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Optimization of Phase jump angle of Series Active Power Filter (SAPF)

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Abstract— ***This paper deals with the optimization of phase jump angle of series active power filter by using particle swarm optimization technique and series active power filter compensates supply voltage distortions/unbalance, supply voltage harmonics in a view as such they do not reach at the load end with very low THD in load voltage. SAPF operates mainly as voltage regulator and harmonic isolator between the non-linear load and the utility system. The main aim of this project is to design the dynamic model of the Series Active Power Filter and minimization of VA rating of the Series Active Power Filter by using practical swarm optimization (PSO). Hence the results are obtained by using the Matlab/Simulink.***

I. Introduction

From the past few decades, the increase in electrical energy demand for industries and domestic use resulted in the higher production of electrical energy which has consequently resulted in higher tariff rates, for industrial and domestically usage A.C Power is essential, In A.C the power factor is described as the ratio of real power to the apparent power.

Reactive power is produced when the current and voltage waveforms are out of phase with each other, in a capacitive load current leads voltage whereas in inductive load current lags voltage, reactive power is denoted as var. Reactive power compensation is essential to increase the power factor quality, which obviously results in the decrease of power consumption and tariffs; finally the aim is to decrease the reactive power. Reactive power can be decreased by placing a shunt capacitor in line but it does not fulfil the problem because it gets in resonance when it gets tuned with reactance of the system. In order to overcome the disadvantages caused by placing a shunt capacitor in line, facts devices have been developed to solve the problem effectively examples of FACTS devices are SC, TSC...etc. Though the power electronic devices known as Facts devices are developed for transmission part of the system its model have been changed from past few years to serve better power quality at low and medium voltages.

49 Series active power filter (SAPF) is presently one of the most cost-effective and thorough solutions to mitigate voltage sags by establishing proper quality voltage level for utility customers [3]. Its function is to inject a voltage in series with the supply and compensate for the difference between the nominal and sagged supply voltage. The injected voltage is typically provided by an inverter, which is powered by a dc source [4]–[7], such as batteries, flywheels, externally powered rectifiers, and capacitors.

Voltage restoration involves determining the amount of energy and the magnitude of the voltage injected by the SAPF.

The series active power filter is implemented with a PWM voltage-source inverter and operates in conjunction with a resonant LC, Interconnected in parallel to the power lines and is able to compensate current harmonics and the fundamental negative and zero sequence voltage components generated by nonlinear unbalanced loads. The proposed configuration is based on a three-phase PWM voltage-source inverter connected in series with the power lines through three single phase current transformer. A parallel LC filter must be connected between the nonlinear loads and the current transformers. Current harmonic and voltage unbalance compensation are achieved by generating the appropriate voltage waveforms with the three-phase PWM voltage-source inverter. Although there are a number of articles which deal with the analysis and design of active power filters connected in series, Conventional voltage-restoration technique is based on injecting a voltage being in-phase with the supply voltage [7]–[10].The injected voltage magnitude will be the minimum, but the energy injected by the SAPF is nonminimal.

In order to minimize VA rating concept is proposed in [10]–[13]. It is based on maximization of the active power delivered by the supply mains and the reactive power handled by the SAPF during the sag.

