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A Standalone Residential PV System with Improved Power Quality Based on an Optimal Method

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ABSTRACT:

The installation of standalone residential photovoltaic (PV) systems have been widely increased in nowadays, this PV systems are secured energy sources which are clean and maintenance is easy. But unreliable operations and capital cost are the main drawbacks for installation of autonomous residential PV system. T avoid this drawbacks, to get desired power supply, less failure ,efficient and economical operation, design of standalone residential PV system with power quality parameters with national and international standards are necessary, to this direction important parameters of residential PV systems are legitimately determined. In addition to this an outline methodology that meets demanded standards and improves power quality. At last an optimization method is compose using artificial techniques i.e, Genetic algorithm. The systamatic results are authenticated by extensive simulation and insightful discussions and efficiency of planned design are provided.

Index terms:
Genetic algorithms, photovoltaic (PV) systems, power quality.

1.INTRODUCTION:

PV systems are most promising technologies of renewable energy sources. Nowadays most of remote areas (islands, rural territories, etc.) are supplied by their own installation of residential PV systems, because of increased electrical costs from suppliers and increased technologies in conversion of solar energy to electrical energy. So consumers are interested installing PV systems. Now these investments are subsidized and encouraged where transmission and distribution works are difficult to developed. designing of autonomous PV residential systems and their PQ parameters with national and world wide benchmarks is an important matter. Apart from other benefits these systems will give uninterrupted power supply, avoid compatibility problems, and moderate operational cost for long time. Here power indices must satisfy the demands of national and worldwide standards and at the same time her we have to avoid the extreme equipment dimensioning and designs.From existing technical literature power quality concepts in standalone PV systems is discussed by two different methods, the first one as designing the energy storage unit through improved load demand management[1][4] and second one as controlling the supply voltage through the adaptation of sophisticated control loops [5][7]. Outputs of above mentioned works are saying that high power quality can obtained in standalone application even under highly distorted and unbalanced loads. in our work if we select design parameter of system arbitrarily, we will not guarantee to power quality. But selecting these parameters in standalone systems under steady state. But this concept is only small scale installations.To this work we present new methodology based artificial intelligent for design purpose. By finding and giving the correct values to critical variables of standalone systems, it is possible to power quality with in limitations. For this work we are applying this methodology to typical power levels like 20kw and 50kw of standalone PV systems

2.SYSTEM DETAILED ANALYSIS :
2.1.System Configuration:
The main elements of system are study in the fig.1

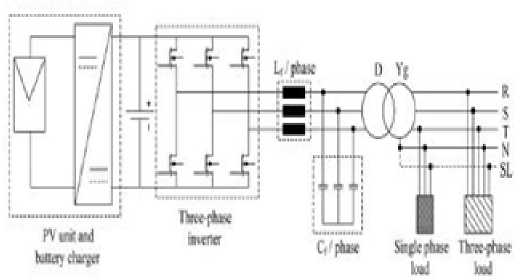

Fig1. Configuration of System under Study (SL is ground conductor)

The series and parrel connection of PV's are connected to inverter and the battery bank is charged by a PV unit through a series charger, the 3 phase inverter is supplied by battery bank. The above shown configuration is the most common type for standalone PV residential units. There are some sophisticated energy storage systems which are proposed in [2][4]. But for our study the actual selection energy storage is not need, because our main target is optimal selection of design parameters of harmonic filter, inverter and transformer. Here it is assumed that inverter input voltage is constant even though battery bank nominal DC voltage is variable in this work

Coming to inverter topology, the most common commercial inverter for residential application is the classical inverter for residential application is the classical 3-phase full bridge inverter topology.There are some various multi level inverter topologies [8] in autonomous micro grids having many advantages like efficiency and power density. We can select various types, it is not a limit so for our methodology any inverter topology voltage transfer function is important.Coming to transformer, the transformer turns ratio may affect the dc voltage level, because the load voltage depends on its value. their relations are studied as

$$V_{\mathrm{inv},N} = \sqrt{\frac{3}{2}} m_a \frac{V_{\mathrm{dc}}}{2} \quad (1)$$

$$\overline{V}_{1N} = \overline{V}_{\mathrm{inv},N} - \Delta\overline{V}_{\mathrm{Lf}} \quad (2)$$

