ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

A Novel MPPT Strategy for Power Management in Remote Area Power Supply Systems

Anupama K Pillai[1], Sheleel F[2]

PG Student, Dept. of Electrical Machines, Sree Buddha College of Engineering Alappuzha, Kerala, India[1]

Assistant Professor, Dept. of Electrical Machines, Sree Buddha College of Engineering Alappuzha, Kerala, India[2]

ABSTRACT: In order to maximize solar energy extraction, maximum power point tracking (MPPT) is considered as the most promising technique in solar-photovoltaic (PV) power generation systems. It is proposed to operate the solar-PV system to manage power balance in a remote area power supply (RAPS) system. This is based on three operating modes: 1) Frequency control mode; 2) Active power control mode; 3) MPPT control mode. These modes are decided based on the load level and the operating mode of the diesel generator (i.e. synchronous condenser mode or generator mode). This power management strategy balances the generation and load demand without using the dummy load. The proposed strategy is capable of improving the diesel generator life time and also its operating efficiency. Due to the life time extension and efficiency improvement of the diesel generator, cost savings can also be achieved in long run.

KEYWORDS: Diesel generator, frequency control, maximum power point tracking (MPPT), photovoltaic (PV), power management, remote area power supply (RAPS) system, voltage control.

I.INTRODUCTION

RAPS systems are typically employed in areas where the long-term cost of connecting to a utility grid is more expensive than the life-cycle cost of a RAPS system.Diesel has been used as the dominant energy resource in many early RAPS systems [1]. The diesel engine generator (DEG) has the advantage of high reliability, but environmental and economic factors prohibit its continuing expansion. Diesel price is increasing and it puts heavy burden on the electricity consumers. Additionally, greenhouse gas emission and air pollution caused by diesel combustion adversely affect the environment. Another constrain is its poor efficiency under low load condition. Usually, the load in a RAPS system fluctuates frequently, and may result in very low load factor. The DEGs in diesel-only RAPS systems are commonly oversized to meet the peak demand, and operating efficiency can be low during the off-peak period. Therefore, utilisation of renewable energy resources in RAPS systems has gained wide attention. Maximum power point tracking (MPPT) techniques ensure photovoltaic (PV) generation unit extracting maximum energy from the irradiance on the surface of PV arrays. Power management in a RAPS system is more challenging than the utility grid, since there is usually no dominant energy resource in RAPS systems, especially when non-schedulable renewable energy resources are utilised. Both active power and reactive power requirement can be balanced between generation and load demand to achieve frequency and voltage regulation of the RAPS system. Storage system can effectively mitigate the impact of active power fluctuations in a RAPS system. The energy storage component absorbs surplus energy when generation is more than sufficient to supply power to the load, and injects power when energy deficit occurs in the system.

II. SYSTEM MODELING

The proposed RAPS system is presented in Figure. 1. A two-stage converter converts the DC power generated by the PV array to AC. The boost converter regulates the operating point of the PV array whereas the inverter produces sinusoidal voltages while maintaining the voltage on the DC-link constant. The diesel engine drives the SM through a clutch. When the clutch is engaged, the SM can operate as a generator. Otherwise, the SM operates as a synchronous condenser.

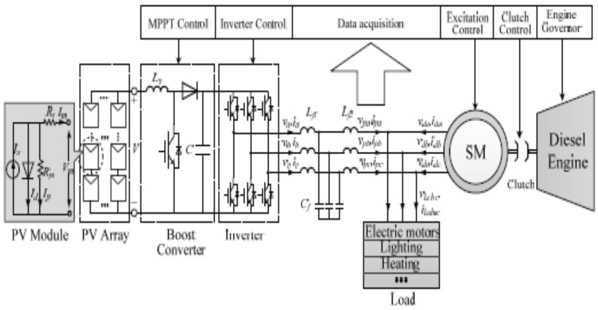

Figure 1. Architecture of the PV-diesel RAPS system.

