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www.arpnjournals.com FEASIBILITY ANALYSIS OF GRID/WIND/PV HYBRID SYSTEMS FOR INDUSTRIAL APPLICATION Wayan G. Santika, Sudirman and I Nyoman Suamir Bali State Polytechnic, Bukit Jimbaran Campus, Bali, Indonesia E-Mail: wayan.santika@pnb.ac.id ABSTRACT The present study offers technical and economical analyses of grid-connected hybrid power systems for a large scale production industry located in Bali. The peak load of observed system can reach 970.630 kW consuming on average 16 MWh of electricity a day. Software HOMER was utilized as the optimization tool. The proposed hybrid renewable energy systems consist of wind turbines, a PV system, a converter, and batteries. The system is connected to the grid. Optimization results show that the best configuration is the Grid/Wind hybrid system with the predicted net present cost of -884,896 USD. The negative sign indicates that revenues (mostly from selling power to the grid) exceed costs. The levelized cost of electricity of the system is predicted to be -0.013 USD/kWh. The present study also conducts sensitivity analysis of some scenarios i.e. 50%

and 100% increases in grid electricity prices, 50% reduction of PV and WECS prices, and 10 USD and 50 USD carbon taxes per ton CO2 emission. Implications of the findings are discussed. Keywords: renewable energy, wind energy, PV, grid-connected supply, hybrid system, net present cost, HOMER. INTRODUCTION According to World Energy Outlook 2014, global energy demands are predicted to increase by 37% in 2040 [1]. In 2013, industrial sectors in Indonesia consumed about 52 millions TOE which is 38% of the total final energy consumption [2]. Renewable energy contributed only 8% of Indonesia's total primary energy mix in 2013 and is expected to reach 23% in 2025 under the national energy policy (KEN) scenario. Since industrial sectors consume most of the energy, their contribution to greenhouse gas (GHG) emissions is also the highest. Reducing fossil fuel consumption in industrial sectors through energy efficiency measures is well studied [3, 4, 5]. However, less study discusses the reduction by means of renewable energy applications [6, 7]. The present study offers technical and economical analyses of Grid /Wind/PV hybrid power supply configurations for a large scale production industry located in Bali. The peak load of observed system can reach 970.630 kW consuming on average 16 MWh of electricity a day. HOMER, a renewable energy system (RES) software developed by National Renewable Energy Laboratory (NREL), was utilized as the optimization tool. It is chosen as it is widely used by RES experts all around the world. We also did sensitivity analyses to find out which hybrid systems perform the best in different scenarios. LITERATURE REVIEW Renewable energy systems have been extensively studied for application in sectors other then industrial sectors, such as homes [8,9], small and large hotels [10,11,12], a school building [13], remote villages [14, 15], and other buildings [16, 17]. Dalton et al [12], for example, found that Grid/Wind hybrid system is the optimum hybrid configuration with comparable net present costs (NPC) to the grid only system at 2004 electricity price. HOMER Simulation Program HOMER simulates and optimizes various power system configurations, such as grid only, grid/PV, grid/PV/wind, grid/PV/wind/batteries, autonomous diesel generator, PV/batteries, and PV/batteries/diesel hybrid power system. HOMER serves two main purposes; to determine system feasibility and to estimate the life-cycle cost of the system [18]. A system is feasible if it can satisfy the loads and limitations set by the user. Simulation is performed on a hourly basis over a one-year period. HOMER calculates electric and thermal loads and energy production of the system, compares them, and decides what to do with the energy surplus or deficit. Life-cycle costs are calculated based on total costs and revenues of the system over its lifetime. HOMER uses the total net present cost (NPC) to represent the life-cycle cost. NPC is the present value of the total cost paid over the lifetime of the project minus the total revenue. Costs include investment costs, replacement