Neural Predictive Control of IUT based on Focused Time Delay Structure

M. Sadeghi, M. Gholami

***Abstract*—** Neural network Controller methodology is a nonlinear control fashion equipped with a novel method of Neural Predictive Controller (NPC) as an intelligent optimizer that in this cased based on the Focused Time Delay Neural Network (FTDNN) for modeling the nonlinear system and performing the optimization procedure. In case of prediction and control, two individual strategies are concerned for the current projects. The first is FTDNN procedure modeling the dynamics of system. The other is an optimization unit expected for minimization of optimization index. In this regards the Intelligent Universal Transformer (IUT) which will be raised in the Advanced Distribution of Automation (ADA) are discussed. IUT is an electrical key point introducing as a heart of ADA in case of Intelligent Electrical Devices (IED). ADA is the state of art, comprising the flexible electrical architecture and open communication construction empowered synergistically each other to contribute the tomorrow's distribution automation. IUT construction relay on the bases of power electronic devices that employs the modern technologies of high voltage-low current solid-State equipment to cope with the deficiencies of current traditional transformers. So the IUT topology emphasizes on rectifiers, converters and PWM inverters in both input-output stages. These could be controlled via the intelligent control fashion for enhancing the robustness and stability of system in condition of variation take place. The proposed predictive control technique is a moderated control strategy using artificial neural networks to investigate the three phase power PWM converters of IUT for designing the current and voltages regulators in input-output stages. These result in the smooth regulation in IUT control and improve the system characteristics under load and source disturbances. At first the FTDNN model the power inverter dynamics of IUT. Then the optimization procedure takes place to minimize the optimization index for constructing the duty cycle of inverters as a control signals.

Keywords— ADA, IUT, NPC, FTDNN

I. INTRODUCTION

THE energy exchange model is a multi-functional system which describes the Advanced Distribution of tomorrow "ADA". It comprises the flexible electrical architecture and open communication construction introducing as a platform for exchanging both data and information between the participants and system component. It is described in lieu of a traditional static distribution system with a single functional capability for only delivering the energy to end-users [3-4].

AS the described ADA is equipped with the full automation and control functionality, it is integrated via the distributed devices. These resulted to the new approach in control and management for distributed automation systems. In the other word the ADA open and flexible architecture together with the dynamic system of monitoring leads to the interoperable network of electronic devices which will improve the functionality, reliability, performance and system power quality.

Re developed electrical architecture with open communication construction, facilitate exchanging Data and information in a dynamic manner which in this case these two are synergistically empowered each other and will comprise the future of distribution system "Fig. 1".

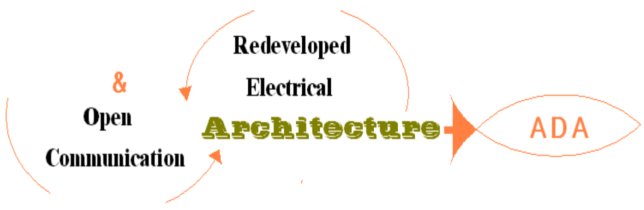

Fig. 1. Topology of ADA for Distribution Automation of future comprising the open communication construction and redeveloped electrical architecture

In this case ADA debates new novel technologies evolving the Distributed Energy Resources (DER), Intelligent Electronic Devices (IED), new sensors and new power-electronic appliances [1-2].

IUT is the one of these intelligent devices that works as multi-functional equipment that will take the role of current traditional transformers [6-9] with the major benefits and advantages that are mentioned in following:

Automatic sag correction with a real time voltage regulation, the DC voltage option together with the reliable diverse power like 240V AC 400Hz, three-phase power services in case of a single phase line input, energy storage options, harmonic filtering, flicker mitigation, and dynamic system monitoring.

"Fig. 2", illustrates the difference IUT utilization in near future [17].

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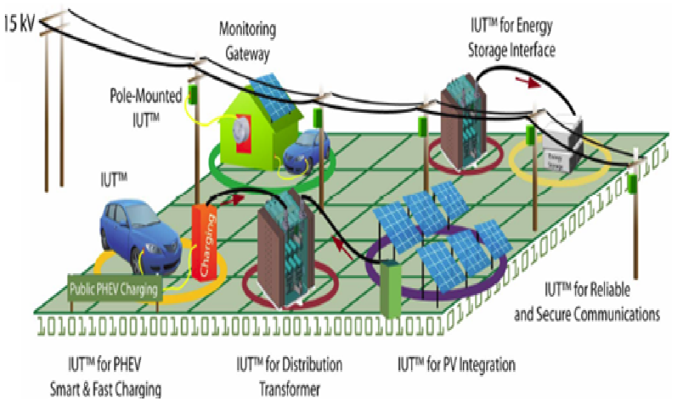


Fig. 2. IUT utilization in smart grid of future indicating on smart and fast charging of automobile, IUT for distribution Transformer, IUT for photo voltaic integration, IUT for reliable and secure communication and IUT for storage energy

Different topologies, design methods and applications are described for Intelligent Universal Transformers [14-16].