A. PV GENERATOR MODELLING

The equivalent circuit of a PV module is composed of a current source *Is*, a parallel diode, a parallel resistor *Rp*, and a series resistor *Rs*. The voltage across the two terminals of the module is *Vm*. The mathematical representation of the equivalent circuit has the following form:

$$I_m = I_s - \underbrace{I_r\left[\exp\left(\frac{q(V_m + IR_s)}{\eta kT}\right) - 1\right]}_{I_d} - \underbrace{\frac{V_m + IR_s}{R_p}}_{I_p} \qquad (1)$$

where*Im*is the module output current and *Is* is the photocurrent which is proportional to the solar irradiance. The *Ip*is the current through the parallel resistance and *Id* through the diode. *Ir*is the diode reverse saturation current, *q* is the electrical charge (1.6 × 10-19 C), *η* is the p-n junction quality factor, *k* is the Boltzmann constant (1.38 × 10-23 J/K), and *T* is the ambient temperature (in Kelvins).
The nonlinear current-voltage relationship of the PV module, which is known as the *I-V* photovoltaic characteristics, is presented by the dashed curves in Figure 2.

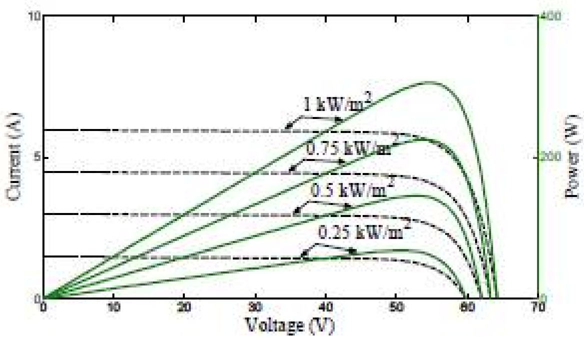

Figure2.*I-V* characteristic and power characteristic of a PV module.

B. DIESEL ENGINE GENERATOR MODELING

The diesel engine consumes fuel and produces mechanical torque based on the governor response. The basic block diagram shown in Figure 3 models the controller with a second order transfer function, and the fuel injection actuator with a third-order transfer function. A time delay TD is added into the model to represent the time delay between the fuel injection and mechanical torque developed at the shaft of the diesel engine. The engine speed in per unit is approximated by:

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

$$\omega = \frac{1}{2H_d}\int (T_d - T_e)dt \qquad (2)$$

whereHd is the diesel engine inertia constant, Td is the engine mechanical torque.

III. POWER MANAGEMENT STRATEGY

DEG regulates the active and reactive power through diesel engine governor and SM exciter respectively, whereas d-axis and q-axis components of inverter current control the active power and reactive power from the PV generator respectively. This section presents the traditional power management strategy for the PV generator, and the proposed power management strategy for the PV-Diesel RAPS system.

A. MPPT STRATEGY FOR SOLAR-PV

In grid-connected PV generation systems, the MPPT is a common approach to determine the optimal operating point to maximize the solar energy extraction. The PV generation system operates as a current source while extracting maximum energy from the solar irradiance. If required, the PV generator can provide voltage support for the grid by supplying or absorbing reactive power. The perturbation and observation (P&O) method, and incremental conductance (IC) method are two commonly used MPPT strategies for solar-PV systems. The P&O method is implemented by imposing periodic positive or negative perturbations for the terminal voltage of the PV array. If the varying direction (increase or decrease) of the PV output power is the same with the varying direction of the terminal voltage, then the same voltage perturbation is applied to the next step. Otherwise, a voltage perturbation of opposite polarity with the present step perturbation is imposed in the next step. The P&O has the advantage of ease of implementation whereas sudden irradiance variation may confuse the controller and oscillations around the MPP are inevitable. The IC algorithm is claimed to be able to overcome the drawbacks of P&O. IC is based on the fact that the derivative of the power with respect to the voltage at MPP is zero. Hence, the following equation is derived.

$$\frac{dI}{dV} + \frac{I}{V} = 0 \qquad (3)$$

By adding a simple PI controller, the IC method performance can be improved with less oscillation in steady-state and improve the tracking performance.

