PERFORMANCE ANALYSIS OF A SINGLE PHASE SELF-EXCITED INDUCTION GENERATOR DRIVEN BY PHOTOVOLTAIC (PV) SYSTEM FOR LOW POWER ISOLATED STAND-ALONE APPLICATIONS

MOHAMMAD JAVAD OKHRAWI

Department of Electrical Engineering, Faculty of Engineering
Azarbaijan University of Tarbiat Moallem, Tabriz, Iran
mjokhrawi@yahoo.com

ABSTRACT
This paper presents performance analysis of a single-phase self-excited induction generator driven by photovoltaic (PV) system with maximum power point tracking (MPPT) system for low power isolated stand-alone applications. A single-phase self-excited induction machine can work as a self-excited induction generator (SEIG) when its rotor is driven at a suitable speed by a photovoltaic powered dc motor. Its excitation is provided by connecting a single-phase capacitor bank at stator terminals. Either to augment grid power or to get uninterrupted power during grid failure stand alone low capacity ac generators is used. These are driven by hybrid PV- battery system. Self-excitation with capacitor at the stator terminals of the induction machine is well demonstrated experimentally on a PV powered dc motor-induction machine set. The parameters and the excitation requirements of the induction machine run in self-excited induction generator mode are determined. The operating modes of (MPPT) system, terminal capacitance and load power factor (P.F.) on the machine terminal voltage are studied.

INTRODUCTION
Owing to increased emphasis on renewable resources, the development of suitable isolated power generators driven by energy sources such as photovoltaic, wind, small hydroelectric, biogas and diesel has recently assumed greater significance. A single-phase self-excited induction generator has emerged as a suitable candidate of isolated power sources. Over the years, different types of generator have been developed and their performance analyzed. However in almost all such cases the machine used is of synchronous type. They are normally used for low power rating and have brushes and slip rings in the rotor. They are less reliable due to need for continuous maintenance and susceptibility to failure. An electronic voltage regulator is required to alter the field current to obtain the required terminal voltage at varying loads and finally they lack an enclosing frame. The reliability of the system depends upon the reliability of the components used therein. All theses negative points can be eliminated by using single-phase capacitor self-excited induction generator. Single-phase self-excited induction generator has been found to be an alternative proposition in view of certain inherent advantages over synchronous machines such as ruggedness, brushless rotor, absence of a separate dc source, less maintenance, decreased unit cost, compact and built in totally enclosed fan cooled frames. System is self-regulating for constancy of terminal voltage and dose not requires an electronic voltage regulator. In addition to these technical advantages, the new system is cheaper due to smaller size, reduced materials and ease of manufacture. Photovoltaic generator convert solar energy to dc electrical power, which may be used directly by some loads where energy is stored in storage units such as batteries, capacitors [1] and superconducting magnets [2] or converted to ac power using dc-ac inverter [3]. The

simplest way in order to avoid additional costs such as inverter unit and storage unit is to convert PV power to mechanical as to drive a dc motor [4].

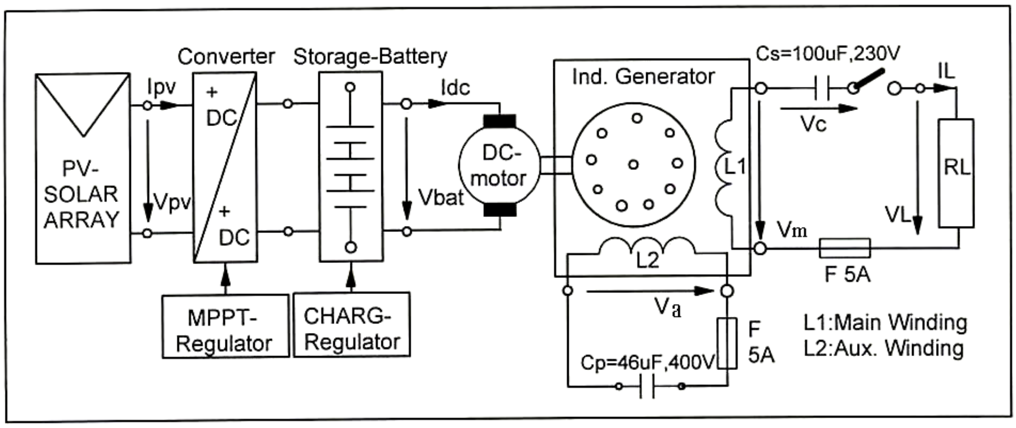


Fig.1: System Configuration

SYSTEM CONFIGURATION

The system considered here consists of the following subsystems (Fig. 1):

