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Hybrid System for Sustainable Grid Voltage in Low Power Application

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Abstract: The static pollution-free Photovoltaic (PV) Cells are considered as one of the most important and promising type of renewable energy systems. Photovoltaic power generation is however possible only on a sunny day, and there is complete absence of power on a cloudy day .The suggested solution to this problem is a hybrid system. Hybrid systems such as Solar-Wind, Solar-Wind-Fuel Cell Hybrid systems etc are defined as energy systems combining two or more complementary power generation devices where the best features of each source is captured. A Novel Stand-Alone Photovoltaic –Synchronous Generator Hybrid system is proposed here, in which the Maximum Power Point of the PV generator is tracked, and is used to control the AVR of the Synchronous Generator .This AVR is now used to control the Voltage of the common coupling point of the Synchronous Generator and the PV Generator Thus the voltage of the PCC will be the voltage corresponding to the MPP. A Power control unit is incorporated to control the driving torque of the synchronous generator once the PV generator becomes unable to meet the requirements of the motor because of reduction of the solar irradiance and/or increase of the load.

Keywords: Photovoltaic Cell, Maximum power point tracking (MPPT), Automatic voltage regulator (AVR), Synchronous generator.

I. INTRODUCTION

Nowadays, the exploitation of different sources of renewable energy, like the sun and the wind, is harnessed to generate the power, which is very crucial for the human life, and its demand is greatly increased. In fact, it can be used to reduce the need of electricity and to decrease the pollution effects.The static pollution-free photovoltaic (PV) cells are considered as one of the most important types of renewable energy systems [1]. By incorporating the grid with PV generators via different interfacing stages is possible, can enhance the total power production and reduce the dependency on the conventional fossil fuels.Hybrid systems are defined as energy systems combining two or more complementary power generation devices where the best features of each source is captured [2]. They are normally used to power lumped or distributed rural (off-grid) loads. Hybrid electrical energy sources have been proposed and implemented in different topologies with various controllers and interfacing stages [3].If the hybrid power system has different voltages, then DC–DC converters are used to match the load rated voltage. DC–AC inverter is used at the terminals of the PV array for AC loads or to connect the hybrid energy source with grid at nominal frequency.In the proposed system, a stand-alone hybrid-powered power system is introduced and a three phase induction motor is connected as a load [4]. The hybrid energy system comprises conventionally powered synchronous and PV generators. The main idea behind equipping the conventionally powered synchronous generator is the insurance of the system reliability [5]. The PV array is integrated to the synchronous generator via DC–DC converter, three-phase DC–AC inverter and Inductor-Capacitor (LC) filter [6]. If the output power of the PV generator becomes lower than the power demanded by the motor because of reduction in the solar irradiance level and/or increase in the motor load, the synchronous generator compensates these requirements [7]. The main contribution of this paper is the configuration of the proposed system which combines a hybrid energy source represented by synchronous and PV generators.The proposed system can provide power to small community, or are sometimes connected to electric power networks. There are many of these installations around the world, particularly in developing nations as they can provide an economical source of energy without the purchase of fuel.

II. PROPOSED SYSTEM

In the proposed system, a stand-alone hybrid-powered power system is introduced and a three phase induction motor is connected as a load. Fig. 1 shows the configuration of the proposed system. It is a three-phase induction motor hybrid powered by conventionally driven synchronous and PV generators. The output of the PV generator is integrated to the terminals of the synchronous generator via DC–DC buck-boost switch mode converter, three-phase DC–AC switch mode sinusoidal pulse width modulation (PWM) inverter and LC filter.

