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Cost Reduction of Hybrid System Using Current Loop Control for Inverter and Wind Variation Control

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Abstract-**The hybrid renewable energy system (HRES) is a combination of renewable and conventional energy sources. It can also combine two or more renewable energy sources operating in standalone mode or in network mode. In this work two models have been created in with we have proposed a model of hybrid system in which inverter is controlled by a designed internal current loop controller and wind variations are adjusted using a algorithm. It was found to be that the proposed system gives 1150 VA output which is considerably more than the 1000VA output of the system with basic voltage control. The efficiency is enhanced from 68 % to 70%. The system cost was found to be 70483.53 units in the system having basic voltage control and with the internal current loop control, it was reduced to 66795.26 units. Thus it can be drawn from this work that while designing an inverter control strategy the proposed internal current loop control can serve the purpose with better results in terms of power, efficiency and system cost.**

***Keywords*: HERS, Storage system, Cost analysis, internal loop control.**

I. INTRODUCTION

Electricity is the main factor of a country's industrialization, urbanization and financial growth. There are different types of conventional and unconventional energy sources for power generation. Solar and wind energy systems are one of the most important sources of energy. The use of solar and wind energy systems is gaining popularity due to its modular and ecological nature.

The solar wind has experienced considerable growth over the past two decades in the widespread use of autonomous systems to power interactive wind systems. Solar and wind energy systems generally operate in autonomous mode or connected to the grid, but the efficiency of these sources is lower due to the stochastic nature of solar and wind resources. Renewable hybrid energy sources with network integration overcome this unpredictable disadvantage.

The hybrid renewable energy system (HRES) is a combination of renewable and conventional energy sources. It can also combine two or more renewable energy sources operating in standalone mode or in network mode. HRES, which combines the key resources of solar and wind energy, operates in two ways: simultaneous and sequential. In simultaneous operation, solar and wind energy systems generate energy simultaneously with sequential mode electricity production.

Hybrid power and methodology

The general Hybrid power system mainly consists of three stages:

A. Power Generation Stage

B. Converter / Controller Stage

C. Distribution Stage

A.1 Solar Energy

Energy is essentially the radiant energy emitted by the sun, another term called solar energy. Solar energy is the form of radiant light and solar heat used in many technologies, such as solar heat, photovoltaic power plants, solar thermal power stations and fused sail systems. Solar energy is a very important source of renewable energy.

Its technology is classified as passive and active solar technology. It mainly depends on how solar energy is extracted and distributed or converted to solar energy. Active solar technologies include photovoltaic systems, concentrated solar energy and solar water heating. Passive solar techniques include the alignment of a building with the sun, the selection of materials with favorable thermal or light distribution properties and the design of spaces in which air naturally circulates.

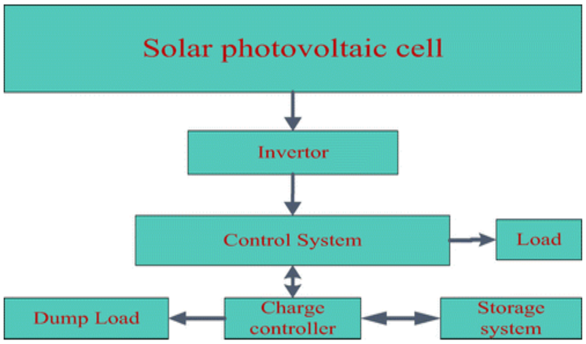

Figure 1. Architecture of PV hybrid system.

A.2 Wind Energy

In the wind turbine, the wind is used to produce electricity. The wind turbine includes wind turbines that convert wind kinetic energy into mechanical energy. It also includes a generator that can convert mechanical energy into electricity.

Wind energy is an abundant, renewable, generalized and clean energy source. No chemical gas is released, no water is consumed and little land is used. This has no impact on the environment as a non-renewable energy source. Many wind turbines are connected to the transmission network. The power of wind energy is not stable, but variable. Wind turbine wind turbines are connected to a transmission. The transmission is the electromechanical interface. The transmission power is transmitted to the permanent magnet synchronous generator (PMSG), which generates alternating current.