IUT three layers topology are discussed in the next section. Neural predictive controllers and control strategy are verified in section III. Simulation results are shown in section IV and last section elucidates the conclusion with the prospective features.

II. Intelligent Universal Transformer as an Intelligent Electronic Device of Tomorrow's Automation

A. IUT Basic Concept

Traditional transformer nowadays basically composed of copper and iron [11-13]. IUT basic concept comprises semiconductor devices equips with the modern high voltage low current power electronic devices results in intelligent control fashion that is impossible in the current transformers [25-26].

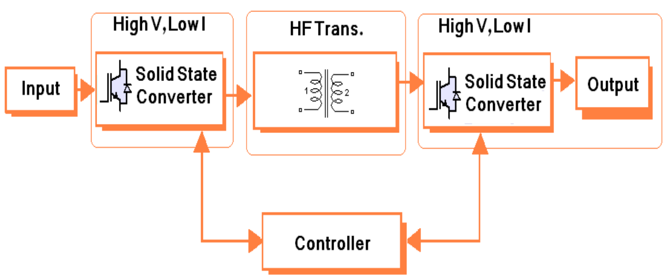


Fig. 3. IUT HV-LC power electronic construction with intelligent control capability

This feature of intelligent control brings the IUT in the field of intelligent electronic devices those are the most important parts of ADA.

The control strategy is based on high-frequency switching patterns comes from the inverters for controlling the output voltage to the desired levels which may be requested by end users and may involve in the vast variety of changes.

All changes occurring in the utility distribution line and the secondary voltages shall not affect any variation in the sinusoidal primary current [10] this feature could be success in case of power full intelligent control in input inverters of IUT.

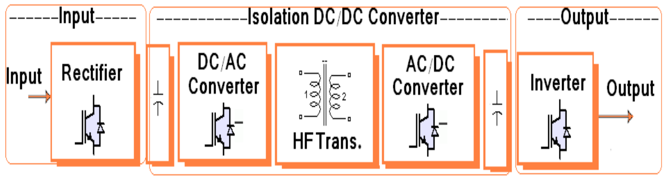


Fig. 4. IUT high voltage, low current and low power electronic base transformer, basic component diagram

IUT expands the capabilities of distribution transformer to DC voltage option, automatic sag correction, real time voltage regulation, reliable diverse power as 400Hz service option for communication usage, three-phase power from a single phase line, Harmonic Filtering, Flicker mitigation, options for energy storage and dynamic system monitoring.

B. IUT Three Layers Topology

IUT three layers topology are shown in "Fig. 5".

First of all the AC input voltage is modulated by the static converter to the High Frequency (HF) square wave that passes through the HF transformer and then demodulated by synchronous converter.

As the transformer size is dependent inversely on the frequency, the HF IUT will have noticeably reduction in physical dimension, weight and stress factor, in contrast with the traditional transformer. In the other word, IUT is the High Voltage – High Frequency (HV-HF) oil free transformer results in oil elimination, physical dimension and weight reduction and leads to maintenance free equipment.

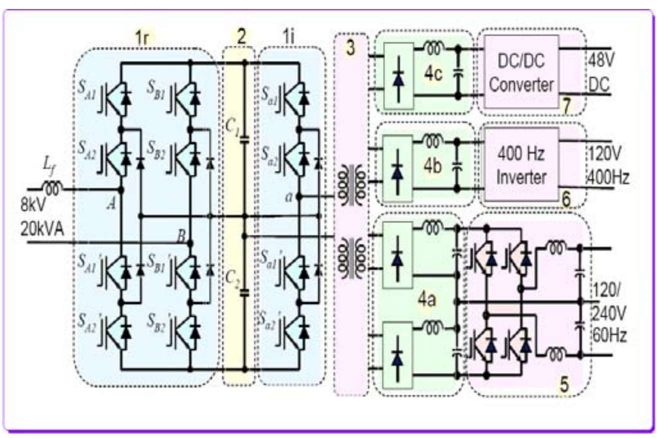


Fig. 5. IUT Multi-Converter-Based transformer considering three layers topology

The proposed topology involves seven main individual blocks comprising the power electronic equipment and high frequency transformer [5].

