Solar Fed 15 Level Cascaded Multilevel Inverter with ANFIS Control Strategy for Enhancement of Power Quality

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Abstract. Solar PV energy conversion systems suffer from degraded power quality issues because of harmonics in the system. In order to eliminate harmonics, this paper focuse on a solar-powered 15-level cascaded inverter. A number of controllers such as PI, Fuzzy Logic Neural Network and ANFIS are used in this study in order to manage the PWM frequency (Proportional Integral, Fuzzy Logic, NN and Adaptive Neuro Fuzzy Inference System, respectively). A PV-fed 15-level cascaded multilevel inverter for power quality improvement will be developed by using an ANFIS controller. The suggested ANFIS controller has a lower harmonic distortion than conventional controllers; hence the quality of the power improves. The PI, FL, ANN, and ANFIS controllers simulated results are analyzed in MATLAB.

Keywords: *ANN, ANFIS, Power Quality, Photo Voltaic (PV), Cascaded Multilevel Inverter and Fuzzy Logic (FL).*

1. Introduction

As a way to improve their standard of living, many developing countries' rural areas must have electricity [1–4]. In today's society, the most significant topics to research are energy efficiency, electrical supply, and sustainability. There can be no advancement in any country's economy or human or industrial development without a reliable and consistent source of energy. The need for more efficient energy consumption has grown due to dwindling petroleum supplies and a growing reliance on foreign sources of fossil fuels. Some time ago, thermal and nuclear power were employed to generate energy. There are advantages and cons to using each of these resources. The growing emphasis on reducing CO_2 emissions has spurred an increase in non-fossil fuel energy research. As a result, every industry, including residential, transportation, manufacturing, and agricultural, requires a more environmentally friendly source of energy.

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This unanticipated demand and challenge to our environment has pushed energy production companies to go even further and more successfully. [5] Today, the complexity of much energy legislation and investment opportunities around the world has been reduced. Renewable energy is defined as "lifelines from limitless natural resources". A few examples of renewable natural energy sources include: solar energy; water; air; biomass; and geothermal heat. To put it another way, the potential for renewable energy resources in a certain geographic area is enormous when compared to other energy sources like fossil fuels. Energy security would improve and environmental harm would be minimized with rapid deployment of renewable energy's numerous advantages.

Governments will save millions of dollars on healthcare costs as a result of reduced pollution [6–8]. Renewable energy sources are frequently employed in rural areas to generate electricity, heat water, move people and goods, and provide other energy-related services (off grid). Because of this, we can confidently forecast that renewable energy assets will play a major role in boosting energy availability in rural locations. Concentrated solar power, solar heating, and concentrated photovoltaics are all examples of technologies that use the sun's rays to generate electricity. Either active or passive, depending on your perspective. To convert light energy into electrical energy, photovoltaic (PV) systems make advantage of the photoelectric effect. MPPT systems are therefore required to extract the most energy out of solar panels. The most typical way to do this is via PVs that track the sun. The sun-tracking photovoltaics adjust to global insolation variations and enhance their acquired sunlight radiation for maximal output at constant voltage. Efficient PV system panels are chosen based on the solar array's capacity to convert sunlight into energy.

Because solar PVs are a reliable source of renewable energy, they can easily be connected into the grid. An issue with solar energy is that its output does not always match up with what people actually need. Most of the responsibility goes to PV's erratic generation. As a result, several problems emerge, including voltage regulation. Transmission and distribution voltage can be adjusted for a long time using active and reactive powers. When we talk about voltage regulation, we are referring to the differential in voltage between the transmission and distribution ends. To guarantee that voltage across is kept below acceptable ranges under load, there are a number of devices that collaborate, including as STATCOMs and SVCs. A common cause of voltage regulation problems is impedance, which can produce either an overvoltage or a voltage drops below the usual range while running at high loads. To fix the voltage imbalance, a power electronic interface can be connected between the power supply and the load. This interface is responsible for regulating the output voltage and increasing the quality of the power output. The use of a multi-inverter, which is brand new, has the potential to provide two distinct advantages. The expression "three level converters" is the etymology of the term "multilevel". This can be achieved by using several DC sources and the commutation of semiconductor switches. Higher power quality, improved electromagnetic compatibility and fewer switch losses are just a few of the benefits that multilevel inverters offer over single-level inverters [9-10].