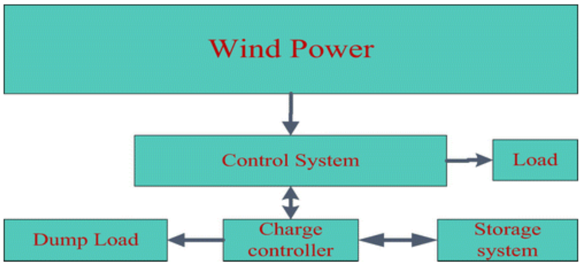

Figure 2 Architecture of wind hybrid system.

II. LITERATURE REVIEW

ShahbazHussain et al. [1] This study presents a hybrid system for renewable energy with a minimum overall project cost and maximum reliability. The system is modular and consists of a photovoltaic system (PV), a wind turbine, a storage battery, an alternating load and a tilt load. Reducing excess unused energy is also considered one of the design goals. In this study, the design of the wind turbine hybrid photovoltaic system uses a new technique called iterative filter selection to achieve the best possible solution, taking into account all design objectives.

T. Adeferati et al. [2] This study examines in depth research into the technical, environmental and economic benefits of integrating renewable DGs, such as reducing online losses, improving reliability, economic benefits and optimization. Environmental pollution. These advantages can be maximized if all renewable DG units are optimally sized, organized and configured. This study will also examine the current status of renewable DG technologies based on the various characteristics and operational aspects of the integration of renewable DGs in electrical systems. Recent advances in renewable energy technologies and changes in the infrastructure of electric utilities have increased the utility of utilities in using decentralized power generation resources for electricity generation.

eiyuan Li et al. [3] This article proposes the CC optimization strategy in DFIG wind turbines with current converters (CSC). In CSC based systems, the converter losses depend on the DC bus current. It is therefore important to minimize it. DC is selected as the largest current value of the rotor side converter (RSC) and the mains side converter current (GSC). The RSC current is generally higher than the GSC current because it also supplies the generator excitation current. If the generator stator can supply reactive power to deliver a part of the excitation current and the SGC balances that portion of the reactive power to keep the network in the power factor of the unit, the DC bus can be further reduced.

Lihui Yang et al. [4] This document presents an advanced control strategy for the rotor and power converters of the double wind turbine (DFIG) induction generator to improve low voltage bypass capacity (LVRT) as a function of network connection requirements . As part of the new control strategy, the rotor side controller can convert the unbalanced power into kinetic energy of the wind turbine by increasing the rotor speed when a low voltage occurs due to a network error in z. the common coupling point (PCC). The proposed network-side control scheme introduces a compensation term that reflects the instantaneous current of the DC link of the rotor side converter to smooth out the DC link voltage fluctuations during the network error.

III. METHODOLOGY

The model has been developed in MALAB/SIMULINK environment. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It has following key features:

- High-level language for scientific and engineering computing
- Desktop environment tuned for iterative exploration, design, and problem-solving
- Graphics for visualizing data and tools for creating custom plots
- Apps for curve fitting, data classification, signal analysis, control system tuning, and many other tasks
- Add-on toolboxes for a wide range of engineering and scientific applications
- Tools for building applications with custom user interfaces
- Royalty-free deployment options for sharing MATLAB programs with end users

The modeling of Dual Voltage Source Inverter system is done which is capable of feeding the load with either solar or wind resources depending on the availability thus making the system more reliable.

Modeling of different parts of the system has been further discussed. The modeled photovoltaic system using MPPT technology for its optimal operation was examined, the permanent magnet synchronous generator (PMSG), connected to the wind turbine.

The Dual Voltage Source Inverter (DVSI) is powered by a solar system, which is then integrated with the wind turbine to become a hybrid system. The DC memory capacitor system was also modeled according to the DVSI standard. These are connected to the network on the PCC and provide a non-linear and unbalanced load. The VSI supplies the network with the power available at the distributed power source (DER). The DER can be a DC or AC source with a rectifier coupled to a DC connection.

i) PV Module modeling:

PV cells have single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I. A simple equivalent circuit of PV cell is shown in Fig. 6.

