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Genetic algorithm optimization methodology for PWM Inverters of Intelligent universal transformer for the advanced distribution automation of future

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Abstract

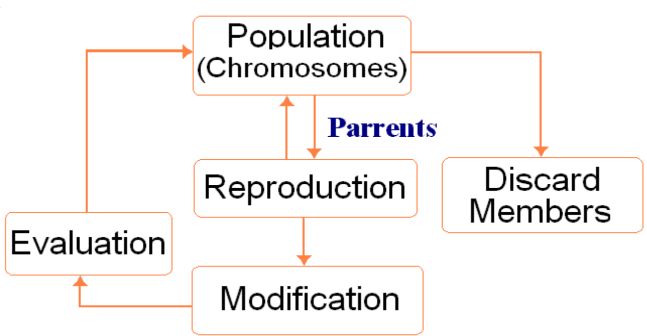
This paper intends to optimize the control fashion of PWM inverters of Intelligent Universal Transformer (IUT) using Genetic Algorithm (GA). IUT is the state of art proposed as an electrical key point of Advanced Distribution Automation (ADA) technology. It comprises the power electronic construction and high frequency transformer. ADA will be raised for tomorrow's distribution system to perform the exchanging platform for both data and information which will be fully monitored and automatically controlled. IUT is introduced as intelligent electronic devices in lieu of traditional transformer with the controllable architecture that enhances the reliability and system performances and leading to the various services and user benefits like desirable output voltage, level and frequency, DC voltage options and sag correction. In case of oil elimination benefit it also yield to size and weight reduction. In this approach current and voltage source controllers based on GA optimization are developed for controlling the firing angle of switching pattern of PWM inverters which are recommended for voltage level and frequency control of IUT. The GA smart optimization fashion with the proposed three levels IUT topology emphasizes on the very smooth control and voltage regulation in both input and output inverters of IUT. GA improves the system characteristics under load and input disturbances with regulating the voltage and harmonic elimination.

Keywords: ADA; DA; IUT; IED; Power electronic; GA; THD.

Introduction

The novel control methodology based on genetic algorithm is proposed controlling of three phase PWM inverters in IUT. GA is an optimization algorithms based on the numerical principle inspired from the natural population of Living organisms, it is used in many distributed control system engineering (Clark & Mason, 1993). GA is introduced for optimization of smart and adaptive controllers in case of unknown and nonlinear systems whose objective functions are haphazard or highly nonlinear and are not continuous, no differentiable and not recommended for standard optimization regulations. GA functions sequences are shown in Fig.1.

Fig.1. GA Functions sequences



GA is an arithmetic model optimizing the solutions by imitating the defined genetic. It produces the population of solutions in each of iteration to approach the optimal point. The next population is computed using random generated numbers. At first the initial population is generated, fitness evaluation is the second process. Genetic selection, crossover and mutation are the followed process.

GA imitates the biological evolution utilizing reproduction and crossover as a powerful genetic operators. It is evolving binary strings regard of parameters which simulate the genes of chromosome constitute the population. Each substring with the specific length is extracted from the string, decoded and mapped into the corresponding space. (Rabi Justus *et al.,* 2007) proposed GA for power quality enhancement in adjustable speed drives using PWM method for inverters controllers. (Jegathesan, 2010) used GA for PWM converter switching for voltage source inverter feeding an induction motor drive. This way is investigated for voltage and current source PWM inverters of IUT to find out the best optimal switching patterns.

The PWM signal will be determined in each of iteration, based on outputs and the references result in low Total Harmonic Distortion (THD) with the fast transient response of sinusoidal outputs. In this approach a brief survey of ADA is described first; then Intelligent Electronic Device (IED) is introduced, IUT basic construction and topology is brought later. The control and optimization strategy and simulations results of corresponding system are discussed in last, indicating the conclusion of using IUT and GA control methodology.

