ppi 201502ZU4659
Esta publicación científica en formato digital es continuidad de la revista impresa
ISSN 0254-0770 / Depósito legal pp 197802ZU38

Hacia los 130 años de creación de la Universidad del Zulia

REVISTA TÉCNICA
DE LA FACULTAD DE INGENIERÍA

Una Revista Internacional Arbitrada que está indizada en las publicaciones de referencia y comentarios:

- SCOPUS
- Compendex
- Chemical Abstracts
- Metal Abstracts
- World Aluminium Abstracts
- Mathematical Reviews
- Petroleum Abstracts
- Current Mathematical Publications
- MathSci
- Revencyt
- Materials Information
- Periódica
- Actualidad Iberoamericana

"Buscar la verdad y afianzar los valores transcendentales", misión de las universidades en su artículo primero, inspirado en los principios humanísticos. Ley de Universidades 8 de septiembre de 1970.

UNIVERSIDAD DEL ZULIA

VOLUME 43 SEPTEMBER - DECEMBER 2020 NUMBER 3

Smart PV Solar Concentration Arrays for MPPT using FPGA Technology

Sandoval-Ruiz, Cecilia E.

Facultad de Ingeniería, Universidad de Carabobo, Venezuela. cesandova@gmail.com

https://doi.org/10.22209/rt.v43n3a02

Received: 10/02/2020 **|** Accepted: 29/06/2020 **|** Available: 01/09/2020

Abstract

The present research includes the study of photovoltaic systems and current techniques for maximum power point tracking, in relation to irradiance and temperature, a flap of proposing a reconfigurable PV scheme, simplifying the number of actuator components in the arrangement solar monitoring and regenerative heat recovery circuits, applying neural control in the adaptation of the coefficients of efficiency of the stages of the system. The method consists of identifying the correspondence of the SFVs with the LFSR circuit architecture and the identification of adaptive coefficients, in order to generalize the optimization model on a parameterized ANN. The VHDL description of the architecture was made for its synthesis on FPGA technology, in order to efficiently deal with the computational complexity, parallel processing and technical-environmental feasibility of the design. The results present an alternative technique based on self-similar circuits, with stages of adaptive gain, storage and configurable feedback. This research leads to the concept of intelligent concentration systems, which provides a valuable model, which can be applied in the area of engineering, design and scientific research.

Keywords: photovoltaic systems; optical concentrators; maximum power point tracking; programmable gate arrangement by FPGA field; LFSR model.

Arreglo Inteligente de Concentración Solar FV para MPPT usando Tecnología FPGA

Resumen

La presente investigación comprende el estudio de los sistemas fotovoltaicos y las actuales técnicas para el seguimiento del punto de máxima potencia, en relación a la irradiancia y temperatura, a fin de proponer un esquema FV reconfigurable, la simplificación del número de componentes actuadores en el arreglo de seguimiento solar y circuitos de recuperación de calor regenerativo, aplicando control neuronal en la adaptación de los coeficientes de eficiencia de las etapas del sistema. El método consiste en identificar la correspondencia de los SFV con la arquitectura circuital LFSR y la incorporación de coeficientes adaptativos, de forma de generalizar el modelo de optimización sobre una ANN parametrizada. Se realizó la descripción en VHDL de la arquitectura para su síntesis sobre tecnología FPGA, a fin de tratar de manera eficiente la complejidad computacional, procesamiento paralelo y factibilidad técnica-ambiental del diseño. Entre los resultados se presenta una técnica alernativa, basada en circuitos auto-similares, con etapas de ganancia adaptativa, almacenamiento y realimentación configurable. Esta investigación conduce al concepto de sistemas inteligentes de concentración, el cual aporta un modelo valioso, que puede ser aplicado en el área de ingenieria, diseño e investigación científica.

Palabras Clave: sistemas fotovoltaico; concentradores ópticos; seguimiento de punto de máxima potencia; arreglo de compuertas programables por campo FPGA; modelo LFSR.

Introduction

Given the importance of optimizing non-conventional renewable energy systems (NCRE), in relation to the energy density of the converters and the efficiency of the components, various investigations in this field are presented, which revolve around control schemes for maximum power point tracking (MPPT), through artificial intelligence, particle swarm optimization and other hybrid methods [1]. In this research we have reviewed the methods based on artificial neural networks (ANN), arrangements with Linear Feedback Shift Register (LFSR) structure applied in renewable energy [2-9] and adaptive algorithms [10].

The study starts from the behavior of the system, in order to detect technological gaps in the generalization of optimization strategies based on the model. Analyzing the dynamics of NCRE sources (based on intermittency), they present challenges for their control [2-3], such as computing capacity and concurrent processing, where the Field Programmable Gate Array (FPGA) technology is emerging as an alternative to solution to implement, in an efficient way, embedded systems in hardware descriptor language (VHDL), which allows supporting circuit training and dynamic adaptation.

In the case of photovoltaic (PVS) systems, the optimization of functional stages is possible, in terms of independent variables, such is the case of the irradiance, power received per unit area, and temperature of the modules, giving rise to combinations of optimization methods [11-12]. In this area, the need for a mathematical model has been detected that incorporates the system parameters, describes the components and their behavior, in order to define dynamic control by applying adaptive coefficients, based on the identification of correspondence between each of the subsystems.

The importance of the proposed method is given by a structural generalization for intelligent reconfiguration and dynamic optimization of the coefficients that affect the variables of the model, through an ANN on FPGA [13-14], with LFSR architecture. As well as the hardware design of the PVS numerical MPPT method, through the synchronization between passive optimization techniques: array interconnection, solar concentration, which increase the efficiency of the PV panel [15], and active techniques: distributed MPPT, multilevel inverters, dynamic reconfiguration (relay arrangement), relocation, electrical rewiring, by extrapolating reconfigurable hardware technology to the power system. In addition to proposing innovative techniques: configurable optical arrangements [12] and irradiance spectral modification.