A multilevel rectifier (1r), rectifies the AC 50-60 HZ frequency input at the first stage. Then in the multilevel Inverter (1i) produces the High Frequency - High Voltage (HF-HV) square wave.

DC capacitor banks are installed in the stage (2). At the next stage, the high frequency transformer (3) with the ratio of 1:1, isolates primary and secondary from each other. At the fourth stage, rectifiers and filters (4), produce the DC bus of capacitors for outputs. Full main bridge inverter with split DC buses 120/240-V 60-Hz output (5) is the fifth stage. Full auxiliary bridge inverter with single DC bus for 400-Hz output is in the next stage (6). Stage (7) is the buck DC/DC converter, for 48-VDC output.

III. The Proposed Control Strategy NPC for Controlling the IUT Converters and Inverters

Control strategy is based on the Neural Predictive Controller (NPC). Neural controllers are widely used in nonlinear control system in which the system parameters are unknown and the dynamic of system are nonlinear so that the precise mathematical model for the system is so complicated and is unreachable. In addition the system parameters changes are inevitable. The Neural controllers introduce the control methodology that could be applied for both identification and control. In this regards the Neural Predictive Controller (NPC) is more advanced in compare with the last neural control strategies which have been used for IUT controllers [23, 24]. The predictive controllers are well demonstrated in the next stage.

The proposed NPC are introduced for both input and output stages of IUT. It will be trained to elaborate the switching angles for controlling the PWM inverters of IUT.

As the IUT is connected directly to the grid, in primary stage, input current should be sinusoidal and in phase with the input voltage to prevent the harmonic distortion. In this regard the Input current is sensed, predicted and controlled by a current source controller with NPC.

The other controllers are in the output stage of IUT exactly in the DC/AC converters “Fig. 9”. This leads to a constant output voltage inspire of any changes that may be occurred in loads and inputs.

Each inverter in the output stage will be controlled by a voltage source controller through the NPC.

A. Predictive Control Fashion

Predictive control comprises two strategic parts that are separated to prediction and optimization units [19], [21-22].

First part is charged for predicting the future values of outputs via a plant model and the second has duty to generate a future control based on the predicted values. In the Predictive control constraints could be included in design and defined set point would be closer to optimal solution and so the plant operation will be improved automatically [27-28].

In this regards the neural network is novel method applying for identification and modeling the nonlinear dynamic system [20].

Predictive control represents the number of control algorithms that utilizes the explicit process for predicting the future response of plant. It also optimizes the future of plant in each of iteration, using advanced optimization process and control behavior by computing a sequence of future manipulated variable adjustments.

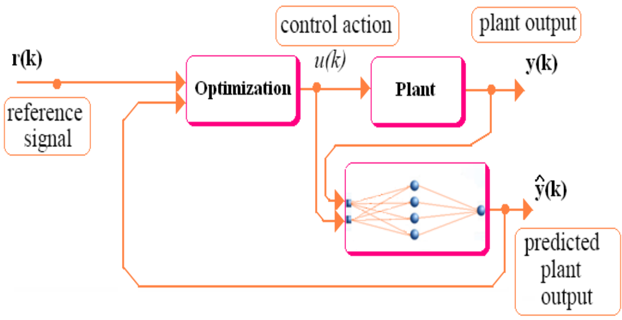


Fig. 6. Neural Predictive Controllers, main topology comprise optimization, prediction and Control

The basic concept of control algorithm is focused on the predicted outputs that are computed by errors between the reference signal and predicted values predicate from the model. This is preferred to emphasizing on only the real output value. So the predictive controller at each instance senses the system state. Then it computes a finite horizon control sequence which will be used in an internal model to predict the system status and behavior. At the end the predictive controller optimizes the cost function without any violation in any of the defined constraints and implements the first part of the optimal sequence with high grade of satisfaction. This results in a new systematic methodology which performs the flexible performance specifications and conveniently handles the constraints.