costs, operation and maintenance costs, fuel costs, and electricity purchased. Revenues mainly come from selling electricity to the grid and the salvage value. The following equation is used to calculate NPC: NPC ? ann,tot C CRF (1) www.arpnjournals.com where Cann,tot is the total annualized cost and CRF is the capital recovery factor, given by the following equation: CRF ? i(1?1)N i(1?1)N ?1 (2) where i is the annual real interest rate and N is the lifetime of the project. Sometime it is useful to compare the levelized cost of energy (COE) of different systems. COE is calculated using the following equation: COE ? C ann ,tot Eprim ? Edef ? Egrid,sales (3) where Cann,tot is the total annualized cost, Eprim is the total amount of primary load served per year, Edef is the total amount of deferrable load served per year, and Egrid,sales is the total grid sales per year. DATA INPUTS Load HOMER requires electricity load, solar resource and wind speed data. We provided hourly electricity load data for at least 24 hours which is then synthesized and randomized by HOMER to develop hourly load profile of the industry for the whole year. Figure-1 shows that a base load of less than 600 kW occurs after office hours and the load increases reasonably during office hours. Resources For solar and wind resource inputs, we have to provide the site's average daily radiation value and the site's average wind speed for each month of the year. Data were collected from NASA's 22-year average daily radiation and average monthly wind speed [19]. Figure- 2 shows global horizontal solar radiation profile over a one- year period. 1,000 Daily Profile Load (kW) 800 600 400 200 0 0 6

12 18 24 Hour Figure-1. Hourly load profile of the industry. Figure-2. Global horizontal solar radiation near the site. Figure-3 shows monthly wind speeds near the site. The Weibull K factor, the autocorrelation factor, and the diurnal pattern strength are assumed to be 2, 0.85, and 0.3, respectively. Economics HOMER also requires some economic inputs such as the annual real interest rate, which is 7% in 2013 [20], and the project lifetime, which is 25 years. The annual real interest rate is the nominal interest rate minus the inflation rate [21]. Constraints Constraints are restrictions imposed by users representing conditions that the system must satisfy to be feasible. We set zero annual capacity shortage for the industry to operate smoothly. The operating reserve is set to be 10% of the hourly load, 25% of the solar power output, and 50% of the wind energy output. Equipment Considered The proposed hybrid renewable energy systems consist of a wind energy conversion system (WECS), a PV system, a converter, and batteries and will be connected to the grid (Figure-4). The proposed wind turbines produce alternating current (AC) which serves the load directly, thus prevents unnecessary losses. PV modules and batteries are connected to the DC bus and the DC should be converted to AC before it can serve the load. 3A 2 MW Vestas V110 wind turbine is chosen with the investment cost (IC) of 2.28 million USD [22] and a 1% annual operational & maintenance (O/M) cost. 25 years are the expected lifetime of the turbines which hub height is 95 m. A PV system with a lifetime, a derating factor and a ground reflectance of, respectively, 20 years, 90%, and 20% was selected. The arrays will use a two-axis tracking system and would cost 3000 USD per kilowatt [23]. The batteries are Surrette 4KS25P with nominal voltage, nominal capacity, and lifetime throughput of 4 V, www.arpnjournals.com 7.6 kWh, and 10,569 kWh, respectively. The IC of a battery and its associated O/M cost are 800 USD and 8 USD/year, respectively [11]. The converter converts DC to AC or vice-versa and costs 730 USD/kW [21, 11]. The converter has the efficiency of 90% and is expected to last 15 years. The sizes to consider are 1000, 1500, and 2000 kW. Figure-3. Monthly wind speeds near the site. WECS Load PV Grid Converte Batteri AC bus DC bus Figure-4. Block diagram of the proposed hybrid system configuration. The grid applies scheduled rates in which the company pays 0.12748 USD/kWh during the peak load hours (17.00-22.00) and 0.08521 USD/kWh during the off peak hours. Excess power of the RES