ADVANCED DISTRIBUTION AUTOMATION FOR TOMORROW

Advanced Distribution Automation is distinct from the current distribution automation (DA) that concerns the automated control on basic distribution functions, while ADA is proposed with the fully automated control capability in regard of each one of controllable equipment in distribution system. This provides the system performance improvements by adding functionality and enhancing reliability, quality, level of security and

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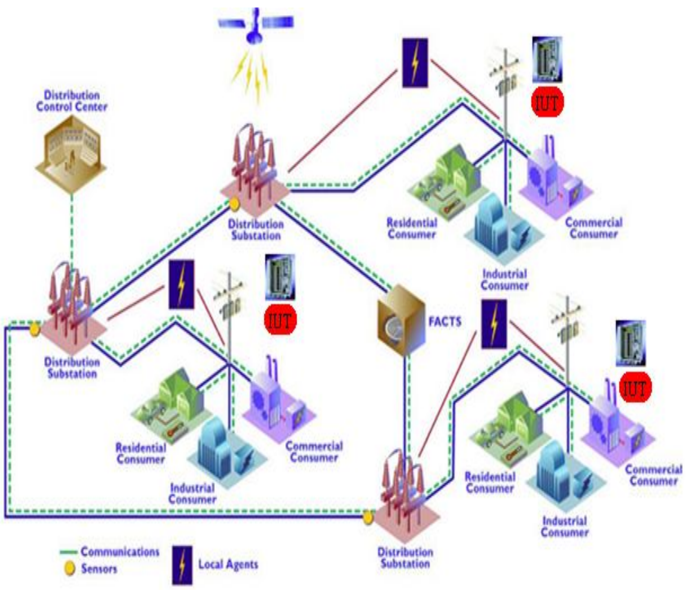
availability in contrast with the today's distribution operations (IEEE Power Engineering Society, 2005).

ADA brings a revolutionary modification in infrastructure of traditional distribution systems which will be occurred in a solstitial fashion to the wondrous investment in heritage systems and the rate in which technology will progress.

Fig. 2. IUT is a key point of ADA construction which is introduced for tomorrows Distribution Automation (EPRI, 2004)



In Fig.2, IUT serves three different functionalities; first as a smart transformer for distribution substation, second as an intelligent device with the desired outage related to commercial customer requests and third for overhead lines in distribution system.

Two critical basic points in the concept of ADA are the flexible electrical architecture and open communication architecture improves the advance monitoring and enhances the control functionality for interoperable network of components. These two parts are synergistic empowered each other to comprise the forthcoming distribution system.

ADA is introduced as a heart of smart power system especially in case of delivering procedure. Flexible electrical architecture employs the Intelligent Electronic Devices (IEDs), distributed resources (DR) and new electrical and electronic technologies. On the other hand communication and control systems which are based on the open communication architecture provide the suitable platform for information exchange. Both the above together with the Real time state estimation provide the most applicable tools for predictive simulations and real time optimization performances like demand and energy management, reliability, efficiency, and power quality control (McGranaghan & Goodman, 2005).

INTELLIGENT ELECTRONIC DEVICES

Intelligent Electronic Device (IED) is the important key point in contributing ADA for near future. IED is defined as an intelligent component which is incorporated among one or more processors for receiving or sending the data or controlling command from or to external sources.

In this regards the multifunctional meters, digital relays and IUT are the well known IEDs introducing for the next generation of distribution automation.

Successful integration of the IEDs should be integrated from the overall distribution system which evolves the protection, control and data acquisition. This leads to reduction in capital and operating costs and brings out the panel reduction. It also releases the designers for providing redundancy in equipment and databases.

Intelligent universal transformer

The most strategic equipment in ADA is the intelligent universal transformer (IUT) proposed as one of the IED's in near future (Maitra & Sundaram, 2009).

IUT BASIC CONSTRUCTION

Recent progress in Silicon Carbide (SIC) materials and their applications develops the HV-HF power electronic devices with 10KV, 15 KHZ switching pattern that extends the PWM usage in high voltage applications.

It is also expected for the revolutionary utilization of power electronic devices in many applications such as motor drive, military applications and power distribution and conversion (Hefner, 2007). EPRI effort for IUT programs, opens a new way in transferring the power in a controlled manner especially in case of distribution system, (Krishnaswami & Ramanarayanan, 2005; Lai *et al.,* 2005; Wang *et al.,* 2007; Iman-Eini *et al.,* 2008).

Application of power electronic transformers for power distribution system have been disused in recent years (Ratanapanachote, 2004) which is used in IUT construction for tomorrows distribution system. Actually IUT is a state of art comprises power electronic based transformer which not only steps voltage in lieu of the current conventional distribution transformers but also acts as intelligent controllable device with the major advantages like DC output or multiple frequency options, ability for converting the single phase to three phase and improve the power quality functionalities like voltage sag correction, harmonic filtering and oil elimination, reduction in weight and physical dimension and interoperability which yields the IUT to serves as an intelligent multifunction node for the upcoming distribution automation (Goodman, 2006; Maitra *et al.,* 2009).