B. Focused Time Delay Neural Network

The proposed neural network plant model is a Time Delayed Neural Network (TDNN) and this model trained offline. In this structure the output in each instance is a variable of all considered outputs in the “n” last samples of outputs and the last considered inputs. This is represented in “Eq. 1”. “f“ is a nonlinear function considered as a function of output [y(k), y(k-1),..., y(k-n)] and input [u(k),u(k-1),..., u(k-m)]. So the proposed nonlinear model will be expressed by:

$$y(k+1) = f[y(k), y(k-1), \ldots, y(k-n), u(k), u(k-1), \ldots, u(k-m)] \quad (1)$$

The variable “n” and “m” are auto regressors and the number of exogenous regressors. For modeling the dynamic systems feedback effect of the ANN is introduced to characterize the application of Recursive ANN (RANN).

Like the ARX models (Autoregressive by exogenous inputs), the network input signals are associated to its own input and past outputs. This structure represents the characteristic of TDNN.

Focused Time Delay Neural Network (FTDNN) is the forward dynamic network including a tapped delay line at input so the dynamic appear only at input layer ("Fig. 7").

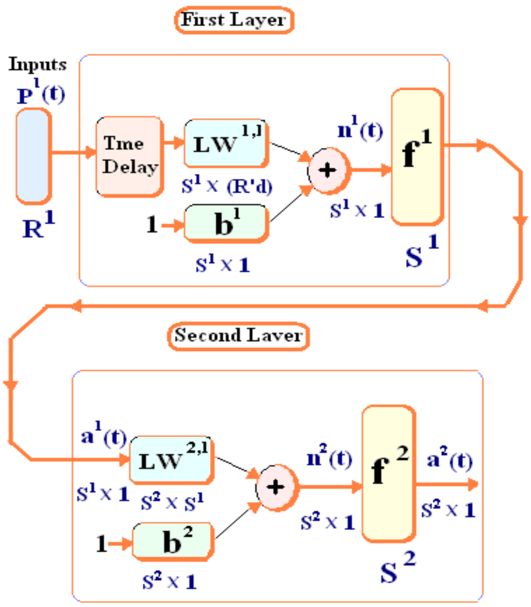


Fig. 7. Focused Time Delay Neural Network structure involving two separate Layers

Weighting factors w_1 and w_2 represent the weights of connections between layers "1-2" and layers "2-3" that are demonstrated in the following figure.

b^1j are the bias hidden neurons and S represents a sigmoid function in the output of each hidden neurons. b^2 is the bias of output linear neuron.

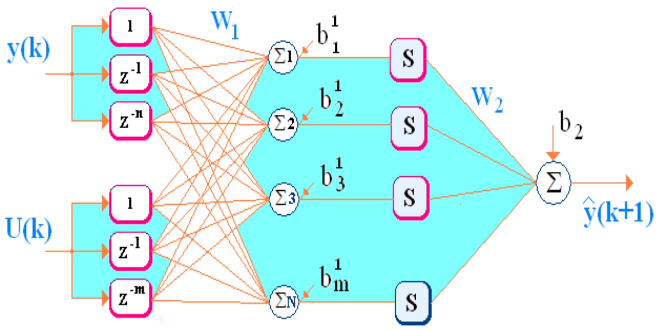


Fig. 8. Focused Time Delay Neural Network construction in Neural Predictive Controllers in discrit time domain

The generic expression for the proposed TDNN model is shown in "Eq. 2" and "Eq. 3" :

$$\hat{y}(k+1) = bs + \sum_{i=1}^{N} w_2(1,i).S(Xi) \quad (2)$$

$$Xi = b(i,1) + \sum_{j=1}^{n} w_1(i,j).y(k-j+1) + \sum_{j=1}^{m} w_1(i,n+j).u(k-j+1) \quad (3)$$

And at last the following equation generalizes the differential of TDNN:

$$e(k+1) = r(k+1) - \hat{y}(k+1) \quad (4)$$

$$\frac{\partial \hat{y}(k+1)}{\partial u(k)} = \sum_{i=1}^{N} w_2(1,i).S'(X_i).w_1(i,n+1) \quad (5)$$

The proposed predictive control models could predict N steps forward so that the optimization function optimizes the whole trajectory of future control in a horizon of N steps ahead [18]. This means that the predictive controller is not limited to one point and expands its duty to the entire vector of N predicted errors so the optimization index is expressed by:

$$J = \frac{1}{2}\left[\vec{E}.\vec{E}^T\right] \quad (6)$$

$$\vec{U}(k+1) = \vec{U}(k) - \lambda \frac{\partial J}{\partial \vec{U}(k)} \quad (7)$$

And

$$\vec{E} = [e(k+1), e(k+2), \ldots, e(k+T)] \quad (8)$$

An optimization index represents the function that is minimized via control procedure for optimizing the future performance of plant.