$$V_{2N} = \frac{\sqrt{3}V_{1N}}{n}. \quad (3)$$

Where ma is the amplitude modulation ratio of the SPWM controller; Vdc is the DC voltage at the inverter dc side; V1N ,V2N are the transformer line to line nominal primary, secondary voltages(rms) respectively; ΔVLf is the voltage drop at filter inductance(rms value); n is the transformer turns ratio. Eq.(1)(3) are derived by SPWM inverter principles[9]. The bar indicators in(2)are phasor quantities. The transformer secondary side is Ygd (grounded star) connected, in order to provide high voltages on load sided and to provide path for zero sequence currents so load voltage free from asymmetry due zero sequence currents absent. Load voltage also free from 3rd order harmonics. Next one is filter, it consists of inductor capacitor bank. It is used to cutoff the lower order harmonics that are generated by nonlinear loads and higher order harmonics by the spwm technique of inverter. The resonance frequency (wr) of filter is given by

$$\omega_r = \frac{1}{\sqrt{L_f C_f}} \quad (4)$$

Where Lf, Cf are inductance, capacitance of filter per phase respectively. wr can be selected up to 3rd order harmonics because wr may not deal with the fifth order harmonic component efficiently. Furthermore inductor of filter also restricts short circuit current level with in acceptance level of safe operation of inverter. Iinv,SC is the 3phase short circuit current of inverter, and is given by formula:

$$I_{\mathrm{inv,sc}} = \frac{V_{\mathrm{inv},N}}{\sqrt{3}\omega_b L_f}. \quad (5)$$

Where Vinv,N is inverter line to line nominal rms value; wb is the load voltage angular frequency.Actually Iinv,sc has to be higher than rated current of inverter, else protection scheme would have poor selectivity. Generally modern inverters of PV applications can withstand up to 280% of nominal current for few seconds time. It is functional use inverter whose rated power is equal to residential peak burdens. if we go for high rated inverter the short circuit current value increases which leads increase of cost and worsens the utilization factor of inverter. In this project the design procedure doesn't depend upon inverter control loop, since it aims to obtain a power quality optimization under steady state condition of system.

2.2 Definitions of design criteria:

There are some parameters which meets the demanded standard of improved power quality for safe and economical operation conditions. The parameters are summarized as follows:

a)Asymmetry due to Single Phase Loads (asym): According to [10],[11] it is defined as ratio of negative sequence voltage component to positive voltage component. We should have to get the asym within limits given by national and international standards (IEC, NEMA, and IEEE) [12]-[15] even under worst load case.

$$\mathrm{asym}(\%) = \frac{V_2}{V_1} \cdot 100 \quad (6)$$

Where V2 is the negative sequence component of voltage at load side(rms value); V1 is the positive sequence component of voltage at load side (rms value) .

b)Total Harmonic distortion due to Nonlinear loads (THDV): It is an important parameter. It gives overall harmonic content in the system.

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Symmetrical component analysis is used to calculate the harmonic distortion of load voltage. it is also within limits imposed by [16] even in worst case.

c)Inverter Short Circuit Current Ratio (sci): It is defined

$$\mathrm{sci} = \frac{I_{\mathrm{inv,sc}}}{I_{\mathrm{inv},N}}. \qquad (7)$$

where Iinv,N is the inverter nominal rms current.

d)Inverter Nominal Power Ratio(scs): It is defined as follows:

$$\left.\begin{array}{l} \mathrm{scs} = \frac{S_{\mathrm{inv},N}}{S_{L,N}} \\ S_{\mathrm{inv},N} = \sqrt{3}V_{\mathrm{inv},N} I_{\mathrm{inv},N}; \quad S_{L,N} = \sqrt{3}V_{2N} I_{2N} = \frac{P_L}{pf} \end{array}\right\} \qquad (8)$$

where Sinv,N=*Vinv,N*Iinv,N; SL,N=*V2N*I2N Where Sinv,N is the inverter nominal apparent power . SL,N = load nominal apparent power.Where scs defines the necessary inverter over dimension in order to meet the power targets and safe economic operation restrictions. It is a techno ecological factor.

e)Inverter Nominal Current ratio (nomi): it is defined as follows:

$$\mathrm{nomi} = \frac{I_{\mathrm{inv},N}}{I_{1N}}. \qquad (9)$$

$$\text{Where}\, I_{1N} = I_{\mathrm{nv},N} + I_{cf} \qquad (10)$$

I1N is the nominal current of transformer at primary winding (rms value) Icf is the filter capacitor current value(rms).The bar in the eq.(10) represents phasor relationship. Here the factor nomi denotes the limitable capacitive current in circuit. It is being restriction for finding of Lf and Cf values properly.

