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THE OPTIONS AND DESIGN IMPROVEMENTS OF THE ELECTRIC GRID OF SARAWAK AS AN EXAMPLE FOR DEVELOPING COUNTRIES

Prashobh Karunakaran
Senior Lecturer, Department of Electrical and Electronic Engineering, Universiti Malaysia Sarawak (UNIMAS), Sarawak, Malaysia

ABSTRACT

This research is a reference for decision makers of electric grids especially in developing countries. This is done by describing the 90 year old Sarawak electric grid, including design improvements to further enhance it. The grid includes the power plants, the substations and the transmission and distribution lines. Grid equipment (notably power stations) is so expensive that only politicians of the highest level can make decisions regarding them. The problem is only a few engineers are in politics. Therefore there is a need for an easily accessible scholarly paper on the power system options for developing countries.

Keywords: *Sarawak, electric grid, options, developing countries, design.*

I. INTRODUCTION

Electric grids are already one of the most expensive installations in the world; currently tagged at six trillion dollars. The grid will grow by 44% from 2008 to 2030 and much of this will be in developing countries [1]. On the other hand engineers have tended to stay away from politics all over the world. Warnings about this problem have been made by many top thinkers because this situation cannot carry on as high technology increasingly becomes an inherent part of economic activities of any country [2]. Engineers with extensive field experience must be among the top decision making bodies of any country [2]. In some countries like China, top engineers are just picked to be politicians but in a democracy, engineers have to be cajoled to leave their comfort zones and become politicians for the good of society [2]. An example of how disasters can occur if engineers are not decision makers is the construction of the Banqiao hydroelectric dam in China. The main engineer (hydrologist), Chen Xing was pushed out of the project by politicians because he was vocal about the design. But when the dam finally burst in 1975 killing 171,000 people, politicians called him back to rebuild the dam and now China is the world leader in dam construction with the largest hydroelectricity generation in the world [3].

The power system of Sarawak, Malaysia was studied and designs were formulated to optimize it further as a reference model for other developing countries.

Sarawak is the largest state of Malaysia (at 124,450 km^2) but with a population of only 2.5 million. The state is located on the equator and therefore has a rainfall of about 4000mm (157 inches) per year compared to a USA average of just 715mm (28 inches) [4]. The topography is of high mountain ranges at the border with Indonesia, with ridges up to 1,200 meters high [5]. The rare combination of all these four factors of large land area, low population density, high rainfall and mountains ranges makes development of hydroelectricity ideal for Sarawak. Added to this, other clean sources of energy are not optimal for equatorial Sarawak. It is for this reason that Sarawak has already built three dams and ten more are in the planning stages. The exploitable potential of hydroelectricity in Malaysia is 123 TWh per year and 70% of this or 86 TWh lies in Sarawak [6]. Sarawak's hydroelectricity resource was studied by the SAMA Consortium. This Consortium came as a technical aid to Malaysia, granted by the German government, via the German Agency for Technical Co-operation (GTZ). A total 51 dam sites were identified, each with a potential to generate more than 50 MW. Their combined hydroelectric generation potential is 20,000 MW [6].

Sarawak faces the same geopolitical situation of many developing countries where decision makers are influenced by big trends in developed countries. Among these trends are the developments of solar and wind power sources. The problem is wind and solar are good options for the Northern and Southern hemisphere but bad for equatorial countries.

Solar is not suitable for a country where cloud cover and blue sky comes and goes many times within the day. Power companies need to be able to predict the availability of power. The problems of solar in cloudy countries is

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explained by solar development in Hawaii where dependence on solar power damaged grid equipment because a cloud cover can take out 70 to 80 percent of power output in less than a minute. Other than hydroelectricity, no other power stations can load the grid or backup this loss that fast. Thus the other power stations in Hawaii and switchgears were damaged as the load drew all their demand from the remaining diesel engines and gas turbines [7].

Decision makers should study carefully the local resource advantage of their country before embarking on expensive electric power projects. Just as solar power will work best in sunny Saudi Arabia and wind power will work best in the windy Norwegian seas, hydro power is the most suitable option for the high rainfall equatorial Sarawak. The dams also help control flooding; a good example is the city of Sibu, Sarawak. Sibu was a city infamous for it's flooding but after the commissioning of the Bakun dam, flooding in the city is almost non-existent [6].