A cell series resistance (Rs) is connected in series with parallel combination of cell photocurrent (I_{ph}),exponential diode (D), and shunt resistance (R_{sh}) , I pv and Vpv are the cells current and voltage respectively. It can be expressed as

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$

Where:

I_{ph}- Solar-induced current

I_s - Diode saturation current

q - Electron charge (1.6e^{-19}C)

K - Boltzmann constant (1.38e^{-23}J/K)

n - Ideality factor (1~2)

T - Temperature ^{0}K

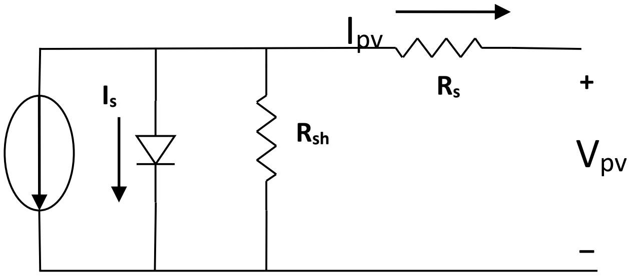

Figure 3. Equivalent circuit of solar pv cell

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$$

Where:

I_{sc}Short-circuit current of cell at STC

k_iCell short-circuit current/temperature coefficient(A/K)

I_r Irradiance in w/m^2

T_c ,T_r Cell working and reference temperature at STC

A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occur at the knee of the curve as shown in the Fig 4.4.

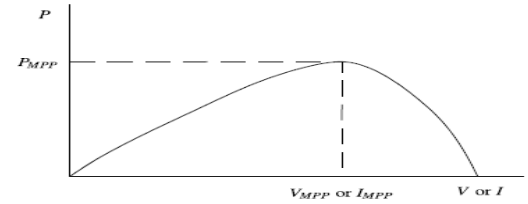

Figure 4. Characteristic PV array power curve

The P&O algorithm will track the maximum power to supply the DCMGs system. The assumptions for model derivation are that the ideal current source can be presented as the PVs behavior. In addition, all power converters are operated under the continuous conduction mode (CCM) and the harmonics are also ignored.

ii) wind energy system modeling:

Model of wind turbine with PMSG Wind turbines cannot fully capture wind energy. Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_p(\lambda,\beta)v^3$$

Where, ρ is the air density (typically 1.225 kg/m3), A is the area swept by the rotor blades (in m2),CP is the coefficient of power conversion and v is the wind speed (in m/s).
The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v}$$

Where $\omega_m$and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively.
The wind turbine mechanical torque output $m\ T$ given as:

$$T_m = \frac{1}{2}\rho A C_p(\lambda,\beta)v^3\frac{1}{\omega_m}$$

The power coefficient is a nonlinear function of the tipspeed ratio λ and the blade pitch angle β (in degrees). Then Power output is given by

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3$$

A generic equation is used to model the power coefficient C_P based on the modeling turbine characteristics described in [2], as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\left(\frac{21}{\lambda_i}\right)}$$

For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor, so the maximum power is extracted continuously from the wind.

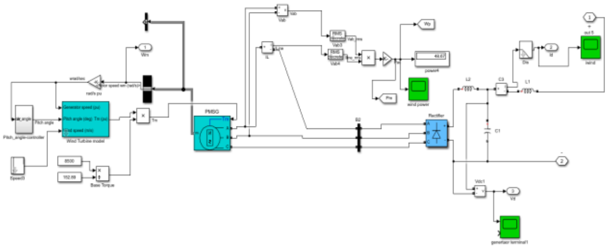

Figure 5 modeled Wind system

This mechanism uses the variable torque output w_m and tries to optimize the output current and voltage waveform to its maximum value.

Table 1 : Wind Energy System Parameters	
Wind Turbine Model	
Nominal Mechanical Output Power (W)	5000
Base Wind Speed (m/s)	12
Maximum power at Base Wind Speed (p.u)	0.73
Base Rotational Speed (p.u)	1.2
Permanent Magnet Synchronous Machine	
Stator Phase Resistance R_s (ohms)	0.9585
Armature Inductance (H)	0.00525
Flux Linkage	0.1827
Pole Pairs	4
Viscous damping	0.0003035
Rotor Type	round

iii) Proposed Control Systems

Internal current loop control for inverter

An efficient control scheme is proposed for power quality enhancement in a standalone system based on four-leg inverter. The proposed controller is based on Internal current loop control mechanism for power enhancement. The load voltage control is achieved by employing both current and voltage control loops to deliver the main inverter input control.

The use of this technique is suited for power industrial applications due to its good performances and robustness under critical working conditions. These advantages are reflected in various recent research works in the field of electrical systems control.