A Neutral Point Clamped or Diode Clamped MLI, a Flying Capacitor MLI, or a Cascaded MLI are other names for this type of inverter.These results were achieved with the help of a Cascaded Multilevel Inverter (CMLI). CMI is a major player when it comes to converting various DC sources, such as batteries or solar cells, into a desired voltage (SDC). If the HB

DC link voltages are equal, the CMLI is said to be symmetrical. Environmental factors typically alter the voltage of solar panels, making asymmetrical inverters highly recommended. Asymmetries in inverter design result in varied DC connection voltages. In order to achieve the same voltage levels, the CMLI uses fewer components than other multilevel inverters. In order to do real power conversions, the CMLI requires distinct DC sources. Even though it has this flaw, solar PV can be used as an energy source to power it. In a solar power circuit, an explanation is given for how to simplify voltage regulator management and improve power quality.

2. Proposed system

Figure.1 depicts the proposed 15-level-MLI system, which is powered by solar PV. Figure below shows the arrangement of the system's solar PV array, cascaded 15-level H-bridge multi-level inverter. This approach uses PD PWM with various controllers, such as PID, FLUZZY, ANN and ANFIS. The ANFIS controller has a lower THD than PI, FLC and ANN controllers.

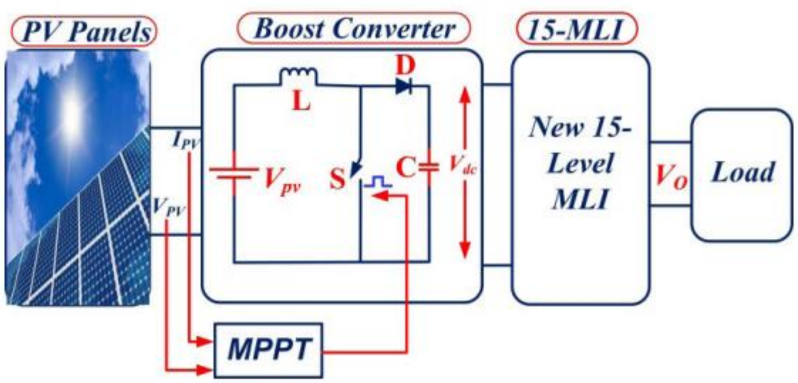

Figure. 1 A 15-level-MLI system powered by a proposed solar PV system

3. Controlling modeling

It is the same manner that a generator or synchronous machine is connected to the grid using an inverter for renewable energy sources like solar PV. Due to variations in the amount of irradiance absorbed by the panel, the rated voltage of a PV system might range from -20% to +20% throughout the day. Stabilized DC voltage in the PV can be achieved by the application of power electronic circuits. Grid voltage is transmitted as an alternating current (AC), therefore stable DC voltage is converted to an alternating current (AC). The suggested experiment uses an inverter with a maximum variance of 1% to ensure accuracy when employing a 48V, 7A solar panel with a variation of 20%.

Fuzzy logic controller

For the first time, Lofti A. Zadeh used fuzzy logic instead of Boolean algebra. The values must be either 1 or 0 if you're using fuzzy logic. (OFF). Unlike Boolean logic, fuzzy logic can accept a range of values between true and false. True or false answers are all that are required in this logic, unlike Boolean logic. Using fuzzy logic, it is possible to draw firm conclusions from data that is itself unclear, hazy, and imprecise. Using a fuzzy logic controller (FLC) to incorporate virtual reality (VR) in the solar PV feed, as shown in Figure.1 For grid compliance, the output voltage (Vo) of a 15-level inverter is compared to the target output voltage (Vref). FLC inputs include the error rate de/dt and the following error, e = Vref - Vo. The FLC consists of five major block sets. The term "fuzzifier" encompasses a wide range of tools, including defuzzifiers, inference systems, rule bases, and databases. Input data is transformed into degrees of membership via fuzzy membership functions. Inverter power circuits' semiconductor switches receive the necessary gating signals from the PWM signals generated by this device. For this signal to appear, Cs is put up against Vef.