Commonly, the tracking system modifies the position (of the x, y axes) of the panels of the PV array [16], in order to obtain the greatest incident solar radiation on its surface. However, this scheme incorporates a set of motors and moving elements to the arrangement that increase its complexity and probable system failures. Therefore, the study of alternatives is proposed, to improve irradiance conditions, in order to extend the number of hours of peak sun (HSP), leaving the position of the earth station panels fixed (decreasing the number of components) , whose function will be the directing of solar radiation, towards the distributed photovoltaic arrangement. All this synchronized with the MPPT and incorporation of thermal storage and transient storage in ultra-condensers (considering the useful time of batteries with respect to the PV panels), regenerative heat recovery (RCR) in the panels, to increase their efficiency.

First, the components of the PVS are studied to identify the models in stages.

Optical arrangement, this corresponds to the geometric configuration of optical lenses, targeting mechanisms, luminescent solar concentrators (LSC) [17], waveguide (optical fiber), photovolatic concentrators (CPV) [18], etc., which can be dedicatedly designed for each conversion element, multiplexed in space, or applying dynamic projection [12]. Its components define a gain, given by the specific coefficients of the model (fixed or adaptive) on the input signal, that is, the effect of the optical device on the path and magnitude of the incident solar radiation.

An adaptive arrangement is proposed, in correspondence with the concept of smart antennas [10], which incorporate lenses with a selective function in two stages: heliostatic targeting and panel concentration, sub-cells (tandem configuration), filtered by radiation spectral component, expressed as Mathematical form in a specific range for energy contributions (see Table 1), which seeks to reduce PV material and increase efficiency. In its design, the correspondence of the model with the LFSR structure has been identified in the elements: contributions of adaptive gain, transient storage (time τ) and feedback of the radiation, given by the reflection in the material.

In a first definition, the coefficients are specified: w_{UV} ultraviolet, w_{FV} visible light, w_{IR} infrared, by λ range, which can then be generalized in the integrated model, according to each of the components of the received irradiance x_i, for concentration / attenuation / collectors function.

Photovoltaic Arrangement comprises the elements of the PV power generation unit. This arrangement

Table 1. Solar Energy and Storage

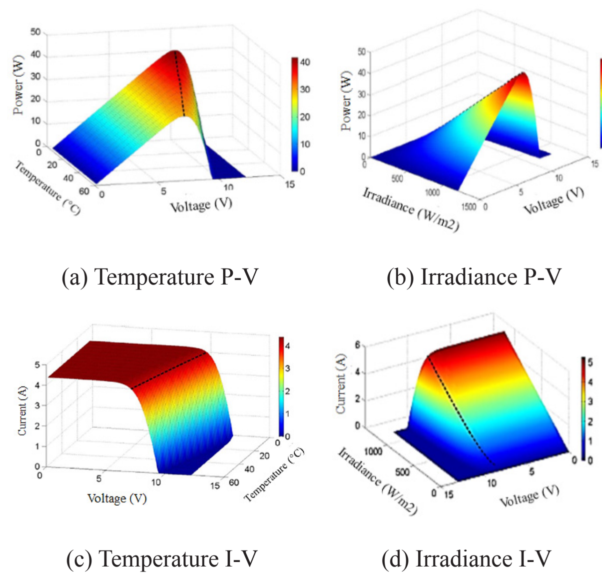
Radiación	Technology	Direct Storage	Formula	Wavelength
Ultraviolet 10,49 %	Sterilization, UV-C	Conservation and post-harvest treatment of biomass	$w_{UV} \cdot x_i + b_i$	10 nm ≤ λ ≤ 400 nm
Photons Visible Light 42,74 %	Photovoltaic	Capacitors / Batteries	$w_{FV} \cdot x_i + b_i$	401 nm ≤ λ ≤ 750 nm
	Photoelectric batteries	Separation of photoactive chemical compounds		
	Chem photosynthesis	Industrial plants (algae)		
	FVPGA synthesis	HW program for photones		
I.R. 46,77 %	Thermo-Solar	Thermal storage salts	$w_{iR} \cdot x_i + b_i$	751 nm ≤ λ ≤ 4000 nm
	Thermo-Electric			

can be reconfigured during operation [19], to minimize losses due to the Joule effect and the effect of panels with specific faults. In this stage it is required to optimize the photoelectric conversion, from the configuration of the arrangement and the control electronics. The PV array connects n_p modules in serial / parallel configuration, for the maximum power point (MPP) of the array and the modules, due to the dynamic nature of this parameter, depending on the conditions of the photovoltaic panels at a specific time, a switching matrix must be defined of the array (MCA). The photovoltaic modules will be responsible for defining the capacity of the process of converting the incident radiation to electrical energy, which is associated with the photoelectric material, the configuration of the cells and panel properties, at the technology level [20].

Power Electronics Arrangement, consists of electronic optimizers, DC-DC converters, transient storage in ultra-capacitors, control feedback for MPPT and inverter modules. The electronic modules comprise the control elements and controlled switches, defining the levels of the system output, at optimal values, applying an algorithm based on a single MPP, which depends on external factors of temperature and irradiance, as shown in the Figure 1.

The curves show the relationship between the independent variables: irradiance and temperature with respect to the electrical parameters of the photovoltaic panel: power, current and voltage, which represents an input for the ANN training and optimization.

Energy Feedback Arrangements, these comprise regenerative energy recovery subsystems, where the feedback model for unconverted photons is proposed, applying PERC technology, bifacial, etc., that allow collecting reflected radiation, residual heat recovery, forced ventilation, cooling of PV panels, for thermal collectors and conversion using thermoelectric material, in order to optimize the use of energy from the PVS. The feedback residual energy can be managed through concepts such as energy harvesting to power electronic devices, applicable for the supply of the optimization



(a) Temperature P-V (b) Irradiance P-V

(c) Temperature I-V (d) Irradiance I-V

Figure 1. Effect of environmental conditions on photovoltaic conversion [21]

stage, maintaining sustainability and low environmental impact as a criterion. In this way, we find a PVS model that coincides with the structure of the stages, where weighting of contributions, intermediate storage of energy and selective feedback by energy components are presented, giving rise to the parameterizable descriptive equation.