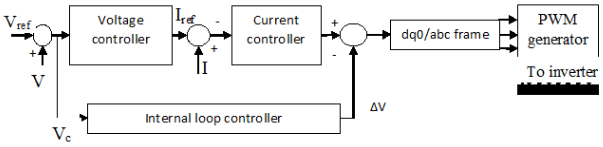

Figure 6: Control algorithm to generate pulses

The outer loop regulates the output voltage and provides the inner control loop current references $\boldsymbol{i}_{\mathrm{Ref}} = [i0_{\mathrm{Ref}}, id_{\mathrm{Ref}}, iq_{\mathrm{Ref}}]^{\mathrm{T}}$

For design purposes, the state-space model associated with the outer loop augments the output voltage states equations (3) with their respective voltage errors, in order to reduce these errors and secure relevant tracking performances even in case of modelling inaccuracy or unpredictable perturbations. The voltage error vector is defined as:

$V_c = [V_{c\,0}, V_{c\,\mathrm{d}}, V_{c\mathrm{q}}]^{\mathrm{T}} = V - V_{\mathrm{Ref}}$

where $V = [V\,0, V\,d, V\,q]^{\mathrm{T}}$ is the output voltage vector and

$V_{\mathrm{Ref}} = [V_{\mathrm{Ref0}}, V_{\mathrm{Ref}d}, V_{\mathrm{Ref}}q]^{\mathrm{T}}$ is its corresponding reference.

Also $Ic = [I_{c\,0}, I_{c\,d}, I_{c\,q}]^{\mathrm{T}} = \mathrm{I} - I_{\mathrm{Ref}}$

where $\mathrm{I} = [I0, Id, Iq]^{\mathrm{T}}$ is the line filter current vector and $\mathrm{I}_{\mathrm{Ref}} = [\mathrm{I}_{\mathrm{Ref0}}, \mathrm{I}_{\mathrm{Refd}}, I_{\mathrm{Refq}}]^{\mathrm{T}}$ is its relating reference.

When the system is subject to critical disturbances such as the presence of non-linear or unbalanced loads, periodic harmonic components appear in the output voltage waveforms, which may worsen the overall system performances. In this way, and in order to take into account these effects in the control objectives, the proposed solution, based on the Inner Control loop controller, adjusts the inverter input control trajectories as the control task is repeated, with the aim of converging to zero tracking error. In this subject, the controller can produce infinite gains at series of frequencies and achieve a high disturbance rejection along with power enhancement.

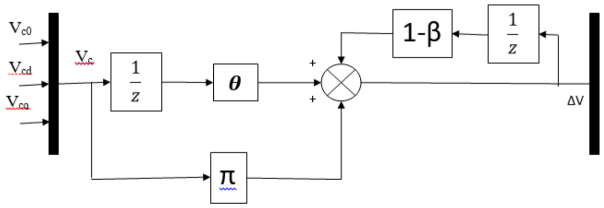

Figure 7 the inner loop control in MATLAB/SIMULINK

IV. RESULTS AND DISCUSSION

i) Simulation Environment

MATLAB stands for Matrix Laboratory, a programming package designed exclusively for logical calculations and quick and easy input / output. In fact, it contains hundreds of integrated functions for a wide range of calculations and many toolboxes designed for specific analytical disciplines, as well as statistics, optimizations, solutions for partial differential equations and information analysis. In this research, the MATLAB platform is used to demonstrate the implementation or simulation of the performance of the implemented algorithm. Measurement toolkits are used and some integrated graphics features are used. The simulation results and the comparison of the performance of the model implemented with some existing models are calculated by the MATLAB functions.

ii) Model Description

The first model was created using the modeling of a hybrid wind and solar system that drives a linear load. In the first model, the inverter was modeled by voltage regulation and the voltage curve was analyzed in MATLAB. In this work, the voltage profile has been improved by an internal controller modified for the inverter. The integration of the system into a battery storage system ensures that the Solarwind hybrid system does not provide enough power for the load. The voltage profile of the system output signal has been re-analyzed to see the difference between the two models.