IUT design is based on high frequency transformer (typically a few kHz) with the isolation functionality. This construction leads to core size reduction that is impossible for the traditional 60 Hz transformers.

IUT Topology

IUT topology comprises power electronic based devices which act as rectifiers and inverters together with

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high frequency (HF) transformer. The HF transformer ratio is 1:1 and it acts as an isolation device. Control unit in Fig.3 represents the intelligent transformer with controllability in input-output stages for providing desired output level options and employing optimization tools for eliminating the harmonic disturbances in outputs and input. IUT Topology 1, Fig.4 (EPRI Product, 2003) considering three levels full bridge AC/DC and three levels half-bridge DC/DC converters, is proposed in this approach.

Fig. 3. IUT Power electronic construction

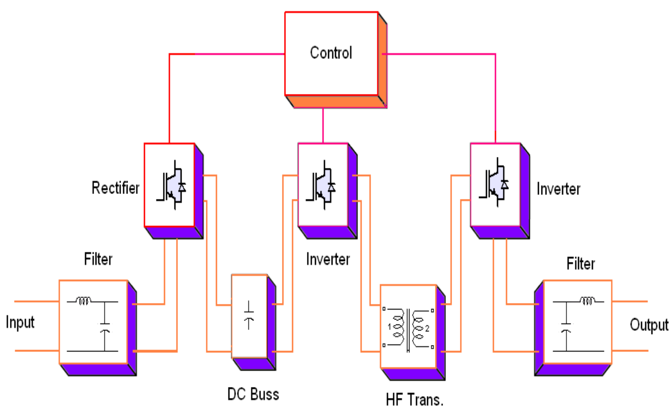
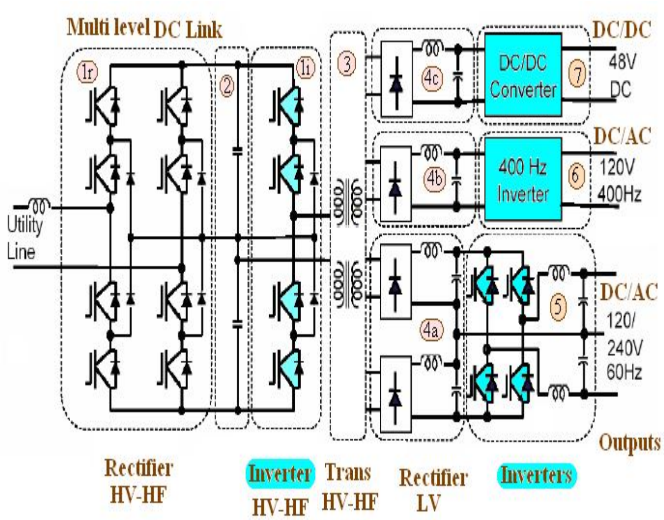


Fig. 4. Proposed IUT topology with three level full bridge AC/DC and three level half bridge DC/DC converters



This topology comprises seven individual blocks. Multilevel rectifier (1r) and multilevel inverter (1i) in first stage rectify and convert the AC input voltage to high frequency square wave. DC bus and capacitors are installed in second stage. High frequency transformer in third stage with ratio 1:1 has a duty of isolation. At fourth part, DC output rectifiers and filters make the full bridge inverter evolving the split DC bus capacitors. Main inverter for delivering outputs with specification of 120/240V AC, 60-Hz is in fifth stage comprising the full bridge inverter and single DC bus capacitors.

Auxiliary inverter is in sixth stage providing 400-Hz output consisting of full bridge inverter and single DC bus capacitor. At last the DC/DC converter is considered for 48VDC output. The controllable parts are rectifier, HF inverter and secondary outputs inverters represent as intelligent unit (Goodman, 2007).

Advanced control methodologies are introduced for IUT controllers. Neural Controller is fully described (Sadeghi & Gholami, 2012a) proposing the online adaptive control via Artificial Neural Network. Developed adaptive Neuro-Fuzzy Inference System is also considered in controlling of IUT (Sadeghi & Gholami, 2012b). In this approach GA optimizes the firing angle for more smooth and robust control fashion. HF inverter in input stage and output inverters are introduced for GA control strategy Fig. 4.