Sarawak needs to tap her hydroelectric resources despite the current low electric demand because cheap electricity is a magnet for large industrialist worldwide. It will bring about a more robust economy as well as reduce greenhouse gasses produced by global industrialists who are currently planning to use fossil fuels to power their growth. Global industrialists will always like to depict a low carbon footprint of their corporations.

The argument about dams has been waging for some time. Some studies claim that the dams damages the environment [8] but if the dams are not built, hydrocarbon energy plant will be built to satisfy human needs somewhere in the world. Also people closest to the issue tend to support the development of the dams. The protesters against the dam are mainly people who are not affected by the dam but used by political agencies solely for the purpose of bringing down incumbents [9]. This is because dams are usually developed in very rural regions whose original inhabitant tend to be far behind in education and other developments. The dams will bring about road access, market for their produce and education for their children [9]. If fossil fuel power plants were used to achieve the equivalent economic development which hydroelectricity can foster in Sarawak, a huge amount of CO_2 and other polluting gasses will have to be emitted. The effects of this emission are far worse than is caused by the initial inundation of land areas as shown in Table 1. In the Table, the last column shows that the CO_2 emission if coal power plants were used to produce all the electricity generated in Sarawak. The third column shows the potential CO_2 which can be absorbed by the lands inundated land by the dams [10].

Table 1: Effects of the dam inundated areas versus coal power

Name of Dam	Power produced (MW)	CO_2 emission in tons if coal power station is used to produce this amount of power (tons)	Land area (km^2)	Potential CO_2 absorbed if land is not inundated (tons)
Batang Ai	104	962058	33	3300
Bakun	2400	22201344	14750	1475026
Murum	944	8732529	245	24500

The figures in Table 1 is derived from the coal power station in Kuching which is 1.056 tons CO_2 emitted per MWh of electricity produced (US EIA published data is 1.085 tons of CO_2 per MWh of electricity produced. Also used for the above table was EIA (U.S. Energy Information Administration) published data that 0.009999822 km^2 of rainforest absorbs 1 ton of CO_2 from the atmosphere [20,11].

II. LITREATURE REVIEW

In 2013, 36 billion tons of CO_2 was emitted to the atmosphere making it the highest yearly emission level in earth's history.

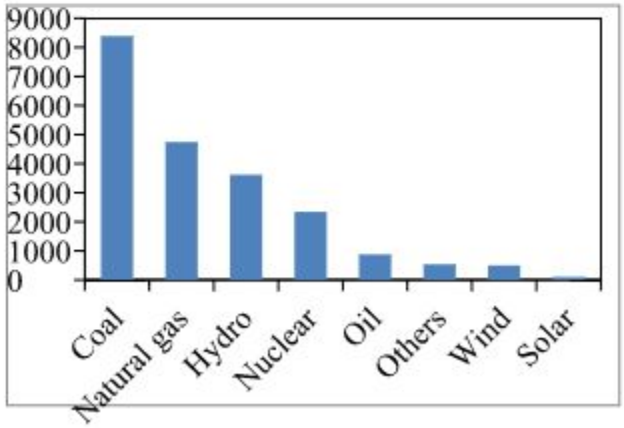

Figure. 1: World electric power generation by sources

And about 32% of this CO_2 is emitted by the electric power industry [11]. Of the total electricity generated in the world, 66% is generated with hydrocarbon sources, which breaks down to 40% from coal fired power stations, 22% by natural gas power stations and 4% by oil powered generation. Figure 1 show the world electric power generation by sources [12]. In summary, of the 32% CO_2 emission produced by the electric industry, coal power stations emits 19%, gas power stations emits 11% and internal combustion engine (ICE) power station emit 2%. This 32% of total CO_2 emission compares with 28% emitted by the entire transportation sector (cars, trucks, planes and ships).

As global electricity consumption increases by 44% over the period 2008 to 2030 the corresponding increase in CO_2 emission will cause a much higher rate of global warming caused disasters, the likes of the blizzards of New York in 2015, the hurricane Sandy in 2012, the Queensland, Australia floods in 2010 and the floods in Malaysia in 2014. All these disasters were never seen before events and most scientists attribute them to global warming [13]. The National Climatic Data Center of USA has reported that 2014 is the hottest year since humans started keeping records [14]. Thus developing countries which are just beginning to expand their electrical energy generation should bypass the previous mistakes of choosing high pollution energy sources. There should be optimization in power system options from the onset.