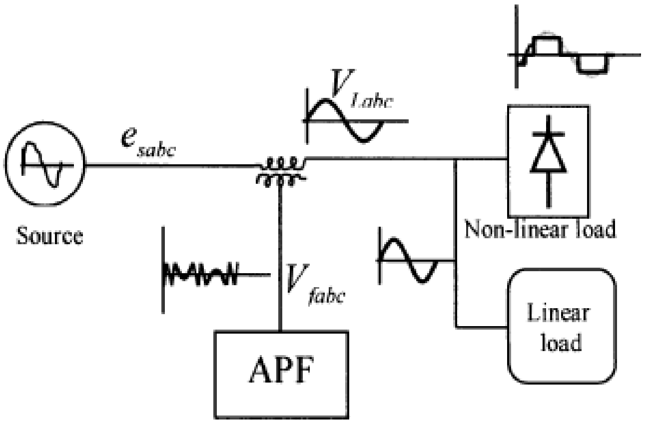

Fig.1.Basic principles of series active power filter

II. Modelling of SAPF and Switching control strategy

2.1 Dynamic modelling of SAPF:

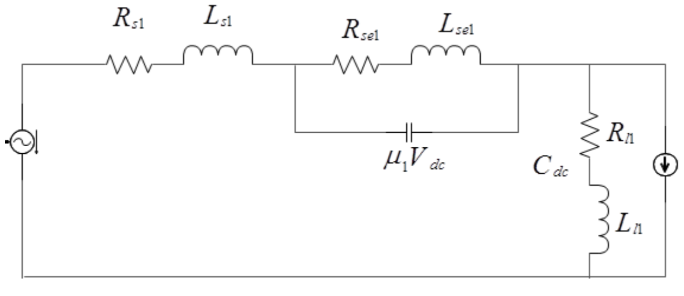

Fig.1. single line equivalent circuit diagram of SAPF

This section presents the SAPF mathematical modelling Fig.1 shows with internal connections of the SAPF, with VSCs, load and the power network.The VSCs are used for injection of controllable voltage $\mu_1 V_{dc}$ in order to control load voltage and PCC bus voltages under the closed loop. The dc link voltage may be self-supported by a dc link capacitor for the case SAPF. The Fig.2 is the single line diagram of of conventional SAPF compensated parallel distribution system. The Filter across the both series inverter is represented byL_{se1} C_{se1}. R_{s1} and L_{s1} are feeder1 resistance and inductance. Nonlinear load i_h with R_l L_l load on feeder1.The VSC$_1$, is supplied by common capacitor, and the voltage across each capacitor is denoted by V$_{dc}$.

By using the Kirchhoff laws in the above equivalent circuit

$$L_{s1}\frac{di_1}{dt} = -R_{s1}i_1 + V_{sd1} - V_{s1} + V_{l1} \qquad (1)$$

$$L_{se1}\frac{di_2}{dt} = -R_{se2}i_2 - V_{sd1} + u_1 V_{dc} \qquad (2)$$

$$L_{sh}\frac{di_3}{dt} = -R_{sh}i_3 - V_{l1} + u_1 V_{dc} \qquad (3)$$

$$L_{l1}\frac{di_4}{dt} = -R_{l1}i_4 + V_{l1} \qquad (4)$$

2.2 Switch control strategy:

Series active power filters have been pro-posed to compensate nonlinear three phase balanced loads and SAPF control strategy is aimed to controlled voltage source and generates mainly to obtain constant load terminal voltage at the desired point at require level

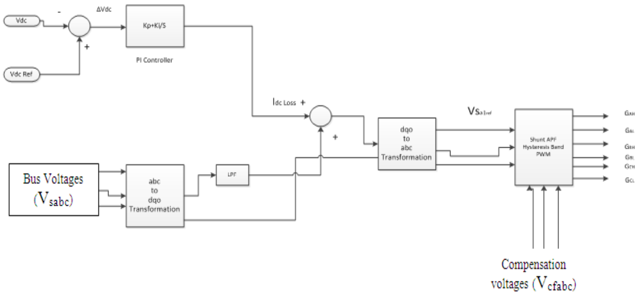

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Fig.3. SRF Based Controlled Series Active Power Filter

The three-phase series active power filter have different approaches:

- By compensating the zero sequence harmonics components generated by single-phase loads, the current flowing through the neutral cable is significantly reduced, and the total harmonic distortion of the line currents waveforms are improved.
- The series active power filter is able to compensate line to line voltage unbalances at the load terminals.

Since the voltage unbalance is caused mainly by fundamental components, with the proposed control scheme, the series active power filter can compensate the negative and zero sequence components of the load voltages and current harmonics simultaneously. Moreover, zero sequence current components flowing through the neutral cable are compensated without sensing the corresponding neutral current thus simplifying the current control scheme. The difference of the supply voltage and the ideal load voltage is compensate by injecting voltage by the series APF. These injected voltages cancel out the distortions in supply voltages. Fig.3 shows series APF block diagram. The synchronous reference (dq0) frame consists of detected source voltage.

$$v_{s\_dqo} = T_{abc}^{dq0} v_{s\_abc} \qquad (5)$$

The instantaneous source voltages and include both oscillating components $(\widetilde{v_{s\ d}}$ and$\widetilde{v_{s_q}})$ and average components $(\overline{v_{s\ d}}$ and$\overline{v_{s_q}})$ and under unbalanced source voltage with harmonics. The source voltage negative-sequence components and harmonic are present in oscillating components $(\widetilde{v_{s\ d}}$ and $\widetilde{v_{s\_q}})$ under distorted load conditions. The objective of maintaining constant source voltage is done series APF even under unbalanced conditions. Therefore, the expected load voltage in the synchronous dqo reference frame $(v_{l\_dqo}^{exp})$ assume to be constant.