3. ASYMMETRY ANALYSIS:

By taking single phase loads from three phase supply, produce the different current ratings on three phases which will cause load voltage asymmetry. We used a, b, c pointers for phases identification and 1, 2, 0 pointer for current and voltage sequence components . The equivalent sequential circuit for single phase loading by symmetrical component analysis is shown in fig. 2.

The singe phase load conditions of system are

$$\overline{I}_a = \frac{\overline{V}_a}{\overline{Z}_L}, \quad \overline{I}_b = \overline{I}_c = 0. \qquad (11)$$

where Ia, Ib, Ic are phase currents. Va is the phase a voltage, ZL is the load impedance. Substituting above values in symmetrical component matrix and by analyzing we get the relation that

$$\overline{I}_0 = \overline{I}_1 = \overline{I}_2 = \frac{\overline{I}_a}{3}. \qquad (12)$$

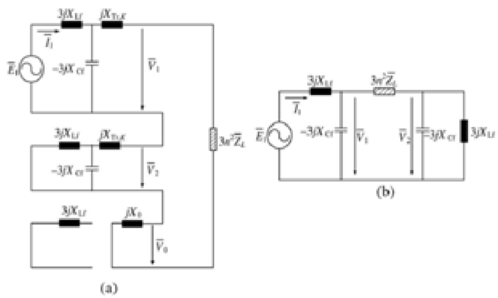

Fig.2 Equivalent sequential circuit for single phase loading. (a) Initial circuit and (b). simplified circuit for XTr,K
= X0 = 0

From fig.2(a) XLF is the filter inductance impedance at load voltage frequency, Xcf is the filter capacitor impedance at load voltage frequency, XTr.k is the short circuit impedance of transformer, X1 is the zero sequence(ground) impedance The circuit fig.2(a) is normalized to primary voltage level and the filter inductance and capacitance are transformed to their equivalent delta connection phase values.Fig.2(b) shows simplified circuit of fig2(a) by assuming that both zero sequence impedance and short circuit impedance equal to zero. The E1 indicates th symmentrical three phase voltage under steady state condition because of SPWM control technique. Here E1 means PV generator, battery bank,and inverter combination representation,from phasor analysis of fig.2(b) gives the following expression for representing asymmetry in single phase loads.

$$\mathrm{asym} = \frac{V_2}{V_1}\cdot 100\% = \left\langle \begin{array}{c} \left\{1+\left[\left(\frac{f_r}{f_b}\right)^2 - 1\right]\frac{n^2 R_L}{X_{cf}}\tan[\arccos(pf)]\right\}^2 \\ +\left\{\left[\left(\frac{f_r}{f_b}\right)^2 - 1\right]\frac{n^2 R_L}{X_{cf}}\right\}^2 \end{array}\right\rangle^{-\frac{1}{2}} \cdot 100\%. \qquad (13)$$

Where fr,fb filter resonant frequency and load voltage frequency respectively, f and q are called as frequency

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By observing the eq.13 we can say that asymmetry of voltage of the circuit depending upon variables f,q, and p.f. Here the power factor is displacement power factor because loads are nonlinear type.

4.HARMONIC ANALYSIS:

We know that due to presence of nonlinear loads which cause the harmonic distortion. In this analysis we are taking three phase nonlinear loads,because they have high shock on load voltage, fig.3 circuit is used for analysis of each single load current harmonic component. Now weare going to replace the index I through harmonic order From the analyzing the circuit is shown in fig.3 we will get following relation for three phase loading.

$$Z_{2,i} = 3n^{-2}\frac{X_{Cf}}{\left[i - \frac{1}{i}\left(\frac{f_r}{f_s}\right)^2\right]} \qquad (14)$$

$$V_{i(TP)} = V_{2,i} = Z_{2,i}I_i. \qquad (15)$$

Where Z2i is the negative system impedance for the ith order load current harmonic component. It is the rms value of the ith order load current harmonic component(per phase). Vi(TP) is the rms value of the ithorder load voltage harmonic component(three-phase loading) The THD was found by following eqation.,it is derived from eq.(15)

$$\text{THD}_V = \frac{1}{V_b}\left\{\sum_{i=3,5,\ldots} V_{i(TP)}^2\right\}^{\frac{1}{2}} \qquad (16)$$

Where vb is the fundamental component of voltage at load side(rms value);assume vb is equal to V2N(transformer line to line nominal secondary voltage(rms value)

5. OPTIMIZATION METHOD:

We are going for optimization techniques, due to more number of variables and parameters of this system,. The main aim of optimization method is to adjust important of variables of proposed system. Since these variables f, q, n, ma(amplitude modulation ratio of SPWM controller) and Vdc(DC voltage at inverter dc side) affect the design parameters of system which areexplained in section 2