Conceptual Development of the LFSR Model for Photovoltaic Systems

The incorporation of a satellite system (made up of one or more optical reflectors) is proposed, as well as the optimization of parameters (depending on topographic characteristics and climatic conditions): number of HSP on the distributed surface of the photovoltaic array, optimum angle of incidence, MPPT and temperature control (see Figure 2).

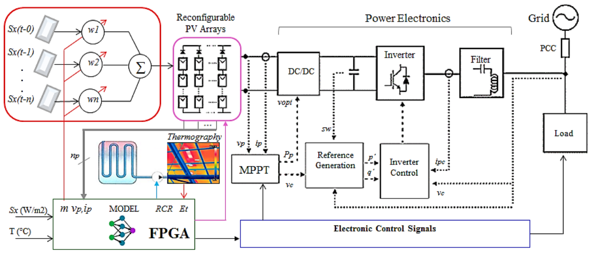


Figure 2. Conceptual Scheme of Updating the MPPT control in PVS

The proposed technique is based on an ANN for modeling the PVS and adapting the coefficients through the optimization algorithm, implemented on an FPGA. From the inputs / outputs of the system: irradiance S_x (S_{UV}, S_{LV}, S_{IR}), current at the point of maximum power I_{MPP}, voltage MPP V_{MPP}, panel temperature T_p and thermal energy *ET*, applying convolutional neural network (CNN) [14] of thermographic images of the PV array, for centralized monitoring system control (driver_motors), panel temperature control (forced ventilation), wasted heat recovery (WHR), configuration (relays), adaptive gain, concentration and MPPT applying pulse width modulation (PWM).

A detailed study of the factors that influence the performance of the photovoltaic array is presented elsewhere [19]. The methods vary in their complexity, necessary sensors, speed of convergence, effectiveness, etc. in relation to the dynamics of the system, requiring advanced MPPT methods (see Table 2), which is done by varying the value of the load so that the PVS can deliver the highest possible power.

This variation of load is controlled by a DC-DC converter, which has the characteristic of raising or reducing a voltage by modifying the duty cycle and the equivalent load of the circuit, achieving such a load, that it consumes it consumes the maximum power of the panel. Where a PWM signal is generated, as the switch control signal, this signal is synchronized with the MPP, for charging the capacitor.

For the MPP, where parameters such as irradiance, temperature and equivalent load are related to the photovoltaic generator, a monitoring algorithm is required [11], [19]. Dynamic reconfiguration enables the performance of the PV array to be improved, through reduced Joule losses. This is how, depending on the environmental conditions, the connection or disconnection of panels would be done using switches. In the optimization stage, one of the points of interest is the power electronics responsible for coupling the photovoltaic generator to the load. The booster DC-DC converter can be controlled by current, voltage, based on the useful cycle of operation or by magnetic control (MC), based on variable inductance.

Experimental

For the design of the hardware-based optimization model, sustainability criteria are proposed, in this sense, regenerative systems must be designed, fed back with input into the energy budget, cycles of reuse, recycling, dynamic reconfiguration and feedback of by-products or energy, in correspondence with the circular model. For this, a qualitative and quantitative analysis of the optimization methods by stage is carried out in the first stage of the research procedure, summarized in Table 3.

Table 2. MPPT Method Study

MPPT Control Technology	Technical Description / PV Arrangement	Solar Concentrator	Ref.
FPGA – Control	Method study using FPGA	-	[1]
ANN	*High Concentrator Photovoltaic* (HCPV)	on the module	[22]
	RTRL, O&P, Hybrids algorithm	-	[23-28]
Fuzzy Logic	Three Stage / FPGA Controller	-	[29-30]
DCS	Distributed photovoltaic modules	-	[31]
ANFIS – FPGA	Neuro-adaptive systems of diffuse inference	-	[32-35]

Table 3. PVS Stage Optimization

	Optimization method	Description of the Technological Concept				
1	**Concentration stage (optical) in the panel / stage prior to the photovoltaic panel**					
	Solar radiation collectors	Optical geometry elements [1],[36-37]				
	Solar Concentration	Doping and LSC material properties [38-39]				
	Wave Transmission	Optical fiber , Stokes *Shift*				
	Optical Capacitors	Waveguide with light reflection in the concentrator				
2	**Conversion Stage (Photovoltaic)**					
	Photovoltaic cell technology	Selection of semiconductors, arrangement of the PV cells in the solar panel or module, superposition of materials for optimization of efficiency, as in the case of spectral conversion [19]				
	Tandem arrangement	Converter layers [20]				
	PERC Technology	Insulating layer for sunlight reflection on the panel				
	Supporting structure of the modules	To increase the efficiency, the amount of energy that reaches the photovoltaic generator can be optimized using as supporting structures of the solar tracking modules, with or without concentrating elements.				
	Storage technology	Storage in Ultra-Capacitors (UC) for energy management, MPP management in synchronization with control logic.				
	Array Configuration	The selected topology for the array and its connection, fixed or reconfigurable. As well as the advances in R-IEDs in ERNC [4-5]				
	Panel cooling for temperature effect compensation	TC Isc	TC Voc	Temperature effect compensation		
		0,044 % / °C	-0,31 % / °C	$w_{IT} * TC_{ISC} * \Delta T , w_{VT} * TC_{VOC} * \Delta T$		
	Artificial Neural Networks	Implementation of neural networks to control optimization parameters and monitoring [2-5]				
3	**Signal Adaptation Stage (Power Optimizer)**					
	MPPT search algorithm	Definition of the operating cycle of the DC-DC converter switch as a booster, to establish the MPP impedance.				
	Power Optimizer (Digital Control MPPT)	Module Level Power Electronics (MLPE), MPP detection on each PV panel, increasing MPP accuracy and array efficiency.				
	Ultra-capacitors	Transient storage [19]				
4	**Inverter Stage (Power Electronics)**					
	Investor Topology	Centralized inverters (string arrays), micro-inverters, power optimizers for each photovoltaic module and central inverter				
	Investor Semiconductors	Characteristics of signal switching switches for DC-AC converter				
5	**Mechanical Stage (monitoring of solar radiation)**					
	Mechanism estimation	Configuration Efficiency Report				
	Arrangement	Fixed Hor.	Fixed Inc.	HSAT	VSAT	HVSAT
	Power (MWh)	69867,45	74818,52	95713,07	91271,15	105874,89
	Plant Factor (%)	20	21	27	26	30

