_{dq0}^{ref} = V_{s1}^{dq0} - V_{L1}^{dq0} \tag{9}$$

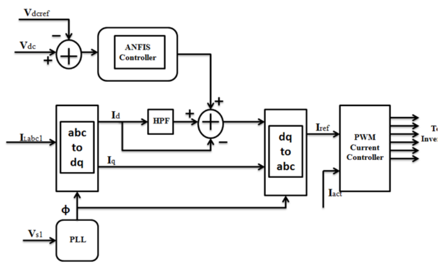


Fig. 2. Shunt Controller

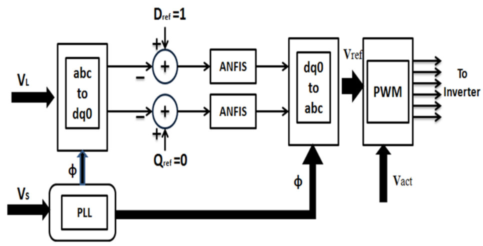


Fig. 3. Series Controller

3 Simulation Results

3.1 Current Profile

The nonlinear load connected to Line-1 injects harmonics into line. Fig.4 shows ANFIS based shunt converter injected currents (Phase-A) to suppress source current harmonics. Before T = 0.1 sec, non-linearities are present in the source current. Here variable load is considered after T= 0.1sec. Post T = 0.1sec, ANFIS based shunt controller is active and suppresses the nonlinearities in current by injecting the opposing current. Here, load current is served by both Source-1 and PV fed shunt injected current

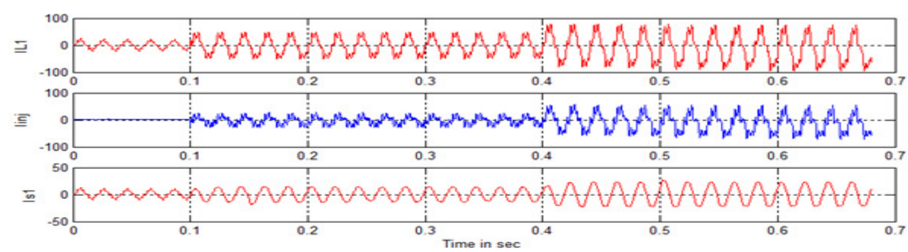


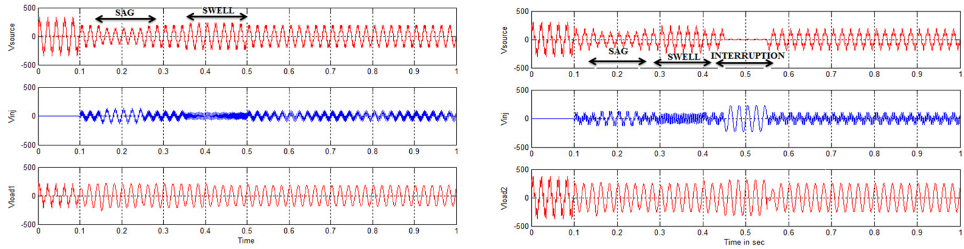
Fig. 4. Load current, Injected current and Source Current on Line-1

3.2 Voltage Profile

On Line-1 load voltage has sag of 25% in the duration 0.15< T < 0.5 & 20% swell in the duration of 0.35<T<0.5. The series voltage converter VSC_{se1} injects required compensating voltage to mitigate swell and sag in the source voltage. The same has been shown in Fig. 5(a). Due to injection of voltage, the Load-1 Voltage (VL1) profile is improved. On Line-2, load voltage has 25% sag in the duration 0.15 < T < 0.25 & 30% swell in the duration 0.3 < T < 0.4. An interruption in voltage is created between 0.45 < t < 0.55 with 3 phase fault.

Series voltage controller VSC_{se2}, injects voltage to compensate sag, swell & interruption. The same has been presented in Fig.5(b). By injecting required voltage, Load-2 voltage profile is improved. Fig.6 shows the unbalanced voltage mitigation.