Control and optimization Strategy

Control strategy is based on controlling the angle of inverter in input-output stage of IUT using GA optimization for harmonic eliminations.

In input stage, IUT is directly connected to grid, so for eliminating harmonic distortion, input current is sensed and controlled by GA to maintain the input current being in phase with input voltage. This action yields to unwanted harmonic elimination. Each of inverters in output stage is controlled and optimized trough GA.

GA employs three basic rules summarizes as selection, crossover and mutation for reproducing next generation based on current population.

At first stage, the individuals representing parents are selected to contribute the next generation of population. In second stage the crossover rules will combine two parents performing children in the next generation. Random changes in the individual parents for contributing children will be performed in mutation rules.

In accordance to IUT topology the variables of control scheme corresponding to the chromosome are the controllable switching angles defined as firing angles $\{\alpha_1, \alpha_2, \alpha_3\}$ for the input stage and each of four outputs of IUT.

Population size is determined 20 which is defined optimum and it is not selected so high for preventing the enhancement both in convergence rate and execution time.

These 20 chromosomes contain six individual rising/falling levels for switching angles of inverters in input and output stages. They will be initialized with random amounts between 0 and 90 degrees. The Fourier transform function for the PWM switching considering three phases is obtained base on the following equation:

$$a_n = \frac{4}{\pi}\left[-1-2\sum_{k=1}^{N}(-1)^k \cos(n\alpha_k)\right] \tag{1}$$

$$b_n = 0 \qquad (k = 1,2,3)$$

With reference to the neutral point and its characteristic for isolation, the third harmonic together with the other triple harmonics will be automatically

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eliminated. In other word, it is necessary to eliminate only the odd values of harmonics which are not factor of three like 5, 7, 11, 13, ect.

In case of first harmonic, modulation index is expected to be defined in the range of zero and 0.9 (M є [0, 0.9]).

In Eq. "(2)", $f_n(\alpha)$, is developed to depict n^{th} voltage harmonic.

$$f_1(\alpha)=\frac{4}{\pi}\left[-1-2\sum_{k=1}^{n}(-1)^k\cos(\alpha_k)-M\right]=\varepsilon_1 \qquad (2)$$

$$f_5(\alpha)=\frac{4}{5\pi}\left[-1-2\sum_{k=1}^{n}(-1)^k\cos(5\alpha_k)\right]=\varepsilon_2 \qquad (3)$$

$$f_7(\alpha)=\frac{4}{7\pi}\left[-1-2\sum_{k=1}^{n}(-1)^k\cos(7\alpha_k)\right]=\varepsilon_3 \qquad (4)$$

$$f_{11}(\alpha)=\frac{4}{11\pi}\left[-1-2\sum_{k=1}^{n}(-1)^k\cos(11\alpha_k)\right]=\varepsilon_4 \qquad (5)$$

$$f_{13}(\alpha)=\frac{4}{13\pi}\left[-1-2\sum_{k=1}^{n}(-1)^k\cos(13\alpha_k)\right]=\varepsilon_5 \qquad (6)$$

$$\alpha_1<\alpha_2<\alpha_3<\frac{\pi}{2} \qquad (7)$$

A cost function is related to the harmonic which should be minimized and is considered as the function of 5, 7, 11 and 13 harmonics for controlling the firing angles in input output inverters of IUT as follows:

$$f(\alpha_1,\alpha_2,\alpha_3,)=\varepsilon_1^{\,2}+\varepsilon_2^{\,2}+\varepsilon_3^{\,2}+\varepsilon_4^{\,2}+\varepsilon_5^{\,2} \qquad (8)$$

The Fitness Value (FV) is calculated for each chromosome Acc. to Eq. "(9)".

$$FV(\alpha_1,\alpha_2,\alpha_3,)=\frac{1}{f(\alpha)} \qquad (9)$$

Fitness Value is an optimization function which should be minimized via control procedure.

Simulation results

In this approach, GA is investigated for optimizing the control angles of input-output inverters of IUT. Proposed IUT topology is demonstrated in Matalb simulink Fig. 5. It depicts three levels IUT topology comprising four outputs levels of 48VDC, 120V 400HZ AC, 120V 60HZ AC and 240V 60 HZ AC. IUT is directly connected to 500V, 3 phase sinusoidal input voltage. In first stage, three phase rectifiers rectify the input current.