This chapter explains how to model the systems in the following two cases:

CASE 1: Hybrid system with common voltage control for inverter

CASE 2: Hybrid system with internal loop controller

The chapter discusses the efficiency, power and cost analysis of the system using two controllers. Also there has been enhancement in wind energy system by designing a control for efficient wind variation accomplishment. The results are in favour of our designed internal loop control which continuously monitors the current forming a loop. The power is thus enhanced with this controller for inverter.

iii) The Outputs from the Hybrid Energy System

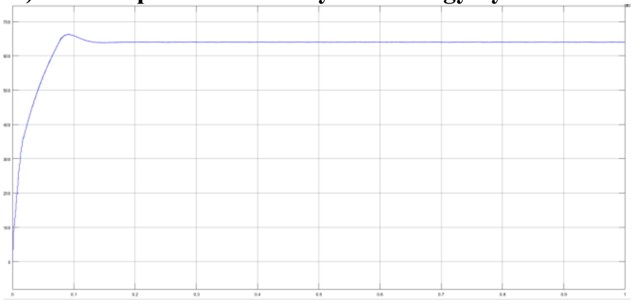

Figure 8. DC output voltage from the hybrid system

The voltage that is given as input to the inverter is approximately 650 volts which is then converted into the AC waveform which is to be used for driving the loads.

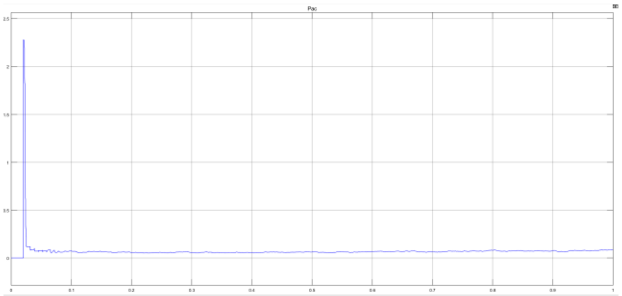

Figure 9. Power output from the wind energy system

The power output from the wind energy system is seen stable while using controller which can accommodate wind variations. It is found approximately to be 0.2 KW. This power is then integrated with the solar system after changing into DC voltage via a rectifier.

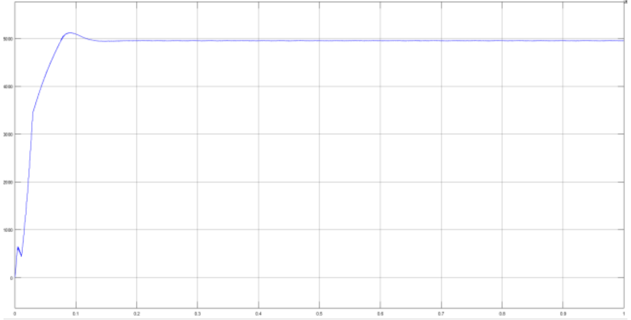

Figure 10. Power output from the solar system

The power output from the wind energy system is seen approximately to be 5 KW. This power is then integrated with the solar system and managed via a battery storage system.

CASE 1: Hybrid system with common voltage control for inverter

The system is designed in MATLAB/SIMULINK environment using simulink library. In this model basic voltage control is being designed based on the studied paper and is provided as pulse to the inverter. In wind energy system the system is designed to produce AC power in accordance with the wind variation. Then the cst and efficiency of the system is calculated

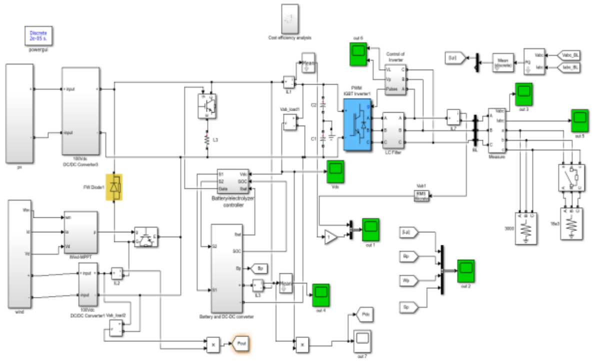

Figure 11. Hybrid system with common voltage control for inverter

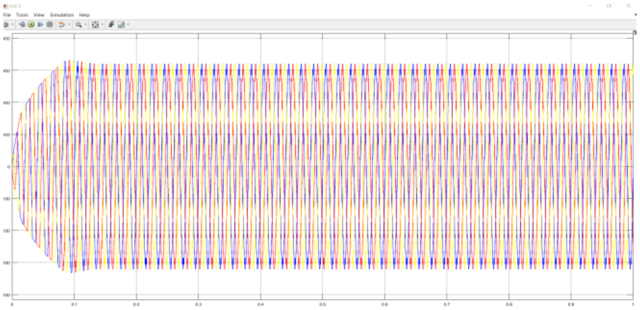

Figure 12. Voltage Output of Hybrid system with basic voltage control for inverter

The phase to phase voltage output from the hybrid system with basic voltage control for inverter is approximately three phase 310 Volts. It is then used for driving the 10 KW resistive load.