The SI unit for magnetic field strength H is A/m. However, if you wish to use units of T, either refer to magnetic flux density B or magnetic field strength symbolized as µ0H. Use the center dot to separate compound units, e.g., "A·m2."

IV. Matlab Simulation

In this approach, neural predictive controllers for three-phase power converters with current and voltage regulators are used to predict the future output voltage of converters response and control the line current and output voltages.

TDNN is considered with six hidden layers "N", four auto regressors "n" (four future control input) and four exogenous regressors "m" (four past plant states and four past control inputs) and use the hyperbolic tangent as sigmoid function.

MATLAB neural network toolbox is used for simulating the Focused Time Delay Neural Network, which will be trained incrementally.

Three layers IUT topology in Matalb is demonstrated in "Fig. 9". AS it shown the input is directly connected to the 500V, 3 phase sinusoidal input voltage. The proposed scheme is utilized for mitigating the power-line disturbances resembling voltage sags and swells in lower voltage devices. IUT outputs are 3 phase sinusoidal and 240V DC. In the first stage IGBT rectifiers, rectify the input voltage and produce the DC bus.

The DC bus capacitors are chosen based on handling the ripple current and storing the energy. And because of the factor of storage capacitor in selection of DC bus capacitors the size of DC bus capacitors are normally enough for the ripple current cancellation.

Input current should be sinusoidal and in phase with input voltage for harmonic distortion cancellation. This is done trough the NPC in input stage. The IGBT Inverters in the next stage convert DC voltage to High Frequency square wave.

This High Frequency wave will pass via High Frequency transformer with ratio of “1:1” which isolates the two stages of transformer from each other. Four AC/DC converters rectify the AC voltages and produce four DC bus capacitors for the four outputs. Then four inverters in outputs convert DC voltages of DC bus to the four IUT desired outputs as 48V DC, two 240V AC 60 HZ outputs and 120V AC 400 HZ for communication usage.

Clamping diodes in rectifier IUT construction clamps the voltage stress.