From the estimates obtained in the study of the monitoring arrangement configurations: fixed, horizontal axis tracking (HSAT), vertical axis tracking (VSAT) or two-axis tracking (HVSAT), applying an estimator [40], it is observed the contribution of monitoring in the earth station, at a cost of implementation of the set of drive motors for the positioning of the panels in relation to the weight of the mobile structure, in the matrix of np elements. So a simplification of the PVS is proposed without reducing its efficiency, through an adapter, applying the commutative property between stages, which directs the radiation at a certain height, with an optimal angle of incidence on the fixed photovoltaic arrangement.

The strategies for controlling the factors to be optimized in the PVS and identification of the terms of the mathematical model were defined (see Table 4).

The modeling was carried out through the description of the PVS's behavior by functions, the ANN can make adjustments to the mathematical model, through the identification of configuration and parameters, from the energy balance:

$$E_c(n) = w_c\left(w_{FV} \cdot S_x(n)\right) + b_s \cdot E_{FV}(n-1) + w_{RCR} \cdot E_T(n-1) \quad (1)$$

Where w_c is a coefficient associated with the optimization model (concentration, angle of incidence), w_{PV} the conversion coefficient of the PV panel (typical of PVS technology), b_s selective enablement, $E_c(n-1)$ the feedback energy: $E_p(n-1)$ reflected energy and $E_T(n-1)$ residual thermal energy, with w_{WHR} as feedback gain to the conversion system. Thermal effects can be compensated: $w_T (1+TC_{ISC} \cdot \Delta T) \cdot I_{FV}$, with current proportional to irradiance conversion, wT being thermal optimization coefficient. The actuator control signals are identified from these terms (see Table 5).

Table 4. PVS optimization factors

Factor to optimize	Optimization Techniques	Technical Description	Description Hardware by component
PV panel contamination	Self-cleaning	Electric shocks on the panel	- coef. cleaning to 1.
Energy Density	Bifacial PV	It allows photons to enter the panel through the back surface, where energy efficiency and density are increased, modeled as feedback of reflected energy.	y(t) <= wrf and y(t-1)_f -- feedback -- w_r (wrf,wrt,wre)
	Retractable PV	Smart surface adaptation to HSP	If HSP < opt then -- code; end if
Thermal losses	Regenerative heat recovery	WHR integration and forced ventilation on the back of the photovoltaic panel	w_T*TC_Isc*dT*I_pv -- feedback Et(n-1) y(t) <= wrt and y(t-1)_t
TiAE - Energy Amortization Time	Panel Efficiency Optimization	Electronic control of the efficiency of the PV module	-- coef. PV y(t) <= wpv * S(t)
	HCPV concentration	Adaptable lenses formulated for maximum concentration	-- coef. C y(t) <= wc * S(t)
PV Array Power Losses	Power Optimizers	Micro-Inverters and Power Optimizer Technologies	-- MPPT y(t) <= wp * Impp(t)
Electromagnetic radiation capture (in this case solar)	Smart Beamforming & Fractal Geometry Antennas	Neural networks applied to the efficient uptake and monitoring of the radiation pattern, fractal schemes with line of sight	-- adaptive algorithm w(n+1) <=w(n)+u*s(n)*e(n); --- optimal tracking y(n) <= w(n) * s(n);
Permanent Electronics (Programmed Obsolescence)	Application of a power optimizer in VHDL	Update in time of the optimizer HW, on FPGA technologies	-- Self Generation For i in 0 to m generate -- descriptive equation

Static Arrangements / Dynamic Fitting for max. performance	Neural networks in intelligent PVS design and reconfigurable array	Component of a reconfigurable (multiplexed) matrix based on FPGA technology, with LFSR architecture	If Impp < cond then
			-- Assign settings
			array_PV <= matriz (i);
			end if;

Static technology, with recycling limitations of PV modules	Encapsulated modules with access to inner layers	Additive manufacturing, 3D machining, easily replaceable components, recycling of insertable replacement layers.	-- Reconfigurable hardware (HW)

Table 5. Description of the control stages of PVS actuators

Application	VHDL Hardware Description Codes
Refrigeration Control	If t_ref < ANN_WHR then Bomba <= '1'; else Bomba <= '0'; end if; -- Implementation of the WHR waste heat recovery unit.