- PV Generator
- Voltage regulator and control unit for maximum power point tracking
- Storage batteries
- DC motor
- Single-phase self-excited induction generator

Each system has its own operating characteristics, which is the volt-ampere characteristics for the PV generator and the dc motor, and torque-speed characteristics for the induction generator. The dc motor drives the induction generator whose torque requirements depend on its electrical load, exciting capacitor and speed. The dc motor is supplied from the storage batteries whose state of charge (SOC) depend on the solar radiation variations of the PV generator and on the current drawn by the dc motor [5]. There is a unique point on the volt-ampere characteristics at which power output from the PV generator is maximum and for optimum utilization, the equilibrium operating point coincide with this point (Fig.2). However, this can be obtained using maximum power point tracker (MPPT) system.

I. SINGLE-PHASE SELF-EXCITED INDUCTION GENERATOR

The system consists of an induction generator and a combination of capacitors connected to its terminals. A fixed capacitor is connected in parallel with one stator winding, termed as excitation winding and another fixed capacitor is connected in series with the second stator winding termed as load winding. The auxiliary winding is used as the exiting winding while the main winding is used for the loading purpose. This it may be noted, has been done with a view to extracting more power from the given machine as the volt-ampere rating of the main winding is larger than that of the auxiliary winding.

When the squirrel cage rotor of the generator is spinned at constant speed by the dc motor prime mover, a small voltage is induced in the excitation winding due to the residual flux. Due to capacitor self-excitation phenomena, the resultant flux in the air gap is increased, which increases the voltage induced in the winding. This cumulative process continuous till the voltage across the capacitor matches the induce voltage due to magnetic saturation is reached so that no further rise in voltage or current is possible. The steady ac current flowing in the winding establishes an air gap flux pulsating in time, due to which an induction of voltage takes place in the load winding via the rotating rotor. A current flows in the load winding when an external electric load is connected. As the loading is increased, load current increases and the terminal voltage decreases. The series capacitor connected with the load winding counters voltage reduction so that the variation in terminal voltage from no load to full load is with in acceptable limits at different operation power factors.

II. PV GENERATOR

A PV generator consists of an array of PV modules connected in series parallel combinations to provide the desired dc voltage and current. The overall volt-ampere characteristics of the array depend on the number of cells in series and number of parallel strings. For a typical PV generator consists of 18 parallel strings, 324 cells in series per string, such that the overall volt-ampere characteristics are given by [6].

$$V_{PV} = 23.68 Ln\left(111.11(I_{PH} - I_{PV}) + 1\right) - 0.9 I_{PV} \qquad (1)$$

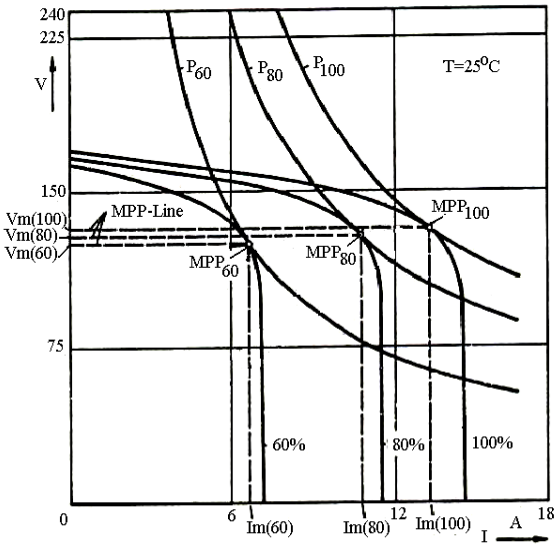


Fig.2: I-V Characteristics of PV Modules

V_{PV} and I_{PV} are the terminal voltage and current. The photo-current I_{PH} is directly proportional to radiation, I_{PH}=14.4 A at 100% radiation. Figure 2 is a plot of (1) for various radiation levels. Utilization efficiency of the PV generator, the operating point must follow this locus as the radiation varies: For loads having their own volt-ampere characteristics follow different locus with that the maximum power locus, matching is necessary to have these two locus as close as possible. This could be done using peak power trackers, which will increase the cost of the overall system. It is also notable that operating line approaches the maximum power line as the radiation increases.

III. CONTROL UNIT FOR MAXIMUM POWER POINT TRACKING (MPPT)

As well as seen from fig.2, the operating point of photovoltaic cells depends intensively to environmental factors, i.e. radiation and temperature. Therefore, with smallest variation in these factors the operating point of PV modules is changing from MPP. After variation in the environmental conditions, input resistance of system must be regulated in such way that PV modules work in a new operating point. This regulation is applied by MPPT circuit. The MPPT circuit consists of two basic parts: 1) DC to DC converter 2) Control system.