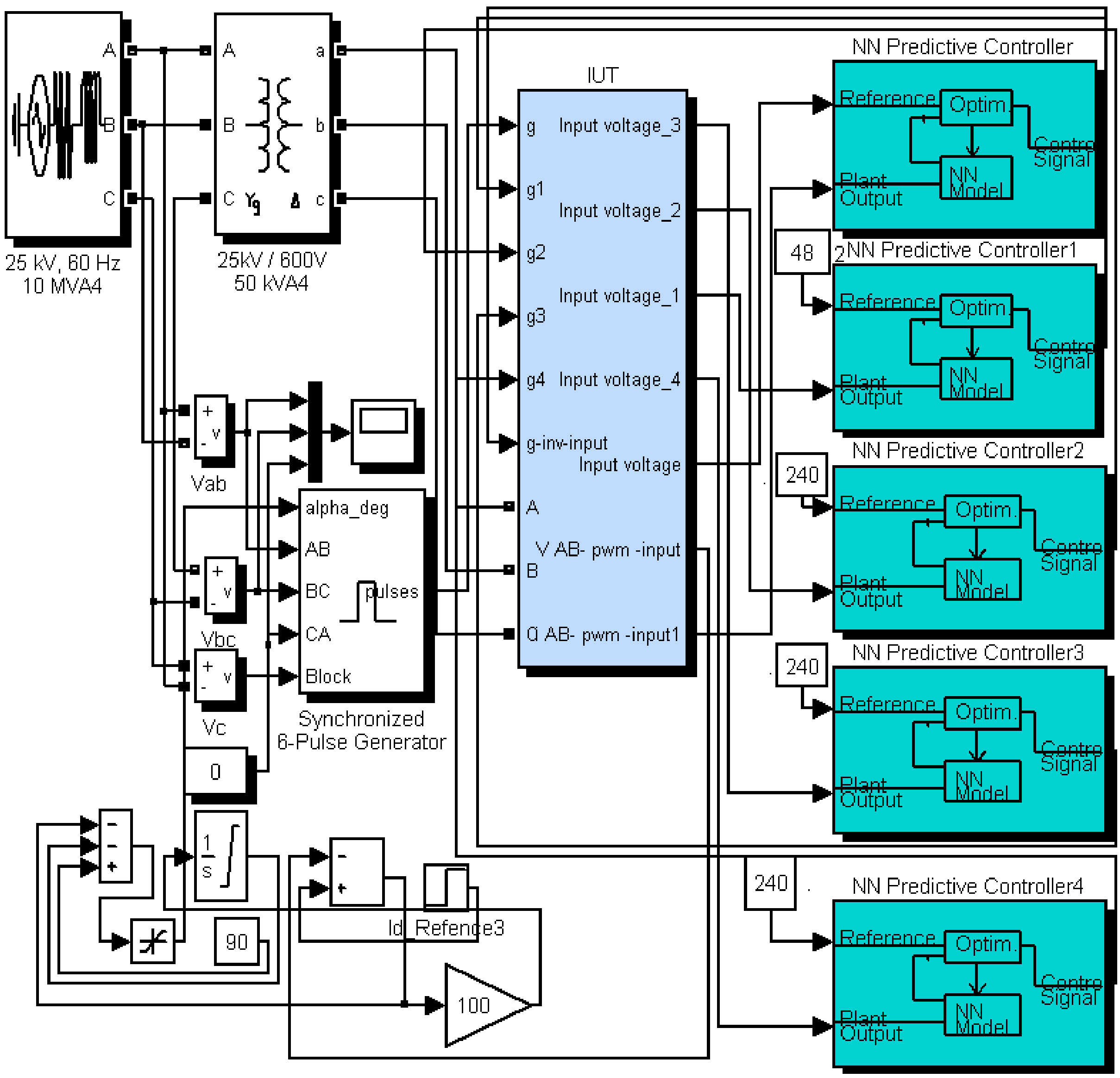


Fig. 9. IUT and NPC controllers for Input-Output : input current regulation by NPC in input stage and four NPCs for regulating the four defind output voltages of IUT

To cope with the nonlinearity and became in adaptability to the changes in parameters the adaption law is considered as below:

$$\lambda = \lambda_0 \cdot \left[\frac{20}{\pi} (y(k))^{-5/2} \right] \quad (9)$$

With considering $\lambda_0 = 6 \times 10^{-4}$, and using adaptive algorithm, λ is computed in each step, and the system adapts to minimize the error. NPC current source controller in input stage predicts and regulates the input current and prevents from harmonic distortion. Four NPC in output, control the output voltages. In response to set of trial control inputs, neural network predicts four future states of inverters indicating the four outputs corresponding to the next four seriate future states of the inverters which will keep in four memories. Four past states of inverters are kept in four memories in NPC construction. The NPC predict the future outputs of inverter in conjunction with the four past states of inverter and four future states the inverter and the future control inputs. Simulation results are shown in “Fig. 11”.