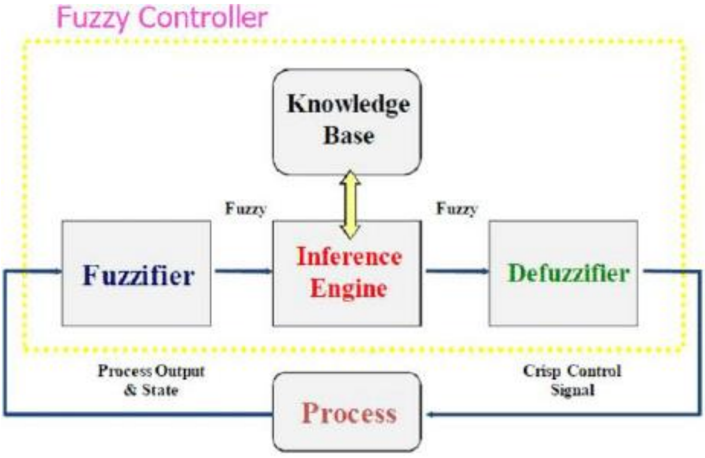

Figure.2 Fuzzy logic controller design and construction

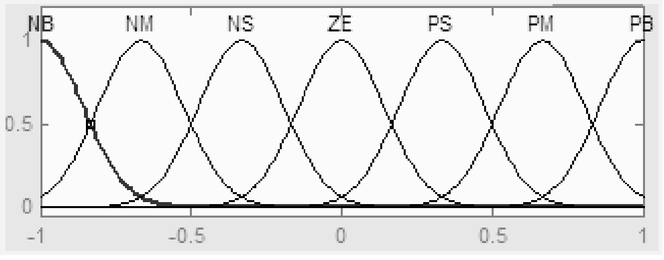

Figure. 3. The error signal's membership function

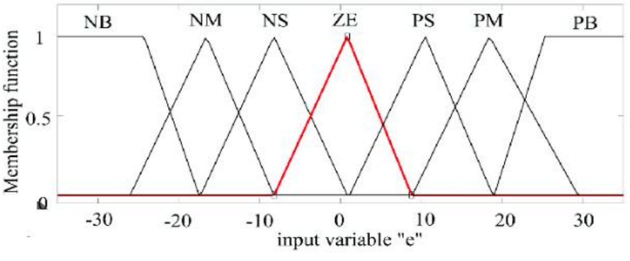

Figure. 4. Variation in error signal MF

Table-3.1 A rule matrix for FLC

K_d		E_c						
		NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
E	**NB**	PS	PS	ZO	NS	NM	PB	PB
	NM	NS	PS	NS	NS	ZO	PB	PB
	NS	NS	NB	NS	NS	ZO	PM	PM
	ZO	NB	NB	NM	NS	ZO	PM	PM
	PS	NB	NB	ZO	NS	ZO	PM	PS
	PM	NM	NS	PS	NS	ZO	PS	PS
	PB	PS	NS	ZO	NM	ZO	PS	PS

The figure 6 depicts the PID controller in use in a variety of feedback systems. PI based controllers demand more attention to controller gains than FLCs because of the complexity of the rules and MF parameterization in FLCs. An error signal from the variable irradiance is taken into account while adjusting the gain of the PI controller. PI controllers produce a reference signal when the input solar PV error signals fluctuate.

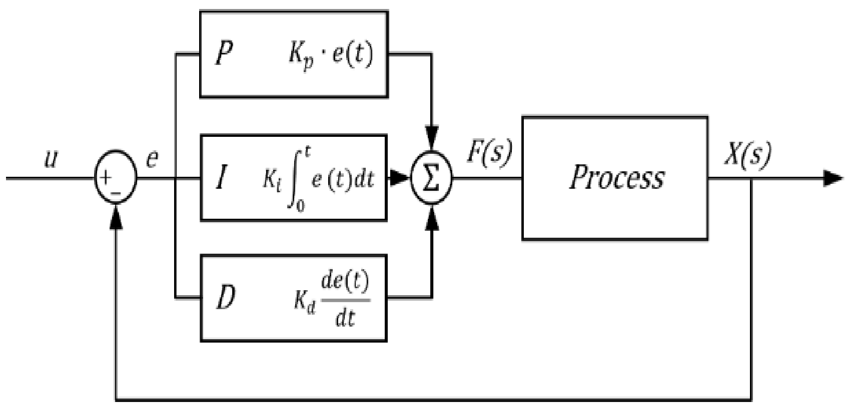

Figure. 6. The PID Controller's architecture

The gain of the PI controller is changed depending on various error signals relating to variations in irradiance. A reference signal is generated by the PI controller for each error signal generated by the solar PV.