MPPT algorithm	dI_mpp <= I_mpp – I_mpp1; dV_mpp <= V_mpp – V_mpp1
	if clk ='1' and clk'event then I_mpp1 <= I_mpp; V_mpp1 <= V_mpp; end if;
	P_mpp <= I_mpp * V_mpp; -- P_mpp > P_mpp1
	-- Power balance considering thermal effect:
	P <= FF *((1+TC_ISC*ΔT) * I_PV)*((1+TC_VOC*ΔT) * V_OC);
	if ANN_mppt = '1' then s1<= '1'; else s1 <= '0'; end if;

Drive Control	-- Defines the direction of rotation of the mechanical solar tracking step motor.
	If ANN_SGM1= '0' then
	For i in 1 to 4 loop driver_m1 (i-1) <= '0'; driver_m1 (i) <= '1' after 10ms; end loop;
	else
	For i in 4 downto 1 loop driver_m1 (i+1) <= '0'; driver_m1 (i) <= '1' after 10ms;
	end loop; end if; -- was defined with Eq. LFSR selective drive mode
	-- *∑wi * xi --> GF(m): yn <= w(i) and x(i) or w(i-1) and x(i)… xor y(i-1)*

In this way, the control is established from the outputs of the ANN, relay combinations of configuration of the connections of the array, WHR, MPPT of each panel of the array, control signals of the motors of the solar tracking mechanism (height, elevation and azimuth angles, complementary to the angle of incidence of the PV array, among others). Once the dynamic modeling optimization method has been selected, the hardware description techniques are applied to manage the optimization coefficients and the behavior description in VHDL of the circuits. In this way, the mathematical structure for the systematized descriptions of the optimizer ANN is standardized. Finally, the synthesis of intelligent electronic devices (IED) is implemented on FPGA.

Results and Discussion

From the analysis of the methods, complexity of implementation and factorization of the optimization coefficients, the heliostatic monitoring system was modeled, with a line of sight towards the PV array, with a line of sight towards the PV array, with radiation targeting, selective wavelength and UV radiation filtering, in order protect the surface of this type of waves, which can have wide application in the protection of fauna, glaciers and forest environments. All of the formers with the purpose of establish optimal parameters of height, concentration and angles of incidence / reflection, which will be adapted by the ANN. This intelligent arrangement allows us to simplify the solar tracking module (reduction of the number of actuators in the arrangement), representing a technological innovation. The proposed technique is based on the developed model (see Table 6) and includes the adaptation of coefficients on the energy balance model, in order to obtain maximum efficiency: in the stage of spectral concentration of visible light, conversion stage, stage of power electronics, energy harvesting and storage, jointly at the PVS.

Starting from the identification of a common structure for the stages studied, a regenerative system comprising storage and feedback is identified, as well as a hybrid control stage that combines MPPT with adaptation of model coefficients. Thus, a generatrix equation is found for the geometric (architectural configuration) and parametric description, using the synthesis tool for VHDL [41] and the instantiation of the neural components (see Table 7).

In the VHDL description, the ANN has been parameterized, where the synaptic weights correspond to the optimization coefficients of the developed model. The configuration parameters (number of neurons, layers, learning rate, synaptic weights) are established according to the system, environmental optimization criteria and monitoring targets (based on a set of training, validation and testing), for the ANN adaptation on hardware [5], connected online with the PVS.

Table 6. Technical Characteristics of the Optimizer Model

Technical characteristics	Innovation Achievements	Reasons for its implementation
Hardware Oriented	Synthesizable over FPGA technology	Design portability
Multi-stage model (parameterizable)	Variables of the various stages are included for the MPPT	Optimization coefficients are defined at each stage
Generating equation	Systematization of the description	Parameterizable for particular systems
Commutability	Simplification of components and actuator elements	Management of terms by incidence factor on the arrangement.
Scalability	Ability to include modules with the same LFSR structure	At custom optimizations can be implemented
Flexibility	Updatable and reusable components are described.	Increased lifetime of hardware designs
Dynamic reconfiguration	Modular / differential for stage update	Distributed PVS support and model extrapolation
ANN-MPPT	Adaptation of model coefficients (considering the panel efficiency curves)	The high demand for computation of control in NCRE by the system dynamics, requires the optimization of the sequential algorithm disturbs and observes for MPPT
Correspondence	Identification of LFSR structure in the PVS and neural optimizer, where the ANN weights have physical significance in the optimization coefficients.	

Table 7. Description of the parameterized ANN model

ANN Hardware Description Codes in VHDL	ANN Training
ANNF: For k in 1 to 3 generate -- - generation the layers of the ANN LAYER1: For i in 0 to np| if k= 1 generate -- Layer 1 N1: neurona_layer1 port map (xn,w1(i),b1(i),s1(i)); -- instantiation n1 -- sn <= wi1*xi1 +…+ win*xin + bi; end generate LAYER1; yn <= s1(var_in) & … & s1(5) & s1(4) & s1(3) & s1(2) & s1(1) & s1(0); LAYER2: For i in 1 to np | if k= 2 generate -- Layer 2 N2: neurona_layer2 port map (sn,w2(i),b2(i),y2(i)); -- instantiation n2 end generate LAYER2; ANN <= y2(señal_ctrl) &…& y2(2) & y2(1); end generate ANNF;	type matriz_peso is array of (m downto 0) of std_logic_vector (7 downto 0); -- Adaptation of the weight matrix by iteration: if clk'event and clk ='1' then e(n) <= t(n) – y(n); wi(n+1) <= wi(n) + u* xi(n)*e(n);

Circuit	*Slices*	*4-LUTs*	*FF*	*Factor · parameterized units*
ANN (*var_in,np,señal_ctrl*)	100	198	0	n_layer (neuron · synaptic_weights · m bits)
Adaptive algorithm	80	148	48	(n1 · var_in + n2 · signal_ctrl) · m bits
Descriptive expression:	$\sum_{i=1}^{sc,np} w_{MPP} *$		$\sum_{i=1}^{np} w_{SFV}(n) * x_i(n) + w_R * E_F(n-1)$	
ANN layers / function	Layer 2,3 / Optimization		Layer 1 / Modeling PVS	
CS elements of centralized monitoring on panel set n_p				

In a specific PVS configuration, the intelligent optical arrangement has been incorporated for the maximum use of incident radiation S_x, with *wadap* coefficients [42], temperature control and WHR for recovery of residual energy from the panels:

$$y(t) = \sum_{k=1}^{m} w_{CS}(k) * \sum_{j=1}^{np} w_{MPP}(j) * \sum_{i=1}^{np} w_c(i) * w_{FV}(i) * x(t) + w_R * y(t-1) \quad (2)$$