Human beings inevitably need industrial production, the choice for humans is use highly polluting coal fired power plants or clean energy sources like hydroelectricity, wind or solar. If Sarawak fully utilizes all her hydroelectric potential, many of the heavy industries planned for construction in China can be relocated in Sarawak thereby taking out the huge increase of CO_2 emissions from power plants in China which are mostly coal powered. Other than CO_2, coal fired plants also emit other toxic gases like sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter or soot (fly ash), mercury (M), lead (Pb), carbon monoxide (CO), hydrocarbons and arsenic (As) [14].

Industrial production needs lots of cheap energy. The story of Japan after World War II (WWII) depicts this fact. The USA was concerned that Japan might engage in another war to acquire resources so nuclear energy was encouraged, thereby enabled her huge spurt of industrial production [15]. With the large amount of energy, industrialization will come almost automatically. Japan actually went through a phase of eliminating the dependence on nuclear power after the Fukushima disaster in March, 2011, but by 2015 decided to restart the nuclear energy because this short experimentation with fossil fuel replacement was just too expensive and resulted is too much pollution. The decision to restart the nuclear power plants was aided by professor emeritus, Kiyoshi Kurokawa's investigation which showed that the Fukushima disaster was not caused by the natural disaster but by lax safety protocol in the design and construction of the plants [15].

Currently India is planning to achieve a similar spurt in economic activity and energy security via the development of thorium based nuclear energy. To achieve this, Indian scientist came up with a three stage nuclear program. India has 30% of the world's supply of thorium [16].

In Europe the International Electrotechnical Commission (IEC) did research to determine how extensive usage of renewal energy can be achieved to prevent global warming and reduce dependence on fossil fuels. Their proposed design is a Europe wide grid to cater to the intermittent sources of electric power like wind or solar. This way, extra power from fossil fuel or nuclear power stations can back-up a sudden low wind situation around wind farms or sudden cloud-cover over solar farms. Therefore the Synchronous Grid of Continental Europe was built and it is currently the largest electrical grid in the world. The frequency of the grid is 50Hz and it serves over 400 million customers in 24 countries. Large energy storage has also been determined to be one of the solutions; batteries with liquid electrodes have been suggested as a form of grid energy storage. In Germany, solar panels power pumps water up a high tank and in the night water is released from these tanks to produce hydroelectricity [17].

Similarly in the USA a large substation called the Tres Amigas is being built to interconnect three large grids; the Western Interconnection, the Eastern Interconnection and the Electric Reliability Council of Texas (ERCOT). In this super substation electricity is converted to DC and flows in smaller high-temperature superconductor (HTS) cables over a 58 km^2 area where any of the three grids can load or unload power [18]. In these HTS wires, electric resistance drops abruptly to zero at a relatively high temperature of around 90K (-183°C) compared to when superconductivity was first discovered in 1911. Current flowing in HTS wires can keep flowing within the substation for up to 100,000 years, making it an optimum energy storage device [18]. With Tres Amigas, traditional energy sources can backup intermittent solar or wind farms. This super substation can initially handle 5 GW and is expandable to 30 GW [19].

III. THE CURRENT DESIGN OF THE SARAWAK GRID

The backbone of Sarawak's grid is one line of 275 kV towers from the south of the state to the north. Inductive compensation is used to control the power quality and frequency but capacitive compensation has so far not been introduced in the 275 kV line. Capacitive compensation starts in the 33 kV substations. No HVDC lines have been introduced and no interconnections with the northern state of Sabah or the country of Brunei have been implemented. A direct 275 kV line to the Indonesia in the south is being built without a back-to-back HVDC system in-between. It is actually quite difficult to implement power quality correction devices designed by big four of the electrical industry (GE, Siemens, ABB and Schneider) on the 275 kV line because the line need to be shut down, for which the population and politicians will not agree [20].

The construction of the 13 dams planned or already built have a main purpose of powering the heavy industries near in Samalaju which has recently became the load center for Sarawak, surpassing the capital city of Kuching where most of Sarawak's population live. Other renewables like wind and solar were tried out in Sarawak but failed to proof feasible [20].

Solar power in Sarawak is a problem because though there is sunlight, it is quite often blocked by heavy cloud cover, typical of equatorial areas. Also fungus grows very fast in equatorial climates. This fungus even consumes the minerals within glass on the photo voltaic (PV) cells. Thereby as the sunlight is eventually blurred out, reducing the solar energy reaching the PV [22].