A buck chopper is used in the DC to DC converter. In this converter always, the output is lower than input voltage. Fig.3 shows the function of this converter. When transistor T1 is on, the input energy transfers to load (storage batteries), and some of it is stored in inductor L and capacitor C2.

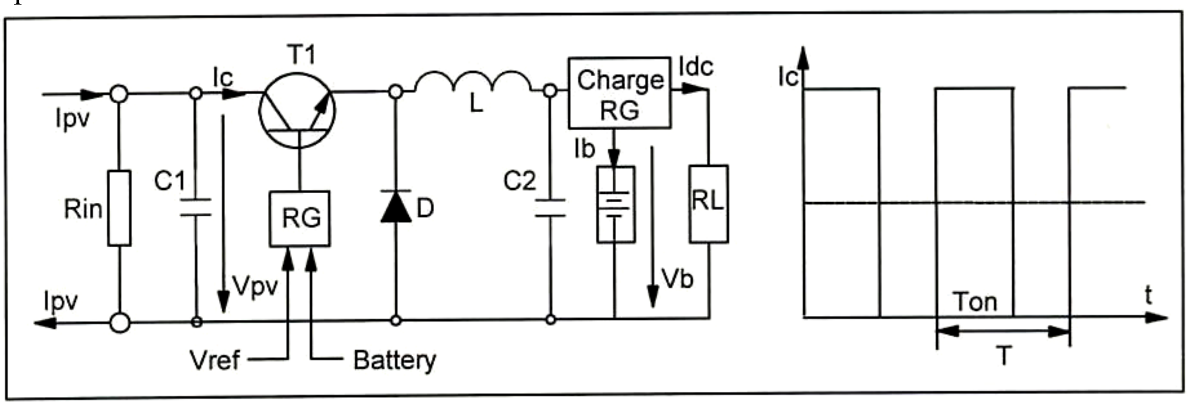


Fig. 3: DC to DC Converter

During the cut off time of transistor T1, the stored energy in inductor L is returned and transferred to load by diode D. Also at this time, the capacitor C2 operates as an output voltage regulator. When all of the energy in the inductor L is returned to load, diode D is turned off and capacitor voltage is discharged. Therefore, after this time the output voltage is reduced. Finally, transistor T1 turns on and the above cycle is repeated. Therefore, this converter is suitable for charging of energy storages batteries. $(\frac{V_o}{V_{in}} = \frac{T_{on}}{T} \leq 1)$.

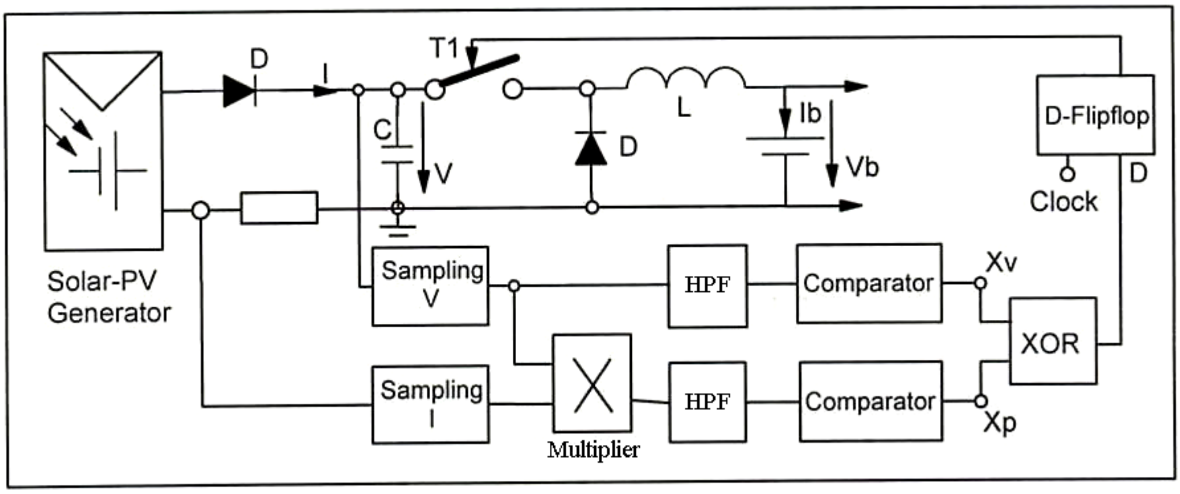


Fig.4: Control system for MPPT

In this paper the control system is used for turn on and off of transistor T1 (switch) in this circuit the voltage and current of reference module is measured and sampled and finally the pulses of switch (T1) is generated as shown in Fig.4. The power of modules is calculated by multiplying the measured voltage and current. In this paper for calculation, the oscillation parts of modules power is used a high pass filter. The out put signal of this filter is applied to a comparator in order to generating binary signal Xp as below:

If $\frac{dp}{dt} < 0$ then $X_P=0$ If $\frac{dp}{dt} > 0$ then $X_P=1$

Like above procedure, the voltage variation of modules is applied to another comparator and finally binary signal X_V is obtained as below:

If $\frac{dV}{dt} < 0$ then $X_V=0$ If $\frac{dV}{dt} > 0$ then $X_V=1$

The X_P and X_V signals through a XOR logic gate are applied to a latch (D-flip flop) for generating the pulses of switch (T1).Table 1 shows the operating modes of MPPT control system.

Table 1: Operating modes of MPPT control system

Condition	dp/dt	dv/dt	X_P	X_V	S	Switch	V
$v<=V^*$	> 0	> 0	1	1	0	Opens	Increases
$v<=V^*$	<= 0	<= 0	0	0	0	Opens	Increases
$v>V^*$	> 0	<= 0	1	0	1	Closes	Decreases
$v>V^*$	<= 0	> 0	0	1	1	Closes	Decreases

IV. PERFORMANCE OF THE SEIG ON LOAD WITH PV DRIVEN DC MOTOR

Following test were performed on 0.75 kW, 230 V, 2 pole, 50 Hz, 6.0 A, single phase self-excited induction generator [7][8], when single-phase self-excited induction generator coupled with photovoltaic powered dc motor.

- Performance on resistive load with C_{shunt}=46µF

The single phase self-excited induction generator was driven with the help of PV power driven dc motor, and an external resistive load connected to its main winding. Different experiments carried out to achieve the best voltage regulation from no load to full load. A shunt capacitor was connected in parallel with the auxiliary winding to ensure the self-excitation. The test results testify the fact that the induction machine works satisfactory in the generating mode. However, it is found that the terminal voltage reduced from 260 V on no load to 200 V on full load.

- Performance on resistive load with C_{shunt}=46µF and C_{series}=100µF

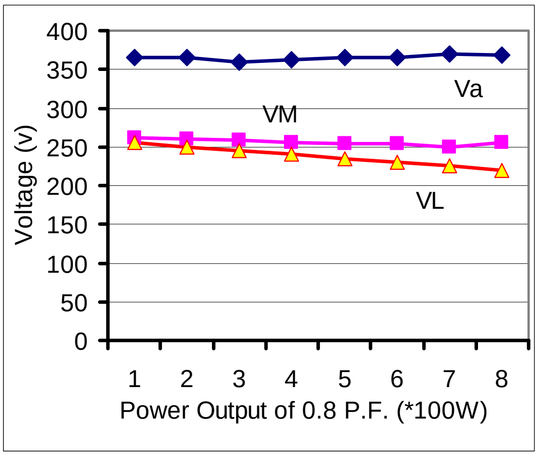
By obtaining the load characteristics of single-phase self-excited induction generator without series capacitor in the circuit, the voltage regulation in this case was found to be 25% as voltage was varying over the range of 262 V to 200 V. When a capacitor of 100µF was connected in series with the main winding and the load, this results the improvement of the voltage regulation from 25% to 20%.

- Performance with inductive load of 0.8 P.F.

This time the resistive load was replaced by an inductive load of 0.8 P.F. . A small change in voltage regulation was observed from 20% to 22% with 0.8 P.F. load.

- Effect of auto-transformer

By adding an auto-transformer in the circuit, the voltage the voltage regulation gets improved from 22% to 10% as shown in fig. 5. Therefore in the course of these tests, one comes across an interesting finding i.e when an auto-transformer is added to the circuit the best voltage regulation from no load to full load is achieved.