B. PROPOSED SUBOPTIMAL MPPT STRATEGY

In a PV-diesel RAPS system without energy storage, if the typical MPPT strategy is implemented, dummy load should be used to consume the surplus energy when the generation is greater than load demand. In addition, DEG may operate at a very light loading level when the PV generator is operating at the MPP, which deteriorates the DEG life time and operating efficiency. Therefore, it is beneficial for the PV generator to tailor its power output deliberately in some situations, i.e. operating at suboptimal power point. In this way, dummy load can be eliminated whereas low loading limit can also be guaranteed for the DEG. Consequently, DEG life time can be prolonged and operating efficiency can be improved. IC MPPT algorithm is used to detect the MPP at a particular irradiation level and stores the maximum power value PMPP. Based on the comparison between the maximum power and load demand Pload, a proper operating mode for the PV generator can be chosen from the three possible operating modes:

1) If the maximum power is larger than load demand, the PV generator operates in frequency control mode and shifts to a suboptimal operating point to match with the load.

2) If the maximum power is less than the load by more than the designed minimum loading level, the PV generator runs in the MPPT mode.

3) If the load drops in the range between the previous two cases, power control mode is applied to the PV generator and results in a suboptimal operating point.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

The decision making process is illustrated in Figure 3.

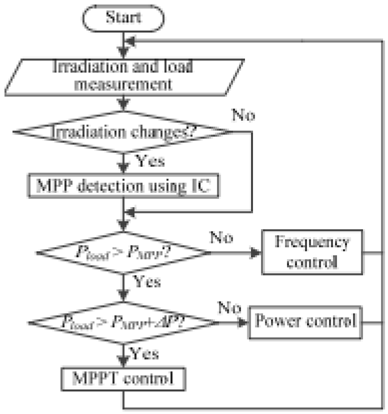

Figure 3 Suboptimal MPPT control strategy.

C. POWER MANAGEMENT IN PV-DIESEL SYSTEM

Both the PV generator and the diesel generator are capable of providing voltage support to the RAPS system. However, by demanding reactive power from the PV generator, the PV interfacing inverter requires additional MVA capacity. Contrarily, SM absorbs or injects reactive power through excitation control. Therefore, the DEG has been assigned for reactive power management. As far as active power is concerned, the RAPS system may operate in following three different modes depending on the operating mode of the PV generator.

Mode I: If the PV generator operates in frequency control mode, no active power is demanded from the DEG. However, SM should operate in synchronous condenser mode to regulate voltage in the RAPS system though excitation control. The clutch mounted on the diesel engine shaft and the SM shaft is disengaged to separate the SM from the diesel engine, and the diesel engine is shutdown. The PV generator establishes the RAPS system frequency and supplies active power to match with load. As shown in Figure. 4, by shifting the PV array terminal voltage on the power characteristic curve, the power output can be adjusted to a suboptimal point to match with the load. The left side of the MPP is chosen for power regulation.

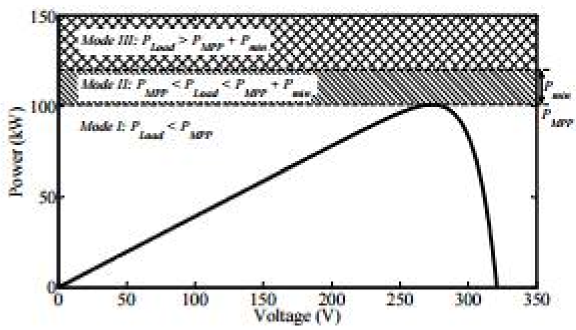

Figure 4 PV-Diesel RAPS system operating modes

Mode II: In this mode as indicated by the diagonal-line shaded region of Fig. 5, the load satisfies (9). In order to reduce the operation and maintenance (O&M) cost, the loading level of the diesel engine generator is expected to be above a predesigned value. Hence, power control mode forces PV generator to compromise the MPPT strategy and adjusts its operating point to ensure minimum loading for the DEG. The active power setting for the PV generator is defined by:

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

The DEG operates in grid-forming mode and regulates both the frequency and voltage in the system. The clutch connecting engine shaft and machine shaft should be engaged to transfer mechanical torque from the engine to the machine.