Inverters in outputs with the ability in control provide desired levels for outputs voltages. Matlab Simulation results are shown in the following pictures: Fig. 6-13. Fig.6 indicates fitness value versus generation, concerning with the best fitness value and mean fitness. The best fitness value of zero is detected.

Current best of individuals for three defined variables are shown in Fig.7. Optimized firings angles have computed by GA are: "69.1" for α_1, "7.94" for α_2 and "11.99" for α_3. Individuals' criteria versus generation are depicted in Fig.8.

Fig. 5. IUT Simulation in matlab

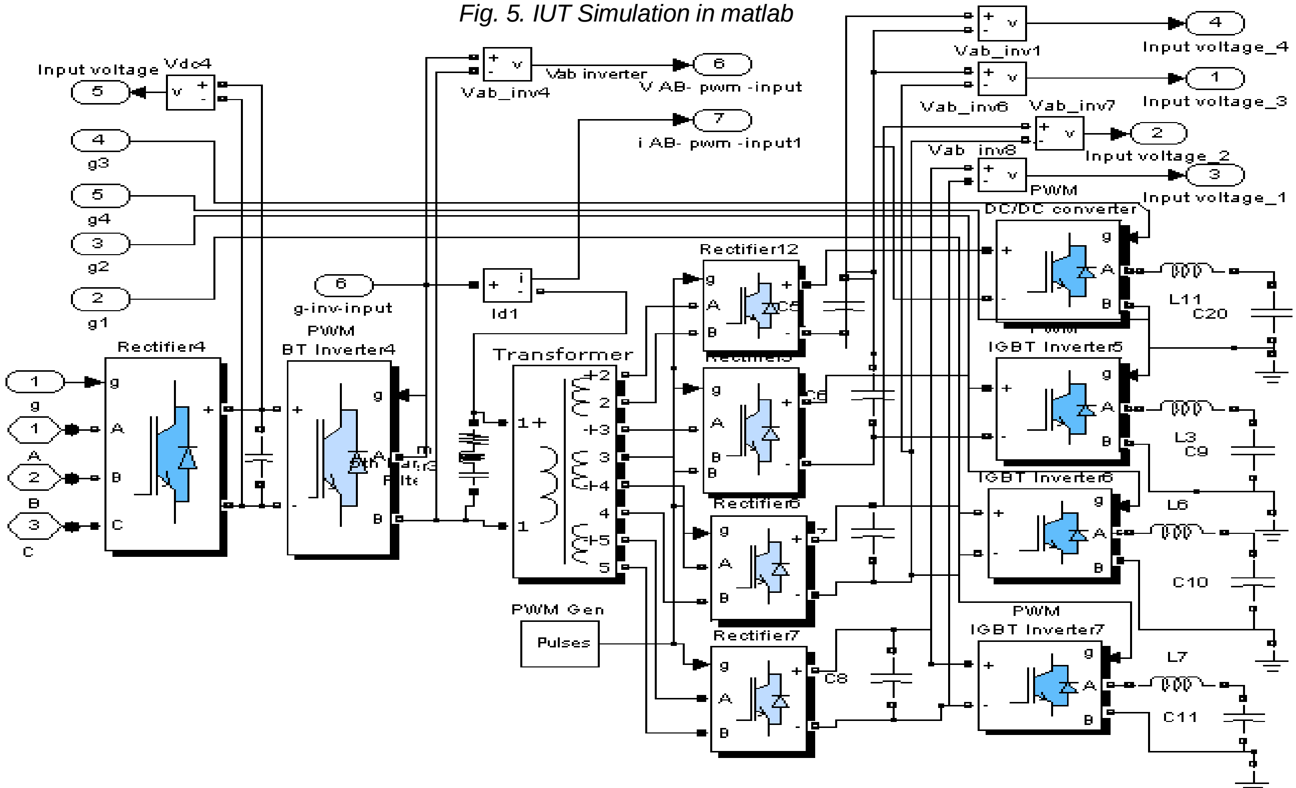

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Fig. 6. Fitnes value versus Generation indicating Best fit ness value on 0.010252