Controller based on artificial network

There is no obvious distinction of subtasks assigned to each unit in a neural network, and each unit performs its functions simultaneously. The input-output dataset's voltage regulation is provided by the neural network controller. Verror = Vref – Vactual is a formula used to calculate voltage error. The ANN is trained using these error values. Using the ANN's optimal switching angles, a stable output voltage can be achieved at the inverter circuit's output end. The following steps are required to train an ANN: Input and output data must be provided, and weights must be calculated. The weights must be updated when the input changes. Neural networks that have been trained on a range of samples at various intervals are used to process the error signal.

ANFIS controller

The ANFIS makes use of neural networks and fuzzy logic, as well as lower-level computing abilities. In order to simulate complex and nonlinear systems, ANFIS requires just a few simple input and output parameters. The fuzzy interference system may be fine-tuned with the help of a neural network. In order to build correlations between input and output, ANFIS' hybrid learning technique makes use of both human experience and data on input and output. Analyse non-linear functions and detect non-linear parameters in online control using ANFIS, and use time series models to forecast parameters in time series models the layered structure of the ANFIS, as shown in Figure 10, is typical of the system. Nodes for input, fuzzification and product, normalization and defuzzification are included in this system. Squares indicate adaptive nodes, while circles represent fixed nodes. PG (t 1) and P (t) L are the inputs of ANFIS, and our output target is a reference power for HRES (P) based on PG (t). The new ANFIS approach is able to produce and alter rules quickly because of the use of relative parameters.

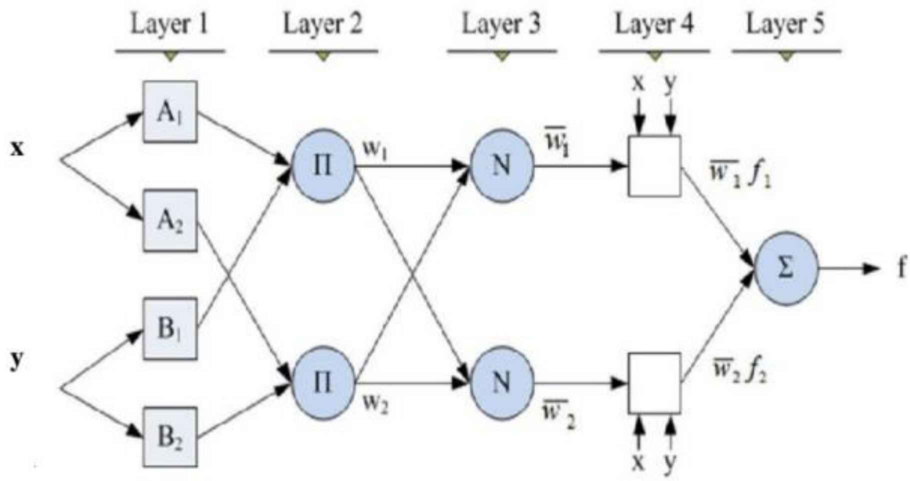

Figure.7. Structure of the ANFIS

The ANFIS layer structure is elegantly shown in Fig.8 and the corresponding depiction is supplied as follows,

Layer 1: Fuzzification is the name given to this layer. Each input variable's degree of membership function diversity is calculated in this layer. The ANFIS input variables are error (e) and error change (e). Reduced error is achieved by using trapezoidal and triangular enrolment capacity, with the following node conditions:

Assuming that the input to the node function is i, f_i and the membership function is μ_{Ai}, thepremise parameter set is as follows:

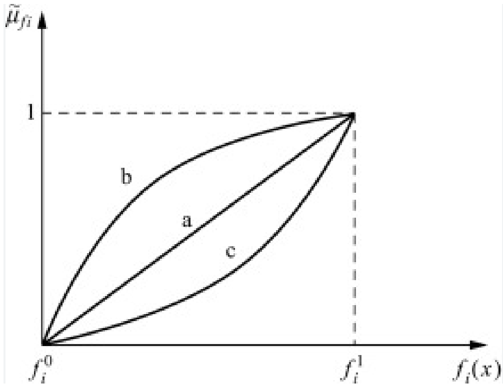

Figure. 8. Fuzzy membership functions.