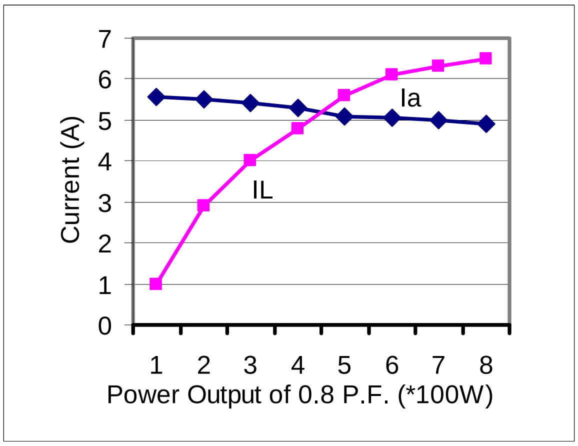


Fig.5: Single-Phase SEIG Load Characteristic (Current and Voltage)

V. CONCLUSIONS

The main objective of this investigation was to examine the possibility of using a self-excited induction generator driven by a PV powered dc motor. The result of the investigation reported confirmed the fact that normally designed single-phase squirrel cage induction motor can be used as a self-excited induction generator for supplying the load demand and it is found to be a perfect match for the PV powered dc motor. The load characteristics of single-phase self-excited induction generator for isolated and stand alone application based on capacitor self-excitation phenomena is presented here. Experiments are conducted on a PV powered dc motor induction generator set to determine the parameters and the requirements of the induction machine in self-excited mode. Due to their simplicity, ruggedness and low cost of construction, squirrel cage induction machines offer a relatively inexpensive alternative to ac generation using renewable energy systems in stand alone mode in parallel with battery storage system or in parallel with other conventional sources like diesel in an hybrid PV or wind-diesel isolated power system.

VI. REFERENCES

[1] *A. Abete, F.Spertino, R. Tommasini.* "Optimum management of hybrid Photovoltaic System", World Renewable Energy Congress VI (2000).
[2] *S.C. Tripathy, M. Kalantar.* "Dynamic and stability of wind and diesel turbine generators With superconducting magnetic energy storage unit on an isolated power system", IEEE Trans. on Energy Conversion, vol. 6, no. 4, December 1991, pp. 579-585.
[3] *S.Olud Amrouche, M. Belhamel, A. Malek, A.Maafi,* "DC/AC Solar Inverter for Solar Applications", World Renewable Energy Congress VI (2000).
[4] *M.Kalantar. J. Jiang.* "Power generation using photovoltaic induction generator in an isolated power network" 16th International power system conference (2001).
[5]*Hans kurt Koethe.* " Stromversogung mit Solarzellen" 2. Aufl.- Muenchen : franzis, 1991.
[6] *S. M. Alghuwainem* ." Performance analysis of a PV powered dc motor driving a 3-phase Self-excited induction generator, "IEEE Trans. Energy Conversion, vol. 11, no. 1, 1996, pp.155-161
[7] *Y. Koyakumaru.* "An analysis of load characteristics of SEIG," Journal of electrical Engineering in Japan, vol. 94, No. 2, 1974.
[8] *P.L.Alger.* Induction Machines, Volume I. New York: Garden and Breach Science Publisher, 1995.

FOTOELEKTRİK MƏNBƏDƏN QİDALANAN, AZ GÜCƏ MALİK AVTONOM SİSTEM KİMİ TƏTBİQ OLUNAN, SABİT CƏRƏYAN MÜHƏRRİKLİ BİRFAZLI İNDUKSİON ÖZÜHƏYACANLANAN GENERATORUN XARAKTERİSTİKALARININ ARAŞDIRILMASI

OXRAVİ M.C.

Məqalədə fotoelektrik mənbədən qidalanan sabit cərəyan mühərriki ilə hərəkətə gələn özühəyacanlanan birfazlı induksion generatorun xarakteristikaları araşdırılmışdır. Maşının nominal çıxış gərginliyində, iş rejimi, çıxıh tutum və çıxış gücü tədqiq edilmişdir.

АНАЛИЗ ХАРАКТЕРИСТИК САМОВОЗБУЖДАЮЩЕГОСЯ ОДНОФАЗНОГО ИНДУКЦИОННОГО ГЕНЕРАТОРА С ПРИВОДОМ ОТ ДВИГАТЕЛЯ ПОСТОЯННОГО ТОКА, ПИТАЮЩЕГОСЯ ОТ ФОТОЭЛЕКТРИЧЕСКОГО ИСТОЧНИКА ДЛЯ ПРИМЕНЕНИЯ В КАЧЕСТВЕ МАЛОМОЩНОЙ АВТОНОМНОЙ СИСТЕМЫ

ОХРАВИ М.Дж.

В статье представлен анализ характеристик однофазного индукционного генератора с самовозбуждением, приводимого в движение двигателем постоянного тока с питанием от фотоэлектрического источника. Определены параметры и условия возбуждения индукционной машины, работающей в режиме генератора. Изучены режимы работы, выходная емкость и выходная мощность при номинальном выходном напряжении машины.