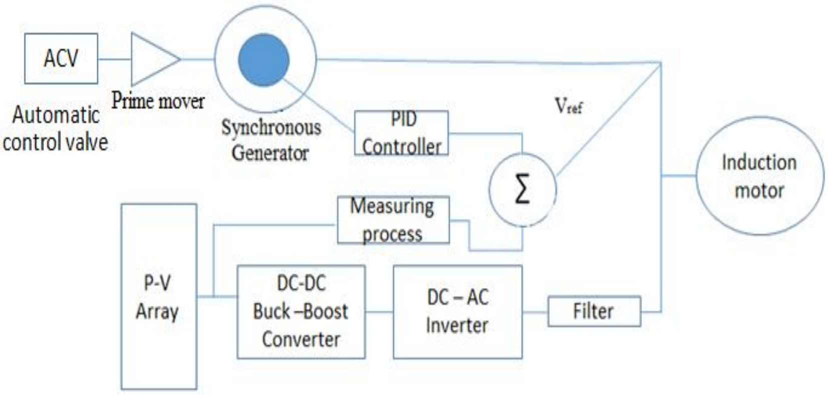

Fig 1: Proposed system

III.PV PANEL

The PV array consists of several solar modules. Basically, modules are connected in series to increase the voltage capability of the array. To increase the current capability of the array, additional modules are connected in parallel. The output voltage of the array is highly non-linear with respect to the current. The general mathematical description of I-V output characteristics for a PV cell has been shown below.

The voltage-current characteristic equation of a solar cell is given as,

$$I = I_{ph} - I_S[\exp(\frac{q(V+IR_s)}{KT_cA})-1] - \frac{(V+IR_s)}{R_{sh}} \quad (1)$$

Where I_{ph} is a light-generated current or photocurrent, I_s is the cell saturation of dark current, q (= 1.6 ×10−19 C) is an electron charge, k (= 1.38 ×10−23 J/K) is a Boltzmann's constant, T_c is the cell's working temperature, A is an ideal factor, R_{sh} is a shunt resistance, and R_s is a series resistance. The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as,

$$I_{ph} = [I_{sc} + K_1(T_c - T_{Ref})]H \quad (2)$$

Where I_{sc} is the cell's short-circuit current, K_1 is the cell's short-circuit current temperature coefficient, T_{Ref} is the cell's reference temperature, and H is the solar insolation in kW/m^2. On the other hand, the cell's saturation current varies with the cell temperature, which is described as,

$$I_S = I_{RS}(\frac{T_c}{T_{Ref}})^3 \exp(\frac{qE_G(T_c - T_{Ref})}{T_{Ref}T_cKA}) \quad (3)$$

Where I_{RS} is the cell's reverse saturation current at a reference temperature and a solar radiation E_G is the bang-gap energy of the semiconductor used in the cell. The ideal factor A is dependent on PV technology.

MATLAB model of PV array is shown in fig 2. Fig 3 and 4 shows the output of PV array at varying irradiance condition.

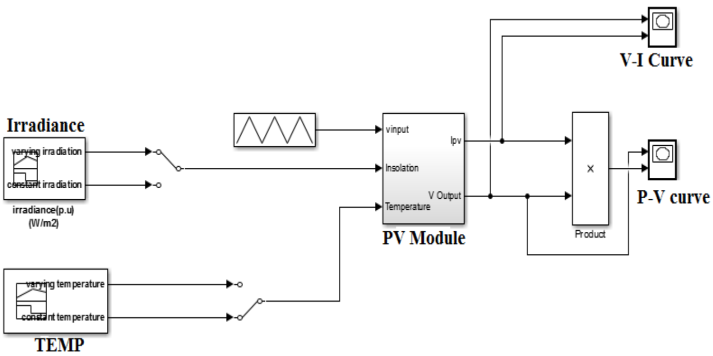

Fig 2: Modelling of PV array

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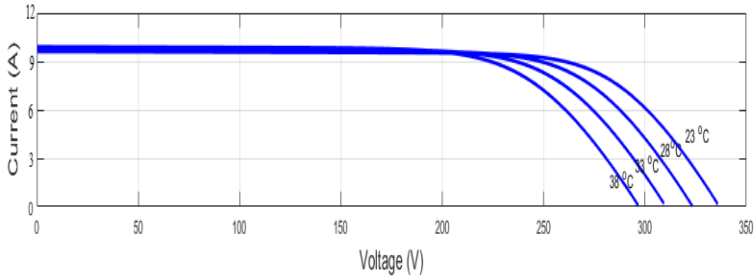

Fig 3: V-I Characteristics of PV panel.