Layer 2: Rule inference is performed by this layer. Nodes are multiplied and then sent out in this layer because they are all fixed nodes. There are two ways to measure a fuzzy rule's firing strength.

Layer 3: In a way, this is a foundational layer. The letter N is used to identify each circle node in this layer. Firepower is calculated by multiplying the rule's firing power by all other rules.

Layer 4: The following layer is this one. There is an adaptive mode for all nodes, where W_i is the Layer 3 output and (a_0, a_1) is the consequent parameter set.

Layer 5: Currently, the output layer is on top of the current layer stack. There is just one node designated to calculate the overall output from all of the incoming signals in this layer. The back propagation error term is used to update all ANFIS parameters.

The error (e) and the change in error (Δe) multiplied by the coefficients k1 and k2 are input signals.

Where α is a parameter of ANFIS, and η is the rate at which it learns. The next cycle of training will result in a smaller mistake.

4. Mathematical modeling

Solar cell modeling

In fig.1 shows a photovoltaic (PV) cell analog circuit. It is necessary to link two devices in series with the solar cell in order to cure it by observing the equations (1) and (2).

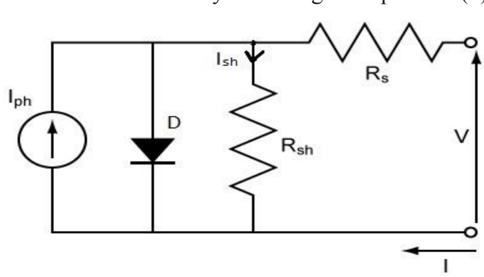

Figure.9 Equivalent circuit of the Solar PV module

From Figure 9: Use KCL to figure out what will happen.

$$I_{ph} = I_d + I_{sh} + I \quad (1)$$
$$I = I_{ph} - (I_{sh} + I_d) \quad (2)$$

Cascaded h-bridge MLI modeling

The cascaded multilevel inverter may produce five levels with eight switches, seven levels with twelve switches, nine levels with sixteen switches, and eleven levels with twenty switches. Thirteen levels with 24 switches, fifteen levels and so on.

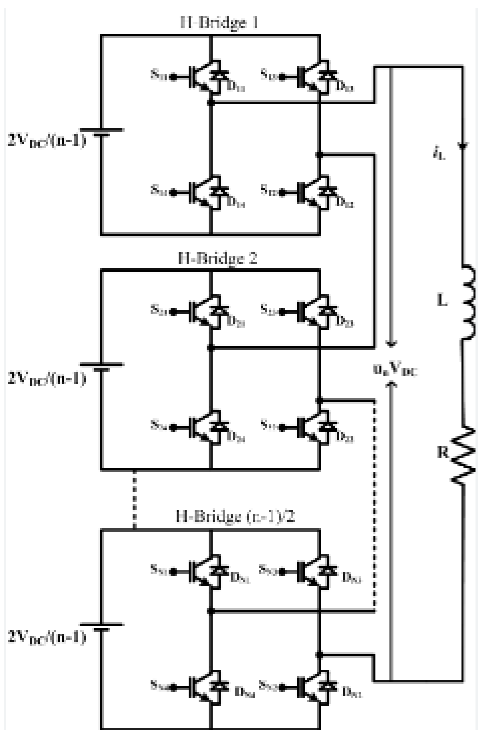

Figure.10: Inverter with n-level cascading

A cascaded H-Bridge n-level inverter is presented schematically in Fig.10 and fig 11. There is a separate dc supply for each phase. An H-Bridge inverter has separate dc sources for each branch. Equation describes the number of output phase voltages.