With w_{CS} tracker gain (for the *m* elements of the proposed arrangement), w_{MPP} dynamic optimizer gain: MPPT, temperature control, etc., *x(t)* total irradiance, w_R feedback enabler of residual energy components *y(t -1)*. Highlighting that an operator can be an LFSR circuit with the function concatenated in its structure:

$$y(t) = f_{OPT}\left(f_{FV}(x(t))\right) + w_R * y(t-1), con\ f_{FV} = \sum_{i=1}^{np} w_f(i) * x_f(i) + E_f(t-1) \quad (3)$$

As a result, the optimization model is obtained, based on the LFSR scheme, which allows the dynamic configuration and description of intelligent control over FPGA devices. Additionally, selectors (relays) are included for the branches of operators by arrays, so the coefficient of a branch defines the corresponding weight or the ON / OFF selection, in the case of being an LFSR operator (see Figure 3).

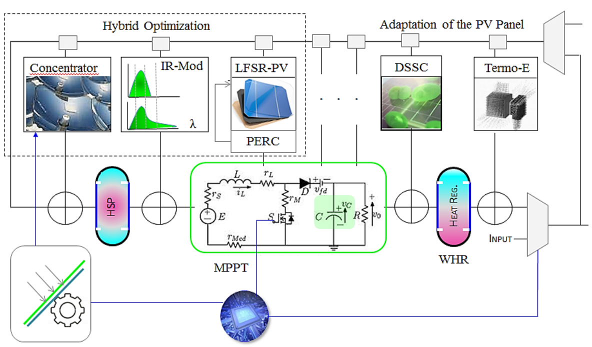


Figure 3. LFSR model of optimization by solar concentration arrangement

The LFSR-PV model is intended to formulate the configuration: photoelectric, thermoelectric, using ANN optimization. Likewise, the correspondence with reconfigurable functional modules is established (see Table 8), to determine the properties of the CSL concentrator, stages of the PVS and terms of feedback (electrical, thermal, photonic).

The identification of correspondence between the models, PVS coefficients (first layer) and optimization coefficients (deep layers) of the ANN [5], allows the adjustment of the efficiency response, MPPT of the total system, and the generation of the code in VHDL. At the same time ANN [13] learning transfer can be applied for modeling and fine tuning service for remote optimization of the PV system.

In the context of the current 82% decrease in PV energy costs [43], the spectral optimization of direct, diffuse and reflected radiation [44] is of interest as partial contributions to the model. The results achieved can be extrapolated in to eolic MPPT [45], NCRE [2], regenerative systems in engineering, on hardware ANN formulation [46] for PV sensitization, optical arrangements, thermal modeling of bifacial panels [47], panel cooling for MPP PV / T [48], power optimizers [49] and hybrid power generation systems [50], energy efficiency [51] and development of technologies with minimal environmental impact [52-53].

Conclusions

Thanks to the optimization model on solar PV concentration arrangements for MPPT, based on ANN, LFSR architecture and adaptive algorithms responsible for adjusting the system coefficients, it has been possible to provide intelligence to the PVS, applying parallel processing circuits and dynamic reconfiguration of the arrangement, which introduces an improvement in the use of irradiance conditions, HSP, spectral modification, temperature control of the PV modules and feedback

Table 8. LFSR Model Correspondence

LFSR	Operation layers	Storage	Feedback
Fractal ANN	Neuro-Operators	TDL	*y(t-1)*
Optics	Concentrator Gain	Luminescence (Shift Stokes)	Photon reflection
Photovoltaic	Tandem PV	Current Shift / Residual Heat	PERC / λ irradiance
electronics	DSP / PWM	UC ultra-capacitors	Reg. Heat Recovery
Smart Grid	IEDs- Converters	Energy storage	E. Reversible
CSR model	COD / WHR	τ (radiation delay)	Optimization coefficients

of residual energy components, to increase the total performance, through the contribution of each stage .

In this way, the concept of Photovoltaics 2.0 is advanced, within the framework of the dynamic update of the hardware and incorporating digitalization techniques, energy harvesting, intelligent arrangements, HCPV and modularity, using FPGA technology, with important advantages in performance and flexibility, compared to fixed systems that require more intervention in update or migration processes.

Likewise, the developed optimization model presents significant contributions in the identification of the physical parameters, storage and selective feedback, given its correspondence with the LFSR architecture, which allows the adjustment of the system coefficients by applying conventional adaptive algorithms or designs of hardware-oriented approaches, for intelligent management of the contribution of solar energy, as well as factors not initially contemplated in the configuration of the ANN model.

Observing the efficiency reports of the monitoring mechanism and combination of methods, the direction of the solar energy towards the fixed photovoltaic arrangement was proposed, in combination with the optimization. Thus, the results achieved give rise to new areas of development and competitive techniques in smart grid applications and virtual power plants.

Being important the understanding in the design concepts of aspects such as socio-environmental feasibility, which incorporate the updating of human talent in renewable energy technology, teleconfiguration, new areas of sustainable development, eco-responsibility with fauna, habitat, materials and natural resources, optimal use of infrastructure (for reconversion of conventional energy production units), reconfigurable hardware technology for dynamic adaptation / updating over time (reuse and recycling), energy efficiency of devices, based on the model developed.

References

[1] Mellit A., Kalogirou S. A. : “MPPT-based artificial intelligence techniques for photovoltaic systems and its implementation into field programmable gate array chips: Review of current status and future perspectives”. Energy, Vol. 70, N° C, (2014) 1-21.

[2] Sandoval-Ruiz C. : “Modelo VHDL de Control Neuronal sobre tecnología FPGA orientado a Aplicaciones Sostenibles”. Ingeniare. Rev. chilena de ingeniería, Vol. 27, N° 3, (2019) 383-395.

[3] Sandoval-Ruiz C. : “Control de Micro-Redes de Energía Renovable a través de estructuras LFCS Reconfigurables en VHDL”. Ciencia y tecnología, Vol. 18, (2018) 71-86.