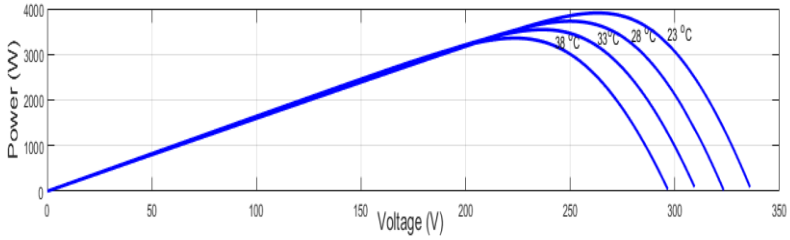

Fig 4: P-V Characteristics of PV panel

IV. INDUCTION MOTOR

Mathematical modelling equations of induction motor is given below, Stator and rotor voltage equations are,

$$V_{ds} = R_s i_{ds} + \frac{1}{\omega_b}\frac{d}{dt}F_{ds} - \frac{\omega_e}{\omega_b}F_{qs} \quad (4)$$

$$V_{qs} = R_s i_{qs} + \frac{1}{\omega_b}\frac{d}{dt}F_{qs} + \frac{\omega_e}{\omega_b}F_{ds} \quad (5)$$

$$V_{dr} = R_r i_{dr} + \frac{1}{\omega_b}\frac{d}{dt}F_{qr} + \frac{(\omega_e - \omega_r)}{\omega_r}F_{dr} \quad (6)$$

$$V_{qr} = R_r i_{qr} + \frac{1}{\omega_b}\frac{d}{dt}F_{dr} - \frac{(\omega_e - \omega_r)}{\omega_r}F_{qr} \quad (7)$$

Where V_{ds}, V_{qs}, V_{dr} and V_{qr} are the stator and rotor d axis voltages and q axis voltages respectively. R_s and R_r are stator and rotor resistance respectively. ω_e is the angular speed and ω_r is the rotor speed. i_{ds}, i_{qs}, i_{dr}, and i_{qr} are the stator and rotor d axis currents and q axis currents respectively. F_{ds}, F_{qs}, F_{dr} and F_{qr} are the flux linkages.

Flux linkage expressions are,

$$\frac{d}{dt}F_{qs} = \omega_b[V_{qs} - \frac{\omega_e}{\omega_r}F_{ds} + \frac{R_s}{X_{ls}}(F_{mq} - F_{qr})] \quad (8)$$

$$\frac{d}{dt}F_{ds} = \omega_b[V_{ds} - \frac{\omega_e}{\omega_r}F_{ds} + \frac{R_s}{X_{ls}}(F_{md} - F_{ds})] \quad (9)$$

$$\frac{d}{dt}F_{dr} = \omega_b[V_{qr} - \frac{\omega_e - \omega_r}{\omega_r}F_{dr} + \frac{R_r}{X_{lr}}(F_{mq} - F_{qr})] \quad (10)$$

$$\frac{d}{dt}F_{dr} = \omega_b[V_{dr} - \frac{\omega_e - \omega_r}{\omega_r}F_{qr} + \frac{R_r}{X_{lr}}(F_{md} - F_{dr})] \quad (11)$$

Where F_{md} and F_{mq} are the mutual flux linkages of d axis and q axis respectively.

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Torque equation,

$$T_e = \frac{3}{2}\frac{P}{2}\frac{1}{\omega_b}(F_{ds}i_{qs} - F_{qs}i_{ds}) \tag{12}$$

MATLAB model of induction motor is shown in fig 5.