The other option of wind will not work unless a proper calculation of the dimension of the wind turbine is made in accordance with the low wind speed typical of equatorial regions. A wind turbine designed for China, Europe or USA will not work in equatorial Sarawak; sailors of old dreaded the equator because they could be stuck in these regions for weeks due to the lack of wind (they named these regions doldrums). The formula below indicates the utility of wind speed in the dimensions of a wind turbine. The energy extracted from a wind turbine is given by:

$$E_{k\ max} = (\tfrac{1}{2}\rho A V^3)16/27 \qquad (1)$$

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Where A = area, V = wind speed [23]. Notable from equation (1) is that the wind speed is the most important factor because it is cubed in the equation. Therefore wind energy will not work in the equator unless the full dimension of the fins are designed taking into account the low wind speeds of the equatorial regions. One wind turbine project in Sarawak where a wind turbine from a temperate country was just imported and installed, not considering the low wind conditions of equatorial Sarawak was a dismal failure [20]

With solar and wind not feasible, the only renewal energy for Sarawak is hydroelectricity. Also no power generator works as efficiently as a dam because it uses only one engine, the generator. The simplicity of hydroelectric dams makes them very reliable. There have been no reports of failures in the Batang Ai dam for 25 years [20]. The simple logic is that in a dam, the falling water replaces the complicated gas turbine (GT), the coal fired steam engine or and Internal Combustion Engine (ICE) of other power stations. Upon receiving a phone call from the power control center in Kuching, a single generator can be started and load 180MW of power from the Bakun dam onto the Sarawak grid within 20 seconds. This is compared to 45 minutes for a GT, an hour plus for an ICE, and eight hours for a coal power station. Also the staff at the Batang Ai power stations do not face hazards of up to 103 dB(A) of sound pollution as in some parts of the ICE power stations or the high frequency noise of GT. The preventive maintenance (PM) at the ICE stations is also hazardous. Huge pistons the size of trucks need to be taken out and placed in a container of kerosene to be scrubbed with bare hands. The diesel and kerosene outgassing have a very negative impact on the health of the staff [20].

At the GT in Bintulu the high frequency noise attracts a four inch long insect called Emperor Cicada. The whole floor of the power station is littered with these dead insects [20]. If these dead insects are swept away, the floor will be filled again with them the next day. The high frequency noise of the GT must be similar to the sound these insets make explaining their attraction, but they die as they reach the GT. If the power station noise can kill this healthy and sturdy looking insect, there must be causing some harm to humans. Statistically both GT and ICE power station staff of SEC have the worst health in the company [20]. On the other hand, the hydroelectric power station staff has the best health statistics, better than the administrative staff in the offices. The Batang Ai dam staffs get free food in terms of an easy catch of fish from the reservoir of the dam, fresh air, almost no sound pollution, zero emissions and minimal work due to the reliability of the power plant [20].

Table 2: Current power generation in Sarawak

Generator name and type		Capacity (MW)	Running (MW)
Biawak (ICE, GT)		99	0
Bintulu (gas turbine)		524	405
6 X 33MW GT,			
2X105MW GT			
1X116MW Combined Cycle			
Miri (gas turbine)		79	60
Total gas =	**603**		
Sejingkat (coal power) Unit 1 & 2 = 50MW, 3 & 4= 55MW		210	180
Mukah (coal power) capacity 2 X 135 MW		270	257
Total coal =	**480**		
Batang Ai (hydro)		104	80
Bakun (capacity=300MW each) Currently all 8 units running 180MW each		2400	1440
Murum (Hydro 4 X 236MW = 944 MW). Currently 2 units running		944	260
Total hydro =	**2504**		
Grand Total		**4630**	**2422**

Currently the majority of Sarawak's electric power is from hydroelectric dams. The other major sources of electricity are coal power stations, GT and ICE. Table 2 depicts the power generation in Sarawak [19]. The spinning reserve or the generation that is not used by customers is 350 MW to 700MW. This is the extra generation to cater to one Bakun generator going down; this is also the reason why the Bakun generators are currently running at only 180 MW and not it's designed capacity of 300 MW [20].

In Sarawak where hydroelectricity is the main source of electricity the spinning reserve doesn't cost that much money or CO_2 emission impacts but in countries like China it seems like polluting the environment without ROI (Return On Investment). So a design improvement must be made to reduce the spinning reserve as much as possible.