will be fed into the grid at the sellback rate of 0.07723 USD/kWh (1 USD = 13.000 IDR). The CO2 emissions factor of the Indonesia electricity production is assumed to be 741 g/kWh [24]. RESULTS The total net present cost (NPC) is used by HOMER to calculate the life cycle cost of the system [18]. All costs and revenues that occurs within the lifetime of the project are calculated into the present costs. Costs include investment costs (IC), replacement costs, operation and maintenance (O/M) costs, fuel costs, emission penalties, and grid power purchasing costs. Revenue include grid sales and the salvage value of the components. Table-3 shows results of HOMER optimization. HOMER ranks the configurations according to NPC. The best configuration is the Grid/Wind hybrid system with the predicted NPC of -884,896 USD. The negative sign indicates that revenues (mostly from selling power to the grid) exceed costs. The capital cost of the system is 4.56 million USD. 88% of the energy is produced by the wind energy conversion system (WECS). The levelized cost of electricity (COE) of the wind/grid hybrid system is predicted to be -0.013 USD/kWh (the negative sign suggests that producing electricity out of a wind energy conversion system/WECS actually creates money). In the present study, HOMER calculates COE by dividing the total annualized costs of the system by the total electric energy production. Since the total revenue of selling power to the grid exceeds total costs, the total annualized costs of the system have a negative value, thus negative COE. At this point of the simulation, HOMER suggested to consider adding more wind turbines for more optimal results. Recalculation with more wind turbines shows that adding more turbines constitutes lower NPCs. It suggests that selling electricity to the grid is profitable at the present price that adding more turbines increases profit. HOMER also calculates the economic metrics of the proposed system (Grid/Wind system in this case) and to do so a base system should be chosen (in our case a grid only system). NPC of the Grid/Wind system is -$884,896 and the grid only system $6,426,468. Table-1 shows the

results of the economic metrics of the Grid/Wind system which base system is the grid only system. The performance of WECS is promising (see Table-2). The average power of the wind turbines is predicted to be about 36% of their rated capacity and 211% of the average load. They operates for about 8301 hours of the total 8760 hours available a year. Tabel-1. Economic metrics of the grid/wind system. Metric Value Present worth $ 7,311,358 Annual worth $ 627,391/yr Return on investment 22.3 % Internal rate of return 22.2 % Simple payback 4.48 yrs Discounted payback 5.56 yrs Tabel-2. WECS performances. Quantity Value Units Total rated capacity 4 MW Mean output 1.44 MW Capacity factor 36.0 % Total production 12,618 MWh/yr Maximum output 3.917 MW Wind penetration 211 % Hours of operation 8,301 hr/yr www.arpnjournals.com Table-3. Optimization results of all hybrid configurations. No Grid PV V110 Batteries Converter Capital cost NPC COE Grid Net purchases Renewable fraction (kW) (kW) (kW) ($M) ($M) ($/kWh) (MWh/yr) 1 1300 - 2 - - 4.56 -0.88 -0.013 -6,641 0.88 2 1300 - 2 50 1000 5.33 0.14 0.002 -6,627 0.88 3 1300 500 2 - 1000 6.79 0.81 0.012 -7,679 0.91 4 2000 500 2 50 1000 6.83 0.89 0.013 -7,667 0.91 5 2000 - - - - 0 6.43 0.092 5,978 0.00 6 2000 - - 50 1000 0.77 7.44 0.107 5,978 0.00 7 2000 500 - - 1000 2.23 8.00 0.115 4,939 0.19 8 2000 500 - 50 1000 2.27 8.06 0.116 4,939 0.19 9 2000 - 1 - - 2.28 2.25 0.035 -331 0.73 Tabel-4. Electricity productions and consumptions. kWh/yr % Production Wind turbines 12,617,832 88 Grid purchases 1,660,577 12 Total 14,278,409 100 Consumption AC primary load 5,976,933 42 Grid sales 8,301,437 58 Total 14,278,369 100 Excess electricity 0.00525 0.0000 Unmet electric load 1,402 0.0234 Capacity shortage 5,728 0.0958 4,000 Power (kW) 3,000 2,000 1,000 AC Primary Load V110 0 1 2 3 January 4 5 6 7 Figure-5. Hourly load profile vs. Vestas 110 wind energy production on the first week of January. Table-4 tells us that wind turbines produce 88% of the total electrical energy production. It means that 88% of the electricity is from the renewable