$$v_{l\_dqo}^{exp} = T_{abc}^{dq0} v_{l\_abc}^{exp} \qquad (6)$$

Here the *a* *bc* reference frame $(v_{l\_dqo}^{exp})$ represents assumed load voltages and synchronous dqo reference frame represents compensating reference voltage $(v_{cf\_dqo}^{ref})$ and given by

$$v_{cf\_dqo}^{ref} = v_{s\_dqo} - v_{s\_dqo}^{exp} \qquad (7)$$

By using SPWM voltage control technique dqo compensating reference voltage is then transformed back into the *abc* reference frame.

III. VA Rating of SAPF

From the phasor diagram of Fig. 3 if load currents are assumed $i_{l1} = i_{l2}$ with fundamental power factor equal to cosφ, active power demand in the load remains the same.

$$v_{s1}i_{s1} = v_{l1}i_{l1}\cos\phi = cons\tan t \qquad (8)$$

In the case of sag, when $v_{s1} < v_{s2}$ if k denotes the rate of sag (0<k<1), then

$$v_{s2} = (1\text{-}k)\ v_{s1} \qquad (9)$$

Now, to maintain constant active power

$$v_{s1}i_{s1} = v_{s2}i_{s2} \qquad (10)$$

$$i_{s2} = \frac{i_{l2}\cos\phi}{(1-k)} \qquad (11)$$

As the injected voltage is produced in the quadrature with the supply, the resulting load voltage v_{l2} makes the angle θ with the supply v_{s2}

$$v_{inj} = \sqrt{(v_{s1}^{2} - v_{s2}^{2})} \qquad (12)$$

The series VA rating is given by

$$v_{inj} i_{s2} = v_{s1} i_{l1} \cos\phi \tan\theta \qquad (13)$$

3.1 Optimization of injected angle by using PSO:

The PSO algorithm basically learned from animal's activity or behaviour to solve optimization problems. In PSO, each member of the population is called a particle and the population is called a swarm. Starting with a randomly initialized population and moving in randomly chosen directions, each particle goes through the searching space and remembers the best previous positions of itself and its neighbours. Particles of a swarm communicate good positions to each other as well as dynamically adjust their own position and velocity derived from the best position of all particles. The next step begins when all particles have been moved. Finally, all particles tend to fly towards better and better positions over the searching process until the swarm move to close to an optimum of the fitness function

The PSO method is becoming very popular because of its simplicity of implementation as well as ability to swiftly converge to a good solution. It does not require any gradient information of the function to be optimized and uses only primitive mathematical operators. As compared with other optimization methods, it is faster, cheaper and more efficient. In addition, there are few parameters to adjust in PSO. That's why PSO is an ideal optimization problem solver in optimization problems.

For each iteration of the particle during the execution of the algorithm, the velocity of each particle is modified using its current velocity and its distance from personal best position "*pbest*" and global best position "*gbest*" according to

$$v_i^{n+1} = \text{w}(n) * v_i^n + c_1 * \text{rand1}(\,) * (pbest_i^n - x_i^n) + c_2 * \text{rand2}(\,) * (gbest_i^n - x_i^n) \qquad (14)$$

v_i^{n+1}: ith dimensions Velocity of particle at $(n+1)^{th}$ iteration

v_i^n : i^{th} dimensions Velocity of particle at n^{th} iteration;

c_1: acceleration factor related to gbest;

c_2: acceleration factor related to Pbest;

rand1 ( ): random number generation between 0 and 1;

rand2 ( ): random number generation between 0 and 1;

$gbest_i^n$: global best position value in the i^{th} dimension;

$pbest_i^n$: Particle best position value in the i^{th} dimension;

x_i^n :Current position in the i^{th} dimension at n^{th} iteration;

After the velocity update is done, each particle move to their new positions according to

$$x_i^{n+1} = x_i^n + v_i^{n+1} \qquad (15)$$

Considering minimization problems, then the personal best position at the next time step n+1, is calculated as

$$pbest_i^n = \begin{cases} pbest_i^n; & \text{if } f(x_i^{n+1}) > pbest_i^n \\ x_i^{n+1}; & \text{if } f(x_i^{n+1}) \le pbest_i^n \end{cases} \qquad (16)$$

Where 'f' is the fitness function.