[4] Sandoval-Ruiz C. : “Códigos Reed Solomon para sistemas distribuidos de energías renovables y smart grids a través de dispositivos electrónicos inteligentes sobre tecnología FPGA”. Memoria Investigaciones en Ingeniería, Vol. 16, (2018) 37-54.

5] Sandoval-Ruiz C. : “LFSR-Fractal ANN Model applied in R-IEDs for Smart Energy”. IEEE Latin America Transactions, Vol. 18, N° 04, (2020) 677-686.

[6] Sandoval-Ruiz C. : “Modelo Neuro-Adaptativo en VHDL, basado en Circuitos NLFSR, para Control de un Sistema Inteligente de Tecnología Sostenible”. Rev. Universidad, Cienc. y Tecnol. Vol. 21, N° 85, (2017) 140–149.

[7] Sandoval-Ruiz C. : “Métodos Numéricos en Diferencias Finitas para la Estimación de Recursos de Hardware FPGA en arquitecturas LFSR(n,k) Fractales”. Ingeniería Investigación y Tecnología. Vol. XX, N° 03, (2019) 1-10.

[8] Sandoval-Ruiz C. : “Plataforma de Investigación de Redes Eléctricas Reconfigurables de Energías Renovables aplicando Modelos LFSR”. Universidad, Ciencia y Tecnología, Vol. 23, N° 95, (2019) 103-115.

[9] Sandoval-Ruiz C. : “Operador matemático LFC(n,k) en campos finitos basado en concatenación fractal para GF(2m) – Extendido”. Ciencia e Ingeniería, VOl. 41, N° 2, (2020) 197-204.

[10] Castellanos J., Sandoval C., Azpúrua M. : “Implementación sobre FPGA de un Algoritmo LMS para un arreglo de antenas inteligentes”. Rev. Téc. Ing. Univ. Zulia, Vol. 37, N° 3, (2014) 270-278.

[11] Rodríguez-Gallegos, Carlos D., et al. : “Global Techno-Economic Performance of Bifacial and Tracking Photovoltaic Systems”. Joule Vol. 4, (2020) 1-28.

[12] Sandoval-Ruiz C. : “Proyecto Cometa Solar – CS para optimización de sistemas fotovoltaicos”. Universidad, Ciencia y Tecnología,, Vol. 24, N° 100, (2020) 74-87.

[13] Whatmough P. N., Zhou C., Hansen P., Venkataramanaiah S. K., Seo J. S., Mattina M. : “FixyNN: Efficient hardware for mobile computer vision via transfer learning”. Proceedings of the 2nd SysML Conference (2019).

[14] Shawahna A., Sait S. M., El-Maleh A. : “FPGA-based accelerators of deep learning networks for learning and classification: A review”. IEEE Access, 7, (2018) 7823-7859.

[15] NREL National Renewable Energy Laboratory, Best Research-Cell Efficiency Chart, (2020).

[16] Fernández-Ahumada, L. M., et al. : "A novel backtracking approach for two-axis solar PV tracking plants". Renewable Energy Vol. 145, (2020) 1214-1221.

[17] Parola I. : "High performance fluorescent fiber solar concentrators employing double doped polymer optical fibers". Solar Energy Materials and Solar Cells, Vol. 178, (2018) 20-28.

[18] Angulo, M. : "Desarrollo de un Sistema Fotovoltaico de Concentración para aplicaciones de Co-Generación". Tesis de Maestría, Centro de Investigación en óptica, México (2018).

[19] González de la Fuente, J. M. : "Utilización de ultra-condensadores para la mejora de eficiencia de una instalación fotovoltaica". Tesis Doctoral. Universidad de Valladolid (2015).

[20] Sandoval-Ruiz, C. : "Arreglos Fotovoltaicos Inteligentes con Modelo LFSR-Reconfigurable". Revista Ingeniería, Vol. 30, N° 2, (2020) 32-61.

[21] Kermadi, M., Berkouk, E. M. : "Artificial intelligence-based maximum power point tracking controllers for Photovoltaic systems: Comparative study". Renewable and Sustainable Energy Reviews, Vol. 69, (2017) 369-386.

[22] Almonacid, F., Fernández, E. F., Rodrigo, P., Pérez-Higueras, P. J., Rus-Casas, C. : "Estimating the maximum power of a high concentrator photovoltaic (HCPV) module using an artificial neural network". Energy, Vol. 53, (2013) 165-172.

[23] Viloria-Porto, J., Robles-Algarín, C., Restrepo-Leal, D. : "A novel approach for an MPPT controller based on the ADALINE network trained with the RTRL algorithm". Energies, Vol. 11, N° 12, (2018) 3407.

[24] Viloria Porto, J. P. : "Diseño e implementación de un controlador neuronal artificial dinámico para optimizar el algoritmo de perturbación y observación en el seguimiento del punto de máxima potencia de un módulo fotovoltaico". Universidad del Magdalena (2018).

[25] Ahmed, C. C., Cherkaoui, M., Mokhlis, M. : "MPPT Control for Photovoltaic System using hybrid method under variant weather condition". In 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems – WITS (2019) 1-5.

[26] Salimi, M. : "Artificial Neural-Network-Based Maximum Power Point Tracking for Photovoltaic Pumping System Using Backstepping Controller". RTUCON (2018) 1-7.

[27] García, B., Carmona, C., Rivera, A., Jesús, M., Aguilera, J. : "A differential evolution proposal for estimating the maximum power delivered by CPV modules under real outdoor conditions". Expert Systems with Applications, Vol. 42, N°13, (2015) 5452-5462.

[28] Punitha, K., Devaraj, D., Sakthivel, S. : "Artificial neural network based modified incremental conductance algorithm for maximum power point tracking in photovoltaic system under partial shading conditions". Energy, Vol. 62, (2013) 330-340.