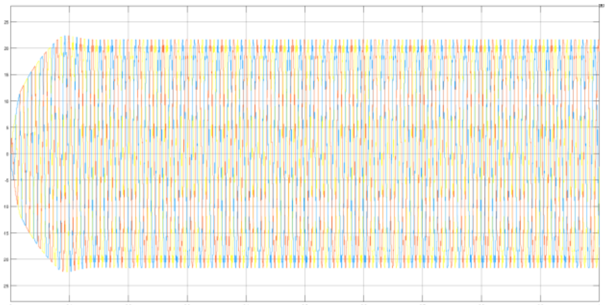

Figure 13. Voltage Output of Hybrid system with basic voltage control for inverter

The phase to phase current output from the hybrid system with basic voltage control for inverter is approximately three phase 21 Amperes. It is then used for driving the 10 KW resistive load.

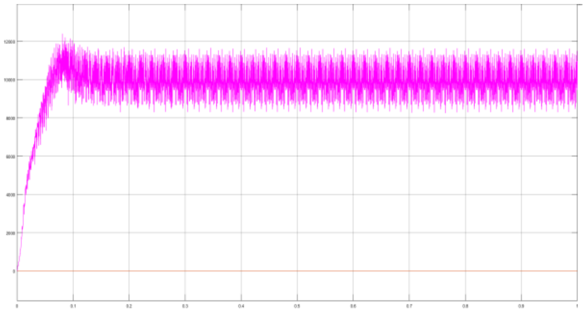

Figure 14. Power Output of Hybrid system with basic voltage control for inverter

The active power output from the hybrid system with basic voltage control for inverter is seen varying between 9 KVA to 11 KVA. This power is used for driving loads.

4.5 CASE 2: Hybrid system with internal loop controller

In this proposed system two different controls are being designed so as to obtain the objective of better efficiency and lower system cost. Firstly the system inverter is provided with internal current loop control which is seen as improving the output power and hence reducing the system cost. Further the wind energy system is enhanced with providing the variation control algorithm for the wind system such that it will give output adjusting the frequent wind variation.

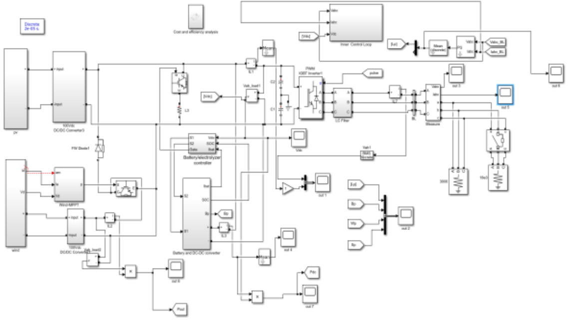

Figure 15. Hybrid system with internal loop controller

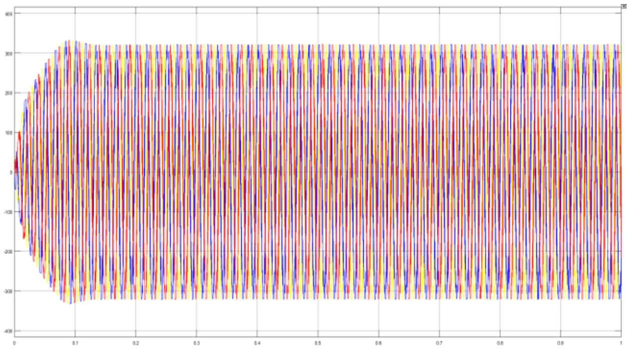

Figure 16. Voltage Output of Hybrid system with internal loop controller

The phase to phase Voltage Output of Hybrid system with internal loop controller for inverter is approximately three phase 310 Volts. It is then used for driving the 10 KW resistive load

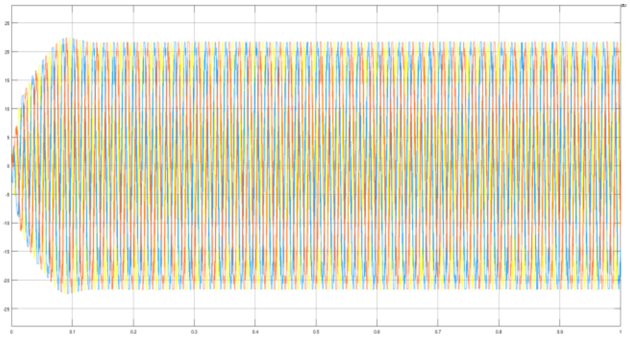

Figure 17. Current Output of Hybrid system with internal loop controller

The phase to phase current output from the hybrid system with basic voltage control for inverter is approximately three phase 23 Amperes. It is then used for driving the 10 KW resistive load.