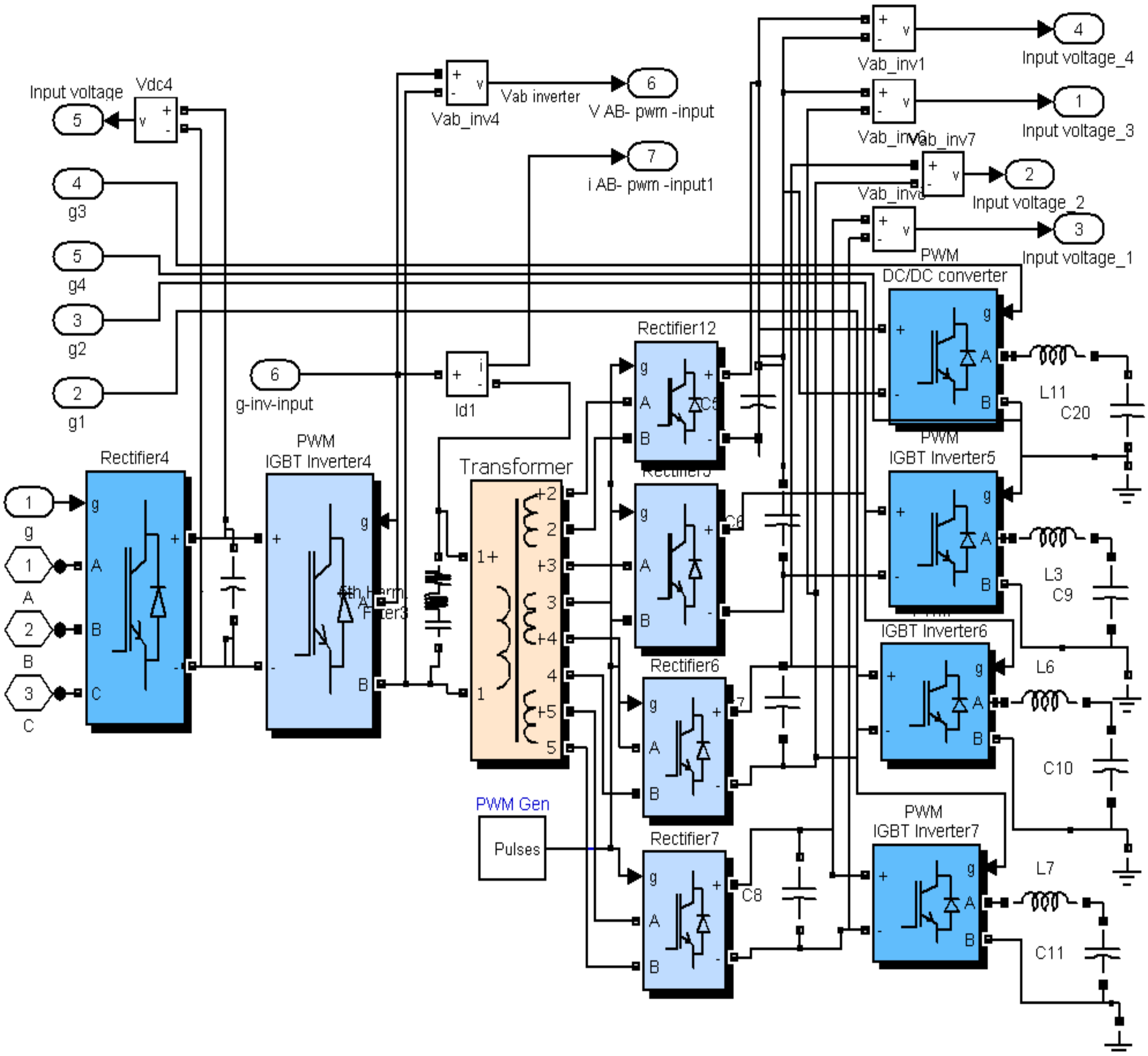
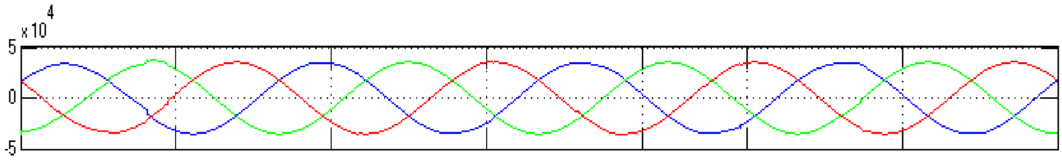


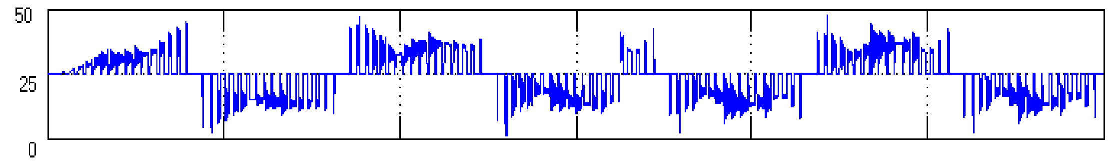
Fig. 10. IUT three layers Matlab simulation model Involving seven individual blocks of rectifires, converters, transformer, DC bus, inverters and four defined outputs.

Fig (11-a), illustrates Three phase input voltage applies on IUT; Fig (11-b) is modulation index in DC/DC converter. Control action is depicted on Fig (11-c). DC output voltage, reference voltage and predicted voltage are shown in last figure (11-d).

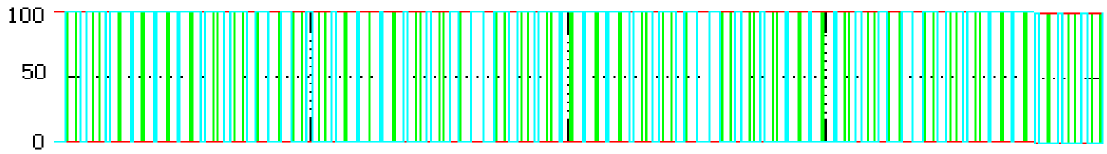
Voltage reaches the steady state of 48V DC at 5.5 second. This is the α degree for IGBT inverters in DC/DC converters.