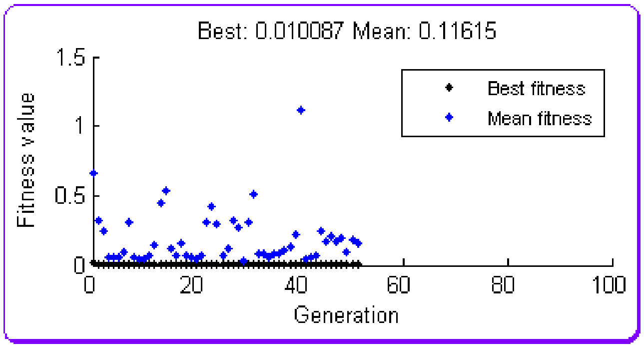


Fig. 7. Current best individuals ($\alpha 1$=69.1, $\alpha 2$=7.94, $\alpha 3$=11.99)

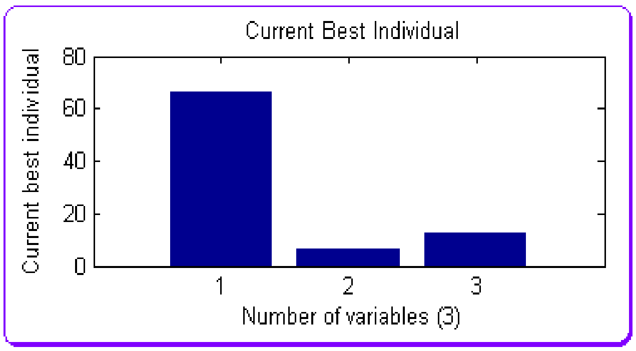


Fig. 8. Individuals criteria versus Generation

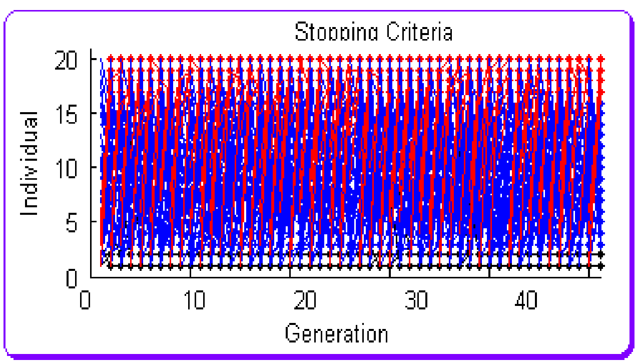


Fig. 9. Fitness of each individuals

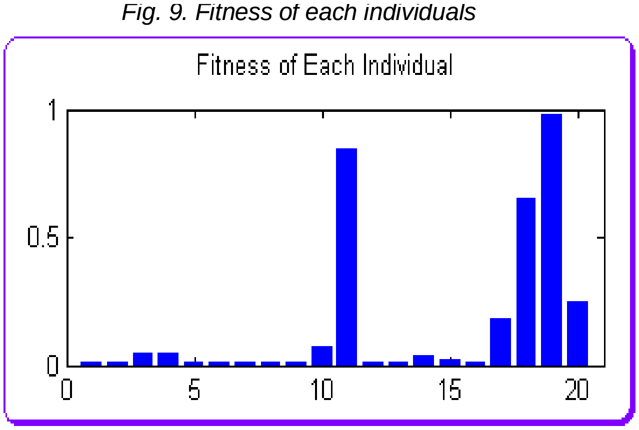


Fig. 10. Average distance between individuals versus generation

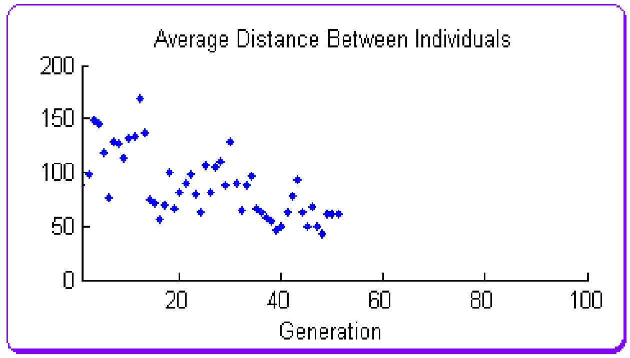


Fig. 11, Selection function of individuals

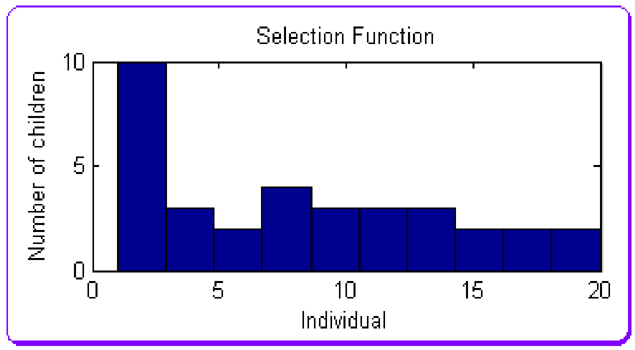


Fig. 12. Control signals α_1, α_2, α_3

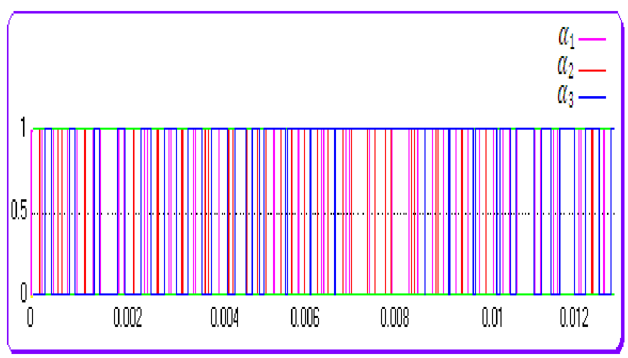
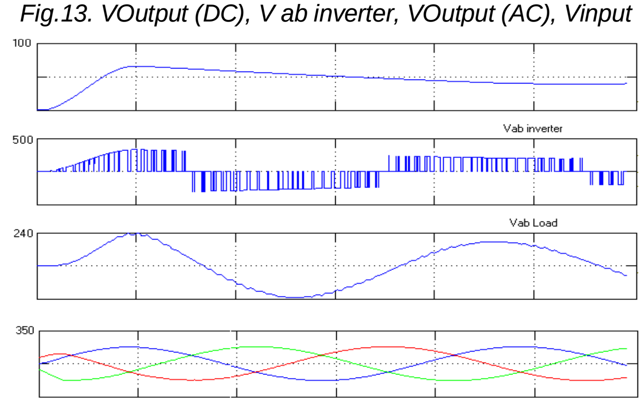


Fig.13. VOutput (DC), V ab inverter, VOutput (AC), Vinput



Fitness of each individuals are demonstrated in Fig.9 indicating the best fitness value for any of 20 individual in the population that is the smallest fitness value for any of 20 individual in the population.

Average distance between individuals versus generation are shown in Fig.10, as the average distance between individuals is suitable and is not so large, the best individuals are well selected for the optimal solution.

No. of children versus individuals are shown in Fig.11 demonstrate the selection function of individuals in the next generation, called children.

Control action is demonstrated in Fig.12 evolving α_1, α_2, α_3 for IGBT inverters in DC/DC converters. 48V DC output voltage, Vab inverter of 240V AC output, 240V AC load output voltage and three phase inputs are shown in Fig.13.

Conclusion

Advanced infrastructure technologies are concerned with the forthcoming distribution automation which will bring up novel technologies like IEDs in general and IUT in specific. IUT is a key point for Advanced Distribution Automation results the major benefits that are well demonstrated in previous sections.

IUT brings a controllable transformer with a fully automated and monitoring pattern. Three levels full bridge AC/DC and three level half-bridge DC/DC converters are considered in IUT topology to providing 48V DC output service together with three 240V AC outputs.

In this case IUT uses GA for optimizing firing angle of PWM inverters in input output stages. GA describes adaptive fashion for advanced controlling especially under the nonlinearity, changes and disturbances of loads. It is introduced for both constrained and unconstrained optimization problems which are based on natural selection algorithm emphasizing on biological evolution. It improve system performances trough unexpected distortion elimination procedure.

GA modifies a population by random selection of individuals in current population to achieve a new solution for new children in next generation. This cycle is continuing till finding an optimal solution.

GA optimizes α_1, α_2, α_3 in input stage for regulating input current and performing the unit power factor. It is derived from holding the input current in phase with the input voltage in spite of any distortion that may be accord in grid. GA in outputs of IUT regulates four IUT outputs and guarantees system stability. System stability, efficiency and reliability are all enhanced by proposed IUT topology and GA.

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