Mode III: When load demand exceeds (PMPP + Pmin) as shown in the diamond shaded region of Figure. 5, PV generator can operate at the MPP, whereas DEG is loaded above its lower loading limit. Like Mode II, DEG establishes the RAPS system and manipulates system frequency and voltage by diesel engine governor and SM excitation control. PV generator is controlled under MPPT strategy. Clutch needs to be engaged in this mode as with Mode II. The active power produced by diesel generator can be determined using:

The details of the transition logic between the system operating modes mentioned above are illustrated in Figure. 5.

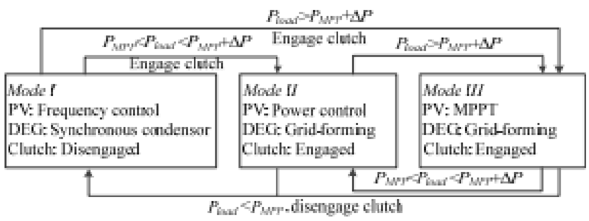

Figure 5.RAPS system operating mode transition.

IV. RESULT AND DISCUSSION

This case study demonstrates the PV-system's capability to track maximum power from the solar as well as to adjust its power output to match with load. Generally, when solar irradiance change is detected by the PV system, the PV system transits to MPPT control mode and the maximum available power can be determined. If the maximum power is higher than the load, then the PV system lowers its power output accordingly. The simulation starts with a solar irradiance of 1 kW/m2 and the total load of 50 kW + j 20 kVAr. The MPP is detected as 100 kW which is above the load active power. Hence, the RAPS system transits to operate in suboptimal MPPT mode at around t = 0.2 s. The PV supplies all the active power demand of the load while maintaining system frequency, hence the active power output of the DEG is zero as shown in Figure. 6-(a). The load changes to 65 kW + j 35 kVAr at t = 3 s and is lowered by 5 kW + j 5 kVAr at t = 6 s. The load is accurately tracked by the generation in the process until solar irradiance lowers to 0.75 kW/m2 at t = 9 s. The PV senses the MPP again and returns to suboptimal MPPT operation mode as the available maximum solar power is around 75 kW, which is still larger than active power demand of the load. As it can be seen in Figure.6-(b), the DEG supplied all the reactive power demand in the RASPS system by running at the SC mode during the 12 s time period. Figure.6-(c) shows that the voltage is regulated in the range of (1 ± 0.05) pu and frequency is within (50 ± 1.0) Hz.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