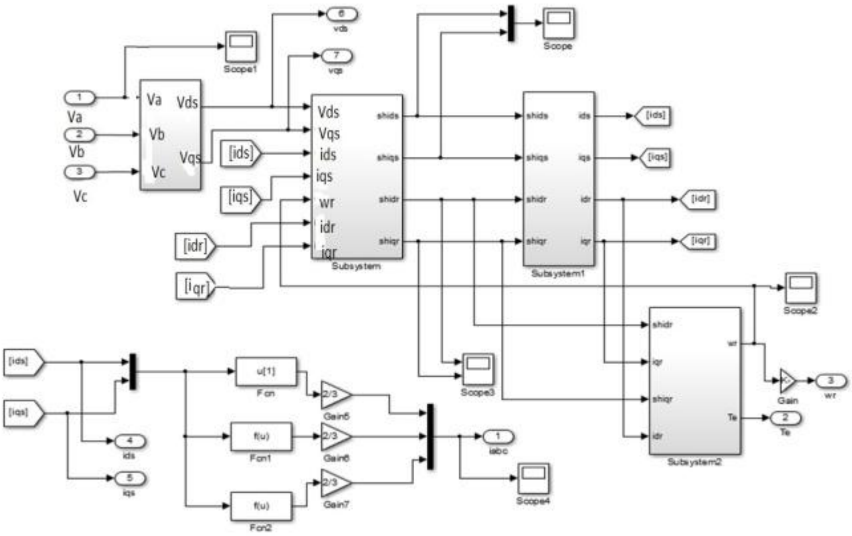

Fig 5: MATLAB model of induction motor

V. RESULT AND DISCUSSION

Based on the complete non-linear dynamical mathematical model, numerical simulations have been conducted after successive step changes on the load coupled to the induction motor at two solar irradiance levels. System response after successive step changes on the level of solar intensity has also been observed for given mechanical load coupled to the motor.

A. *Case I*

Study of system response after successive step changes on the mechanical load coupled to the motor at 80% full solar irradiance.

Fig. 6-11 shows the response of the system after step change on the mechanical load coupled to the motor from 4.2 to 3.25 Nm followed by step increase to 3.8 Nm when the PV array is 80% intensified. As far as the solar intensity level has not changed during the simulations, the voltage of the common coupling point which is the terminal voltage of the motor remains unchanged. Actually, it is equal to the value corresponding to the MPP of the PV generator at this solar intensity level. As the mechanical load coupled to the motor decreases, the power demand of the motor decreases, the driving torque of the synchronous generator decreases accordingly which comes as a result of the constant power developed by the PV generator. The corresponding current output from the synchronous generator decreases as a consequence and the rotational speed of the motor increases. Vice versa behavior is detected during the last part of the simulations when the load coupled to the motor jumps from 3.25 to 3.8 Nm. At the very beginning when the motor drives the full load of 4.2 Nm, it consumes an active power of about 971 W, a reactive power of about 903 VAR. At these operating conditions, the PV generator delivers an active power of about 852 W, a reactive power of about 594 VAR and the synchronous generator delivers relatively small amount of active power of about 119 W and a reactive power of about 309 VAR. In all cases, the total power delivered by the two generators is consumed by the motor. Generally, the proposed stand-alone hybrid-powered power system has successfully withstood the wide range of step changes in the mechanical load coupled to the motor with relatively small power contribution from the conventionally powered synchronous generator at a net apparent power output from the PV generator equal to the MPP at this solar irradiance level.

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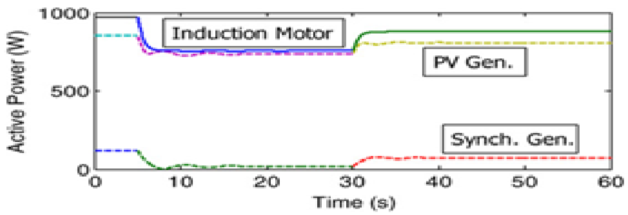