The parameters asym, THDv, sci, scs, and nomi must obey limits of table 21

TABLE1. Parameters limitations

Parameter	Limit (%)	Parameter	Limit
asym	<5	scs	<2
THDv	<8	nomi	<1.5
		sci	<5

To get good power quality and safe operation of system, we should follow the limits. NEMA and IEC standards have given limits for asym and THDv. The limit selection for scs, nomi, and sci is based on the techno economical criteria. Because of non linearity, large number, and complexity of derived equations we are going for PSO (particle swarm optimization based on swarm intelligence. It is simple and easily completed. In order to adjust our parameters f, q, n, and Vdc, we have to minimize our optimization function.

$$e(k) = \frac{\text{asym}}{w_1} + \frac{t_5}{w_2} + \frac{t_7}{w_3} + \frac{t_{11}}{w_4} + \frac{\text{sci}}{w_5} + \frac{\text{scs}}{w_6} + \frac{\text{nomi}}{w_7} \qquad (17)$$

where w1,2,...7 are weight factors are set to upper limit of table.1 for normalizing design parameters. and where t5, t7, t11 are maximum permissible harmonic component. They are computed as follows using X nonlinear loads

$$t_i = \frac{X \cdot Z_i \cdot I_i}{230} \qquad (18)$$

Where i=5,7,11. The weight factors take following values w1=0.05,w2=0.06, w3=0.05, w4=0.035, w5=5, w6=2, and w7=1.5. according to table.1. And k is a column vector containing the variables k1, k2, k3, k4.

K=[k1, k2, k3, k4]T =[f, q. n, Vdc]T . (19)

Lastly, the range of variables in column vector k are defined as f=2-4, q=0.1-10,and n=0.5-10

Vdc={ 100<Vdc<300
300< Vdc<600
600<Vdc<800}

Vdc is between 100 and 800V. To solve eq. 17 not only pso Here the both Vdc and ma are variables different from other two. The range of these values is decided by designer and by technical restrictions.

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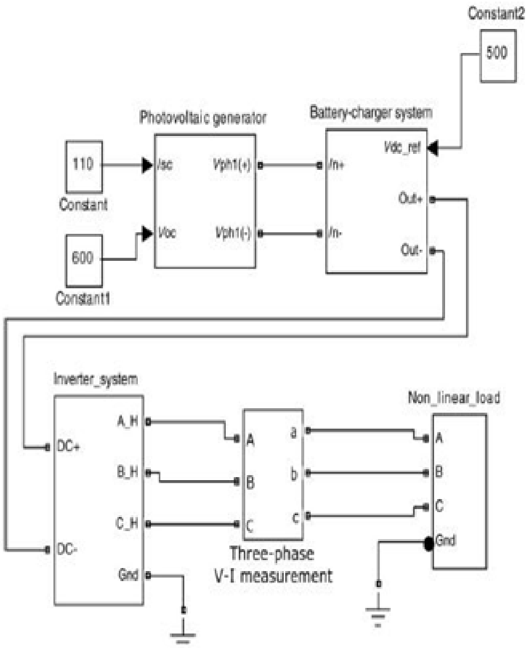


Fig3.simulink block model of system under study, ground connector is used as neutral line connection for single phase loads.

6. SIMULATION RESULTS:

The discussed design example is considering two autonomous installations with maximum load power of 20kw and 50kw respectively. Assume the power factor for both cases is equal to 0.85. X set to 9 for both cases, indicating that load is highly distorted. Consider Vdc varies between 300 and 600 for simple reasons and ma is set to 0.5. Following power quality table.1, the final selection of 20KW PV installation is f=2.0762 q= 0.199, n=0.712 and vdc=400.16. Thus, the values of technical parameters are Lf=0.43mH, Cf=5.4mF, Sinv,N=33KVA and V1N=160. Similarly, the final selection of 50-kw PV installation is f=2.0158, q-=0.2250, n=0.785 and Vdc=500. Thus values of technical parameters are Lf=0.22mH, Cf=9.9mF, sinv,N=75KVA and V1n=180

Table 2 MATLAB/simulink selected Simulation results

Test	Asym(i)	Asym(ii)
	Sim(**)	Sim(**)
Single phase loading at $P_L/3$	5.375%	5.445%