Here, unbalanced and distortions are created in Source voltage. Under these conditions also proposed model successfully suppresses the voltage variations and sinusoidal voltage is supplied to load. Fig.7 shows power factor improvement with the integration of shunt controller after t=0.1 sec from 0.68 to 0.92



(a) Line-1 (b) Line-1

Fig. 5. Source, injected and Load-1 voltages of Line-1 & Line-2

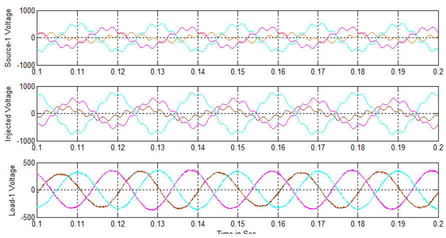


Fig. 6. Unbalanced voltages on Line-1

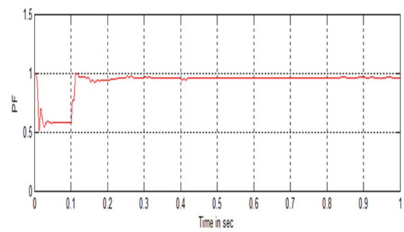
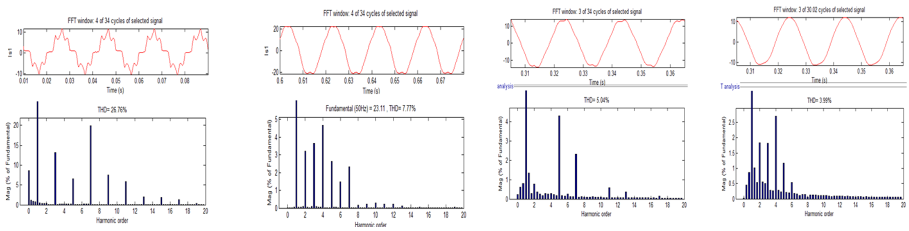


Fig. 7. Power Factor on Line-1



(a) Without Controller (b) With PI (c) With Fuzzy (d) With ANFIS

Fig. 8. Source-1 current % THD

3.3 Harmonics Profile

The harmonics reduction is analyzed under different conditions. Such as without UMCC, with PI-UMCC, With Fuzzy-UMCC and ANFIS-UMCC.

Case1: % THD of supply current without UMCC is presented in Fig.8(a). Supply current (Phase-A) % THD is more because of nonlinear loads.

Table 1. Proposed System Specifications

S. No	Parameters	Ratings
1	Source voltage	3-phase , 230 V, 50 Hz
2	Load-1	R_l=26.66 Ω,L_l=50mH
3	Load-2	R_2=10 Ω, L_2=0.03mH
4	DC link	V_{dc} = 450 V
5	Solar Cell	35V,7.5 A

Table 2. Comparison of Power Factor, % THD for Source current and Load voltage

Terms	Without UMCC	With PI - UMCC	With Fuzzy - UMCC	With ANFIS UMCC
%THD of Current				
Source current I_{s1}	26.76	7.77	5.04	3.99
% THD of Load Voltage				
Load Voltage(V_{l1})	28.5	3.35	2.89	1.51
Load Voltage(V_{l2})	35.5	2.23	2.15	1.32

Case2: UMCC is connected at T = 0.1 sec, post T = 0.1 sec, % THD of supply current with PI controlled UMCC is shown in Fig.8(b). Reduced %THD of supply current due to suppression of harmonics is 7.77%. With traditional controller proposed system achieves closer IEEE limit of %THD. For further improvement Fuzzy logic is utilized in replacement of PI controller. % THD of supply current with Fuzzy controlled UMCC is shown in Fig.8(c). Reduced %THD of supply current due to suppression of harmonics is 5.01%. To have effective error tuning ANFIS used in replacement of PI controller. % THD of supply current with ANFIS controlled UMCC is shown in Fig.8 (d). Reduced %THD of supply current due to suppression of harmonics is 3.99%

4 Conclusion

The proposed model efficiently works to compensate voltage disturbances, current harmonics and reactive power supply. It also shows the effective sharing of power between two lines. Model also integrates PV unit at DC link.. The Fuzzy based controller proves improved harmonic reduction compared to traditional PI based controller. The model achieves the following objectives.

- ANFIS based controller achieves the THD of 3.99% for source current.
- Voltage sag/swell/interruption are suppressed effectively.
- PF is improved with shunt controller activation.

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