Fig 6: Active power at 80% full solar irradiance

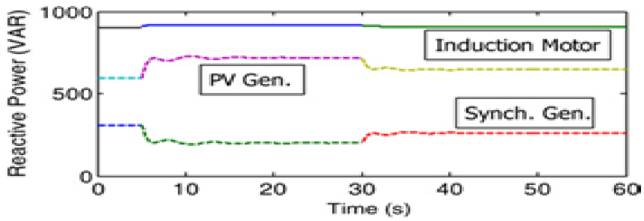

Fig 7: Reactive power at 80% full solar irradiance

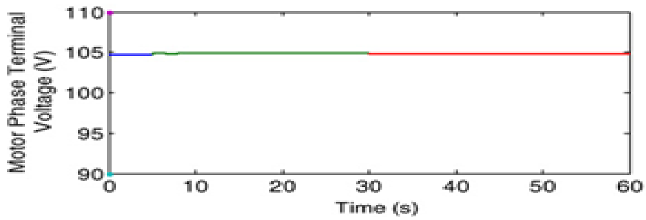

Fig 8: Motor terminal voltage at 80% full solar irradiance

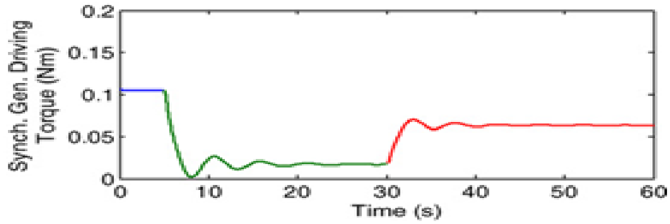

Fig 9: Synchronous generator driving torque at 80% full solar irradiance

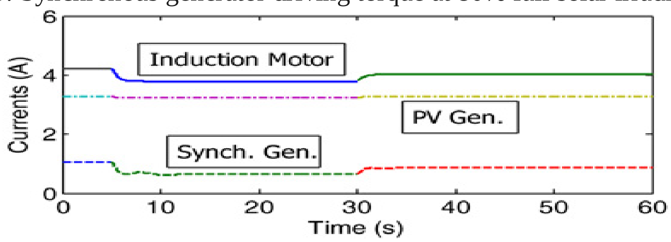

Fig 10: Currents at 80% full solar irradiance

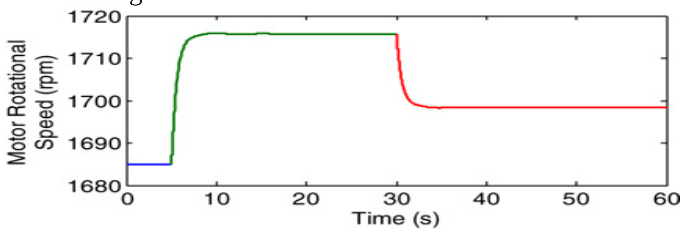

Fig 11: Motor rotational speed at 80% full solar irradiance

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B. *Case II*

Study of system response after successive step changes on the mechanical load coupled to the motor at 50% full solar irradiance.

The simulations at 50% of full solar intensity after step change on the load coupled to the motor from 4.2 to 1.2 Nm followed by step increase to 3 Nm are presented in Fig. 12-17, Again, the running voltage of the system, which is the PV generator voltage corresponding to the MPP, has not changed during the simulations which comes as a consequence of the fixed solar intensity level and therefore fixed AVR reference voltage. As the load coupled to the motor increases, its rotational speed decreases and vice versa. With constant solar intensity level and variable loading conditions, the driving torque of the synchronous generator varies according to the demand of the motor, that is, as the load increases, the output power from the synchronous generator increases and vice versa. The current output from the PV generator has not changed which is justified by the fact that the operating voltage of the PV array remains constant. Similar general conclusions can be withdrawn at this solar intensity which indicates the robustness of the integration between system components at wide range of loading conditions.