$$Vout = 2(S) + 1 \quad (3)$$

Where, S is the no of DC sources

Simulation results

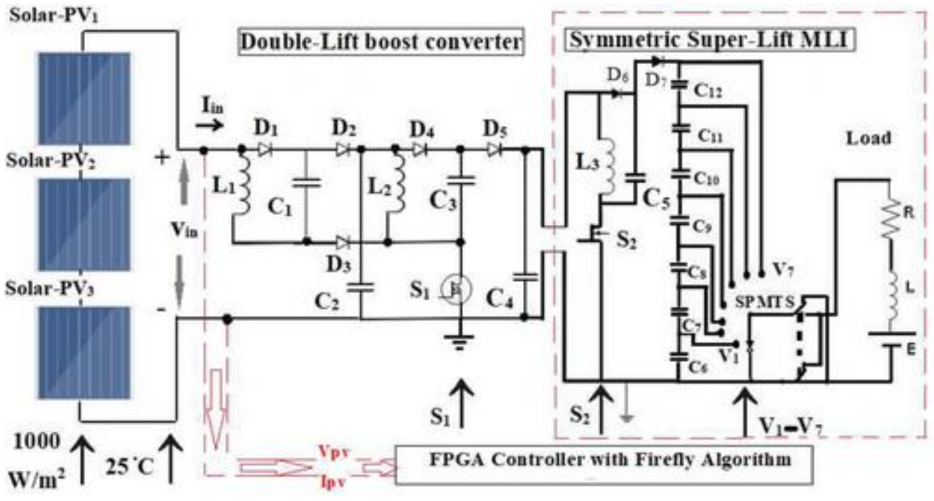

Figure.11 MATLAB circuit diagram of solar fed 15 level-MLI proposed system

Case-1 With PI controller: Output voltage THD% (8.01%)

Case-2 With FLC controller: Output voltage THD% (5.49%)

Case-3 With ANN controller: Output voltage THD% (7.97%)

Case-4 With ANFIS controller: Output voltage THD% (4.17%)

5. Conclusion

The simulation results of a 15-level solar-powered inverter, voltage management and power quality improvement are analyzed in the design of this system. When the input solar PV variance considered, the results of ANFIS provides improved virtual reality (VR). The ANFIS Controller improves the output voltage and THD valus as compared to PI, FLC and ANN. The proposed system's effectiveness has been tested experimentally and is found to be effective in the commercial use of MLI by providing a steady output voltage.

References

1. Renewable energy methods for rural Africa: Is PV-led renewable energy strategy the ideal approach for providing modern energy to the rural poor of subsaharan Africa?" Energy Policy, vol. 30, pg. 1071-1086, September 2019.
2. NEPAD Energy Initiative Workshop for African Energy Experts on Operationalizing NEPAD Energy Initiative, pp. 1-30, 2-4 June 2003. This initiative is a joint effort of the United Nations and the Republic of Senegal, based in Dakar. Unsustainable Development: Neap Darkes (PDF) (Accessed June 18, 2018, from https://sustainabledevelopment.un.org)
3. T. Digby-Racine, "Renewable decentralized in developing countries: assessment from microgrids project in Senegal," S. Direct, Ed., Renewable Energy, vol. 35, no. 8, pp. 1615-1623, August 2018.

4. World Energy Scenarios: Composing Energy Futures to 2050, World Energy Council, London, United Kingdom: World Energy Council, 2017.
5. Distant future of the Sun and Earth, K. P Schröder and R. C. Smith, Revisited (386(1)), 2008 (Monthly Notices of the Royal Astronomical Society, doi:10.1111/j.1365- 2966.2008.013022 x).
6. Hope dims that Earth will survive the end of the Sun, according to J. Palmer in New Scientist in 2018.
7. For a Sahel country such as Mali, renewable energy options are discussed in detail in an article by the following authors: Volume 12, Number 2, Pages 564-574, February 2017, Renewable and Sustainable Energy Reviews.
8. “Enhanced local grid voltage support approach for high penetration of distributed generators”, Proceedings of the 37th annual IEEE Industrial Electronics Society Conference (IECON'11), pp. 2481-2485, IEEE (2017), Melbourne.
9. Srikanth Sattenapalli and 2V. Joshi Manohar, ‘Performance Analysis of Reference Current Generation Methods with PI Controller for Single-Phase Grid Connected PV Inverter System’,Journal of Green Engineering, Volume-9, issue 4, 2019.
10. Lakshmi Devi, V., Joshi Manohar, V. ‘A genetic algorithm basrd problem detection for unit commitment (UC) problems’ *International Journal of Recent Technology and Engineering*, 2019, 8(2 Special Issue 3), pp. 91–96