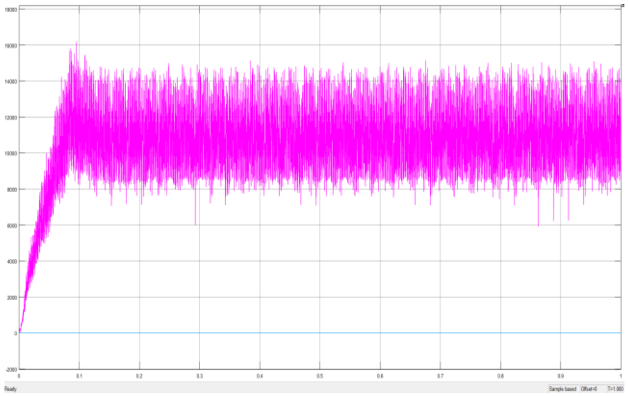

Figure 18. Current Output of Hybrid system with internal loop controller

The active power output from the hybrid system with basic voltage control for inverter is seen varying between 10 KVA to 13 KVA. This power is used for driving loads.

4.6 Power Enhancement in the two systems

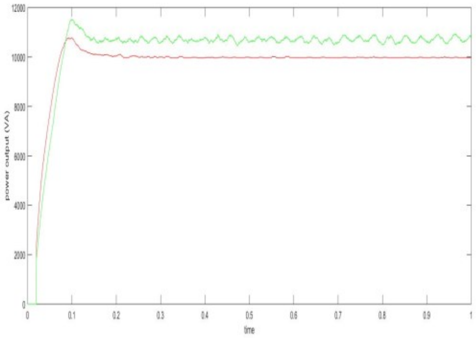

Figure 19. Enhancement in power outputs form the inverter using the internal current loop controller from normal voltage controller

The above figure shows the comparative analysis of mean value of active power outputs from the two system. The green waveform depicts the active power output from the system having inverter controlled by the internal current loop controller and the red waveform is of the active power output from the inverter controller by basic voltage control.

The figure shows that the mean value of the active power output from the system having voltage control is approximately 1000 VA and that from the system with internal current loop control is approximately 1150 VA. Hence there has been considerable enhancement in the powers output just by changing the inverter control

iv) Cost analysis of two systems

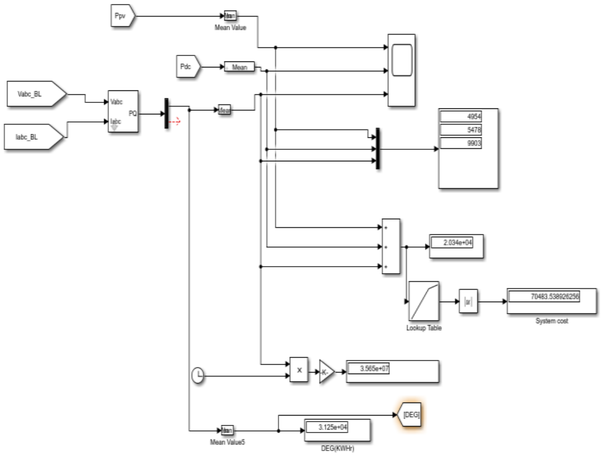

Figure 20. Cost calculation of system owing to normal voltage control for the inverter

In basic system having a normal voltage control the power output is calculated and it has been observed that the system cost is approximately 70483.53 units. The power calculation in MATLAB / SIMULINK environment is being depicted above in the figure.