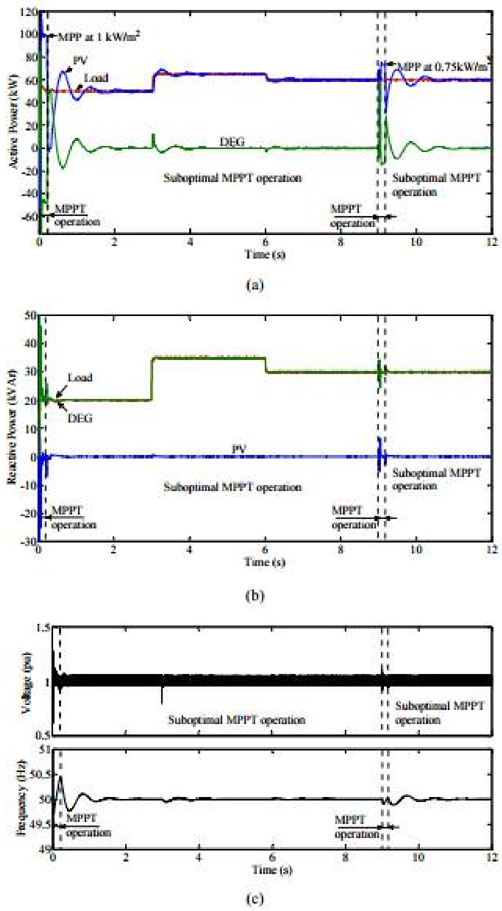

Figure 6.Mode I operation with variable irradiance.(a) Active power management; (b) Reactive power management; (c) Voltage and frequency regulation.

V.CONCLUSIONS

This paper proposed a suboptimal MPPT control strategy for a solar-PV generator to maintain power balance in a PV diesel RAPS system. The proposed control strategy determines the PV generator operating mode and thus the operating mode of the diesel generator. Three combinations of the PV generator and diesel generator modes constitute three power management modes. The optimal coordination between PV generator and diesel generator balances both active and reactive power in the RAPS system by transiting among the three power management modes in accordance with the load change. Voltage is well regulated through synchronous machine excitation control. Frequency excursion is maintained around nominal value except during diesel generator starting period when sudden large power deficiency occurs in the system. The frequency excursion depends on the power deficiency value and the response speed of the diesel generator. The effectiveness of the proposed power management strategy haves been investigated through simulation studies. The simulation results indicated that accurate active power and reactive power management can be achieved with the proposed suboptimal control strategy.

REFERENCES

1. M. Arriaga, C. A. Canizares, and M. Kazerani, "Renewable Energy Alternatives for Remote Communities in Northern Ontario, Canada," IEEE Trans. Sustain. Energy, vol. 4, no. 3, pp. 661-670, 2013.
2. R. W. Wies, R. A. Johnson, A. N. Agrawal, and T. J. Chubb, "Simulink Model for Economic Analysis And Environmental Impacts of a PV With Diesel-Battery System for Remote Villages," IEEE Trans. Power Syst., Vol. 20, no. 2, pp. 692-700, 2005.
3. M. A. G. de Brito, L. Galotto, L. P. Sampaio, G. de Azevedo e Melo, and C. A. Canesin, "Evaluation Of The Main MPPT Techniques For Photovoltaic Applications," IEEE Trans. Ind. Electron., Vol. 60, No. 3, Pp. 1156-1167, 2013.

4. V. Salas, E. Olías, A. Barrado, and A. Lázaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems," Solar Energy Materials and Solar Cells, vol. 90, no. 11, pp. 1555-1578, 2006.
5. M. A. Elgendy, B. Zahawi, and D. J. Atkinson, "Assessment of perturb and observe MPPT algorithm implementation techniques for PV pumping applications," IEEE Trans. Sustain. Energy, vol. 3, no. 1, pp. 21-33, 2012.
6. M. Qiang, S. Mingwei, L. Liying, and J. M. Guerrero, "A novel improved variable step-size incremental-resistance MPPT method for PV systems," IEEE Trans. Ind. Electron., vol. 58, no. 6, pp. 2427-2434, 2011.
7. A. Urtasun, P. Sanchis, D. Barricarte, and L. Marroyo, "Energy management strategy for a battery-diesel stand-alone system with distributed PV generation based on grid frequency modulation," Renew. Energy, vol. 66, no. 0, pp. 325-336, 2014.
8. N. Mendis, K. M. Muttaqi, S. Perera, and M. N. Uddin, "A novel control strategy for stand-alone operation of a wind dominated raps system," in Proc. Industry Applications Society Annual Meeting (IAS), 2011 IEEE, 2011, pp. 1-8.
9. T. Hirose and H. Matsuo, "Standalone hybrid wind-solar power generation system applying dump power control without dump load," IEEE Trans. Ind. Electron., vol. 59, no. 2, pp. 988-997, 2012..