source, which is 2 wind turbines of 2 MW each. Figure-5 compares the hourly load profile of the industry with Vestas 110 wind energy production on the first week of the year as simulated by HOMER. Wind energy production far exceeds energy demands and the excess energy is sold to the grid. In dealing with uncertainty, sensitivity analyses were performed. We considered some uncertainty scenarios, namely CO2 penalties (0, 10, and 50 USD per ton CO2 emissions), PV and WECS investment cost reductions (25%, 50%, and 75%), and electricity price increases (50% and 100%). The main goal is to find the optimal power system to serve the load of the industry. Figure-6 shows optimal system types for different PV and electricity prices when WECS investment costs remain the same and carbon taxes are not applicable. The Grid/Wind system is still the best choice when the electricity price is at the current level even if the PV capital price decreases by 50%. Only when the electricity price simultaneously increases by 50% does the Grid/Wind/PV system outperform the Grid/Wind system. In a more extreme case, such as when the PV capital price decreases by 50%, the CO2 penalty is 50 USD/ton CO2, and WECS investment costs constant or half the current price, the Grid/Wind/PV system performs best even when the electricity price is at current level (Figure-7). Another finding is that the Grid/PV system is never be the best option in any scenarios. Its NPC is always higher than those of Grid/Wind and Grid/Wind/PV hybrid systems. CONCLUSIONS The objective of the present study is to provide analyses on the grid-connected wind and PV hybrid power systems that are technically feasible and economically viable to serve the electric load of a large industry in Bali. Optimization results (Table-1) show that each combination of grid, wind, PV, batteries, and converters systems is economically viable. HOMER have set that it only www.arpnjournals.com performs economic calculations when the system is technically feasible. Technically feasible in this case means that the system in question has the ability to produce enough energy to meet the load. The best option (i.e. the lowest NPC) is the Grid/Wind hybrid system. Around 88% of the energy it generates is renewable energy. Sensitivity analyses show that, in order for the Grid/Wind/PV hybrid system to outperform the Grid/Wind hybrid system, the PV capital costs should be at least half the current level and the electricity price increases by 50%, assuming other things being equal. The other option is to implement CO2 penalty (or carbon taxes) of 50 USD per ton CO2 emissions and to reduce 50% of the PV capital costs simultaneously, assuming other things being equal. Figure-6. Optimal system types for different PV and electricity prices. Figure-7. Optimal system types in a more extreme case. The sensitivity analyses imply that PV price reduction to half the current price (from $3000 to $1500 per kW) does not help Grid/Wind/PV or Grid/PV systems compete with the Grid/Wind system. Energy production from wind turbines is still superior to that from PV panels. It is cheaper in term of the cost of electricity and more profitable in term the total net present cost than that from PV panels. They also imply that any increase in electricity/fuel prices will be a blessing in disguise: It makes the renewable energy power systems more competitive than fossil energy systems. The current (subsidized) price of electricity has hindered the progress of renewable energy penetration in Indonesia. The last conclusion is that applying carbon taxes or CO2 penalties may help renewable energy systems penetrate deeper into the market. REFERENCES [1] International Energy Agency. 2014. World Energy Outlook 2014: Executive Summary. IEA Publications, France. [2] Dewan Energi Nasional. 2014. Indonesia Energy Outlook 2014 (in Indonesian). DEN, Jakarta. [3] Worrell, E., Martin, N., and Price, L. 2007. Potentials for energy efficiency improvement in the US cement industry. Energy. 25(12): 1189-1214. [4] Rohdin, P., Thollander, P., and Solding, P. 2007. Barriers to and drivers for energy efficiency in the Swedish foundry industry. Energy Policy. 35(1): 672- 677. 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