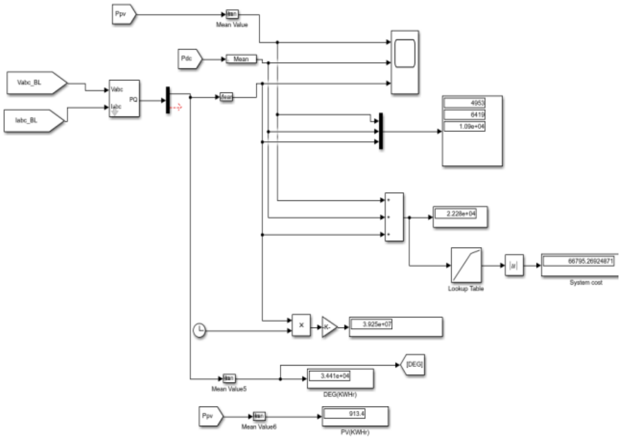

Figure 21. Cost calculation of system owing to internal current loop control for the inverter

In our proposed system in which we have designed a internal current control loop for the inverter, it has been observed that power output has been enhanced and system cost is being reduced to 66795.26 units.

4.8 Efficiency Analysis Of two systems

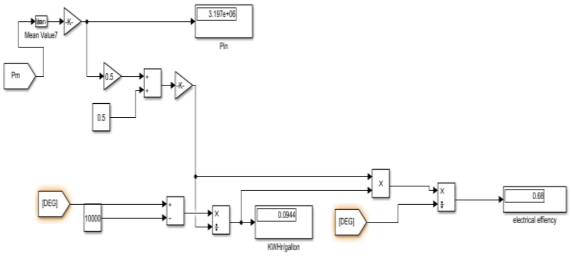

Figure 22. Efficiency calculation of system of system having no wind regulation algorithm

In basic system the basic voltage control loop and no wind variation accommodation algorithm the efficiency of the system is found to be approximately 68%**.**

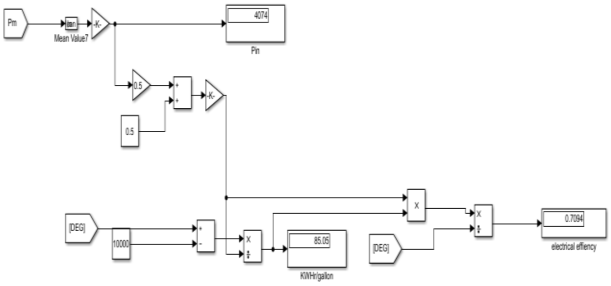

Figure 23. Efficiency calculation of system of system having no wind regulation algorithm

In the proposed system having internal loop control which has led to enhancement in power output of the system and wind variation accommodation algorithm, it has been found that the efficiency of the system is seen to be improved to 70%.

V. CONCLUSION

Renewable energy sources also called non-conventional type of energy are continuously replenished by natural processes. Hybrid systems are the right solution for a clean energy production. Hybridizing solar and wind power sources provide a realistic form of power generation. Here in this work we have designed a solar wind hybrid PV system in MATLAB/SIMULINK environment and have integrated it with battery storage system.

Further, two models have been created in with we have proposed a model of hybrid system in which inverter is controlled by a designed internal current loop controller and wind variations are adjusted using a algorithm. The following main conclusions have been drawn from the results.

- On comparing the active power outputs from the system with basic voltage control for inverter with proposed internal current loop control, it was found to be that the proposed system gives 1150 VA output which is considerably more than the 1000VA output of the system with basic voltage control.
- The system cost has been calculated which was found to be 70483.53 units in the system having basic voltage control and with the internal current loop control it was reduced to 66795.26 units.
- Also the control designed for the wind system which is accommodating the frequently changing wind speed enhances the system efficiency along with the internal current loop control being designed for the inverter. The efficiency was calculated to be 70 % with the two

proposed control as compared to the 68% with no controls.

The above results can be tabulated as below in Table 6.1

Table 2: Comparitive analysis of parameters using proposed control algorithm

Parameters	**With Internal current loop control and wind speed control**	**With basic voltage control**
Active Power Output (VA)	1150	1000
System efficiency (%)	70	68
System cost (units)	66795.26	70483.53

Thus it can be drawn from this work that while designing an inverter control strategy the proposed internal current loop control can serve the purpose with better results in terms of power, efficiency and system cost. This control can also be used in hybrid systems thus making it more reliable controlling method. The system designed is also fitted to feed the nonlinear load.

6. Future Scope

Installing this solar-grid hybrid system will be actually very fruitful because it will reduce the grid dependency. On the other hand, this system promotes green energy which is very important because all the energy sources are depleting day by day. So, people must look for new renewable sources and solar power is definitely one of the best choices in this purpose. In future work an adaptive neural network based control for improved power quality 3 phase grid integrated with nonlinear and linear loads will be designed. The expected control scheme regulates the system voltage and improves the power quality in a very effective manner.

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