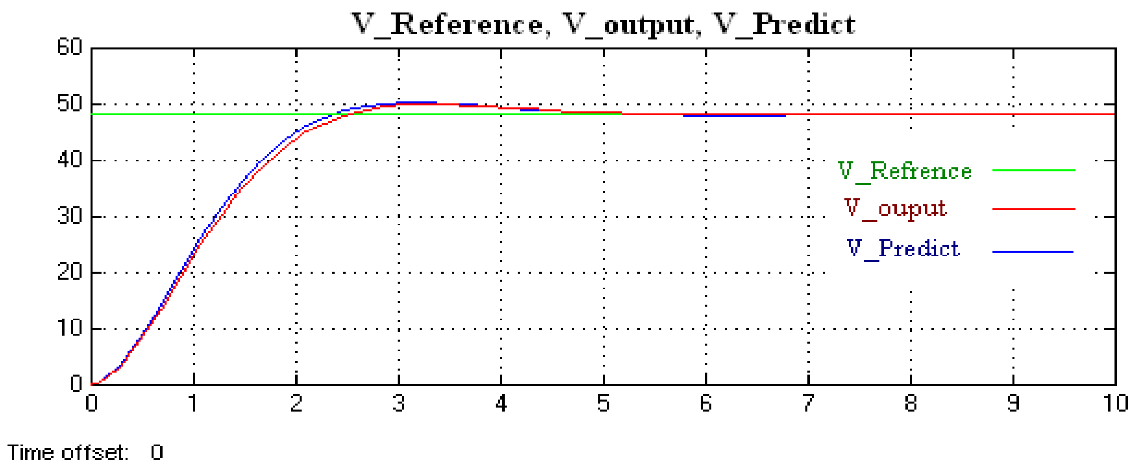
(a)



(b)



(c)



(d)

Fig. 11. (a) Thre phase input signal, (b) Modulation Index, (c) Control Sygnal, (d) V_Refrence, 48 V DC Output and predictive voltage (V_Predict) by NPC

V. Conclusion

Advanced Distribution Automation employs the novel infrastructure technologies and motivating the new modern technologies as IED's and Distributed Energy Resources (DER's). IUT is a Pioneer IED's for the Advanced Distribution Automation with a major advantages which are summarized in part II. Four NPCs in output and one NPC in input regulate the input current and maintain the output voltages in the predetermined level, guaranteeing the system stability in case of input - output disturbances.

48V DC output service options and the other AC outputs could be easily reachable with the proposed three layers IUT topology. In case of control strategy introducing for inverters and converters of IUT, NPC is a powerful method indicates the adaptive procedure which is well known and wildly in used for controlling the complicated plants especially in case of nonlinearity approach in dynamic of system with an unexpected distortion in their behaviors. In this case, NPC produces the predictive control in conjunction with the neural network model for inverters of IUT to predict the future parts of control inputs for adjusting them to the desired amounts. The future control is selected by optimization function. The proposed adaption rules for λ demonstrated the best tracking for achieving to the favorite stages.

Reliability, stability and efficiency are the main factors that all will be enhanced trough the proposed IUT topology and the mentioned predictive controller.

As the applicability of IUT is described with the full network of functionality especially in tomorrow's smart grid the optimization in cost for industrialization of IUT is a part of innovation which could be raised in future for the power electronic technologies and the new control algorithms for efficiency improvements and system performance enhancement that could be stated in forthcoming projects.

ACKNOWLEDGMENT

Authors want to thank the research deputy of Azad University, Islamshahr branch for their efforts and their financial support of this research.

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ITRC “Iranian Telecommunication Research Center“1997-1998, “Synchronous Digital Hierarchy project, she was in charge of designing the management hardware and software which based on micro controller hardware connecting to the PC and connecting to 3 TU “tributary unit “and Com board through dual port RAM and a monitoring program which could show the Alarms of SDH in 2 Mega hertz ,1998-2000. she design TUT3 to TUG3 send and receive by FPGA Max plus 2 ,1996-1998.

ICRC “Industrial Control Research Center”, 1991-1996, she cooperated in designing and Building the Computerized Iron cutting , Identification cart with km93c41”serial EEPROM, Dot matrix monitoring, Temperature sensing and control of 12 channel incubator, Resistance tester with 5 percent resolution, her published articles are on Developing IEC61499 in Industrial Processes, Measurement and Control Systems (IPMCS), Time Synchronizing Signal by GPS Satellites, Robots Adaptive Fuzzy logic controllers for Intelligent Universal Transformers in ADA.