The global best $gbest_i^n$ position at time step is calculated as

$$gbest_i^n = \min(pbest_i^n) \qquad (17)$$

Therefore it is important to note that the personal best $pbest_i^n$ is the best position that the individual particle has visited since the first time step. On the other hand, the global best $gbest_i^n$ position is the best position discovered by any of the particles in the entire swarm.

IV. Results

Table: 1 PSO parameters

Parameter Value	Value
Number of Particles	100
Maximum inertia weight	0.9
Minimum inertia weight	0.4
C_1 and C_2	1.43 and 0.43
Number of iterations	50

By applying PSO for optimizing, an optimum angle (θ_1) can be found out, that result in minimum total VA loading. For an optimum angle θ_1, v_{inj} and α angle can be calculated using equation (13).

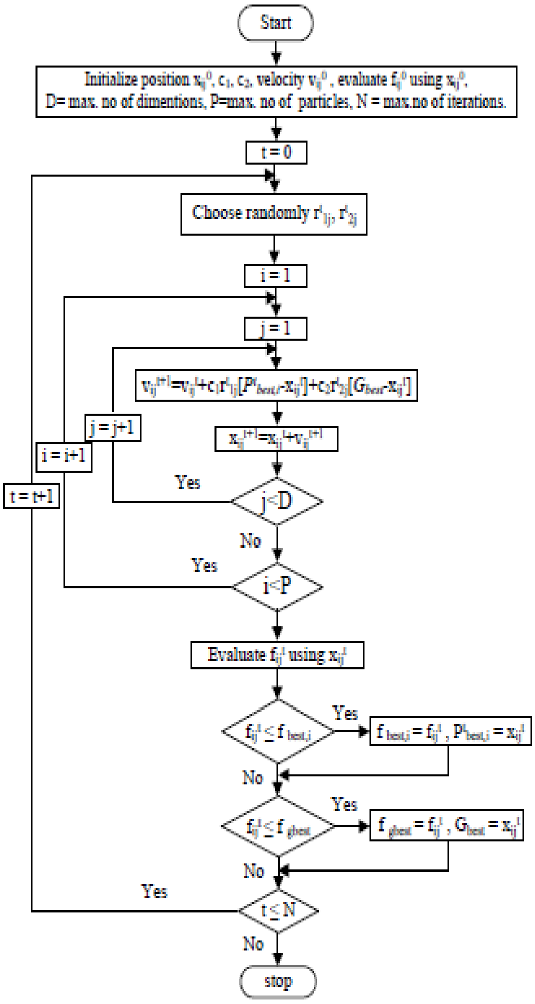

Fig.4. Flow chart of gbest

Fig.4.shows the variation of θ parameters of series active power filter is shown in graph as follows:

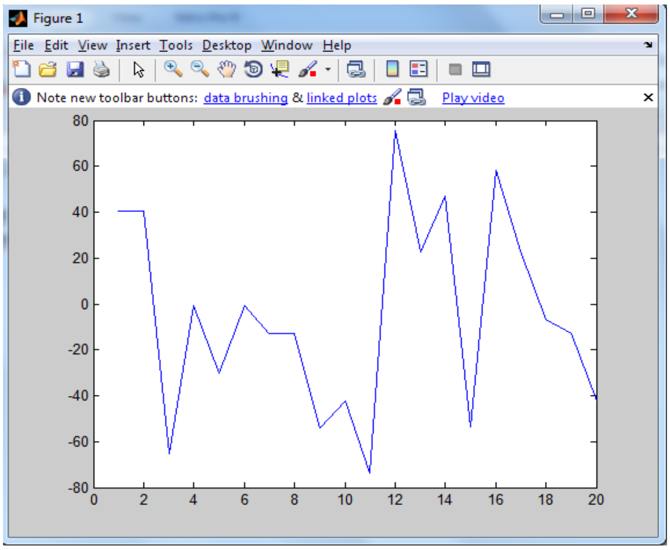

Fig.4. Phase angle Vs iterations

Fig.5 shows of variation of minimization of VA rating of series active power filter by using pso is shown in graph as follows:

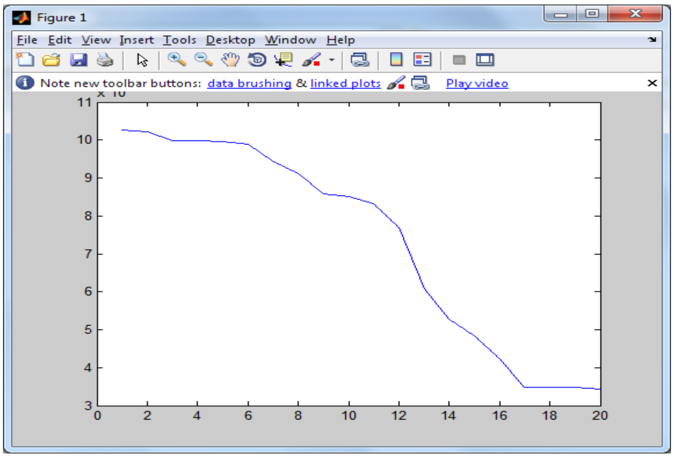

Fig.4. gbest Vs iterations

Above graph gbest = 25.5702 degree and best fitness value fgbest = 3.4200e+004.

Table: 2 System Parameters

System Parameters	Values
System frequency (*f*)	50HZ
Rated voltage	380v
Voltage source v_{S1}	380v,Phase angle 0^0
Feeder-1	1+j0.8Ω
Load-1	A three-phase diode bridge rectifier with an resistor (500) Ω

SAPF PARAMETERS

System Parameters	Values
System frequency (*f*) VSC-1 single-phase transformers (*T*1)	50 HZ 4kVA,230/115,2% resistance and 8% leakage Reactance

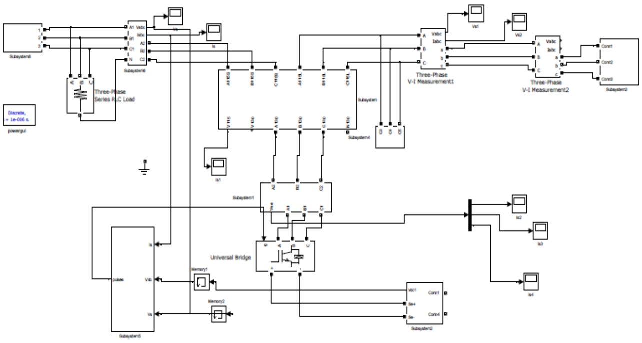

Fig. 6: Simulink model of SAPF

Without the SAPF connected to it is simulated and the magnitude of voltage is as shown in the Fig 7.

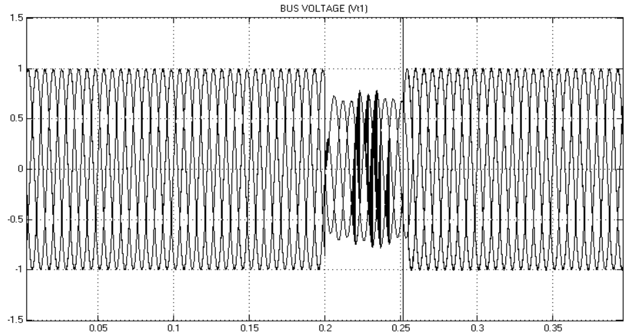

Fig.7. VRMS Voltage at the Load Point of the Sag System without SAPF.

With the SAPF connected to it is simulated and the magnitude of voltage is as shown in the Fig 8.

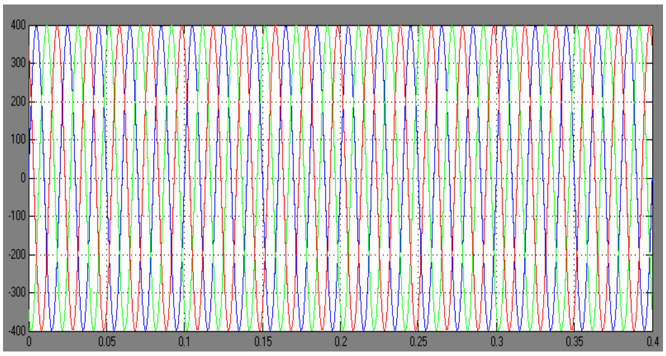

Fig.8. V_{RMS} Voltage at the Load Point of the System with SAPF.

As shown in fig.8, a very effective voltage regulation which is provided by the SAPF can be clearly appreciated. The active power filter supplies reactive power to the system to eliminate the voltage sag. In spite of sudden load variations, the regulated RMS voltage shows a reasonably smooth profile, where the transient overshoots is almost non-existent.

V. Conclusions

The paper deals with the design of SAPF and regulates load voltages under any disturbance. Minimize the VA rating of series active power filter by using pso. Hence here apparent power of series active power filter in volt-amp rating is minimized by pso in Matlab.

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