[29] Pacheco Bautista, D., Cortés Rito, E., Aguilar Acevedo, F. : "Diseño de un controlador de carga de tres etapas para sistemas fotovoltaicos usando lógica difusa". Ingeniare. Rev. chilena de ingeniería, Vol. 27, N° 4, (2019) 540-550.

[30] Youssef, A., El Telbany, M., Zekry, A. : "Reconfigurable generic FPGA implementation of fuzzy logic controller for MPPT of PV systems". Renewable and Sustainable Energy Reviews, Vol. 82, (2018) 1313-1319.

[31] Moon, S., Yoon, S. G., Park, J. H. : "A new low-cost centralized MPPT controller system for multiply distributed photovoltaic power conditioning modules". IEEE Transactions on Smart Grid, Vol. 6, N° 6, (2015) 2649-2658.

[32] Aldair, A. A., Obed, A. A., Halihal, A. F. : "Design and implementation of ANFIS-reference model controller based MPPT using FPGA for photovoltaic system". Renewable and Sustainable Energy Reviews, Vol. 82, (2018) 2202-2217.

[33] Cabello, S. : "Reconfiguración dinámica del campo solar de una planta fotovoltaica para maximizar la producción de energía". Universidad de Sevilla (2018).

[34] Ramos Hernanz, J. A. : "Optimización de modelos de módulos fotovoltaicos y del control del MPPT". Universidad del País Vasco-EHU (2017).

[35] Hassaine, L.. : "Implementación de un control digital de potencia activa y reactiva para inversores". Universidad Carlos III de Madrid (2010).

[36] Daorta, F., Warren, S. : "Concentradores luminiscentes para las aplicaciones fotovoltaicas". Universidad del Callao (2015).

[37] González, G. R., Muñoz, S. O. : "Análisis comparativo de dos técnicas para el transporte vertical de la luz

natural". REVISTARQUIS, Vol.7, N°1, (2018).

[38] Fernández-Balbuena, A. : "Sistemas ópticos para concentración, captación y guiado de radiación solar". Universidad Complutense de Madrid (2011).

[39] Castro, J. A., García-Alvarado, R., Aguilar, H., Sánchez-Friera, P. : "Concentradores Solares Luminiscentes". RChD: creación y pensamiento, Vol.3, N°5, (2018).

[40] Solar E., Explorador Solar aplicación fotovoltaica. Universidad de Chile (2020). http://ernc.dgf.uchile.cl:48080/fotovoltaico.

[41] Xilinx. ISE Design Suite 11.1. (2020). https://www.xilinx.com/products/design-tools/ise-design-suite.html.

[42] Sandoval-Ruiz C. : "Adaptive Control in VHDL Applied to a Solar Oven". Rev. Colombiana de Tecnol. de Avanzada Vol. 1, N° 23, (2014) 142-147.

[43] IRENA, How Falling Costs Make Renewables a Cost-effective Investment, (2020). Recuperado de: https://www.irena.org/newsroom/articles/2020/Jun/How-Falling-Costs-Make-Renewables-a-Cost-effective-Investment.

[44] Gómez Sarduy, Julio Rafael, et al. : "Determinación de la radiación solar directa y difusa en la zona de la costa venezolana a partir de variables meteorológicas". Rev. Téc. Ing. Univ. Zulia, Vol. 38, N° 2, (2015) 150-158.

[45] González, L. G., et al. : "Diseño de un emulador para sistemas de conversión de energía eólica". Rev. Téc. Ing. Univ. Zulia, Vol. 38, N° 2, (2015) 159-168.

[46] Sandoval-Ruiz, C., Ruiz-Díaz, E. : "Optimizador de Eco-Productos de origen vegetal aplicando Control Neuronal en VHDL". Revista de Ciencia y Tecnología Agrollanía, Vol. 15, (2018) 58-64.

[47] Bernuy Bahamóndez, C. : "Modelamiento térmico unidimensional y transiente de una celda fotovoltaica bifacial". Universidad de Chile (2018).

[48] Da Rocha, N. M. M., Brighenti, L., Passos, J., Martins, D. : "Photovoltaic Cell Cooling as a Facilitator for MPPT". IEEE Latin America Transactions, Vol. 17, N° 10, (2019) 1569-1577.

[49] De Souza Silva, J. L., Moreira, H. S., de Mesquita, D. B., dos Reis, M. V. G., Villalva, M. G. : "Study of Power Optimizers for grid-connected photovoltaic systems". IEEE Latin America Transactions, Vol. 17, N° 1, (2019) 127-134.

[50] Sandoval-Ruiz, C. : "Diseño conceptual de un módulo híbrido para Generación eléctrica". VIII Congreso Nacional y 2do Congreso Internacional de Investigación. UC, (2013).

[51] Sandoval-Ruiz, C., and Fedón-Rovira, A. : "CESR-Codificador RS (255, k) eficiente para sistemas reconfigurables". Rev. Téc. Ing. Univ. Zulia, Vol. 37, N° 2, (2014) 151-160.

[52] Sandoval-Ruiz, C. : "Arquitectura Reconfigurable y Redes Inteligentes aplicadas al Diseño Sostenible en Smart City". REC Perspectiva, Vol. 7, N° 12, (2018) 8-21.

[53] Machado, Nelson Andrés López, et al. : "Evaluación del impacto de un techo verde sobre la escorrentía urbana usando un modelo a escala". Rev. Téc. Ing. Univ. Zulia, Vol. 43, (2020) 26-35.

UNIVERSIDAD
DEL ZULIA

REVISTA TECNICA

OF THE FACULTY OF ENGINEERING
UNIVERSIDAD DEL ZULIA

Vol. 43. N°3, September - December 2020

This Journal was edited and published in digital format on August 31st 2020 ***by Serbiluz Editorial Foundation***

www.luz.edu.ve
www.serbi.luz.edu.ve
www.produccioncientifica.org