In gas turbines at Bintulu, the input temperature of the burning gas and compressed air is 900-1400°C and the output is 450-650°C. This exhaust gas is hot enough to heat up water to produce steam to run another generator. This is called a combined cycle or Rankine cycle. Basically a steam engine generator is a heat engine which works with the same principle as heat pump (like an air-conditioner) but in opposite direction. There are four basic parts namely the condenser, the evaporator, the compressor and the expansion valve. The combine cycle (gas turbine combined with steam engine) generator in Bintulu produces 115MW of electricity. The cooling of the condenser in the combined cycle is done with sea water. In non-combine cycle gas turbine, the efficiency of converting the energy of gas to electrical power is 30% whereas in a combine cycle the efficiency can reach 60% [20].

The main grid cables of Sarawak carry between 10 and 59 A per cable. This is quite low if compared to a typical car where the battery sends out about 70 amperes upon starting. This reduction of current is done with a transformer to reduce power loss over the transmission lines which follow the formula (2).

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$P_{loss} = I^2R$ (2)

$P = VI$ (3)

For example following equation (3), the falling water at Bakun has power (P) whose components are V and I. When the V component is raised to a high level the I component reduces (because the water power is fixed) and when this reduced current value in put into formula (3) a low power loss is achieved over the transmission line [20].

One of the intermediary power plant in Sarawak is the Mukah power plant. The plant utilizes the low quality coal found in Mukah. It cost $306 million to build which is a much cheaper initial cost than any of the planned dams in Sarawak. The ash from the Mukah power station is stored in a silo to prevent dust pollution. The plant generates 42,000 tons of ash a year. In the construction of the Murum dam, this ash was mixed with the concrete to make the cement stronger.

The electricity from the Murum and unbuilt Baleh dams has already been booked by energy intensive customers who have invested in Sarawak. The development of the proposed Baleh dam will also benefit the people of Baleh as major roads are built to provide access to the dam sites. These roads will enable the communities in Baleh areas to be more connected to the towns and therefore markets for their farm or jungle produce. By reorganizing these people in smaller resettlement areas there will be more synergy as they work together to transport their produce to the towns. Also there will be better access to education as schools are built for them. Access to town school and tertiary education will also be made more accessible. The option of moving to town jobs and businesses will also be opened for them [21].

Another two power stations on the Sarawak grid are the ICE and coal power station located in Kuching. The ICE generates 96MW at USD0.06 per kWh. The coal power station produces 200MW at USD0.03 per kWh. The electricity is sold at USD0.010 per kWh for most customers [20].

IV. PROPOSED DESIGN IMPROVEMENTS TO THE SARAWAK GRID

The weakest point in the Sarawak grid is the lack of lines carrying power into the second load center of Kuching city. Most of Sarawak's population lives in and around Kuching. But Kuching does not have significant power generation at sufficiently low cost. Strategically the load center should not be dependent on a power source a few hundred kilometers away. In the current setup, Kuching depends on just two double circuits of 406mm^2 cables (12 wires) bringing electricity into the city. These lines could be damaged by lightning strikes or sabotaged. The solution proposed is geothermal energy. 37km south of Kuching is the Annah Rais Hot Spring where surface water temperature can reach up to 80°C. This is above the surface temperature of the successful Salton Sea geothermal plants located near San Francisco whose surface water temperature ranges between 14-33°C. Holes about two km were drilled below the Salton sea to access water at temperatures of 260°C which is sufficient for geothermal electricity production. Comparatively the existing coal power plant in Kuching has an inlet steam of 533°C at a pressure of 7.62 MPa (76.2 bars) to drive a 50 MW generator [19]. So to achieve an equivalent power generation with the lower temperature and pressure steam of Annah Rais, many smaller generators need to be installed. The Salton Sea geothermal project uses 22 generators to produce 800 MW [24] of electricity which is more than the demand of Kuching city. In fact, geothermal energy could potentially be a final solution to solve all the world's energy demand and global warming problem. Deep underground anywhere in the world is heat; it is just a matter of how deep the well need to be dug to access heat needed for geothermal energy. Holes need to be drilled the same way oil wells are drilled. Then water is poured into these holes and steam comes out to run a steam turbine. In volcanic regions the well can be shallow while in non-volcanic regions the wells need to be deeper. If geothermal energy is fully utilized, the 32% of the world’s CO_2 emission from hydrocarbon power plants could potentially be reduced to zero [11].