	THD_V(i)	THD_V(ii)
Non linear three phase load	Sim(**)	Sim(**)
	3.73%	1.919%

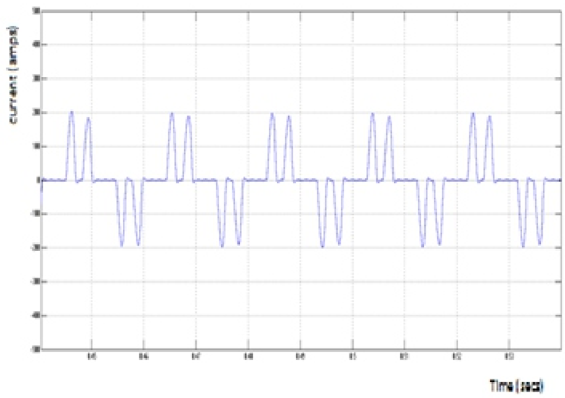
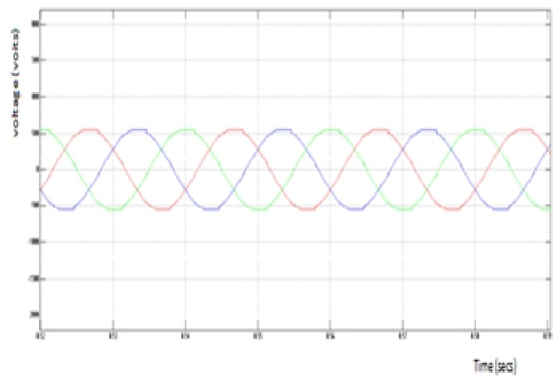
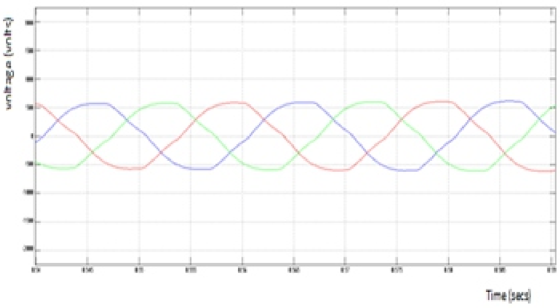
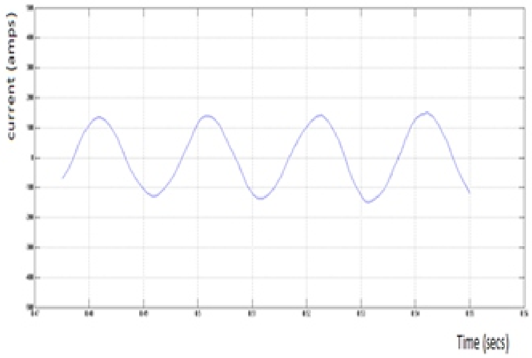


Fig.3 shows the block diagram of the Simulink model and includes all the sub circuits that are shown in fig. 1, namely the three phase inverter (using IGBTs/diodes as switching elements); the SPWM controller (20 kHz carrier frequency); the three phase transformer (Ygd1, short circuit impedance 4%); the filter elements (three phase inductor and capacitor); the photovoltaic generator, which has been simulated as a single voltage controlled current source [17], the battery charger, which has been simulated as a series dc/dc converter in continuous conduction mode, and the battery bank .Table II presents some selected simulation results for the cases of 20 and 50 kW applications.



Additionally, the load voltage and current waveforms for the 50 kW case with maximum produced harmonic distortion and asymmetry are shown in figs. 4 and 5, respectively. It is noted that the distorted load consists of a three-phase diode rectifier with filter capacitor.These simulation results highlight the fact that the selection of system design parameters according to the proposed design method restricts load voltage unbalance and harmonic distortion within the limits of the international standards, even for extremely nonlinear loads. Moreover, these selected results are obtained *Load factor assumed to be 0.85 and X is set as 9 The above figures Load voltages waveforms (upper case) and load current waveform of one line (lower case), for 50-KW three-phase diode rectifier with 3-mF smoothing capacitor; the THDv value is 1.978%.





The above figures load voltages wave forms(upper case) and load current waveform of one line (lower case),for a 17-KW single-phase load connection with 0.85 power factor; the asym value is 5.35%.

CONCLISION:

The power quality improvement through design of stand-alone residential PV system with help of optimum method is has been discussed in this paper. Circuit analysis which is developed in this paper has shown that power quality nature of standalone PV residential systems is strongly dependent on the alteration of important factors that must be suitably chose keeping in mind the end goal, to meet consistence with international power quality standards.

The results of present paper confirm the fittingness of proposed design methodology and demonstrate that good power quality of supply in 3-phase autonomous PV residential application is a realistic target, depending on initial design.

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