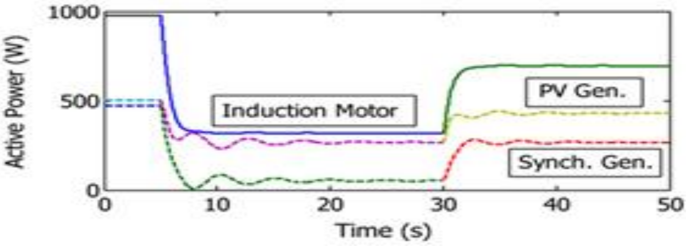

Fig 12: Active power at 50% full solar irradiance

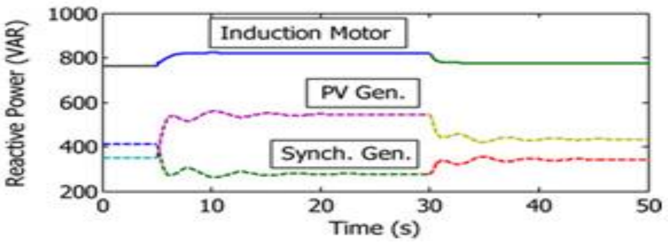

Fig 13: Reactive power at 50% full solar irradiance

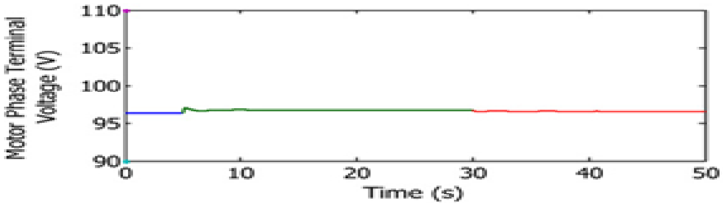

Fig 14: Motor terminal voltage at 50% full solar irradiance

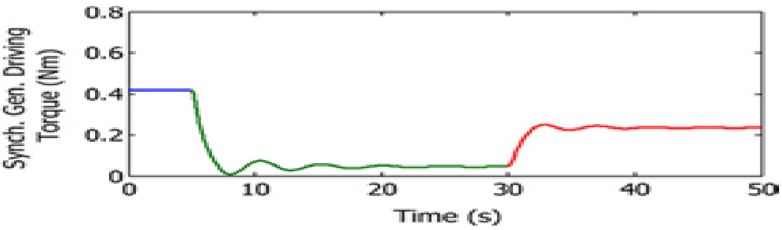

Fig 15: Synchronous generator driving torque at 50% full solar irradiance

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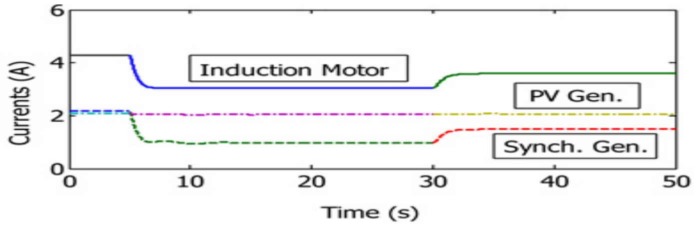

Fig 16: Currents at 50% full solar irradiance

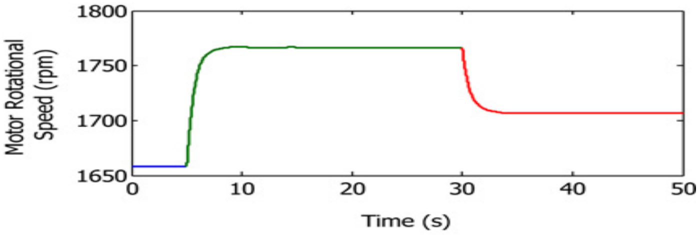

Fig 17: Motor rotational speed at 50% full solar irradiance

VI. CONCLUSION

The proposed Hybrid System along with the 3 Phase Induction Machine Load is modelled in the dq-stationary reference frame and operational characteristics have been obtained using MATLAB/SIMULINK. The analysis includes the response of the system after step changes in the load coupled to the motor and after step changes in the levels of the solar irradiance. The characteristics of the induction motor in case of hybridization at various solar intensities are presented and compared with the case when the motor is powered by fixed terminal voltage. It is concluded that the proposed system can run at wide range of operating conditions and robust enough to withstand system parameters step changes.

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