Another proposed improvement is the installation of solar farms in the existing ICE power station (named TAR), the existing Coal power station (named Sejinkat) and the hydro power station (named Batang Ai). These old power stations have large land areas with experienced SEC staff on hand. Solar energy is now feasible because manufacturing in China has driven down solar panel cost world-wide by about 62.5% from 2012 to 2015 (from $0.8

per watt to $0.3 per watt) [25]. Battery technology to store solar power has also improved vastly due to the high funding for battery research in most top universities because of their wide use in cell phones, laptops and electric cars.

Solar is viable in Sarawak when used in tandem with her plentiful hydroelectric energy; the only power plant that can back up fast enough to counter a 80% solar power loss within a minute due to a sudden cloud cover [7]. But with such timings, it is imperative that the solar panel system to hydro generator startup be automated.

Another proposal is to use LEAP engines. Basically the exhaust coming out of a GT is hot enough to melt even the stainless steel body material. Currently this problem is solved by blowing high pressure air from the compressor section of the GT into holes casted into the body of the turbine section of the GT to cool it down. In the LEAP engines, the body of the turbine is made of ceramics which can withstand the high temperature of exploded gas-air mixture within it. Therefore the air from the compressor section can be fully utilized for the explosion in the combustion chamber producing more mechanical energy to convert into electricity [26].

Another new technology to improve the grid is to encourage people to use Electric Vehicles (EV). EVs are a perfect storage of energy to take out from in case of sudden disruption of power supply. This is because people normally drive to and from work for 20-60 minutes (about two hours to and from work) and park the car for the other 22 hour. If the majority of vehicles are EVs, energy can be taken out from them back up a sudden cloud cover over solar panels, a sudden atmospheric wind speed reduction over wind farms or a sudden mechanical problem which brings down an ICE, GT or hydroelectric generator. With EVs there will be no need for Sarawak to run up to 700MW extra generation as a backup for Bakun generators going down [27]. The solutions for EV utilization are to install bi-directional metered electric power sockets at all car parks, automated battery swap stations at current petrol stations and high voltage fast charging stations located at strategic locations [27]. With full EV implementation, the pinning reserve in Sarawak can be cut off and the current 28% of world CO_2 emission by the transportation industry can be cut off.

The other improvement which has already started is to construct a second 275kV line across Sarawak. Two backbone 275 kV lines across the state will enable the installation of the latest devices developed by the world top electrical switchgear manufacturers [20].

There is also a need to more efficiently manage the grid. The current SCADA Ethernet system from Harris Computers (now owned by GE), USA is too slow to respond to fault triggered, even though signals are currently carried over fiber optic lines. An internet protocol suite (TCP/IP) based system will enable much faster respond time. Currently many power corporations are concerned about sending data over the internet because hackers may eventually control the grid. But the current Ethernet used can just as easily be hacked so that concerned is not justified. Virus protection from established antivirus companies like McAfee (currently owned by Intel) can be contracted to secure the grid from hackers. The grid should also be automated as far as possible. For example if one generator in Bakun fails, taking off 180 MW from the grid, a specified low priority load should be automatically shedded immediately to safeguard the rest of the grid. With a very fast response time to counter faults in a power stations or electrical systems, the spinning reserve can be reduced [28].

V. CLOSURE

With papers such as these, decision makers of electric grid can have a better overall view of the available options especially in developing countries. How electrical infrastructure in Sarawak can effect international decisions notably in the industrial sector of China is indicated. Big international corporations are increasingly being pressed to source their power away from coal; so it is a win-win situation for all. The design improvements to the Sarawak electric grid were detailed and with these implemented; there will be a boost to the industrial developments, particularly the mega power consumers in the Samalaju area as well as solving the extensive pollution in China (which effectively pollutes the whole earth). Improving the grid to help carry all this power is critical to ensuring reliability of the whole system. A paradigm shift has to happen to ensure the population of Sarawak move away from ICE vehicles to EV. EV will bring about revenues for SEC as well as serve as public sponsored storage to take out power from in case of an unplanned interruption in power supply.

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BIOGRAPHIES

Dr. Prashobh Karunakaran is a Senior Lecturer in the Electrical and Electronics Department of University Malaysia Sarawak (UNIMAS). He was a former engineer at Sarawak Electricity Corporation (SEC) which is also known as SEB or SESCO.